REAL TIME DIGITAL SIMULATOR

POWER SYSTEM USER'S MANUAL

December 2012

RTDS Technologies

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6 AC MACHINE MODELS

1 OVERVIEW

This manual provides detailed information about power system component models available on the Real–Time Digital Simulator (RTDS ™). The **RTDS Power System User's Manual** represents one part of the overall Manual Set provided with all RTDS Simulator installations.

The full set of RTDS Simulator documentation includes the following manuals available on–line, through the Manuals icon in the Filemanager Task Bar.

RTDS Manual Set

RTDS Hardware Manual

Power System Users Manual

Control System Users manual

Simulator Interfacing Manual

Tutorial Manual

In addition, module specific help is available through the HELP icon in the Task bar of each of the following RSCAD Modules;

RSCAD/FileManager

RSCAD/Draft

RSCAD/Tlines and Cable

RSCAD/RunTime

RSCAD/MultiPlot

In the **Power System User's Manual,** the general use, capabilities and limitations of the individual power system component models are presented, as well as how to interconnect the individual components to form power system simulation cases.

Although some of the rudimentary features available from the various RSCAD modules are discussed here, detailed information regarding RSCAD software is presented with the HELP documentation.

The **RTDS Tutorial Manual** may be referenced for fully documented example cases illustrating the use of the RTDS. One of the ways in which the user can gain confidence with a specific component model is to apply simulations to that element, in isolation, and observe its response. It is especially useful to perform tests where the component's observed response is directly proportional to its user specified parameters. For example, by simulating the open and short circuit tests on a transformer model, the user can calculate the transformer's leakage and magnetizing branch inductances from observed quantities and verify that they match those entered from the RSCAD/Draft module.

Before introducing the individual power system component models available for use on the RTDS, some fundamental concepts pertaining to the RTDS technology as a whole will be presented. The remainder of this chapter is dedicated to a brief discussion of RTDS hardware and software. This discussion is intended to give the user a general overview of the technology and to introduce some of the terminology which is commonly used when referring to the RTDS. For more detailed information, it is recommended that the user reference other parts of the Manual Set

1.1 INTRODUCING THE REAL–TIME DIGITAL SIMULATOR (RTDS)

The **R**eal–**T**ime **D**igital **S**imulator (RTDS) is a special purpose computer designed to study Electromagnetic Transient Phenomena in real–time. The RTDS is comprised of both specially designed hardware and software. RTDS hardware is **D**igital **S**ignal **P**rocessor (DSP) and **R**educed **I**nstruction **S**et **C**omputer (RISC) based, and utilizes advanced parallel processing techniques in order to achieve the computation speeds required to maintain continuous real–time operation.

RTDS software includes accurate power system component models required to represent many of the complex elements which make up physical power systems. The overall network solution technique employed in the RTDS is based on nodal analysis. The underlying solution algorithms are those introduced in the now classic paper *Digital Computer Solution of Electromagnetic Transients in Single and Multiphase Networks* by H.W. Dommel. Dommel's solution algorithm is used in virtually all digital simulation programs designed for the study of electromagnetic transients.

RTDS software also includes a powerful and user friendly **G**raphical **U**ser **I**nterface (GUI), referred to as **RSCAD**, through which the user is able to construct, run and analyze simulation cases.

1.2 RTDS HARDWARE

Unlike analogue simulators, which output continuous signals with respect to time, digital simulators compute the state of the power system model only at discrete instants in time. The time between these discrete instants is referred to as the simulation time–step (Δt). Many hundreds of thousands of calculations must be performed during each time–step in order to compute the state of the system at that instant. The temporary transients class of studies for which the RTDS is most often used requires Δt to be in the order of 50 to 60 μsec (frequency response accurate to approximately 3000 Hz.). By definition, in order to operate in real–time a 50 μsec time–step would require that all computations for the system solution be complete in less than 50 μsec of actual time.

In order to realize and maintain the required computation rates for real–time operation, many high speed processors operating in parallel are utilized by the RTDS. Two types of processor cards may be installed in each RTDS rack.

The *Triple Processor Card* (3PC) contains three Analogue Devices ADSP 21062 digital signal processors. The ADSP21062 DSP clock speed is 40 MHz.

The RISC Processor Card (RPC) contains two PowerPC 750CXe RISC processors. operating at a clock speed of 600 MHz. The specific PowerPC supplied with your RTDS simulator may not be a 750CXe, as more powerful versions are used as they become available.

The RTDS Simulator can be configured as 3PC only or as a combination of 3PC and RPC.

A *rack* of RTDS hardware is defined as one 19" housing consisting of up to 20 printed circuit boards. Typical configurations include the following number of processor cards:

12 * 3PC,

8 * 3PC, 1 * RPC

In addition to processing cards, an RTDS rack always contains a *Workstation Inter-Face Card* and in the case of multi–rack systems, an *Inter–RackCommunications Card*.

The RISC Processor Card (RPC)

As mentioned, the RPC card contains 2 Power PC 750CXe Processors, each mounted on a daughter card subassembly. The cards communicate through a local high speed ring bus that also includes the back plane. The RPC has no indpendent I/O facilities in the current version, and is used primarily for the rack network solution.

The Triple Processor Card (3PC)

Each Triple Processor Card contains three independent ADSP 21064 processors and their associated memory, backplane interface and input/output ports.

Each 3PC contains the following I/O ports –

24 x analogue output channels (12 bit +/– 10 volt range)
2 x digital input port (16 bit each)
2 x digital output port (16 bit each)

The I/O capabilities of the three processors (A, B & C) are summarized follows.

Each of the three processors (A, B and C) has access to eight analogue output channels. In addition, processors 'A' and 'B' each have access to one digital input port and one digital output port. No digital ports are associated with processor 'C'. Processor C is used for optionally available analogue I/O channels. Application of the I/O ports varies depending upon the type of power system component model which has been assigned to run on the 3PC processors.

In order to import analogue signals to a 3PC card, optional auxiliary hardware is required. The optional OADC is used together with a 3PC card to achieve analogue input. Six independent input channels are available on each OADC (+/− 10 volts peak, optically isolated, differential inputs). When included, OADC boards are rail mounted in the rear of the RTDS cubicle and connected to a 3PC card using fibre optic cable. Processor 'C' of the 3PC card can be optionally fitted with the fibre optic signal receiver when analogue input capability is required. For each OADC board installed in the RTDS, one 3PC is equipped with the fiber optic connection hardware.

WorkStation Interface Card (WIF)

One WIF card is installed per RTDS rack. Each WIF performs four main functions:

1) Rack Diagnostics

2) RTDS−to−Computer Workstation Communications

3) Multi−rack case synchronization

4) Backplane Communications

Rack diagnostics are run whenever the rack power is turned on or when the WIF front panel RST button is pushed. Results from the diagnostics can be accessed using RSCAD/RunTime.

Communication between the RTDS and the host computer workstation is done using a 10/100 baseT ethernet link. The WIF may be directly connected to a host workstation using a 'swap' type cable, or the WIF may be connected to the local area network using an ethernet hub.

The WIF is responsible for maintaining synchronization between individual racks in a multi−rack simulation case. Simulators which include 3 or more racks require a *Global Bus Hub* (GBH). The GBH is installed in the rear of one of the RTDS cubicles and is used to facilitate direct communication of certain signals between RTDS racks during a simulation. RTDS simulators which consist of only one rack do not require a GBH. The WIF cards in a two rack RTDS are directly connected using fiber optic cable and do not need a GBH. The RTDS Hardware Manual contains a complete explanation of the WIF and the GBH.

Within a single rack many signals are exchanged between 3PC, WIF and IRC cards along a common communication backplane. Each card is directly connected to the communication backplane. The WIF card is responsible for coordinating backplane communication.

InterRack Communications Card (IRC)

One InterRack Communication card is installed in each rack of a multi−rack RTDS simulator. The IRC is used to communicate data between interconnected racks. High speed parallel to serial and serial to parallel data converters allow connections to be made between racks. Each IRC includes six bidirectional data communication paths. An RTDS simulator consisting of seven racks can thus have direct communication between all racks.

A pair of front panel LEDs exists for each of the six communication channels on the IRC. The green LED, when on, indicates that the associated channel is active for the simulation case. The LED will only come on when a simulation case is running and if the RTDS software has determined that direct communication between the two racks connected by the channel is needed. The red LED, when on, indicates that an invalid data packet was received. The serial communication protocol between the sending and receiving includes extra bits for error detection (not correction). A single transmission error will cause the red LED to stay on until the simulation case is stopped.

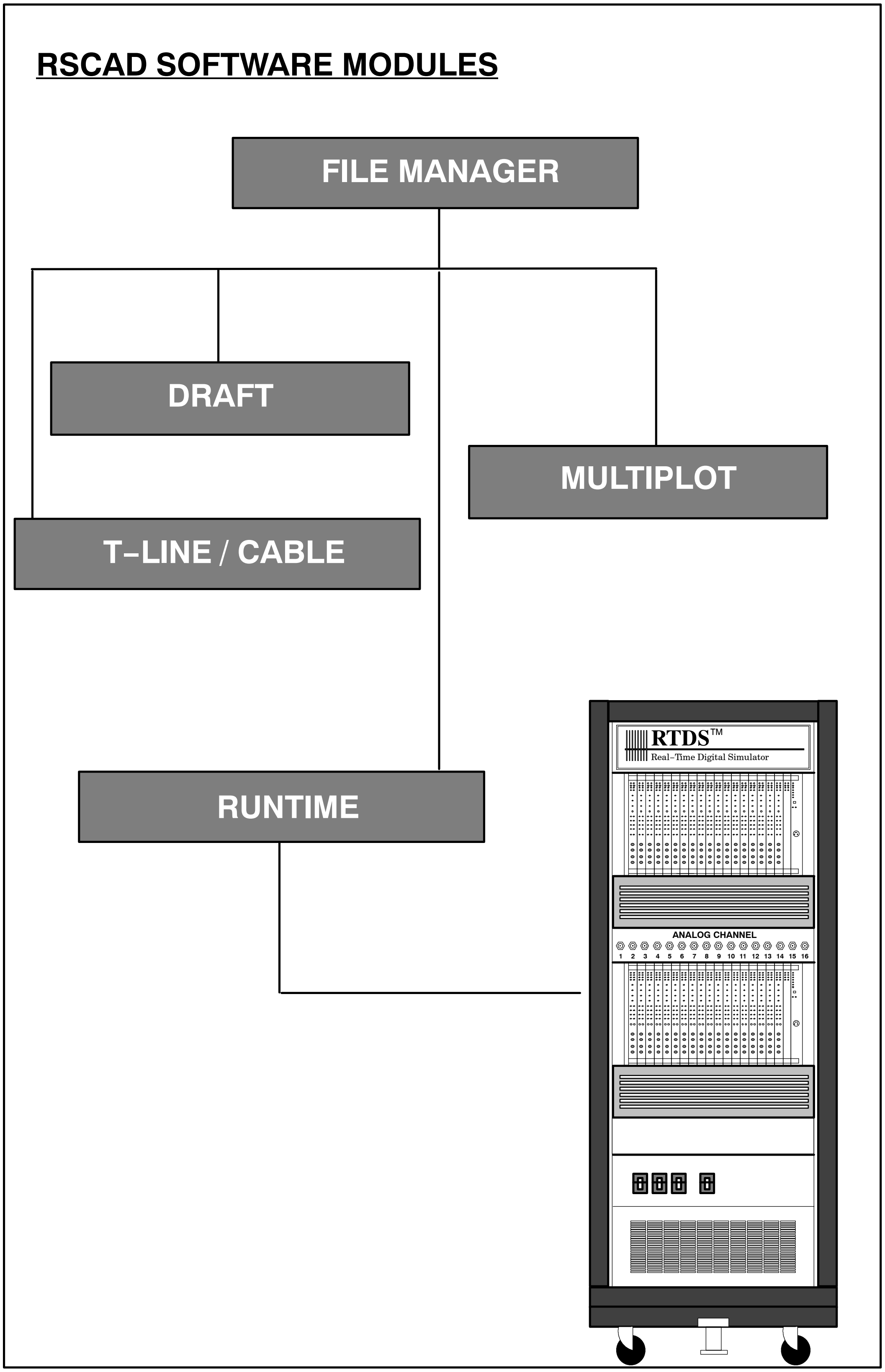
1.3 RTDS SOFTWARE

Software for the RTDS is organized into a hierarchy containing three separate levels: high level graphical user interface, mid level compiler and communications and the low level WIF multi−tasking operating system. The RTDS user is exposed only to the high level software with the lower levels being automatically accessed through higher level software.

RSCAD Graphical User Interface

The high level RTDS software comprises the RSCAD family of tools. RSCAD is a software package developed to provide a fully graphical interface to the RTDS. Prior to the development of RSCAD, another software suite: PSCAD served as the graphical user interface to the RTDS hardware.

RSCAD/FileManager (Fileman) represents the entry point to the RSCAD interface software. Fileman is used for project and case management and facilitates information exchange between RTDS users. All other RSCAD programs are launched from the Fileman module.


RSCAD SOFTWARE MODULES
FILE MANAGER
DRAFT
MULTIPLOT
T–LINE / CABLE
RUNTIME
RTDS™
Real–Time Digital Simulator
ANALOG CHANNEL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

RSCAD/Draft is used for circuit assembly and parameter entry. The Draft screen is divided into two sections: the library section and the circuit assembly section. Individual component icons are selected from the library and placed in the circuit assembly section. Interconnection of individual component icons and parameter entry follows through a series of menus.

RSCAD/T−Line and RSCAD/Cable are used to define the properties of overhead transmission lines and underground cables respectively. Data is generally entered in terms of physical geometry and configuration. Line and Cable constants and equations are solved, resulting in ready to use data for the RSCAD/Draft program. Draft cross−references line and cable output files by name.

RSCAD/RunTime is used to control the simulation case(s) being performed on the RTDS hardware. Simulation control, including start / stop commands, sequence initiation, set point adjustment, fault application, breaker operation, etc. are performed through the RunTime Operator's Console. Additionally, on line metering and data acquisition / disturbance recording functions are available in RunTime.

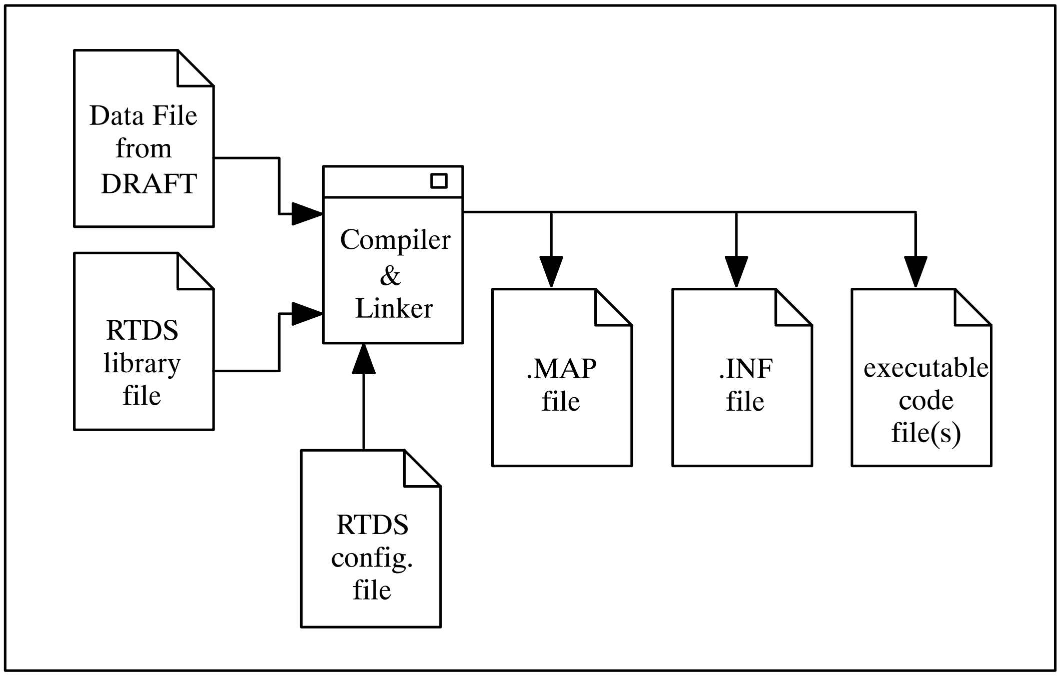
RSCAD/MultiPlot is used for post processing and analysis of results captured and stored during a simulation study. Report ready plots can be generated by MultiPlot.

RTDS Compiler / Linker & Operating System

RTDS mid level software is divided into two separate areas, the operating system and the compiler. Although neither of these elements of the RTDS software are directly accessed by the user, some mention of their role in the overall software structure must be given in order to provide a better understanding of RTDS operating principles.

The RTDS operating system performs many functions. Part of the O/S runs on the host computer workstation while part runs on the workstation interface cards. The major function of the WIF based portion of the O/S is to handle I/O requests which are usually initiated by the user. Diagnostic tests performed by the system administrator are also handled through the operating system level of software residing on the WIF. Finally, cross−rack communication errors, if they occur, will be detected by the WIF based operating system software which will in turn cause the simulation to be stopped and the appropriate LED indicators to be illuminated.

Generation of executable code required for each new simulation case is done through a specially developed set of software programs collectively termed the RTDS compiler. The compiler takes as input the power system data entered by the user through RSCAD/DRAFT along with a hardware configuration file (RSCAD\HDWR\config_file) which defines the hardware making up the user's RTDS installation. As output, the compiler produces all of the parallel processing code required by the digital signal processors, as well as memory allocation and data communication transfer schedules.



In order to generate the executable code, the compiler accesses the lowest level of RTDS software, the component library. The library contains code modules for all available power and control system component models. The code modules generally consist of low level machine language code for the individual component models and also for the overall system solution. Based on the user defined circuit, processor allocation and required library access will be performed by the RTDS compiler in a manner transparent to the user. Processor assignment can be either automatic (i.e. decided by the compiler) or can be manually specified by the user during the RSCAD/DRAFT session. The final product of the compiling process is a file (or set of files) containing DSP code which is transferred to the RTDS over the ethernet using the RSCAD/RunTime Start Command.

The compiler also produces a **.MAP** file. The .MAP file is a user readable file which provides information on processor allocation (ie : cross reference listing for component / processor match–up), input / output channel allocation, analogue output channel scaling and system initial conditions. The .MAP file is particularly useful and important when physical connections are to be made between the RTDS and external equipment.

RTDS Simulator Power System Component Library

As explained in the RSCAD/Draft Manual, icons representing all available RTDS simulator models are stored in one or more libraries. Several libraries have been included in the RSCAD Software installation. These libraries are stored at the "Master" level within RSCAD/Draft.

In general the libraries supplied by RTDS Technologies are separated into the following categories:

3PC Power System Components

3PC Control System Components

3PC IEEE Generator Control Components

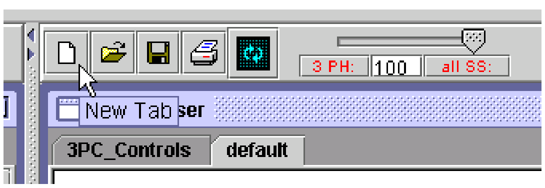
3PC Complex Control Components

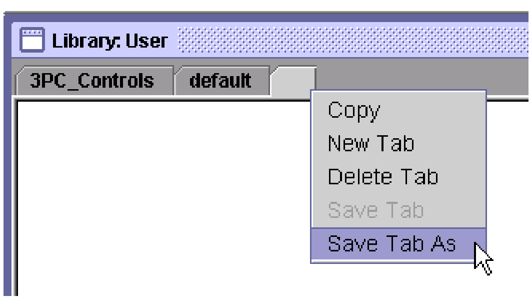
Load Flow Components / Single Line Diagrams (LF_SLD)

The User can select any one of these libraries during a RSCAD/Draft session. The 3PC based power system component models can, for example be accessed from RSCAD/Draft by using;

File−>Open−>Library, selecting Master, and then choosing the 3PC_Power_System tab near the top of the Library window.

In addition to the supplied libraries, the User is able to create and customize additional libraries and store them in the "User" level of RSCAD/Draft by clicking on the New Tab button on the library button bar. This creates a new library, which appears as a blank tab in the library window. The blank library tab may then be saved by right−clicking it, and choosing Save Tab As from the popup menu that appears. The User will then be prompted to provide a name for the library.





The graphical depiction of a Master library does not display all of its possible contents!

Components may be added to a library by right−clicking on the library canvas and choosing Add Component. The component to be added can then be located by first choosing the library type that contains it (User or Master), and then navigating to that folder. Once located, the component may be added by double clicking on it, or clicking Open with the component's file selected. Alternatively, components may be copied (or moved) into a library from another library by right clicking the component and choosing copy (or move) from the pop up window. The component may then be placed into the desired library by clicking on the desired library canvas. Note that the copy operation results in a duplicate of the component being placed, while the move operation results in the relocation of the component (it is removed from its original location).

A complete listing of available 3PC based power system component models is included in Appendix 1A which follows. The tables also include a brief description of each component, the number of 3PC processors required for each component, the component type and a cross reference to more detailed documentation.

APPENDIX 1A) POWER SYSTEM COMPONENT LIBRARY

Two basic types of power system component models are available for use on the 3PC card:

1) Standard

2) Stackable

In addition, several models have been listed as Type Special. These models do not fall into the two main categories and are used for more specialized purposes (eg. UDC model development).

Component Type 1 represents the standard component type. These components cannot be stacked and must be assigned to their own processor.

Component Type 2 includes all stackable models. One processor can be used to perform the computations of one or more stackable components. Stackable component icons are distinguished from others in the library using the following "3–bar" symbol:

☰ SHARC

In order to stack component models, the *rtds_sharc_MUPROC* icon (see Table 9) must be used. The names of the components being stacked must be specified accordingly. Currently a maximum of 5 stackable components can be assigned to a single processor, however, most models can only be stacked 2 or 3 deep.

Component Type 2 includes all UDC (User Defined Component – see Chapter 6 of the Control System Components Manual). One processor can be used to perform the computations of one or more UDC components. UDC component icons are distinguished from others in the library using the following "UDC" symbol:

SHARC
UDC

Table 1a: **Network Solution and Filter Models**			
Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_NET1da**	– SHARC Network Solution – Requires Six Processors (ganged)	Chapter 2	Standard
rtds_sharc_ **_node**	– Electrical Node Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_imonda**	– Branch Current Monitoring Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_rlcda**	– RLC Filter Branch Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_cfiltda**	– C–Type Filter Branch Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_hpfiltda**	– High Pass Filter Branch Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_rrlda**	– RRL Type Filter Branch Component – Requires No Additional Processors *	Chapter 2	Standard
rtds_sharc_ **_ddampda**	– Double Damped Filter Branch Component – Requires No Additional Processors *	Chapter 2	Standard

NOTES : For Table 1a:

* Component Code is run in NETWORK SOLUTION Processors

Table 1b: Network Switches and Event Sequencing			
Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_fault**	– Fault Branch Model – Requires No Additional Processors *	Chapter 2	Stackable
rtds_sharc_ **1phbkr**	– Circuit Breaker Model – Requires No Additional Processors *r	Chapter 2	Stackable
rtds_sharc_ **_SEQUENCER**	– Single Phase Controlled Current Source – Requires One Processor	Contact ** RTDS Tech.	Standard
rtds_sharcu_ **VARFLT**	– Fault Branch Model Variable Resistance – Requires 1 Processor	Contact ** RTDS Tech.	Stackable
rtds_sharc_ **FLTARC**	– Fault Branch Model Variable Resistance – Requires 1 Processor	Contact ** RTDS Tech.	Stackable

NOTES : For Table 1b:

* Component Code is run in NETWORK SOLUTION Processors
** Specific Documentation Unavailable at Time of Release

Table 2: Source and Equivalent System Models			
Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **SRC3**	– Main 3–ϕ Voltage Source with Eq. Imp. – Requires One Processor	Chapter 3	Stackable
rtds_sharcu_ **SRC1PH2**	– Main 1–ϕ Voltage Source with Eq. Imp. – Requires One Processor	Chapter 3	Stackable
rtds_sharc_ **brnch**	– Single Phase Controlled Current Source – Requires One Processor	Chapter 2	Standard
rtds_sharc_ **brnch3**	– Single Phase Controlled Current Source – Requires One Processor	Chapter 2	Standard
rtds_sharcu_ **SRC4**	– Special 3–ϕ Voltage Source with Eq. Imp. – Requires One Processor	Contact RTDS Tech	Special
rtds_sharcu_ **SRC1PH2**	– Main 1–ϕ Voltage Source with Eq. Imp. – Requires One Processor	Chapter 3	Stackable

Table 3a: Transformer Component Models

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_TRF3P2W**	– Main 2–Winding 3–ϕ Transformer – Requires One Processor	Chapter 4	Stackable
rtds_sharc_node **_TRF3P2Wa**	– 2–Winding 3–ϕ Transformer – Includes Selectable Phase Shift – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_TRF3P2Wauto**	– 2–Winding 3–ϕ Auto–Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_TRF2W3TAP**	– Obsolete 2–Winding 3–ϕ Transformer – Original Model With Adjustable Taps – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_TRFG3**	– 2–Winding 3–ϕ Transformer – Neutral Node on Y Side Collapsed – Requires One Processor	Contact ** RTDS Tech	Standard
rtds_sharc_ **_TRF3P3W**	– Main 3–Winding 3–ϕ Transformer – Requires One Processor	Chapter 4	Stackable
rtds_sharc_ **_TRF3P3Wauto**	– 3–Winding 3–ϕ Auto Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_sharc_ **_TRF2WTAP**	– 2–Winding 1–ϕ Transformer – Includes Adjustable Tap – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_sharc_ **_TRF1P2Wauto**	– 2–Winding 1–ϕ Auto Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_sharc_ **_TRF1Pflt**	– 2–Winding 1–ϕ Transformer – Includes Fault Branch – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_sharc_ **_TRF1P3W**	– 3–Winding 1–ϕ Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_sharc_ **_TRF1P3Wauto**	– 3–Winding 1–ϕ Auto Transformer – Requires One Processor	Contact ** RTDS_Tech	Standard
rtds_sharc_sharc_ **_grtrf**	– 2–Winding 3–ϕ Grounding Transformer – Requires One Processor	Contact ** RTDS_Tech	Standard

NOTES : For Table 3: ** Specific Documentation Unavailable at Time of Release

Table 3b: Transformer Component Models			
Component Name	Component Description	Component Reference	Component Type
rtds_sharcu_ **_TRF1P2Wflt2**	– 2–Winding faulted 1–ϕ Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_u **_TRF1P3WAflt**	– 2–Winding 1–ϕ faulted Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu **_TRF1P3Wflt**	– 2–Winding 1–ϕ faulted Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **TRF1P3Wflt2**	– Obsolete 2–Winding 1–ϕ Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **TRF1P4W**	– 4–Winding 1–ϕ Transformer – Requires One Processor	Contact ** RTDS Tech	Standard
rtds_sharcu_ **TRF3P2Wfilter**	– 2–Winding 3–ϕ Transformer – Requires One Processor	Contact ** RTDS Tech	Stackable
rtds_sharcu_ **TRF3P2Wf_dev**	– 2–Winding 3–ϕ Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **TRF3P3W2BUS**	– 2–Winding 3–ϕ Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **_TRF3PSAT**	– 2–Winding 1–ϕ Auto Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **_TRF3ZIGZAG**	– 3–ϕ ZIGZAG Transformer – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_TRFG4**	– 2–Winding 3–ϕ Transformer – Requires One Processor	Contact ** RTDS Tech	Standard

NOTES : For Table 3: ** Specific Documentation Unavailable at Time of Release

Table 4a: Transmission Line Component Models

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_TLINE1**	– 1–Conductor Travelling Wave Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_node **_TLINE2**	– 2–Conductor Travelling Wave Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_TLINE3**	– 3–Conductor Travelling Wave Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_TLINE6**	– 6–Conductor Travelling Wave Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_TLINE9**	– 9–Conductor Travelling Wave Line – Requires Two Processors	Chapter 5	Standard
rtds_sharc_ **_CTLINE9**	– Same as TLINE9 – Common Bus Icon – Requires Two Processors	Chapter 5	Stackable
rtds_sharc_ **_sline9**	– Common Bus Short Line (9–Conductor) – Requires Two Processors	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_TLINE12**	– 12–Conductor Travelling Wave Line – Requires Two Processors	Chapter 5	Standard
rtds_sharc_ **_CTLINE12**	– Same as TLINE12 – Common Bus Icon – Requires Two Processors	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_PI3**	– 3–Conductor PI Section Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_PI6**	– 6–Conductor PI Section Line – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_MUTRL**	– 6–Conductor Mutually Coupled RL Line – Requires One Processor	Contact ** RTDS_Tech	Stackable

NOTES : For Table 4a: ** Specific Documentation Unavailable at Time of Release

Table 4b: Transmission Line Component Models (continued)			
Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_TL16TRM**	– Unified Transmission Line Model – Requires One–Two Processors – Requires Simultaneous Use of TL16CAL	Chapter 5	Standard
rtds_sharc_ **_TL16TRMC**	– Unified Transmission Cable Model – Requires One–Two Processors – Requires Simultaneous Use of TL16CAL	Chapter 5	Standard
rtds_sharc_node **_TL16CAL**	– For Use With TL16TRM / TL16TRMC – No Additional Processors	Chapter 5	Standard
rtds_sharc_ **_TLINE3IFACE**	– Transmission Line Interface Component – For Interfacing to Analogue Simulator – Requires One Processor	Chapter 20	Stackable

NOTES : For Table 4b: ** Specific Documentation Unavailable at Time of Release

Table 5: Machine Models

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_MACM2**	– Synchronous Machine Model (ver.2) – Requires One Processor	Chapter 6	Standard
rtds_sharc_ **_mm**	– Multi–Mass Model for Synchronous Machine – Requires One Processor	Chapter 6	Standard
rtds_sharc_ **_INDM**	– Main Induction Machine Model – Requires One Processor	Chapter 6	Stackable
rtds_sharc_ **_MAC_V3**	– Main Synchronous Machine Model (ver.3) – Requires One Processor	Chapter 6	Standard

Table 6: Measurement Transducer Models

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_CT2**	– Main Current Transformer (CT) Model – Requires One Processor	Chapter 7	Standard
rtds_sharc_ **_CVT2**	– Main CVT Model – Requires One Processor	Chapter 7	Standard
rtds_sharc_ **_1CT**	– Single CT with Alternate Magnetizing Code – Requires One Processor	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_3CTd**	– Three CT Model With Common Secondary – Requires One Processor	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_3CTdlt**	– Three CT Model With Δ Connected Sec. – Requires One Processor	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_4CT**	– Four CT Model With Common Secondary – Requires One Processor	Contact ** RTDS_Tech	Standard
rtds_sharc_ **_CVT1**	– Single Phase CVT Model – Requires One Processor	Chapter 7	Standard
rtds_sharc_ **_CVT3**	– Three Phase CVT Model – Requires One Processor	Chapter 7	Standard

NOTES : For Table 6: ** Specific Documentation Unavailable at Time of Release

Table 7a: Models for Advanced Power System Components			
Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_VGP6V4**	– 6–Pulse Valve Group Model for HVDC – Requires 1 Processor Per 6–Pulse Group	Chapter 8	Standard
rtds_sharc_ **_SA–SAT**	– Converter Transformer Saturation Model – Requires One Processor for 6 or 12–pulse	Chapter 8 **	Standard
rtds_sharc_ **_SWBRC**	– Special Switched Branch / Filter Model – Requires One Processor Per Phase	Chapter 9	Standard
rtds_sharc_ **_1phrectifier**	– 1–Phase Rectifier Model (Embedded Type) – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_1phrct_intf**	– Interfaced Type 1–Phase Rectifier Model – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **_GTOB4**	– Main Voltage Type Converter Model – Requires One Processor	Chapter 14	Standard
rtds_sharc_ **_SCAP**	– Series Compensation Model for T–Lines – Requires One Processor	Chapter 10	Standard
rtds_sharc_ **_TCSC**	– Thyristor Controlled Series Compensation – Requires One Processor Per Phase	Chapter 11	Standard
rtds_sharc_ **_LARR1**	– Line Arrester Model – Requires One Processor	Chapter 15	Standard
rtds_sharc_ **SVC3**	– Main Interfaced Version of SVC Model – Requires One–Three Processors	Chapter 12	Standard
rtds_sharc_ **_SVC4**	– Main Embedded Version of SVC Model – Requires One Processor TSC or TCR Bank	Chapter 13	Standard
rtds_sharc_ _N**Linductor**	– Non Linear Inductor – Requires One Processor	Chapter 16	Stackable
rtds_sharc_ N**Linductor3**	– Non Linear Inductor – Requires One Processor	Chapter 16	Stackable
rtds_sharcu_ **VARL**	– Variable Inductor – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **VSC1PH**	– Voltage Source Converter – 1 ph – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **ARCFURN**	– Arc Furnace – 3 ph – Requires One Processor	Contact ** RTDS_Tech	Standard

NOTES : For Table 7a: ** Specific Documentation Unavailable at Time of Release

Table 7b: Models for Advanced Power System Components			
Component Name	Component Description	Component Reference	Component Type
rtds_sharcu_ **DYLOAD**	– Dynamic Load Model 3 ph – Requires 1 Processor Per 6–Pulse Group	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **RLDload**	– Dynamic Load Model 3 ph – Requires 1 Processor Per 6–Pulse Group	Contact ** RTDS_Tech	Stackable
rtds_sharcu_ **SPARST**	– Single Phase Arrestor – Requires One Processor Per Phase	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **VARRES**	– Variable Resistor – Requires One Processor	Contact ** RTDS_Tech	Stackable
rtds_sharc_ **zrlc**	– Zero Sequence Load – Requires One Processor	Contact ** RTDS_Tech	Stackable

NOTES : For Table 7b: ** Specific Documentation Unavailable at Time of Release

Table 8: ANALOG INPUT / OUTPUT Components

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_DAC16**	– Basic ODAC16 Output Component – Requires One Processor for Each ODAC16	Chapter 19	Stackable
rtds_sharc_ **_DAOVR2**	– Main ODAC16 Output Component – Includes Oversampling Feature – Requires One Processor for Each ODAC16	Chapter 19	Standard
rtds_sharc_ **_DAOVR1**	– Obsolete ODAC16 Output Component – Includes Oversampling Feature – Requires One Processor for Each ODAC16	Chapter 19	Standard
rtds_sharc_ **_OADC3**	– Main OADC Input Component – Must Run On Processor "C" of the 3PC Card – Requires One Processor for Each OADC	Chapter 19	Standard
rtds_sharc_ **_OADCINJ**	– Special Current Injection Input Component – Must be Used Together with OADC3 – Requires No Additional Processors	Chapter 19	Standard
rtds_sharc_ **_FDAOVR1**	– FDAC Output Component – Includes Oversampling Feature – Requires One Processor for Each FDAC	Chapter 19	Standard
rtds_sharc_ **_FDAOVR2**	– Main FDAC Output Component – Includes Oversampling Feature – Requires One Processor for Each FDAC	Chapter 19	Standard
rtds_sharcu_ **DDAC**	– Basic DDAC Output Component – Requires One Processor for Each DDAC	Chapter 19	Stackable
rtds_sharcu_ **FDAC**	– Basic FDAC Output Component – Requires One Processor for Each FDAC	Chapter 19	Stackable
rtds_sharcu_ **OADC**	– Basic OADC Output Component – Requires One Processor for Each OADC	Chapter 19	Stackable

NOTES : For Table 8: * Special Type of Component That Cannot Be Simultaneously Run on a Rack With Any Other Type of Component

** Specific Documentation Unavailable at Time of Release

Table 9: Additional Special Purpose Components

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_MPROC**	– Model Stacking Component – Used for *Stackable Type* Components – Requires No Additional Processors	Chapter 1	Special
rtds_sharc_ **_PLAYBACK**	– COMTRADE Playback Component – Requires One–Nine Processors – No Other Components Models Can Run On a Rack Being Used for COMTRADE Playback	Chapter 17	Standalone *
rtds_sharc_ **_SLIDER**	– Input Slider for Power System Components – Requires No Additional Processors	Chapter 2 Ctrl. Manual	Special
rtds_sharc_ **FIROUT1**	– Firng Pulse Output to Digital Port – Requires 1 Processor	Contact ** RTDS_Tech	Special
rtds_sharc_ **ZCPDIG**	– Zero Crossings to Digital Output Port – Requires 1 Processor	Contact ** RTDS_Tech	Special
rtds_sharc_ **STINJ**	– Component for Combining Current Injections – Requires No Additional Processors	Contact ** RTDS_Tech	Special
rtds_sharc_ **_PLOT**	– Global Variable RunTime Plotting Component – Used for UDC Development/Debugging – Requires No Additional Processors	Contact ** RTDS_Tech	Special
rtds_sharc_ **_dmplot**	– Data Memory Plotting Component – Used for UDC Development/Debugging – Requires No Additional Processors	Contact ** RTDS_Tech	Special
rtds_sharc_ **_stk_AOUT**	– Component for Analogue Output Assignment – Used for UDC Development/Debugging – Requires No Additional Processors	Contact ** RTDS_Tech	Special
rtds_sharc_ **_diagnostic6**	– Internal Variable RunTime Plotting Component – Used for UDC Development/Debugging – Requires No Additional Processors	Contact ** RTDS_Tech	Special
rtds_sharc_ **_CALCULATOR**	– Component to Perform Calculator Functions – Used for UDC Development/Debugging – Requires No Additional Processors	Contact ** RTDS_Tech	Special

NOTES : For Table 9: ** Specific Documentation Unavailable at Time of Release

Table 10: Pre–Processor Components

Component Name	Component Description	Component Reference	Component Type
rtds_sharc_ **_pp_fault**	– Fault Branch Model – Pre–Processor Type – Requires No Additional Processors *	Chapter 2	Standard
rtds_**pp_sharc_** **_split_TLINE3**	– 3–Conductor Travelling Wave Line – Pre–Processor Component – Requires One Processor	Chapter 5	Stackable
rtds_**pp_sharc_** **_split_TLINE6**	– 6–Conductor Travelling Wave Line – Pre–Processor Component – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_PI3_pp**	– 3–Conductor PI Section Line – Pre–Processor Component – Requires One Processor	Chapter 5	Stackable
rtds_sharc_ **_PI6_pp**	– 6–Conductor PI Section Line – Pre–Processor Component – Requires One Processor	Chapter 5	Stackable
rtds_ **_pp_var**	– Pre–Processor Slider Component – Requires No Additional Processors	Chapter 18	Special
rtds_sharc **_pp_capfilt**	– Pre–Processor Slider Component – Requires No Additional Processors	Contact ** RTDS_Tech	Standard
rtds_sharc **_pp_rlcda**	– Pre–Processor Slider Component – Requires No Additional Processors	Contact ** RTDS_Tech	Standard

2 RTDS GENERAL OPERATION

This section presents most of the important concepts and terms regarding the operation of the RTDS. The application of networks and subsystems to the RTDS hardware are described together with the network solution.

The following basic steps are required for the preparation of a new case for simulation using the RTDS.

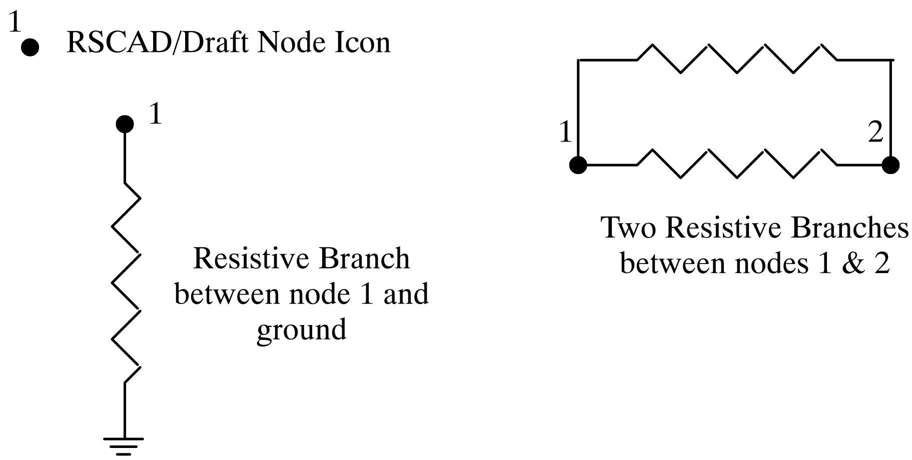
1) Create new Project & Case directories from RSCAD/Fileman (optional)
2) Using RSCAD/Draft, layout the new power system model and define the starting rack number
3) Compile the newly created system model from RSCAD/Draft
4) Run the simulation using the RSCAD/RunTime software
5) Plot and analyse simulation results using RSCAD/MultiPlot

The best way for a novice user to become familiar with RSCAD and the RTDS is to follow the step by step instructions provided in the **RTDS Tutorial Manual**. The Tutorial Manual directs the user through the entire procedure required to perform the simulation of a new circuit using the RTDS.

2.1 THE DEFINITION OF NODES & BRANCHES

A node is defined as the interconnection point between power system component models. A branch is defined as a passive circuit element such as resistor, inductor or capacitor, or certain combinations thereof which are placed between two nodes, or between a node and ground. Ground is not considered to be a node and is defined as an absolute reference of zero volts. The user may define a node to represent a common neutral separate from ground. Note that a node is a single phase entity.

Where more than one passive component is connected in series, the connecting node does not have to be explicitly placed unless the user needs to monitor the voltage at that point. Nodes are often a scarce resource in the RTDS, and they are mathematically absorbed where ever possible.

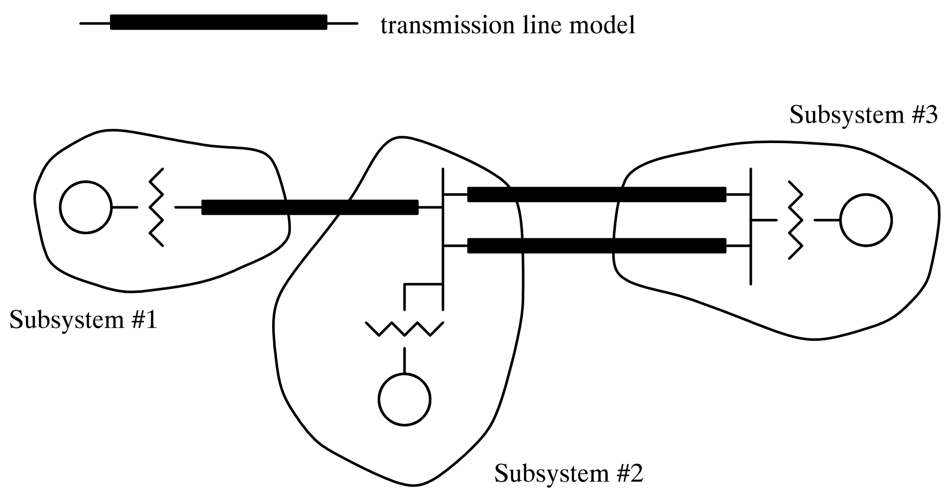


2.2 THE CONCEPT OF SUBSYSTEMS

The concept of a *subsystem* is an extremely important one in relation to the RTDS. Subsystems are also applied extensively in the **EMTDC**™ Electromagnetic Transients Software. A subsystem is defined as a portion of a power system model which is mathematically isolated from other portions of the system, and is usually linked only by travelling wave transmission lines to other subsystems. These specific portions of the network are said to be *decoupled* and may be solved independently and hence in parallel. Subsystems are important because the time required to solve a network grows exponentially with the number of nodes. By splitting one system into two, the total number of calculations is usually reduced by much more than half. In addition, the two subsystems may be solved in parallel.

It is not an absolute requirement to split a system model into subsystems if the user's model fits onto a single rack of RTDS hardware and sufficient nodes are available. A single subsystem may not span more than one rack, but more than one subsystem may exist on a single rack.

The user defines a subsystem with a network solution icon and the power system components attached to its nodes. For 3PC only racks, 2 network solutions (subsystems) are permitted per rack and each network solution can solve 21 nodes. Each rack corresponds to one RSCAD/Draft page, therefore 2 network solutions may be placed on each page. When the network is too large to fit on a rack, transmission line models are normally used to span racks. More than one transmission line can be used to connect the same two racks, as shown below. If an RPC is present in the rack, then 54 nodes are possible, with only one network solution.



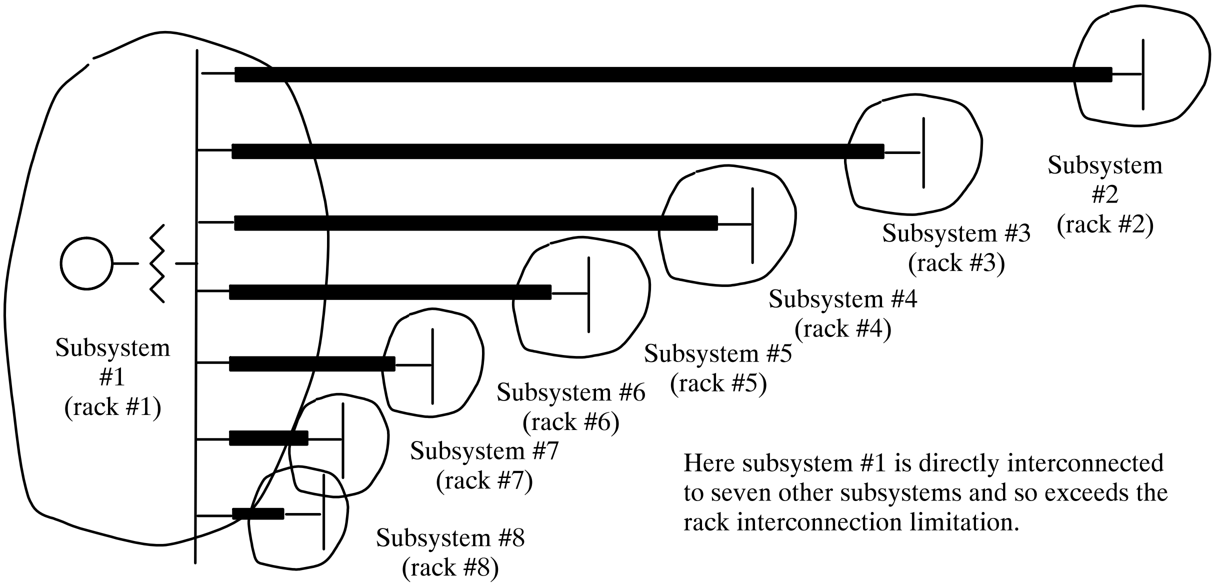
The number of direct interconnections between racks is limited

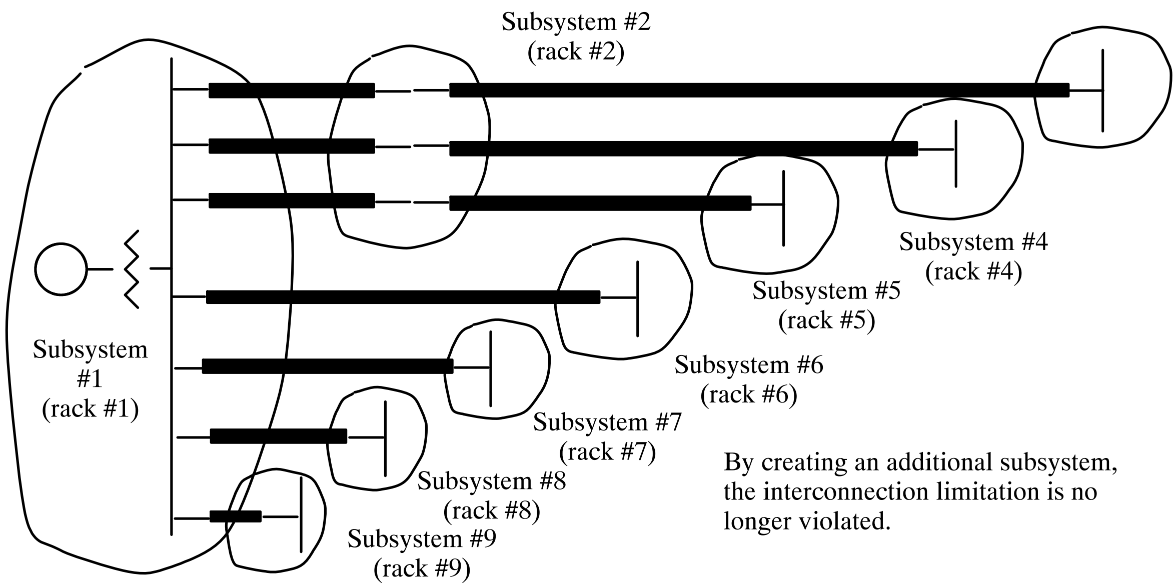
The inter−rack communication card (IRC) is used to communicate data between racks. The number of racks to which a single rack can communicate is limited by the capability of the IRC. IRC's permit direct communication from one rack to six others.

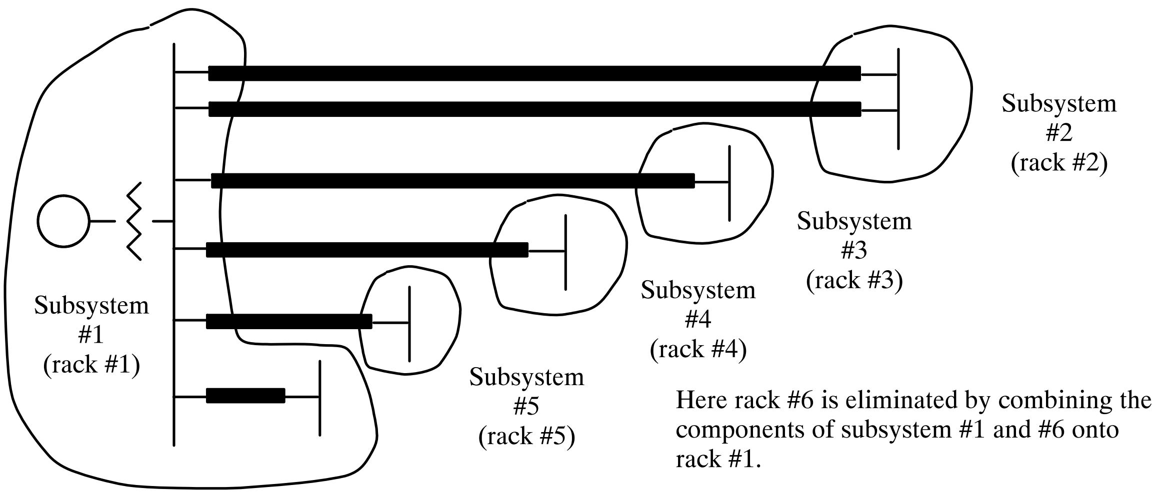
Since power system networks are in general radial, the maximum number of inter−rack connections is not usually exceeded. Furthermore, often more than one subsystem can be modelled on a single rack hence further relaxing the limitation implied here. If necessary, the user may place a short transmission line in order to create an artificial subsystem, thus circumventing the limitation by allocating more hardware to model the network.

For RTDS simulators consisting of a very large number of racks it is possible to install two IRC's, thereby doubling the number of interconnections between racks.

Many transmission line models also support wheeling of transmission line data. This means that if a line needs to connect 2 racks that are connected only through an intermediate rack, the T−Line model can be run on the intermediate rack, gather data from one end, say the sending end, and send it to the destination rack, the receiving end.


Subsystem
#2
(rack #2)
Subsystem #3
(rack #3)
Subsystem #4
(rack #4)
Subsystem #5
(rack #5)
Subsystem #6
(rack #6)
Subsystem #7
(rack #7)
Subsystem #8
(rack #8)
Subsystem
#1
(rack #1)
Here subsystem #1 is directly interconnected to seven other subsystems and so exceeds the rack interconnection limitation.


Subsystem #2
(rack #2)
Subsystem #4
(rack #4)
Subsystem #5
(rack #5)
Subsystem #6
(rack #6)
Subsystem #7
(rack #7)
Subsystem #8
(rack #8)
Subsystem #9
(rack #9)
Subsystem
#1
(rack #1)
By creating an additional subsystem, the interconnection limitation is no longer violated.



Although it is convenient to use transmission line models to split a network into separate subsystems, it is not always necessary. The user may define the sending and receiving ends of a transmission line within the same subsystem simply by placing the two portions of the transmission line icon on the same canvas page within the RSCAD/Draft software.

2.3 MAPPING POWER SYSTEM COMPONENTS TO PROCESSORS

With some background knowledge of how the individual processors within an RTDS rack are allocated to specific power system components, the user can more effectively use the RTDS to perform power system simulations. Allocation of processor cards can be done either automatically by the RTDS compiler or manually by the user. The compiler software essentially converts the graphical representation of a power system entered by the user from the RSCAD/Draft module into machine level code which is directly executed when the case is run. The .MAP file, generated by the RTDS compiler, provides the user with information as to which processors have been allocated to which part of the user's circuit.

When a new power system model is to be constructed, or an existing one is to be modified, the user can easily determine whether enough RTDS hardware is available to simulate that particular system by understanding how the RTDS compiler allocates processors. The following simple rules are used by the compiler when automatically assigning hardware to the user specified power system model.

- DRAFT pages are allocated to racks sequentially; that is page #1 is allocated to Rack #1, page #2 to Rack #2 and so on.

- In the case of an all 3PC rack, each network solution is assigned to DUAL 3PC pair of cards, starting from the lowest numbered pair of cards. In the case of an RPC or GPC card, one RISC processor is allocated.

- 3PC Processors required to model power system components such as transformers, machines etc. are allocated as needed beginning with the first available processor after the network solutions. Some power system components require more than a single processor.

- Many models are stackable; that is they can be combined to run on a single processor.

- A number of components can be executed on one RISC processor. The number of components that can be executed on a processor is determined by the load units. An RPC/GPC processor can be assigned a maximum of 100 units. A PB5 processor can be assigned a maximum of 120 units. The components are allocated units as follows.

Model	Units
Generator Model	20
1–3 Conductor Bergeron Line/Cable Model	10
4–5 Conductor Bergeron Line/Cable Model	20
6–8 Conductor Bergeron Line/Cable Model	30
6 Conductor Bergeron Line/Cable Model with breaker included	40
9–12 Conductor Bergeron Line/Cable Model	40
1–2 Conductor Frequency Dependant Phase Domain Line/Cable Model	20
3 Conductor Frequency Dependant Phase Domain Line/Cable Model	30
4 Conductor Frequency Dependant Phase Domain Line/Cable Model	50
5 Conductor Frequency Dependant Phase Domain Line/Cable Model	70
6 Conductor Frequency Dependant Phase Domain Line/Cable Model	100
Pi–Section Model	10
Switched Filter Model (single phase)	10
UMEC Transformer Model	30

3Phase 2Winding Transformer Model (Ideal, Linear)	10
3Phase 2Winding Transformer Model (Saturation)	20
3Phase 3Winding Transformer Model (Ideal, Linear)	10
3Phase 3Winding Transformer Model (Saturation)	20
3Phase 3Winding Auto Transformer Model (Ideal)	10
3 Phase Source Model	10
SVC4 Model	20
TCSC Model (single phase)	20
Valve Group Model	20
CVT Model (three phase)	10
CT Model (three phase)	10
PT Model (three phase)	10
SCAP with MOV Model	20
Induction Machine Model	20
Single Phase Arrestor Model	10
Three Phase Arrestor Model	20
ARC Furnace Model	20
Dynamic Load Model	10
12 Pulse Valve Group Model	50
12 Pulse Valve Group Model (with optional fourther winding)	70

For example, two generator models and six 3 conductor bergeron line models could be allocated to one GPC RISC processor. By default, the stacking of RISC components is done automatically by the compiler. Alternatively, allocation of RISC components can be done manually. If required a RISC component can request exclusive use of the processor.

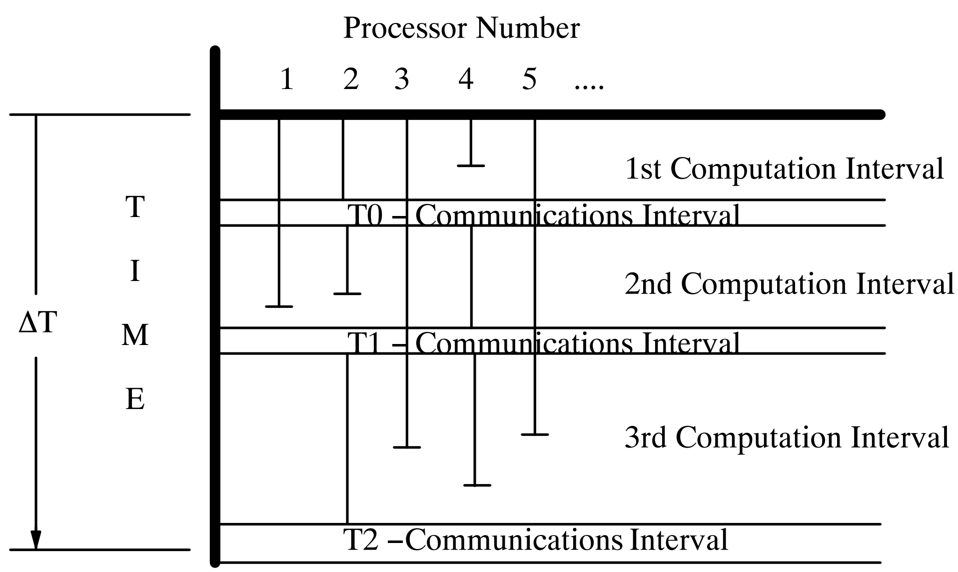
2.4 THE SIMULATION TIME STEP (Δt)

Selection of the simulation time step is important in the preparation of a new simulation case. The state of the power system network is only computed at integral instants of time. The network node voltages and branch currents for a particular instant are based entirely on the voltages and currents from the previous time–steps. It should be quite clear that selection of an exceptionally large time step in relation to system frequency will result in simulation results which will not accurately represent those of the physical circuit. In fact, the user must select a time step which is smaller than the highest frequency of interest. A time step on the order of 50.0 to 60.0 μs is common for studies being performed on the RTDS.

In order to achieve real–time operation, the RTDS must be able to solve all of the equations representing the user's defined power system within the selected time–step. Since an RTDS consisting of a given number of racks and processors has a limited processing capability, the time–step cannot be made arbitrarily small without losing the capability of operating in real–time. Although it is possible to operate the RTDS at less than real–time (i.e. non–real time or off–line) the quantities observed on the analogue output channels no longer represent the true response of the system.

The .MAP file contains the minimum time–step with which the power system model could be simulated in real–time. If the user so wishes, the time step can be re–entered in the RSCAD/Draft module based on that suggested in the .MAP file by the compiler. The case can then be re–compiled in order to achieve operation with the minimum allowable time–step.

2.5 COMMUNICATIONS AND COMPUTATIONS WITHIN RTDS RACKS



Processors in an RTDS rack perform computations in parallel and must exchange data from one to four times during a time step. Time steps are divided into communication intervals and computation intervals, referred to as T0 to T4. The above illustration shows only 3 communication intervals, as T4 is normally not used.

In a typical simulation, most processors performing power system calculations will read node voltages from the previous time step and begin calculating injection currents. Once the last processor has completed its calculations, the T0 transfer takes place, (processor 2 in the above example). At this time, the injections are transferred to the network solution processors. Variables from processors performing control functions can also be transferred at this time. Processors which need information passed in T0 must wait until the transfer is complete before they can read the new data in their local memories and resume calculations. Processors which do not need to read or write new data passed in T0 continue processing uninterrupted, (processor 1, 3 and 5 in the above example). Any time a processor completes it calculations, it stops and enters an idle state, waiting for the next communication interval in which it is to participate.

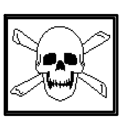
Most models do not require communications during the T1 interval so they continue until T2. The last communication interval, usually T2, is when new node voltages are transferred as well as most control type variables. Generally all processors participate in this communication interval and this is usually the end of the time step.

Variables which are passed on the backplane for monitoring purposes only, are transferred outside of the usual communication intervals. These variables can be monitored without impacting the size of the time step.

2.6 MONITORING OF SYSTEM QUANTITIES

There are two distinct methods of observing system quantities when using the RTDS. First, the user is able to monitor quantities such as node voltages and branch currents by connecting an oscilloscope or other measurement device to the analogue output ports located on the front panel of each 3PC. Second, the user is able to monitor quantities on the host workstation via icons created using the RSCAD/RunTime software. Display on the workstation monitor can be continuous by way of meter icons or can involve plots which capture quantities from the system over a pre−defined period of simulation time. The user can initiate both steady−state and transient data captures from the RSCAD/RunTime software module.

The system quantities which are available for observation during a simulation depend on what particular power system component models are included in the user's circuit and which variables the user has requested for monitoring from the RSCAD/Draft software. The .MAP file produced by the RTDS compiler should be consulted to determine the monitoring points for specific variables.



D/A output may adversely effect equipment interfaced to the RTDS.

If the RTDS is interfaced to external equipment via the analogue channels, the user should ensure that the signals present on the D/A's do not unduly stress the external equipment. Particular caution should be exercised when the RTDS is interfaced via power amplifiers. Certain power system component models generate and display dc signals on the analogue output channels. These dc signals can range anywhere between the d/a output limits of +/− 10 volts. Inadvertently running a case which provides the wrong signal to the amplifiers may in turn cause damage to the amplifiers or any external equipment being supplied at their outputs.

It should be noted that whenever a simulation case is stopped, the output values of all analogue channels are reset to zero volts. Thus, if the user finds that an unexpected or incorrect signal is being passed to the interfaced equipment the case may be halted by pressing the STOP icon on the RSCAD/RunTime window. Such action will stop the simulation case and all analogue output channels will be set to 0 volts.

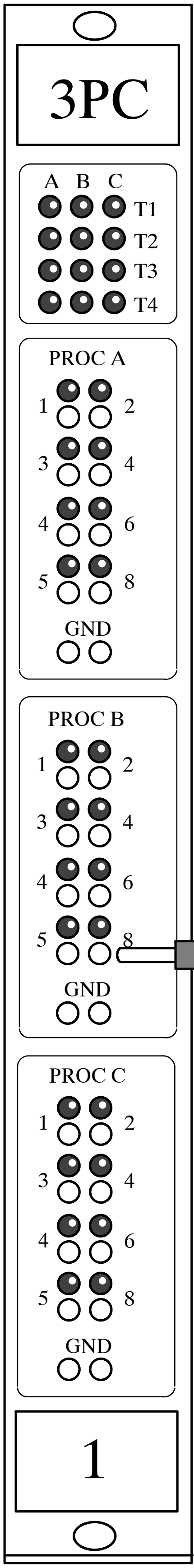
In addition to the on−board 12−bit Digital to Analogue converters described here, the RTDS simulator can also be equipped with optional high precision 16−bit D/A converter units (the FDAC and the DDAC). Chapter 18 in this Manual presents details about these cards and their use.

2.6.1 ANALOGUE OUTPUT CHANNELS

Each 3PC contains 24 analogue output channels which are accessible from the card's front panel. Eight channels are allocated to each processor. Details concerning the D/A converters can be found in the RTDS Hardware Manual.

Use of a particular processor's analogue channels varies depending upon the power system component assigned to run on that processor. The most common use of the analogue channels, however, is for the monitoring of node voltages and branch currents. The user selects which currents and voltages are to be monitored through the RSCAD/Draft software as explained in Section 2.7.

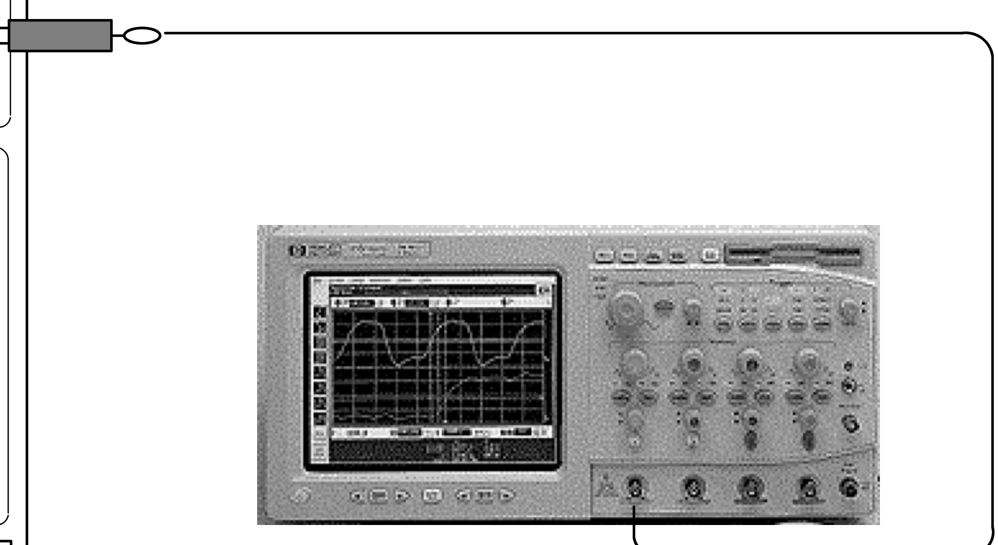
Processors other than those assigned to the network solution use the analogue output channels as necessary. For example, a processor assigned to model transformer saturation and hysteresis assigns one analogue channel to magnetizing current and another to flux. It is thus possible to observe the hysteresis loop by using the X−Y plotting function available on most oscilloscopes.



DAC–8412 DIGITAL – ANALOGUE CONVERTER

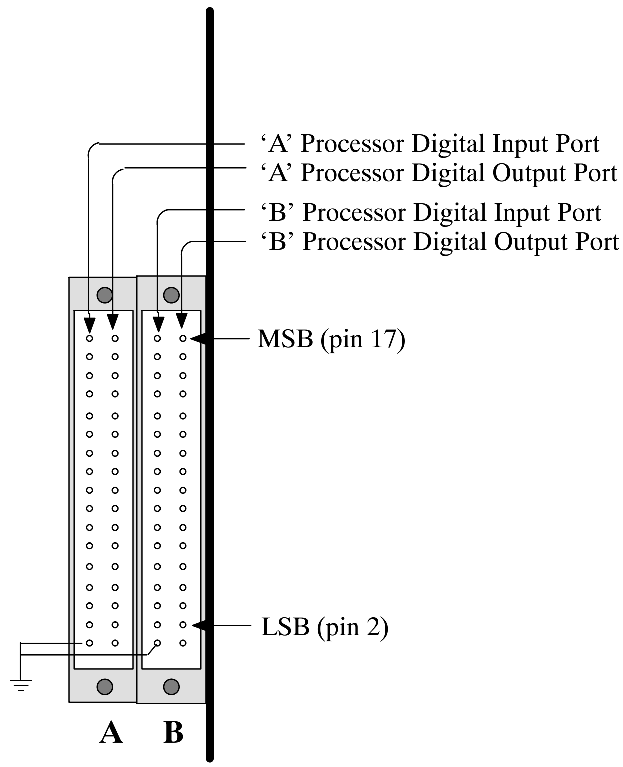
Number of Channels per processor:	8 (2 x quad DACs)
Resolution:	12 bit
Analogue Output Voltage range:	+/– 10 volts
Maximum Output Current:	+/–5 mA
Slew Rate:	2.2 V/µs
Settling Time:	6 µs

Each 3PC includes a total of 24 analogue output channels which can be used to monitor power system signals such as bus voltages, line currents, as well as, a wide variety of other signals associated with power system or control system component models.



2.6.2 DIGITAL INPUT / OUTPUT PORTS

Sixteen bit digital input and output ports are located at the rear of each 3PC (accessible from the rear of the RTDS cubicle). These are directly connected to the A and B processors. No direct digital I/O is available to the C processor. Allocation of the digital ports depends on the power system model assigned to a particular 3PC. For example, the 3PC processor pair processor assigned to the network solution uses the digital input port to read switch (i.e. circuit breaker or fault) open/close commands issued from physical equipment interfaced to the RTDS. The digital output port displays the status (opened or closed) of the switches.



3PC Digital Input/Output Port (View from rear of Cubicle)

If no connection is made to a pin of the digital input port, the processor reads a logic '1'. For a logic '0' the user should connect the digital input port pin to signal ground. The digital output port provides 5 volts as logic '1'.

2.6.3 ON–SCREEN MONITORING USING THE HOST WORKSTATION

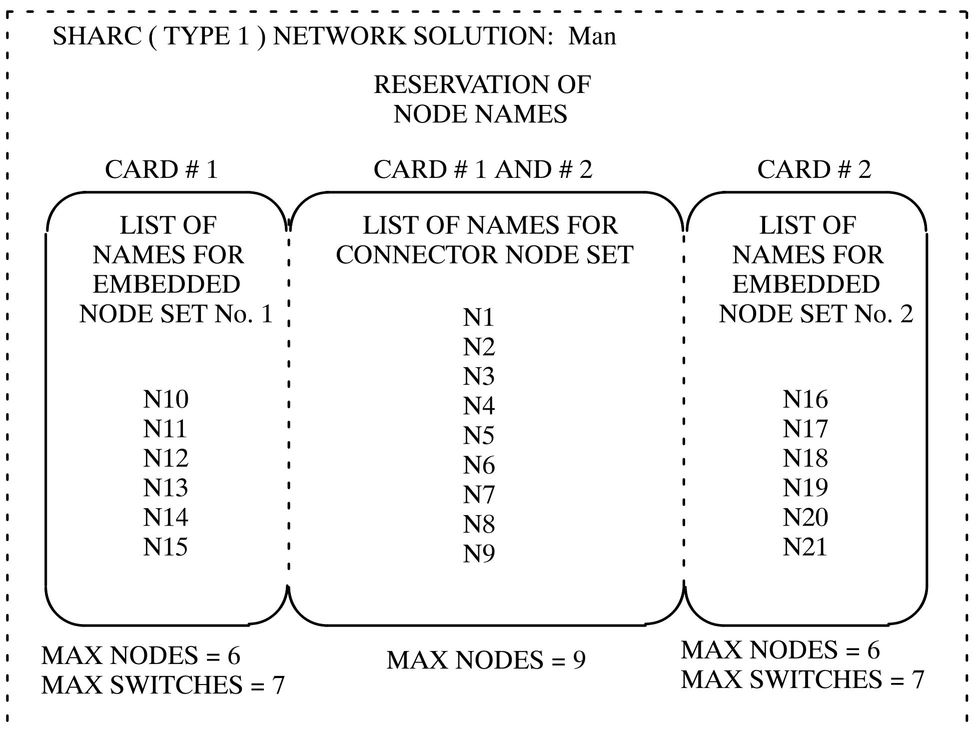
Data computed by the RTDS can be sent back and viewed on the host workstation. Information is communicated between the workstation and the RTDS using the ethernet local area network. The RSCAD/RunTime module allows the user to display the incoming data using various types of meter and plot icons.

As in the case of analogue channel monitoring, node voltages are always available for on−screen monitoring on the computer workstation.

The user is referred to the **RSCAD/RunTime User's Manual** for extensive information regarding the creation and use of meter and plot icons. Individual power system component models offer a variety of monitoring options and hence the user is directed to the particular sections of this manual which deal with the specific models for further details on what variables can be monitored and how monitoring is specified.

2.7 THE 3PC REAL TIME NETWORK SOLUTION (rtds_sharc_NET1da)

This section on the Real Time Network Solution (rtds_sharc_net1da) refers to operation on dual 3PC cards. A Real Time Network Solution for the RPC is available, if an RPC card exists in the rack. See section 2.8.



One or two Real Time Network Solutions are allowed on a rack of RTDS hardware. Each of the possible two Real Time Network Solutions can provide up to 21 nodes and up to 28 single−phase breakers. This gives the possibility of 42 nodes on a rack with up to 56 single−phase breakers. However, nodes belonging to separate Real Time Network Solutions must be treated as nodes in separate subsystems. In particular, the two Network Solutions may only be connected together using travelling−wave transmission line models.

The approach taken in the Real Time Network Solution is to pre−invert for two 6−node portions of the network (Embedded Node Sets No. 1 and No. 2 in the above icon) and to perform LU decomposition in each simulation time−step for the remaining 9−node portion of the network (the Connector Node Set in the above icon). The Embedded and Connector node sets shown in the above icon are interconnected by further mathematically rigorous matrix operations during each time−step.

The TPC NEC−based network solution is not available on a rack when a 3PC−based Real Time Network Solution is used. However, in one simulation a NEC−based network solution can be used on some racks while Real Time Network Solutions are used on other racks.

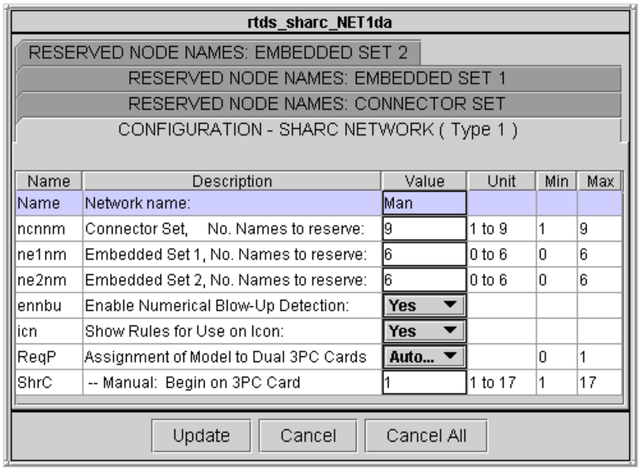
Each Real Time Network Solution is solved on two 3PC processor cards which have been physically connected together to form a set of Dual 3PC cards. A set of Dual 3PC cards has three electrical link−port connections which connect processors on the two cards. This gives a connected set of 6 processors for accomplishing the Sharc Network Solution.

The Dual 3PC cards must be identified as such in the RTDS racks configuration file ("config_file"). Please see Section 2.4 of the RTDS Hardware Manual for details regarding 3PC entries in the "config_file".

2.7.1 HOW TO USE THE REAL TIME NETWORK SOLUTION

The Real Time Network Solution model is invoked by copying the above icon from the Sharc components library and placing it on a canvas in DRAFT. The PARAMETERS menu of the icon may be accessed by choosing Edit −> Parameters from the popup menu that appears upon right−clicking its icon.

The primary function of the PARAMETERS menu is to specify which nodes will be treated by the model as belonging to the Connector Node set and which nodes will be treated as belonging to each Embedded Node set. The CONFIGURATION menu appears as follows:



The Network Name specified in the CONFIGURATION menu will appear on the icon in DRAFT. The name of each Network Solution component must be unique.

As may be noted in the CONFIGURATION menu, the User must reserve at least one name which will be recognized by the model as a Connector type node. Up to 9 node names may be reserved, although it is not necessary to use them immediately. Connector nodes are the most powerful type of node. All 28 single–phase breakers could be connected between Connector nodes. These nodes are related to the portion of the G (conductance) matrix which is constructed and decomposed in every time–step.

Between 0 and 6 node names may be reserved for each Embedded Node set. These Nodes can have a maximum of 7 single–phase breakers incident on them and are related to a portion of the matrix which is pre–inverted.

The RTDS compiler will give an error message if the same name is reserved twice in any one simulation case.

The “ReqP” line of the CONFIGURATION menu (it may be necessary to scroll down to this item; alternatively, the menu window may be resized) allows the User to specify whether the Network Solution model will be automatically (Automatic) or manually (Manual) assigned to a DUAL 3PC card set. If automatic assignment is requested, then the subsequent menu item (ShrC) is ignored. If manual assignment is chosen, then the desired DUAL 3PC card set can be identified by specifying the Sharc card number of the first card in the DUAL 3PC card set in the “ShrC” menu item. If the specified card is not the beginning of a DUAL 3PC card set (according to the config_file), then an appropriate ERROR message will be given. If the DUAL 3PC card set is already assigned to another model, then there will also be a suitable ERROR message.

<u>The Use of the Real Time Network Solution requires some special Sharc components for creating the network.</u> A special Sharc node icon (rtds_sharc_node) which can

be found in the Sharc components library must be used on any rack which has a Sharc Network solution. A special Sharc ammeter icon (rtds_sharc_imonda) must be used. As well, there are special Sharc icons for the tuned RLC filter (rtds_sharc_rlcda); the high−pass filter (rtds_sharc_hpfiltda); the C−type filter (rtds_sharc_cfiltda); the R−R//L filter (rtds_sharc_rrlda) and the double−damped filter (rtds_sharc_ddampda).

2.7.2 RULES FOR USE OF THE 3PC REAL TIME NETWORK SOLUTION

The CONFIGURATION menu, discussed above, asks if the icon should "Show Rules for Use on Icon". If "Yes" is selected, then certain key rules will be displayed at the bottom of the icon in DRAFT. The full set of rules is as follows:

1. Any branch, breaker, or model may connect nodes in one Embedded Node Set to: (1) other nodes in <u>that</u> Embedded Node Set; (2) nodes in the Connector Node Set; or (3) to Ground.
2. No branch, breaker, or model (except travelling−wave transmission line models) may connect a node in one Embedded Node Set with a node in another Embedded Node Set. Travelling−wave transmission line models may span between different Embedded Node Sets because such models do not create connections in the G matrix between the node sets.
3. All nodes in DRAFT must be named with unique names which exist in the lists of reserved names. This enables the Network Solution model to classify the nodes used in DRAFT as Connector, Embedded 1, or Embedded 2. It is not necessary to use all reserved names in a DRAFT circuit. The names used in a network simulation can be a subset of the reserved names in the lists.
4. There must be at least 1 node in a Network simulation which is recognized by name as a Connector type node. There can be a maximum of 9.
5. There can be between 0 and 6 nodes in a Network simulation which are recognized as being in each Embedded Node Set as shown in the icon.
6. The maximum total number of single−phase breakers or faults is 28 in a Sharc Network Solution. Of the 28 possible single−phase switches, a maximum of 7 switches may be incident on nodes in a given Embedded Node Set.

2.8 THE RPC REAL TIME NETWORK SOLUTION

The RPC network solution supports 54 connector type nodes, 56 single phase breakers and runs on the RPC card. Unlike the 3PC solution, it has no direct access to D/A outputs or digital I/O. Node voltages and branch currents are all available to be plotted in Runtime and are all available to be sent to D/A's for display on controls 3PC processors.

No icon is needed to run the RPC Network solution. If a 3PC Network Icon has not been specified, and an RPC card is installed in the rack, the RPC Network solution will be performed by default.

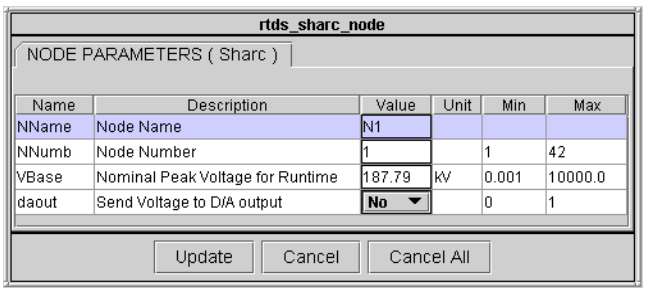
The RPC network solution uses the same node, branch and breaker icons as the 3PC. In the case of the breaker, there is no direct access to a digital input port for control. Breaker control signals can be produced and/or accessed through the controls compiler.

2.9 NETWORK SOLUTION NODES

Sharc Network Nodes

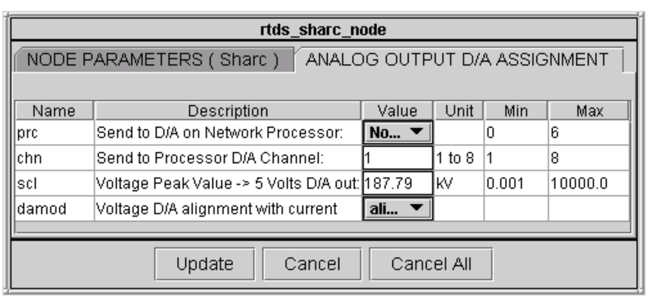
The Sharc Network branch, breaker, and node icons can be found in the Sharc components library. The icons can be used to assign voltage and current output quantities to D/A output channels on the front of the Dual Sharc cards.

In DRAFT, the NODE PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
NName	Node Name	N1			
NNumb	Node Number	1		1	42
VBase	Nominal Peak Voltage for Runtime	187.79	kV	0.001	10000.0
daout	Send Voltage to D/A output	No		0	1

If it is specified that the node voltage should be provided through a D/A output channel, (“Send Voltage to D/A output” set to “Yes”), then a new tab will appear beside the “NODE PARAMETERS (Sharc)” tab labeled “ANALOG OUTPUT D/A ASSIGNMENT”, which will appear as follows:



Name	Description	Value	Unit	Min	Max
prc	Send to D/A on Network Processor:	No...		0	6
chn	Send to Processor D/A Channel:	1	1 to 8	1	8
scl	Voltage Peak Value -> 5 Volts D/A out:	187.79	kV	0.001	10000.0
damod	Voltage D/A alignment with current	ali...			

The above menu contains the item “prc”. Clicking on the entry for Value (which is set at “No...” by default, as well as in the above graphic) pulls open a selection box which contains Network Processors 1A, 1B, 1C, 2A, 2B and 2C. The 1 and 2 refer to the first and second cards in the Dual 3PC card set. Facing the front of the Dual 3PC cards, the card on the left is card No. 1 and the card on the right is card No. 2. The processors on each card are numbered A, B and C on the faceplate of the card.

Likewise, the D/A channels for each processor are also numbered 1 to 8 on the faceplate.

There is a D/A registry in every 3PC Real Time Network Solution. When the case is compiled, an ERROR message will be given if the same D/A output channel is selected for two different signals.

There will be a switch available by signal name in the RunTime CREATE –> Subsystem # –> 3PC D/A –> SWITCH menus for each D/A signal specified. When this switch is turned ON for a named signal, then an LED will light immediately above the D/A output channel which carries the named signal. Such switches will also be available for branch current and other D/A signals produced in the 3PC Real Time Network Solution. Offset and Unity Gain sliders will also be available in the RunTime menus by signal name for adjusting the offset and gain of D/A signals dynamically from RunTime.

In the Dommel algorithm, network node voltages must be calculated before branch currents. In the RTDS simulator, the last items calculated in the network solution before the end of the time–step are the node voltages. Branch currents are calculated in the first part of the next time–step.

The node voltages can be selected for D/A output as soon as they become available near the end of the time–step, by selecting "early" in the ANALOG OUTPUT D/A ASSIGNMENT menu. This approach has the disadvantage of extending the time–step for the 1/2 microsecond that it takes to output each node voltage through D/A output channels on a processor. Alternatively, if "align" is specified in the menu, then the D/A output for the node voltage will be provided in the next time–step along with the currents.

If an Embedded Node voltage is passed to a D/A channel using the "early" option, then a D/A channel on card 1 must be selected if the node is in Embedded Node set 1. If the Node is in Embedded Node set 2, then D/A channel on card 2 must be selected. An ERROR message will be given if this rule is not followed.

Node voltages are always available for monitoring in RunTime.

RPC Network Nodes

As mentioned in Section 2.8, direct D/A assignment of node voltages and branch currents is not possible. Although all the same menues are used as shown for the 3PC network solution, none of the description related to D/A's applies.

2.10 SINGLE ELEMENT AND MULTI–ELEMENT PASSIVE BRANCHES

Single Element Branches

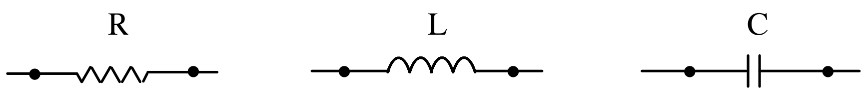
Passive branches consist of simple resistive, inductive, and capacitive elements. Component names in the Draft Library are;

R – **resistor**

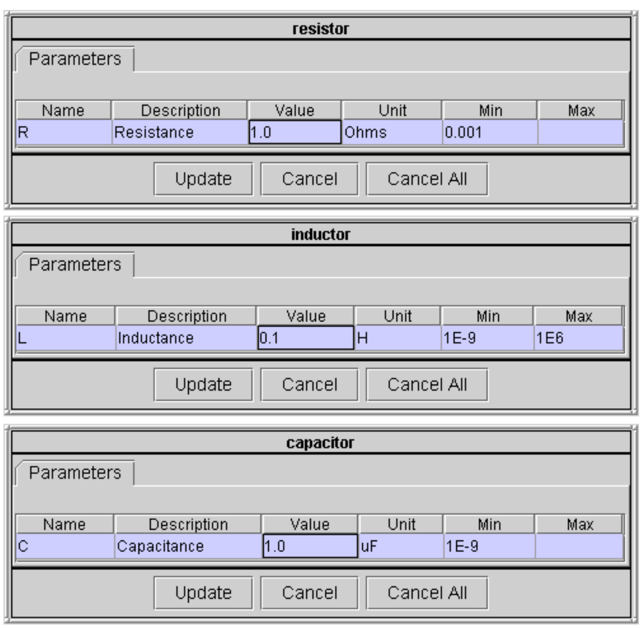
L – **inductor**

C– **capacitor**

In their most basic form, they can be placed as individual components between two nodes or between a node and ground as shown below.



Component values are entered in the RSCAD/Draft software. It should be noted that the capacitance value is entered in μF (i.e. entering 1.0e–6 is interpreted as a 1.0 pF capacitor). The menus for specifying R, L and C values appear as shown below:



resistor

Parameters

Name	Description	Value	Unit	Min	Max
R	Resistance	1.0	Ohms	0.001	

Update | Cancel | Cancel All

inductor

Parameters

Name	Description	Value	Unit	Min	Max
L	Inductance	0.1	H	1E-9	1E6

Update | Cancel | Cancel All

capacitor

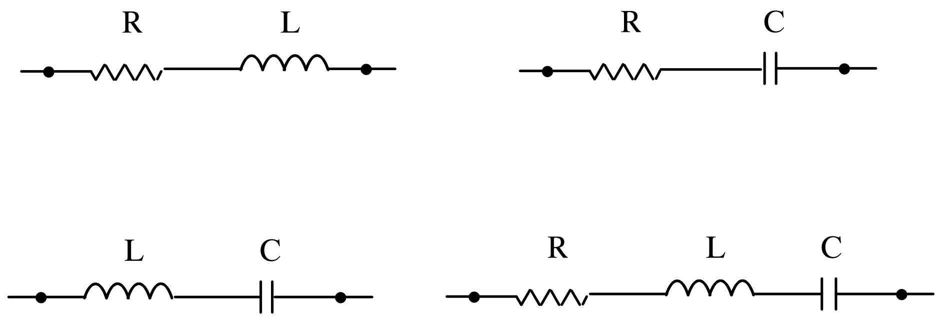
Parameters

Name	Description	Value	Unit	Min	Max
C	Capacitance	1.0	uF	1E-9	

Update | Cancel | Cancel All

Multi–Element Branches

Multi–element series branches can be formed from individual resistors, inductors, and capacitors as shown below:



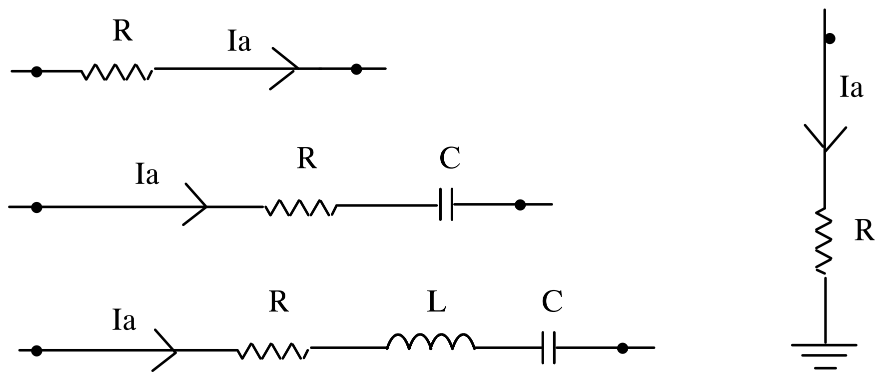
If a node between the individual R, L, and C elements is not named using a node icon, then the DRAFT program will automatically make a RL, RC, LC, or RLC multi–element branch. The voltages of unnamed internal nodes between individual R, L and C elements are not calculated. This saves the limited number of available nodes for other purposes. If the voltage of the intermediate node is required, then it must be marked for calculation by using a node icon as discussed in a preceding section.

Monitoring Currents in Single Element and Multi–Element Branches

The current through a single element or multi–element branch may be monitored using the current monitoring icon illustrated as follows:

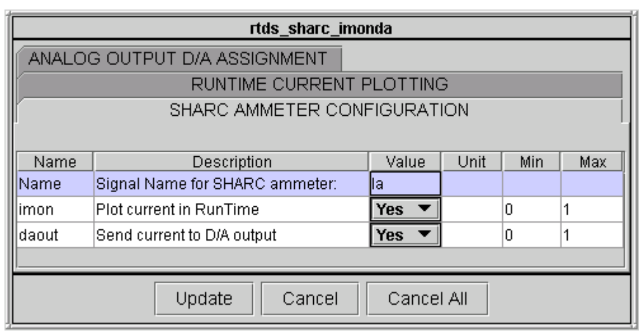
RSCAD/Draft branch current monitor icon

The name of this component is **rtds_sharc_imonda**. In use, the icon is placed in series with a single element or multi–element branch as shown below:



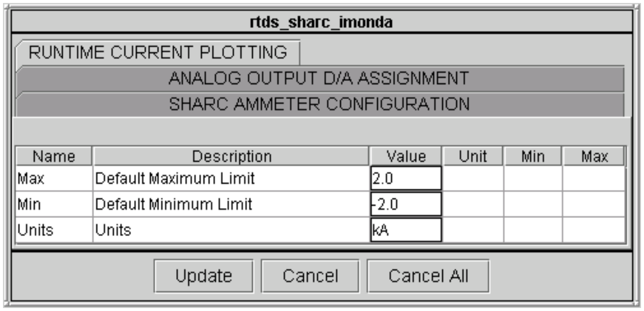
It should be noted that DRAFT will not permit the branch current monitor icon to be placed at the ground end of a ground connected branch. The arrangement of current monitor icons for ground connected branches must have the icon at the node end of the branch as shown above.

The PARAMETERS menu for the branch current monitor icon contains, as shown, a SHARC AMMETER CONFIGURATION tab as shown below:



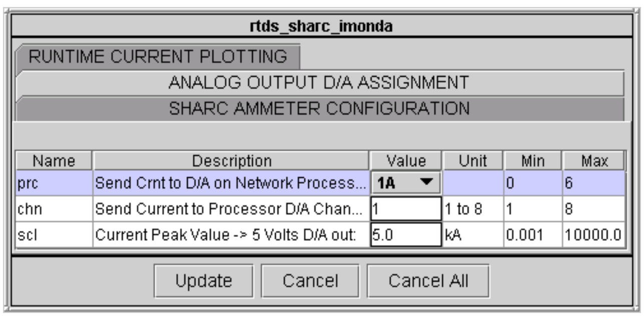
In the CONFIGURATION menu, choosing “yes” in the “imon” entry line makes the current available for monitoring in RunTime. Similarly, specifying that the current should be passed out through a D/A conversion channel on the front of the Dual 3PC card set can be selected by responding “yes” to the “daout” entry. Choosing “no” in either of these entries removes the corresponding tab from the PARAMETERS menu.

The RUNTIME CURRENT PLOTTING menu tab appears as follows:



In general, it is not necessary to change the Default Maximum and Minimum Limits because these can be changed in RunTime at a later time. However, the ability to set default limits in advance is available.

The ANALOG OUTPUT D/A ASSIGNMENT menu appears as shown below. The same icon is used for both the 3PC and RPC network solution, but selections related to D/A output do not apply in the case of the RPC.



The above menu is similar in form and function to the menu describing node voltage D/A output described earlier in this chapter. The first line in the above menu refers to the six processors (1A, 1B, 1C, 2A, 2B and 2C) in the DUAL 3PC card set used to calculate the Real Time Network Solution. The 1 and 2 refer to the first and second cards in the Dual 3PC card set. Facing the front of the Dual 3PC cards, the card on the left is card No. 1 and the card on the right is card No. 2. The processors on each card are numbered A, B and C on the faceplate of the card. In accordance with the permitted selections in line 2 of the above menu, the D/A channels for each processor are numbered 1 to 8 on the card faceplate.

There is a D/A registry in every 3PC Real Time Network Solution. When the case is compiled, an ERROR message will be given if the same D/A output channel for two different signals is selected.

There will be a switch available by signal name in the RunTime CREATE –> Subsystem # –> 3PC D/A –> SWITCH menus for each D/A signal specified. When this switch is turned ON for a named signal, then an LED will light immediately above the D/A output channel which carries the named signal. Such switches will also be available for node voltages and other D/A signals produced in the 3PC Real Time Network Solution. Offset and Unity Gain sliders will also be available in the Run-

Time menus by signal name for adjusting the offset and gain of D/A signals dynamically from RunTime.

In some cases an extremely large dynamic range will be required for monitoring of branch currents. A particular example is in the case when a fault is applied to a lightly loaded transmission line. The fault current may be many hundreds of times higher than the load current. In order to prevent clipping of the analogue output voltage representing current during the fault, the scale factor (“scl”) will have to be set to a very large value. Prior to the fault, however, the analogue output channel representing current may only be a few milli–volts. With 12–bit digital – analogue converters the signal may appear noisy under such conditions. A larger dynamic range can be accommodated using optional RTDS optical D/A converter (FDAC / DDAC) hardware which includes 16–bit D/A converters.

2.11 FILTER TYPE BRANCHES

The 3PC and RPC Real Time Network Solutions provide filters such as tuned RLC, high–pass, double–damped, C–type, and RRL (R series R//L).

Do not use the branch current monitor icon with the Filter Type branches.

If a filter branch current is monitored in RunTime or in the case of the 3PC, the current is output through a D/A channel, then a reference direction arrow will appear on the icon for the branch in DRAFT.

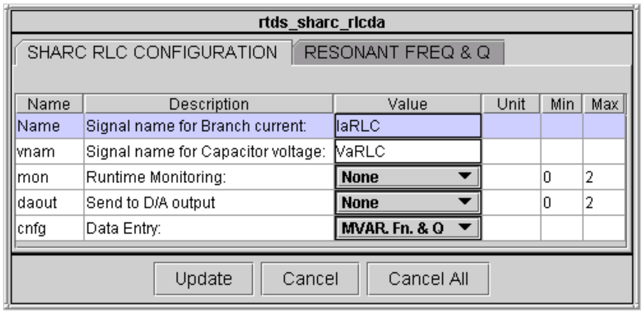
For the 3PC, if the output of a filter or branch quantity is assigned to a D/A output port on a specified processor in the DUAL 3PC card set, then the filter or branch will be calculated on that processor. Therefore, if possible, distribute D/A output quantities fairly evenly among the six processors in the DUAL 3PC set in order to evenly distribute the computation load. However, this is not a critical requirement. The computation time for each processor is shown in the MAP file and indicates the evenness of the distribution of branch and filter calculations.

Tuned Filter Branch (Series RLC) (rtds_sharc_rlcda)

The tuned filter branch consists of a series resistance, inductance and capacitance. This RLC filter branch contains options not available in the RLC branch assembled from individual R, L, and C elements as described in the previous section. In particular, the parameters of the branch can be entered in terms of the capacitive MVAR of the filter branch; the fundamental frequency, the tuned frequency, the quality factor Q; and the rated RMS branch voltage. The User may also monitor the capacitor voltage under limited circumstances.

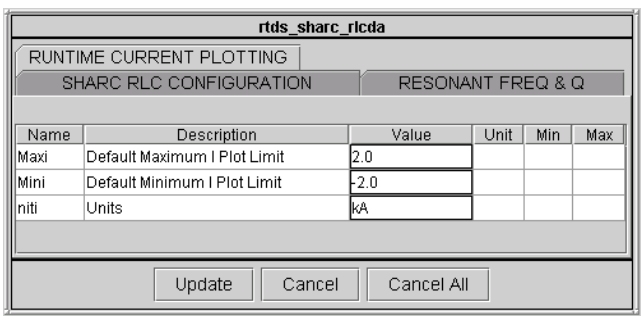
The first menu tab of the PARAMETERS menu is the SHARC RLC CONFIGU-

RATION menu which appears as follows:



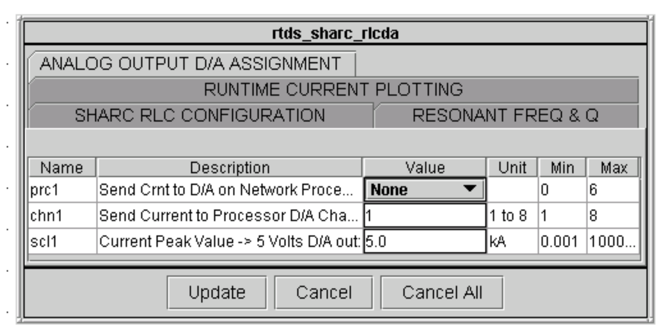
This menu prompts for the branch current name and the name of the voltage on the capacitor. Only one of branch current or capacitor voltage may be monitored in Run-Time at a given time. A similar constraint exists with respect to sending out only one signal to D/A output at a given time. The selections are made in the third and fourth line in the menu.

If the User selects to monitor current in RunTime, then the following RUNTIME CURRENT MONITORING, a new menu tab RUNTIME CURRENT PLOTTING appears:



It is not necessary to change the default plot limits because they can be changed later in RunTime. A similar menu appears if the User selects to monitor capacitor voltage in RunTime.

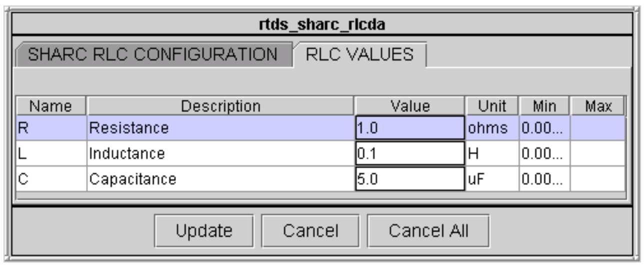
If the User selects to monitor current through a D/A output channel, then a new menu tab ANALOG OUTPUT D/A ASSIGNMENT appears:



This menu is essentially the same as the menu for D/A output explained in the previous section for the single element and multi−element branch models. Please refer to that explanation. A similar menu appears if the capacitor voltage is passed to a D/A output channel.

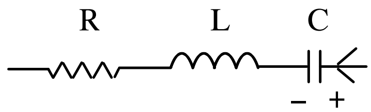
The RLC component values may be entered directly, or alternatively, the filter parameters may be entered upon which RSCAD/Draft software will compute the associated component values. The selection is made in the last line of the SHARC RLC CONFIGURATION menu.

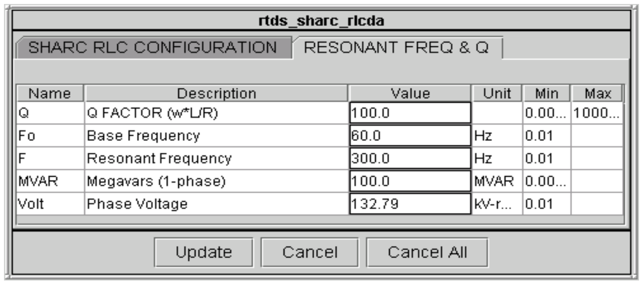
The RLC VALUES menu tab appears as follows and is self−explanatory:



All parameters must be greater than zero. The capacitance is expressed in microfarads.

Alternatively, if parameters are to entered in the form “MVAR, Fn, & Q”, then the “RESONANT FREQ & Q” menu tab becomes available as shown below. The equations for converting to RLC values are also shown.





rtds_sharc_rlcda

SHARC RLC CONFIGURATION | RESONANT FREQ & Q

Name	Description	Value	Unit	Min	Max
Q	Q FACTOR (w*L/R)	100.0		0.00...	1000...
Fo	Base Frequency	60.0	Hz	0.01	
F	Resonant Frequency	300.0	Hz	0.01	
MVAR	Megavars (1-phase)	100.0	MVAR	0.00...	
Volt	Phase Voltage	132.79	kV-r...	0.01	

Update | Cancel | Cancel All

Conversion to RLC values –

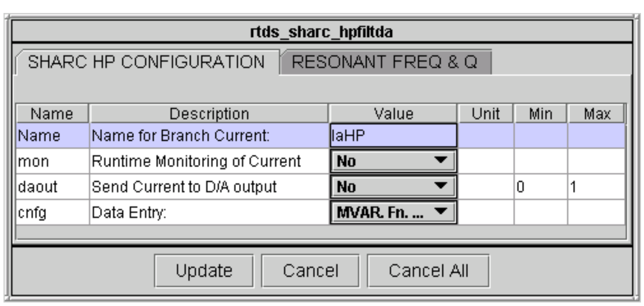
$\omega_o = 2\pi * F_o$ $\qquad\qquad$ $\omega_r = 2\pi * F_r$

$$C = \frac{MVAr}{V^2 * \omega_o} \qquad\qquad L = \frac{1}{\omega_r^2 * C}$$

$$R = \frac{\omega_o * L}{Q}$$

High Pass Filter Branch (HP) (rtds_sharc_hpfiltda)

The main PARAMETERS menu tab of the High Pass (HP) Filter Branch appears as follows.



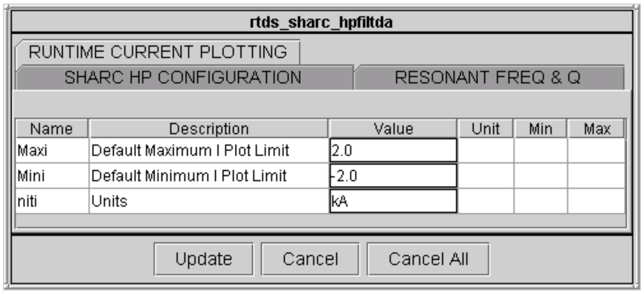
rtds_sharc_hpfiltda

SHARC HP CONFIGURATION | RESONANT FREQ & Q

Name	Description	Value	Unit	Min	Max
Name	Name for Branch Current:	IaHP			
mon	Runtime Monitoring of Current	No			
daout	Send Current to D/A output	No		0	1
cnfg	Data Entry:	MVAR. Fn. ...			

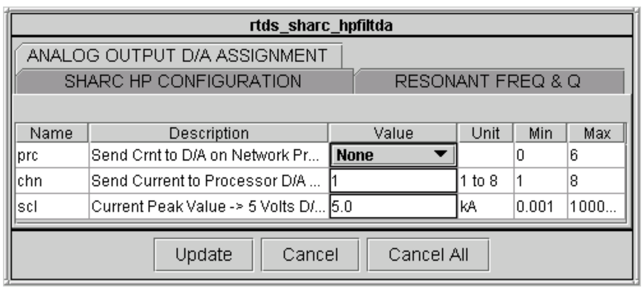
Update | Cancel | Cancel All

If RunTime Monitoring of current is requested, then the RUNTIME CURRENT PLOTTING menu tab appears as follows:



The above menu has the same form and function as the similar menu described for the Tuned RLC Filter branch. Please refer to that description if further explanation is required.

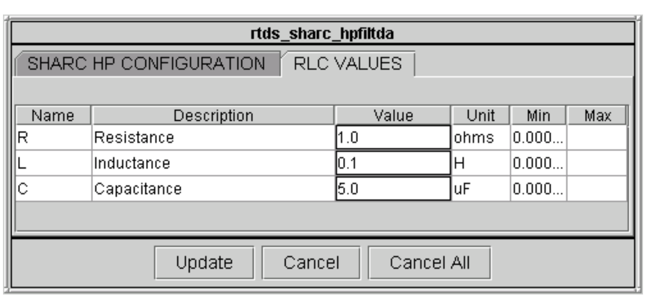
If the current is to be sent to a D/A output channel using the 3PC Network Solution, then the ANALOG OUTPUT D/A ASSIGNMENT menu tab appears as follows:



The above menu has the same form and function as the similar menu described for the Tuned RLC Filter branch. Refer to that description if further explanation is required.

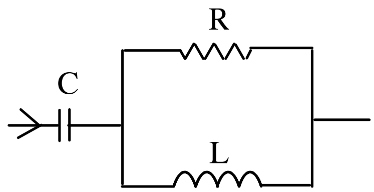
Either the RLC component values or the filter parameters may be entered directly for the HP filter. In the latter case, the RSCAD/Draft software will compute the associated component values. The selection is made in the last line of the SHARC HP CONFIGURATION menu.

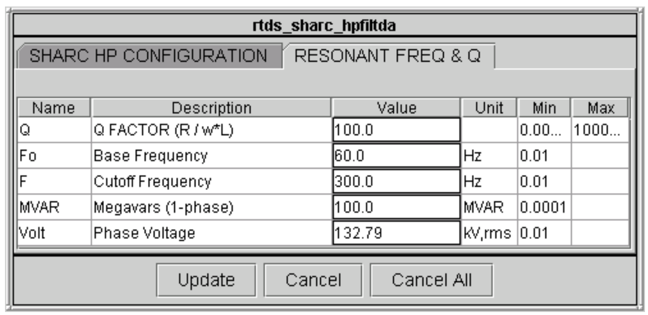
The RLC VALUES menu appears as follows and is self–explanatory:



All parameters must be greater than zero. The capacitance is expressed in microFarads.

Alternatively, if parameters for the HP filter in the form “MVAR, Fn, & Q” are selected, then the “RESONANT FREQ & Q” menu becomes available as shown below. The equations for converting to RLC values are also shown. Note that the definition of Q is different for a HP filter as compared to the series RLC filter.





Name	Description	Value	Unit	Min	Max
Q	Q FACTOR (R / w*L)	100.0		0.00...	1000...
Fo	Base Frequency	60.0	Hz	0.01	
F	Cutoff Frequency	300.0	Hz	0.01	
MVAR	Megavars (1-phase)	100.0	MVAR	0.0001	
Volt	Phase Voltage	132.79	kV,rms	0.01	

Conversion to RLC values –

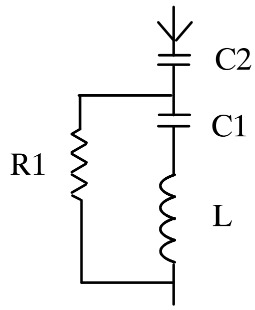
$\omega_o = 2\pi * F_o$ $\qquad \omega_c = 2\pi * F_c$

$$C = \frac{MVAr}{V^2 * \omega_o}$$

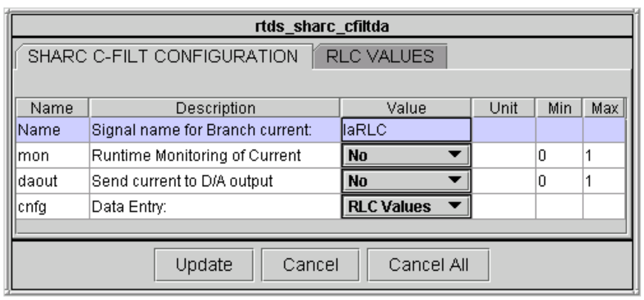
$R = \omega * L * Q$ $\qquad L = \frac{1}{\omega_c^2 * C}$

C–Type Filter Branch (C–Type) (rtds_sharc_cfiltda)

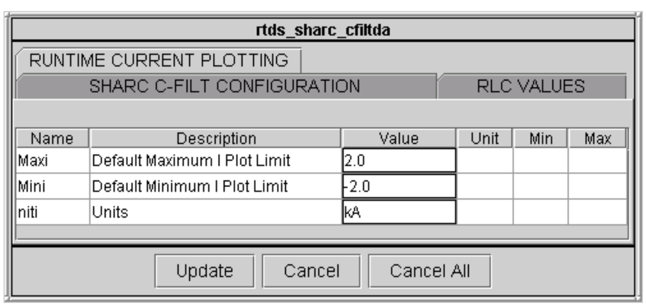
The C–type filter is configured as shown below:



The main PARAMETERS menu of the C−Type (HP) Filter Branch appears as follows. The number of menu tabs depends on selections in the SHARC HP CONFIGURATION menu.

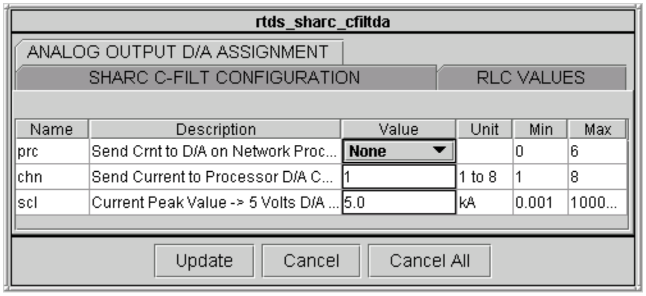


If RunTime Monitoring of current is requested, then the RUNTIME CURRENT PLOTTING menu appears as follows:



The above menu has the same form and function as the similar menu described for the Tuned RLC Filter branch. Please refer to that description if further explanation is required.

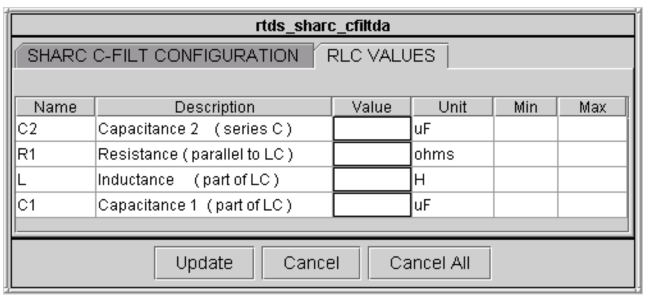
In the case of the 3PC Network Soltion, if the the current is requested to be sent to a D/A output channel, then the ANALOG OUTPUT D/A ASSIGNMENT menu appears (as usual) as follows:



The above menu has the same form and function as the similar menu described for the Tuned RLC Filter branch. Please refer to that description if further explanation is required.

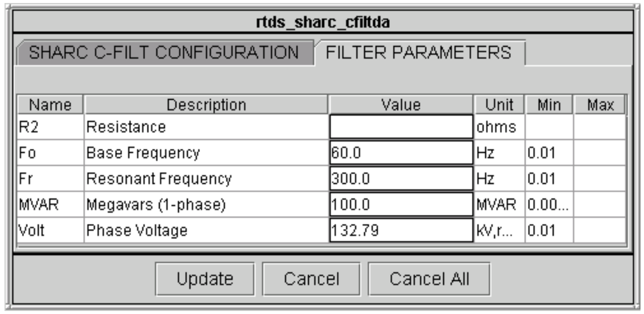
Either the RLC component values or the filter parameters may be entered directly for the C–Type filter. In the latter case, RSCAD/Draft software will compute the associated component values. The selection is made in the last line of the SHARC C–TYPE CONFIGURATION shown above menu.

The RLC VALUES menu appears as follows and is self–explanatory:



All parameters must be greater than zero. The capacitance is expressed in microFarads.

Alternatively, if parameters for the C–Type filter are to be entered in the form “Filter Parameters”, then the “FILTER PARAMETERS” menu becomes available as shown below. The equations for converting to component RLC values are also shown. Note that the User must manually calculate the required R1 resistance value and supply it as R2 in the menu.


rtds_sharc_cfiltda

SHARC C-FILT CONFIGURATION | FILTER PARAMETERS

Name	Description	Value	Unit	Min	Max
R2	Resistance		ohms		
Fo	Base Frequency	60.0	Hz	0.01	
Fr	Resonant Frequency	300.0	Hz	0.01	
MVAR	Megavars (1-phase)	100.0	MVAR	0.00...	
Volt	Phase Voltage	132.79	kV,r...	0.01	

Update | Cancel | Cancel All

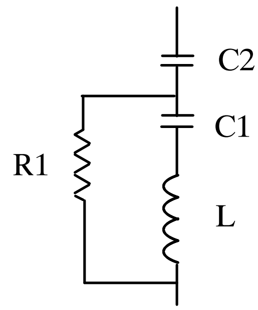
Conversion to RLC values –

$$\omega_o = 2\pi * F_o \qquad \omega_r = 2\pi * F_r$$

$$C2 = \frac{MVAr}{V^2 * \omega_o}$$

$$C1 = C2 \left[(\omega_r / \omega_o)^2 - 1 \right]$$

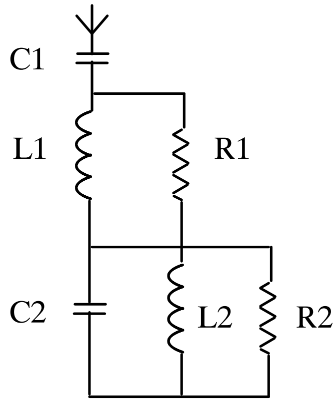
$$L = \frac{1}{\omega_o^2 * C1}$$



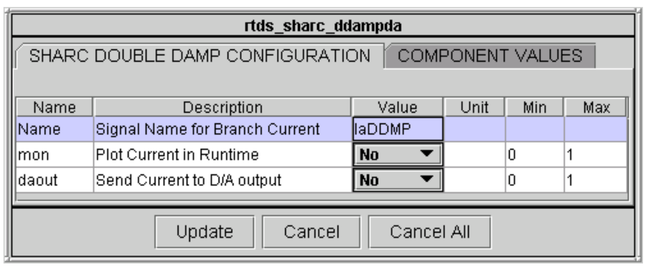
The C1 and L tuned LC arm passes the fundamental frequency current and therefore essentially no fundamental frequency current will pass through the resistance element. Therefore, the “Resistance” item in the menu can be used to choose R1 optimally to damp harmonics without concern for fundamental frequency losses in the resistance R1.

Double Damped Filter Branch (rtds_sharc_ddampda)

The Double Damped filter is configured as shown below. The current reference direction arrow appears when the current value is monitored in RunTime or provided to a D/A channel.



The main PARAMETERS menu of the Double Damped Filter Branch appears as follows. The number of menu tabs depends on selections in the SHARC DOUBLE DAMPED CONFIGURATION menu.



rtds_sharc_ddampda

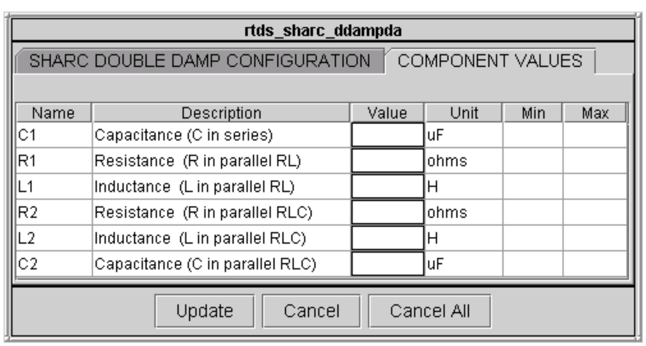
SHARC DOUBLE DAMP CONFIGURATION | COMPONENT VALUES

Name	Description	Value	Unit	Min	Max
Name	Signal Name for Branch Current	IaDDMP			
mon	Plot Current in Runtime	No		0	1
daout	Send Current to D/A output	No		0	1

Update | Cancel | Cancel All

If RunTime Monitoring of current is requested, then the RUNTIME CURRENT PLOTTING menu tab appears. For a 3PC Network solution, ff the current is to be sent to a D/A output channel, then the ANALOG OUTPUT D/A ASSIGNMENT menu tab appears. These menus are exactly the same in form and function as these menus used for the C−Type filter described above. Please refer to that explanation if more information is required.

The COMPONENT VALUES menu appears as follows and is self−explanatory:



rtds_sharc_ddampda

SHARC DOUBLE DAMP CONFIGURATION | COMPONENT VALUES

Name	Description	Value	Unit	Min	Max
C1	Capacitance (C in series)		uF		
R1	Resistance (R in parallel RL)		ohms		
L1	Inductance (L in parallel RL)		H		
R2	Resistance (R in parallel RLC)		ohms		
L2	Inductance (L in parallel RLC)		H		
C2	Capacitance (C in parallel RLC)		uF		

Update | Cancel | Cancel All

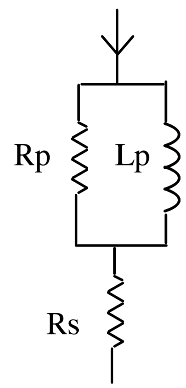
All parameters must be greater than zero. The capacitances are expressed in microFarads.

In general, the L1 C1 parameters are chosen to be resonant at a value between the two resonant frequencies of the filter. For example, if the filter is to be resonant at the

5th and 7th harmonic, then the L1 C1 circuit might be tuned to the 6th harmonic. The parallel L2 C2 circuit would then be chosen to be inductive at the 5th harmonic and capacitive at the 7th harmonic in order to provide the correct zeroes of impedance at the 5th and 7th harmonic for the total filter.

RRL Filter Branch (rtds_sharc_rrlda)

The RRL filter is configured as shown below. Note that the current reference direction arrow appears only when the current value is monitored in RunTime or provided to a D/A channel.



The main PARAMETERS menu of the RRL Filter branch appears as follows. Of course, the number of menu tabs depends on selections in the SHARC RRL CONFIGURATION menu. The values used for the resistor and inductor elements are entered in the SHARC RRL CONFIGURATION menu, which appears as follows:

rtds_sharc_rrlda

SHARC RRL CONFIGURATION

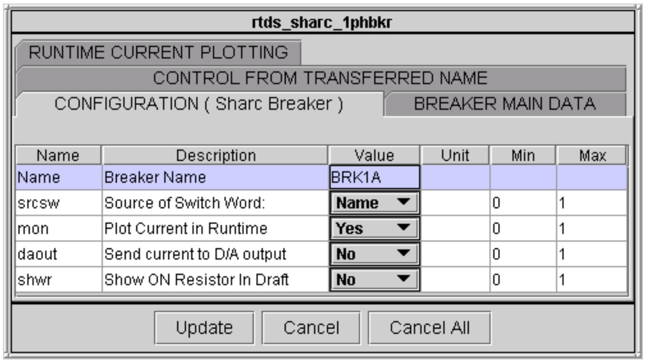
Name	Description	Value	Unit	Min	Max
Name	Signal Name for Branch Current	IaRRL			
mon	Plot Current in Runtime	No		0	1
daout	Send current to D/A output	No		0	1
Rs	Series Resistance	1.0	ohms	0	
Rp	Parallel Resistance	1.0	ohms	0	
Lp	Parallel Inductance	0.1	H	0	

Update　Cancel　Cancel All

If RunTime Monitoring of current is requested, then the RUNTIME CURRENT PLOTTING menu tab appears. In the case of a 3PC network solution, if the current is to be sent to a D/A output channel, then the ANALOG OUTPUT D/A ASSIGNMENT menu tab appears. These menus are exactly the same in form and function as these menus used for the C−Type filter described above. Please refer to that explanation if more information is required.

2.12 BREAKERS and FAULT SWITCHES (rtds_sharc_1phbkr) (rtds_sharc_fault)

A single−phase breaker model and a fault switch model are available for the 3PC and RPC Real Time Network Solution. The two models are exactly the same except for their appearance in DRAFT. The CONFIGURATION menu appears as follows:

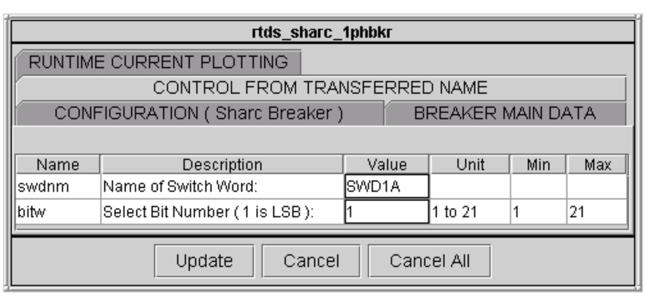


The RUNTIME CURRENT PLOTTING menu tab appears because by default it is specified in the CONFIGURATION menu that current is to be plotted in RunTime.

The last entry in the CONFIGURATION menu only has the effect of changing the appearance of the icon. The function of the model is not affected. This appearance is useful where it is desired to switch a resistive load. In that case, the ON resistance of the breaker can be specified to be equal to the resistance of the load and the ON resistor can be specified to be shown.

Breakers are controlled by Switch Words. The source of the Switch word is specified in the “srcsw” line of the CONFIGURATION menu. The Switch Word can be specified to come from a bit selected from an integer word passed on the backplane (“Name”) or in the case of the 3PC Network Solution, from a digital input port on the Dual Sharc card set (“DigPort ”).

The breaker can be controlled by a word passed on the backplane by selecting “Name” instead of “DigPort” in the CONFIGURATION menu. The backplane word containing appropriate bits may be created in the Controls Compiler. When “Name” is selected the CONTROL FROM TRANSFERRED NAME menu is available. It appears as follows:



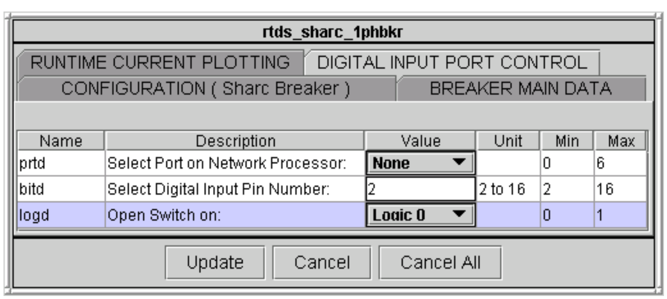
When the breaker is controlled from a switch word (integer number) passed on the backplane, “0” for the selected bit causes the breaker to be physically OPEN and a “1” bit causes the breaker to be physically CLOSED.

Any bit in the word between 1 and 21 (1 being the least significant bit) can be selected.

If an open command is given to the breaker while current is flowing, the absolute value of current will be compared to the level indicated in the last item of the BREAKER MAIN DATA menu, “Extinguish Arc for abs(I) at or below”. If the absolute value of the current is below this threshold, current will be interrupted. This threshold is normally set to 0.0, as interrupting current in an inductive circuit will result in a voltage spike. AC system breakers open at at current zeros, largely created by the external circuit.

A voltage spike or numerical instability resulting in a voltage of 10,000 kV on any node will cause the simulation to stop and an error message to be issued.

Only on the 3PC Network processors, breaker control can come directly from a digital input port by selecting “DigPort” in the CONFIGURATION menu. In that case, the DIGITAL INPUT PORT CONTROL menu becomes available and the CONTROL FROM TRANSFERRED NAME menu disappears. The DIGITAL INPUT PORT CONTROL menu appears as follows:


rtds_sharc_1phbkr

RUNTIME CURRENT PLOTTING | DIGITAL INPUT PORT CONTROL | CONFIGURATION (Sharc Breaker) | BREAKER MAIN DATA

Name	Description	Value	Unit	Min	Max
prtd	Select Port on Network Processor:	None		0	6
bitd	Select Digital Input Pin Number:	2	2 to 16	2	16
logd	Open Switch on:	Logic 0		0	1

Update | Cancel | Cancel All

There is no digital input port on processors 1C and 2C in a Dual 3PC card set and therefore, 1C and 2C do not appear in the pull down menu for the value of the “prtd” menu item. A breaker control can be connected through any of the four digital input ports in a Dual Sharc cards set.

There are two digital I/O connectors side–by–side on the back of each Sharc card. Looking into the rear of the cubicle.

The connector on the left on a Sharc card is for processor A and the connector on the right is for processor B, (See Sec. 2.6.2).

Therefore, looking into the back of the cubicle, the connectors on the back on the Dual Sharc cards are, from left to right, connector 2A 2B 1A and 1B. Within a connector, the column of pins on the left are the input pins and the column of pins on the right are the output pins. The pins are numbered from 1 to 17 starting at the bottom. The bottom pin (pin 1) in the left hand column of pins in each connector is a ground pin. Digital input can be passed into pins 2 to 16 on the left hand side on each connector.

Each digital input pin has an internal pull−up resistor which will pull the voltage of the pin to 5 Volts (logic 1) if it is left unconnected. Connecting the digital input pin (2 to 16) to the ground pin (pin 1) will cause the voltage of the input pin to be pulled to 0 Volts (logic 0).

The physical position of the breaker is selectable to be Open on “Logic 0” or Open on “Logic 1” when control is provided through the digital input port. This selection can be made in the DIGITAL INPUT PORT CONTROL menu as shown above.

Any breaker current can be monitored in RunTime by making appropriate selections in the RUNTIME CURRENT PLOTTING menu. This menu allows pre−set default plot minimum and maximum values. The menu also allows specification of a name for the current that is different from the breaker name.

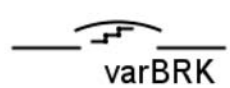
Breaker current can be specified to be output through a D/A channel. In that case, the D/A output channel selection is made in a manner similar to selecting a D/A output channel for a node voltage as discussed above.

2.12a Variable FAULT and BREAKER SWITCHES (rtds_sharcu_VARFLT and _rtds_varBRK)

The variable fault and breaker switches are the same in function but differ in graphical appearance only. The variable breaker is only supported on GPC.

The component icons are shown below:

rtds_sharcu_VARFLT



_rtds_varBRK

These two models are switches with a gradual transition period during the fault/breaker operation. Instead of a sudden change from the ON state to the OFF state the resistance of the switch changes gradually to avoid numerical oscillations when a inductive current is suddenly cut off.

When the switch is opened (fault is cleared or the breaker is opened), the switch resistance *R(t)* changes from *Ron* (a very small value) to *Roff* (a very large value) according to the following equation:

$$R(t) = dR*R(t-delt)$$

where *delt* is the simulation time step and *dR* is a constant (*dR>1.0)*.

When the switch is closed (fault is applied or the breaker is closed), the switch resistance *R(t)* changes from *Roff* to *Ron* according to the following equation:

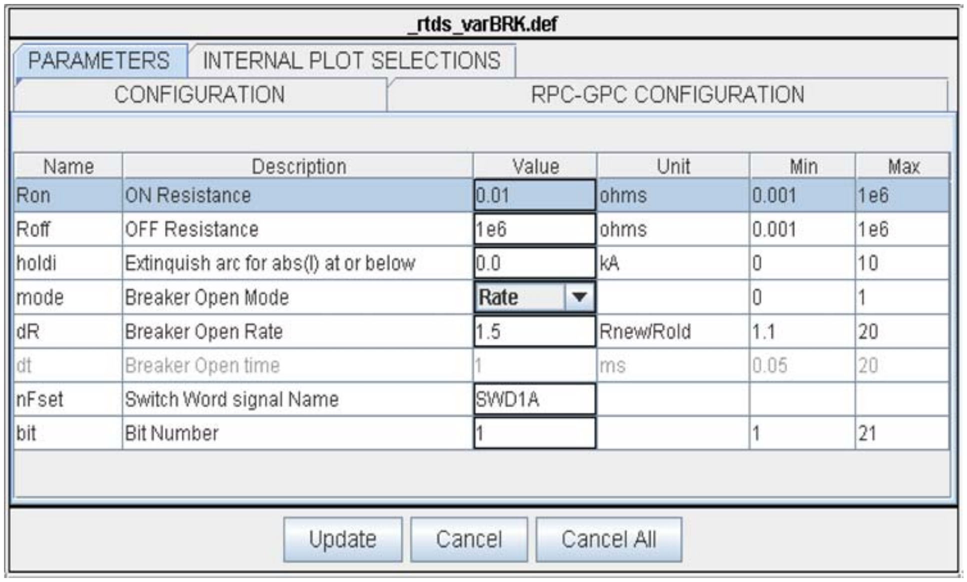
$$R(t) = (1/dR)*R(t-delt)$$

By controlling the value of the parameter *dR*, users can control the rate of change of the switch resistance to avoid numerical oscillations. The component is especially useful as a fault switch on a faulted transformer winding.

2.12a.1 PARAMETER MENU

PARAMETERS:

This menu defines the main parameters of the model.



Ron: – resistance when the switch is ON;

Roff: – resistance when the switch if OFF;

holdi: – if a command is given to the switch to turn OFF while current is flowing, the absolute value of current will be compared to the level entered here. If the absolute value of the current is below this threshold, current will be interrupted. This parameter is normally set to 0.0 as interrupting current in an inductive circuit will result in a voltage spike.

mode: – mode of change:

Rate: the switch resistance changes at a fixed rate specified by the parameter *dR*.

Time: the switch resistance changes at a fixed rate computed based on the parameter *dt* so that the transition is complete by the end of the time specified by the parameter *dt*.

dR – the fixed rate of change for the switch resistance;

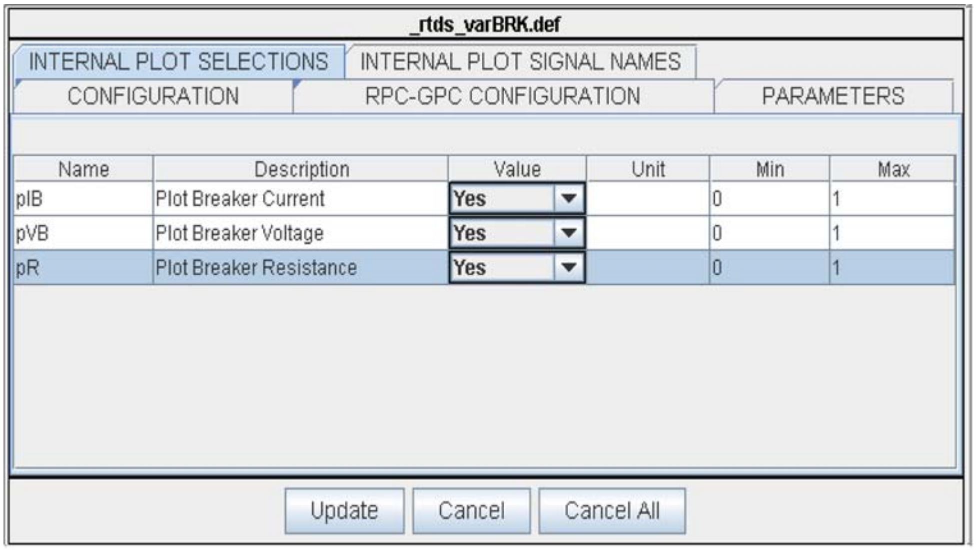
dt – the fixed duration of change for the switch resistance;

nFset – the name of the switch word;

bit – bit number of the switch word.

When the specified bit in the switch word is 1, the switch is ON. When the bit is 0, the switch is OFF.

INTERNAL PLOT SELECTIONS:

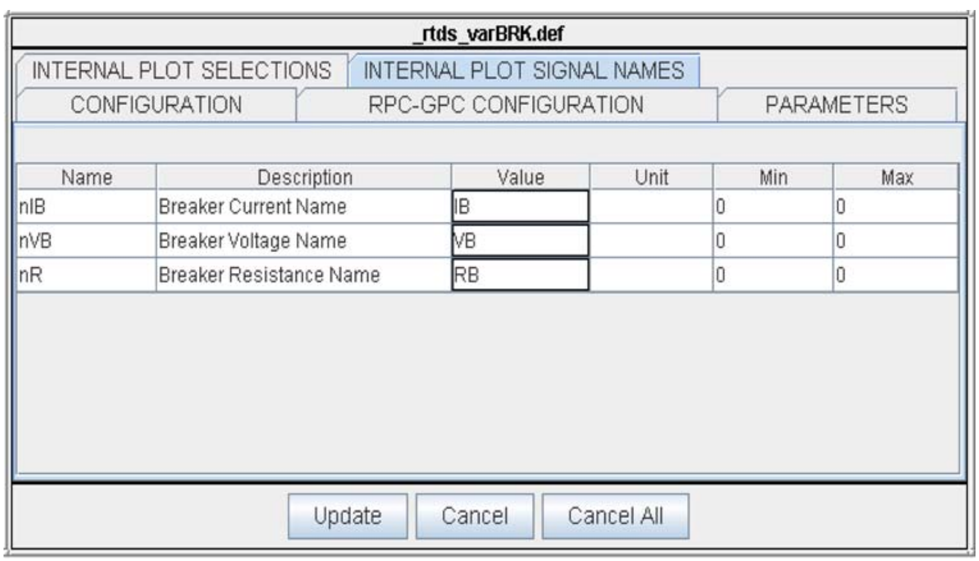


pIB – whether or not to plot switch current;

pVB – whether or not to plot voltage across the switch;

pR – whether or not to plot switch resistance;

INTERNAL PLOT SIGNAL NAMES:



nIB – signal name for switch current;

nVB – signal name for voltage across the switch;

nR – signal name for switch resistance;

2.13 EMBEDDED MODELS

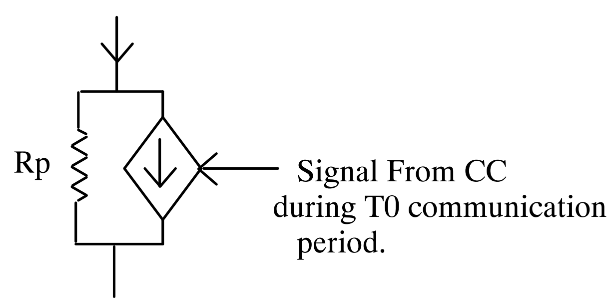
The 3PC Real Time Network Solution allows models to place varying G values onto the Connector Node portion of the G matrix before that portion of the G matrix is decomposed in each time–step. This approach allows models to be created which become an extension of the main network solution. This total elimination of interfaces is very helpful in cases where there may be no suitable inductance for stabilizing an interface. This approach has been taken with the TCSC model, the 6–pulse Valve Group model, the Switched Branch model, and SVC4 model described in Chapter 8 through Chapter 13.

APPENDIX 2A USER – DEFINED BRANCHES USING THE CONTROLS COMPILER

The material in this section is an advanced topic and is not required for general RTDS operation.

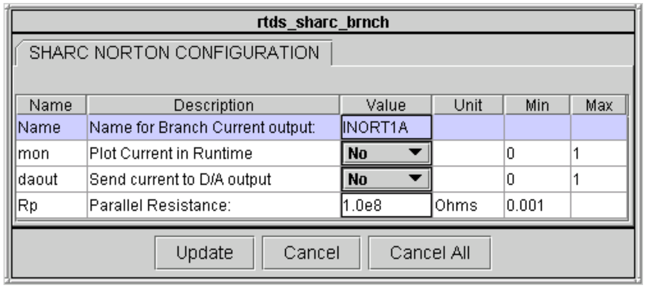
A component "rtds_sharc_brnch" is available to permit the creation of a custom branch model with the aid of calculations which can be carried out in the Controls Compiler. Note that this component is not included in any of the shipping libraries, and so will need to be added to library, as was discussed in the previous chapter. Using the "rtds_sharc_brnch" component is perhaps most useful from the point of view of providing a tutorial facility. For continued use of a new branch type, the User may be better advised to use the User Defined Component facility.

The component "rtds_sharc_brnch" is configured as shown below. The current reference direction arrow appears when the current value is monitored in RunTime or provided to a D/A channel.



The SHARC NORTON CONFIGURATION menu of the branch appears as follows. The number of menu tabs depends on selections in this menu. The value used for the resistor element is also entered in this menu.

The SHARC NORTON CONFIGURATION menu appears as follows:



rtds_sharc_brnch

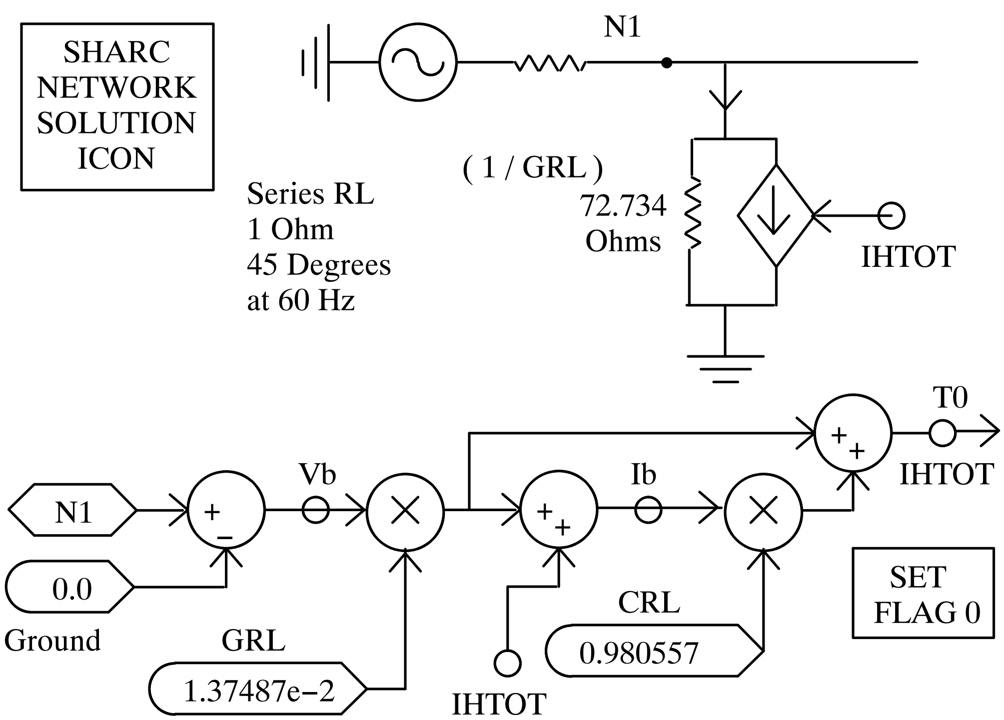
SHARC NORTON CONFIGURATION

Name	Description	Value	Unit	Min	Max
Name	Name for Branch Current output:	INORT1A			
mon	Plot Current in Runtime	No		0	1
daout	Send current to D/A output	No		0	1
Rp	Parallel Resistance:	1.0e8	Ohms	0.001	

Update | Cancel | Cancel All

If RunTime Monitoring of current is requested, then the RUNTIME CURRENT PLOTTING menu tab appears. If the current is to be sent to a D/A output channel, then the ANALOG OUTPUT D/A ASSIGNMENT menu tab appears. These menus are exactly the same in form and function as these menus used for the C−Type filter described above. Please refer to that explanation if more information is required.

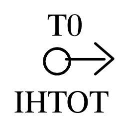
As an example, a typical circuit is shown below which solves the equations for a series RL branch.



The value of IHTOT (the history current) used in the above equations is the history current produced in the last time−step by the control system. Vb is the branch voltage. Ib is the branch current. The control system is configured in the above schematic to operate in “Priority” mode (as opposed to “Automatic” mode). Please see the Controls Compiler documentation for more information on these alternative modes. In any case, operation in “Priority” mode means that the User is responsible for assigning “Priority” numbers for the control blocks on a processor in order to specify the sequence in which calculations will be conducted. In the above control schematic, the summing junctions, multiplier blocks, and SET FLAG 0 block are numbered from left to right with ascending Priority numbers (1 to 6 in this example). This assures that the calculations are conducted in the proper sequence before the new history current is passed in the T0 transfer period (in the middle of the time step).

The Controls Compiler (CC) normally passes variables only in the T2 transfer period at the end of the time−step. In order to force the transfer of a variable in the T0 transfer period while operating in “Priority” mode, the User must use the rtds_ctl_SENDT0 and rtds_ctl_SETFLAG which are shown below. The User sets the priority number of the T0 transfer on a processor using the rtds_ctl_SETFLAG component. The User identifies signals which should be transferred in the T0 transfer period with the rtds_ctl_SENDT0 component. If the User is operating the CC in “Automatic” mode, then use of the rtds_ctl_SETFLAG component is not required.

rtds_ctl_SENDT0



rtds_ctl_SETFLAG

The RL branch equations which are being solved by the CC in the above schematic are as shown below:

Ib(t−dt) = GRL * Vb(t−dt) + IHTOT(t−2dt) and

IHTOT(t−dt) = GRL * Vb(t−dt) + CRL * Ib(t−dt)

where

GRL = delt / (2L + delt R) and

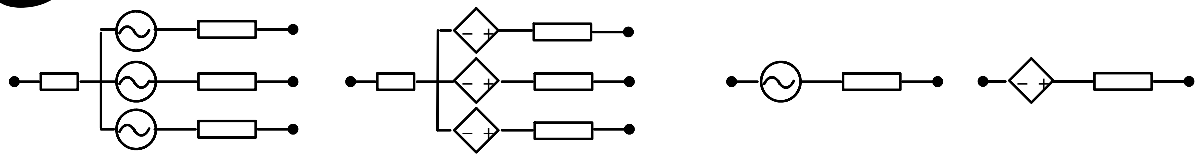
CRL = (2L − delt R) / (2L + delt R)

where L is inductance
R is resistance and
delt is the time−step size in seconds

Using the above method, Dommel type equations for any type of Dommel branch containing many internal nodes can be developed. However, the rtds_sharc_brnch component does not allow the branch conductance (GRL in the above example) to be changed dynamically during a simulation.

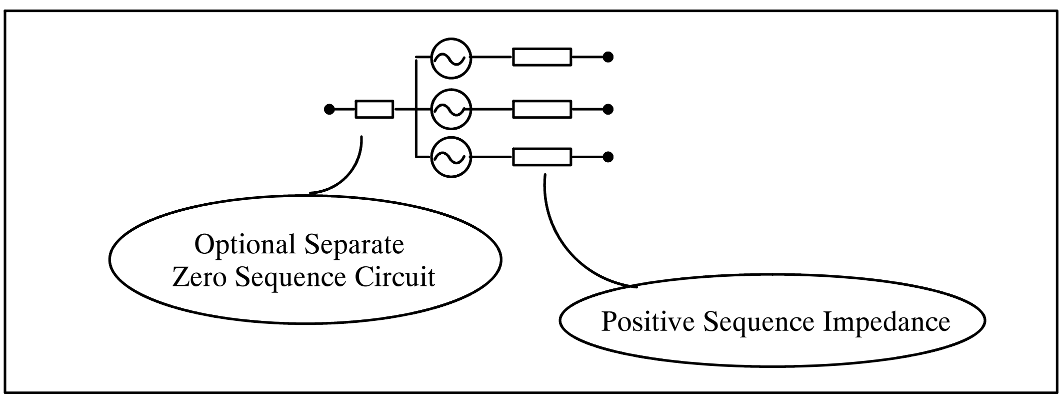
The techniques described above are best used in a academic or tutorial type environment for experimentation because they require the User to develop the equations for the Dommel equivalent branch.

3 SOURCE MODEL



Single and three phase equivalent source models simulate infinite bus voltage signals behind user specified system impedances. Both single and three phase source models exist. Single phase source models can be used to generate waveforms that are either purely sinusoidal ac, ac with superimposed harmonics, dc, and ac modulated. Three phase source models are normally used to represent a balanced sinusoidal three phase infinite bus voltage behind the chosen impedance. A maximum of four harmonics can be specified and superimposed on the balanced fundamental frequency component of voltage.

Various equivalent system impedance options exist. The user specifies the source impedance through the source's RSCAD/Draft component. For the three phase source model, a separate zero sequence circuit can be defined.



All source models allow dynamic variation of voltage magnitude using sliders created in the RSCAD/RunTime Operator's Console. Depending on the source type, sliders may also be created to dynamically alter the source frequency and phase angle during the simulation run. An option exists to define the source waveform using controls components. It is also possible to cause a sudden, timed reduction of the source voltage in order to simulate an internal fault behind the source impedance.

3.1 SOURCE MODEL DESCRIPTION *[lf_rtds_sharc_sld_SRC] [rtds_sharc_SRC1PH2N]*

3.1.1 COMPONENT DESCRIPTION

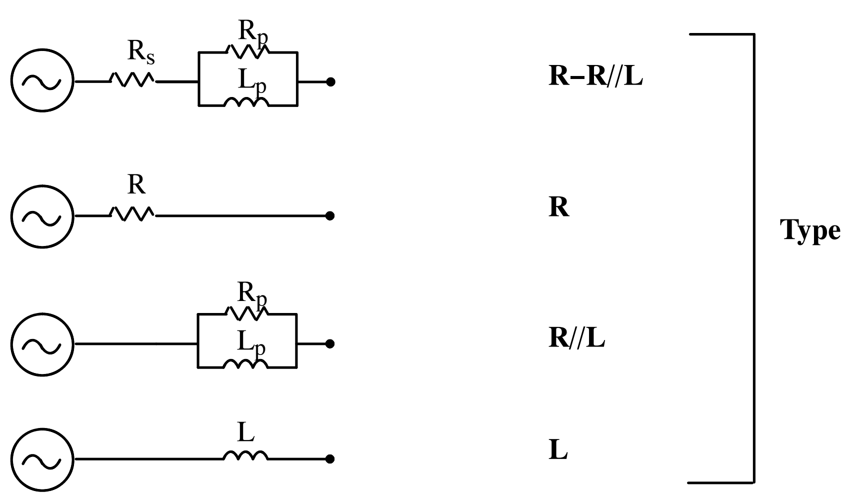
The three phase source model described in this chapter is named *lf_rtds_sharc_sld_SRC*. The single phase source model described in this chapter is named *rtds_sharc_SRC1PH2N*. Each component can be found in the Power System default library and/or can be added by using the RSCAD/Draft Library Add Component feature. Numerous previous iterations of these models exist but are now considered obselete. These models can still be used in a Draft circuit but use of the latest models is strongly recommended.

3.1.2 INTERNAL IMPEDANCE REPRESENTATION

Separate source models are available to represent single and three phase units. In the case of the three phase model, individual positive and zero sequence circuits may be defined. The source model's neutral point may be connected either to ground or to a defined node.

Positive Sequence Impedance

Four different positive sequence source impedance circuit configurations may be chosen. The same configurations are available for both the single phase and three phase source components. One of the configurations listed below can be chosen from the source model configuration menu during the Draft session. The final appearance of the source model icon will reflect the specified impedance.



Source Model Positive Sequence Impedance Options

R−R//L Impedance Parameter Entry

The R−R//L source's positive sequence impedance may be specified in absolute terms by entering the actual Rs, Rp and Lp parameters. Alternatively, the source impedance magnitude, damping angle and harmonic number at which the damping angle equals that at fundamental frequency may be individually selected. Conversion from the latter to the former is performed by the RSCAD/Draft software.

Given a system impedance $|Zp| \angle \Phi$ where −

- $|Zp|$ is the equivalent system short circuit impedance magnitude.
- Φ is the system damping angle at fundamental frequency.
- N represents the harmonic number at which the impedance angle is also equal to Φ.

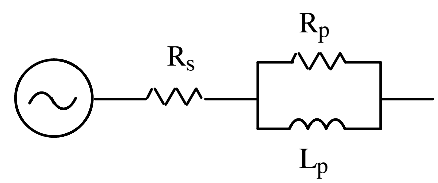
Then the R−R//L parameters may be calculated as follows −

$$A = |Zp| \sin(\Phi)$$

$$E = \sqrt{A} * N(1-N)$$

$$F = A \tan(\Phi) * (1-N^2)$$

$$G = A^{(3/2)} * (N-1)$$



$$B = pos\left[\frac{-F +/- \sqrt{F^2 - 4EG}}{2E}\right]$$

$$\omega L_p = B^2 + A$$

$$R_p = \frac{\omega L_p \sqrt{A}}{\sqrt{\omega L_p - A}}$$

$$k = \frac{(\omega L_p * N) / (R_p \tan(\Phi)) - ((\omega L_p * N) / R_p)^2}{1 + ((\omega L_p * N) / R_p)^2}$$

$$R_s = k * R_p$$

R Impedance Parameter Entry

The R source's positive sequence impedance data entry is the most direct. It is specified in ohms regardless of the impedance data format.

R//L Impedance Parameter Entry

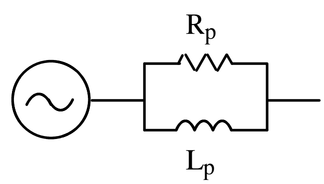
The R//L source's positive sequence impedance may be specified either in absolute terms by entering the actual Rp and Lp parameters, or by entering the source impedance magnitude and damping angle. Conversion from the latter to the former is performed by the RSCAD/Draft software.

Given a system impedance $|Z_p| \underline{/\Phi}$ where –

$|Z_p|$ is the equivalent system short circuit impedance magnitude.
Φ is the system damping angle at fundamental frequency.

Then the R//L parameters may be calculated as follows –

$$\frac{R_p * jX_p}{R_p + jX_p} = |Z_p| \underline{/\Phi}$$



R_p and X_p are solved for using this expression, and then

$$L_p = X_p / (2 \pi f)$$

where f is the base system frequency

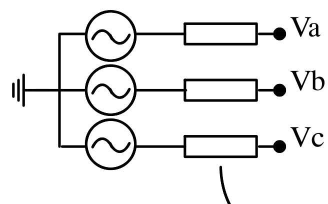
L Impedance Parameter Entry

The L source's positive sequence impedance may be specified in absolute terms by entering the actual Lp parameters or alternatively by entering the source impedance magnitude.

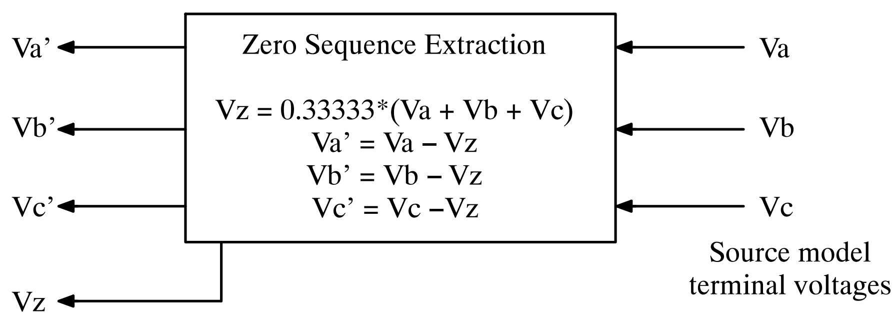
NOTE: Series L Source Impedance is not Recommended. Some caution should be exercised when using the series L source impedance. Since a series L circuit presents a large impedance to high frequency currents, should such currents arise during a simulation and be forced to flow through the series L source impedance numerical instability could occur. A parallel combination of R and L is recommended.

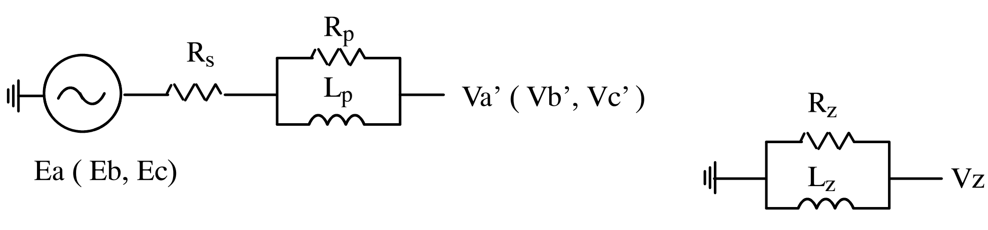
Zero Sequence Representation

Zero sequence impedance may be specified separate from the positive sequence to be used as part of the source model. By specifying in RSCAD/Draft that no separate zero sequence circuit is to be included, the positive and zero sequence components of the terminal voltage are applied to the user specified positive sequence impedance.



When a separate zero sequence impedance is specified, the zero sequence component of voltage measured at the terminals of the source model will be extracted and applied to the zero sequence impedance. Only the remaining purely positive sequence component of voltage will be applied to the positive sequence impedance. In this way equivalent systems whose zero sequence impedance is either greater than, equal to, or less than the positive sequence impedance can be represented.



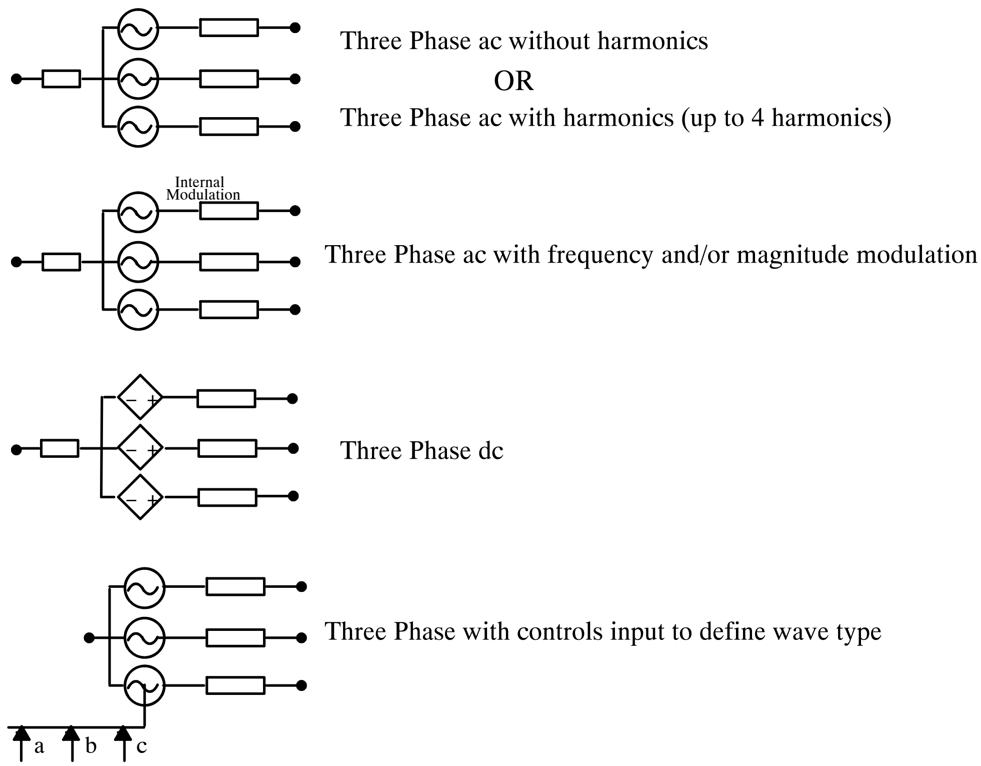


The optional zero sequence circuit consists of a resistive branch and an inductive branch connected in either parallel or series. The zero sequence parameters can be can be entered as either the R_Z and L_Z values or the Z_Z and Φ_Z. In the latter case, RSCAD/Draft will convert the values to R_Z and L_Z internally.

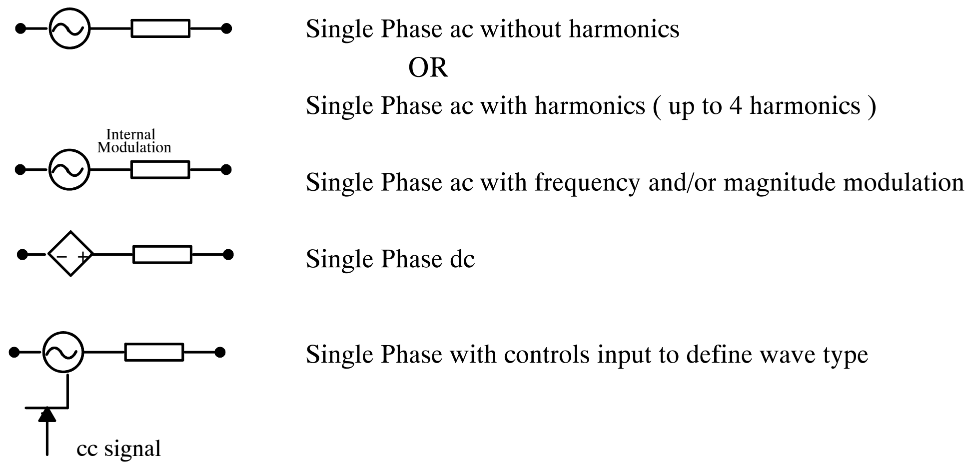
3.1.3 SOURCE MODEL WAVEFORM OPTIONS

In most applications source models are used to represent a sinusoidal voltage behind one of the impedance configurations described in the previous section. However, a source model may produce voltage waveforms which are not purely sinusoidal. For example, a signal may be selected with some specified harmonic components superimposed on the fundamental ac voltage. In other cases, a dc voltage may be applied to some component or portion of a circuit.

The waveform type may be selected in the main configuration menu (see Section 3.3 of this chapter) of either the single or three phase source model, the type of waveform may be specified. The choice is made by choosing from the drop down menu of the *Source Wave Type* entry line. The following table summarizes the wave types associated with the single and three phase models.



Three Phase Source Model Waveform Options



Single Phase Source Model Waveform Options

3.2 DYNAMIC CONTROL

A number of quantities associated with the RTDS source models can be modified while the simulation is running. Generally RSCAD/RunTime slider components are used to control such quantities.

Depending upon the type of source being represented (ie: waveform type) and on the number of phases, the list of dynamically controllable quantities may include :

– three phase voltage magnitude
– single phase magnitude
– frequency
– relative phase angle
– source impedance

In addition, all source models allow the application of a sudden reduction in voltage behind the specified impedance in order to represent a fault behind the source impedance. The magnitude and duration of the reduction are specified when the circuit is created in RSCAD/Draft. Application of the pre–defined internal fault can be repeated as many times as required using a RSCAD/RunTime push–button component. The table below summarizes the control features for each available type of source model.

Source Type	3ϕ mag	1ϕ mag	freq	phase	Int. Flt	Dyn. SRC Z
1ϕ ac (w/o harm)		**X**	**X**	**X**	**X**	
1ϕ ac (c/w harm)		**X**	**X**	**X**	**X**	
1ϕ dc		**X**			**X**	
1ϕ (c/w mod)		**X**	**X**	**X**	**X**	
3ϕ (w/o harm)	**X**		**X**	**X**	**X**	**X***
3ϕ (c/w harm)	**X**		**X**	**X**	**X**	
3ϕ (c/w mod)	**X**		**X**	**X**	**X**	
3ϕ dc	**X**				**X**	

* RPC/GPC/PB5 model only.

With the exception of the internal fault, all dynamically adjustable quantities are controlled through the RunTime Operator's Console using sliders. The internal fault is controlled using a push–button component. The three phase modulated source model and the dynamic source impedance can be controlled either internally via Runtime sliders or externally via a CC signal.

3ϕ Voltage Magnitude

The source 3 phase voltage magnitude can be changed dynamically by creating a slider component in RSCAD/RunTime. Select –

Subsystem #N:Sources:Name:ABCmag

The slider requires line to line rms voltage as input. When created, the slider shows a range of between 0 and two times the rated l–l, rms voltage as entered in RSCAD/Draft. The initial value upon creation of the slider will correspond to the initial voltage specified in RSCAD/Draft. All adjustments are applied through the voltage input time constant (see Configuration Menu in section 3.3). If no slider is created, the 3 phase source voltage magnitude will remain fixed at the initial voltage value entered in RSCAD/Draft.

1ϕ Voltage Magnitude

For the single phase source model select the

Subsystem #N:Sources:Name:ABCmag

component to modify the source voltage magnitude. The input scale is in l–n, rms for AC type source and an absolute magnitude for the DC type source.

Frequency

Source frequency may be dynamically modified for the source model. The slider variable is –

Subsystem #N:Sources:Name:Freq

The slider will have the default value entered as the initial frequency in the RSCAD/Draft component.

Phase Angle

Source phase angle may be dynamically modified for the source model. The slider variable is –

Subsystem #N:Sources:Name:Phase

The slider will have the default value entered as the initial phase in the RSCAD/Draft component. The phase angle slider requires input degrees and a change is applied instantaneously.

Internal Fault Application

An instantaneous, timed reduction in source voltage (ie: fault behind the source impedance) may be specified. A RSCAD/RunTime Button component –

Subsystem #N:Sources:Name:Ftrg

must be created to initiate the source fault.

Source Impedance

For the three phase source component, the source impedance values may be dynamically changed during RSCAD/Runtime if the parameter *DymImp* is set to *Dynamic*. When this option is enabled the source impedance data format is defaulted to RRL values. Either CC signals or Draft/Runtime sliders can be used to control each value indepedently. When the latter approach is used to control the source impedance the following RSCAD/RunTime sliders will become available.

Subsystem:#N:Sources:Name:L0

Subsystem:#N:Sources:Name:R0

Subsystem:#N:Sources:Name:R1S

Subsystem:#N:Sources:Name:R1P

Subsystem:#N:Sources:Name:L1P

The sliders will have the default values entered in RSCAD/RunTime. All changes to these RRL values are applied through a real−pole filter having a time constant specificied by the RSCAD/Draft parameter Tcc.

If the ratio of the positive sequence equivalent resistance and the negative sequence equivalent resistance becomes too large then the the model will tend to become unstable as a result of precision limitiations. This ratio is continually monitored by the component and when the ratio exceeds 1e6, parameter adaptation is halted.

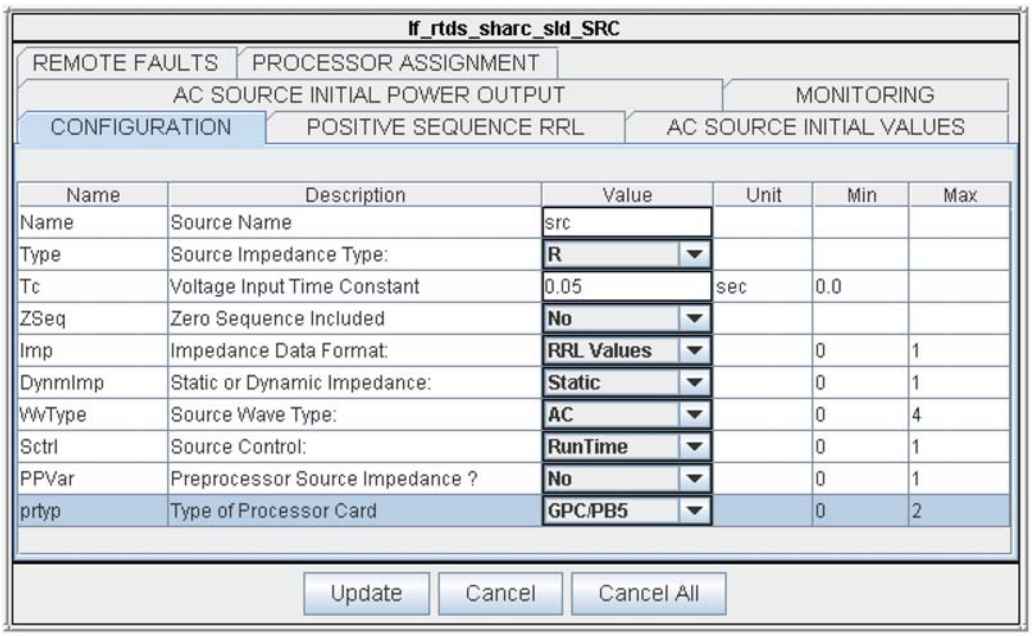
3.3 REQUIRED INPUT DATA

3.3.1 THREE PHASE SOURCE MODEL INPUT DATA

In this section, the RSCAD/Draft icons for both the single and three phase source models are presented together with their respective input menus. Each menu is described in detail in order to understand what data must be provided for the voltage source model.

Depending on the options chosen in the CONFIGURATION menu, some menu tabs may or may not be available.

CONFIGURATION MENU



Name	Description	Value	Unit	Min	Max
Name	Source Name	src			
Type	Source Impedance Type:	R			
Tc	Voltage Input Time Constant	0.05	sec	0.0	
ZSeq	Zero Sequence Included	No			
Imp	Impedance Data Format:	RRL Values		0	1
DynmImp	Static or Dynamic Impedance:	Static		0	1
WvType	Source Wave Type:	AC		0	4
Sctrl	Source Control:	RunTime		0	1
PPVar	Preprocessor Source Impedance ?	No		0	1
prtyp	Type of Processor Card	GPC/PB5		0	2

Name – The source name can be any name beginning with a letter. Following the first letter, the name can contain up to nine more alpha–numeric characters. This name is used in all cross-referencing between Draft and RunTime. If an appropriate name is not assigned to the source in question, an error is issued in the Draft window.

Type – One of the positive sequence impedance options outlined in section 3.1 must be selected by appropriately choosing the source type. Available configurations are again, R, L, R//L and R–R//L.

Tc – The voltage input time constant must be defined for the source in question. The source voltage magnitude on start–up and any subsequent changes to it made through RunTime sliders, are always applied through a real pole function whose time constant is Tc, entered in seconds. For instantaneous changes,Tc must be defined as 0.0.

Note that RunTime adjustments to frequency, phase angle and internal (or remote) faults are not subject to this time constant. Only the single and three phase voltage magnitudes are passed through the time constant.

ZSeq – As previously mentioned, a zero sequence impedance can be defined which is separate from that defined for the positive sequence. Choosing *Yes* for ZSeq will cause the 'Zero Sequence Options' and 'Zero Sequence RL' menu tabs to appear. The former allows the user to select the configuration of the zero sequence impedance; it may be either an R–L or R//L connection. The 'Zero Sequence RL' tab is where the R and L values are entered. If *No* is chosen for ZSeq then no zero sequence information is entered.

Imp – The option is given of entering the positive (and zero) sequence impedances for the source as either impedance magnitude and angle or as resistance in Ohms and inductance in H. Choosing the *Impedance* option indicates to Draft that information is in the form of $|Z|$ and Φ and that it must internally convert this to resistance and inductance. Conversion for R//L and R–R//L is according to that outlined in section 3.1.1. Note that entering *Impedance* will cause the available menu tabs to change from Positive Sequence RRL to Positive Sequence Impedance, and from Zero Sequence RL to Zero Sequence Impedance.

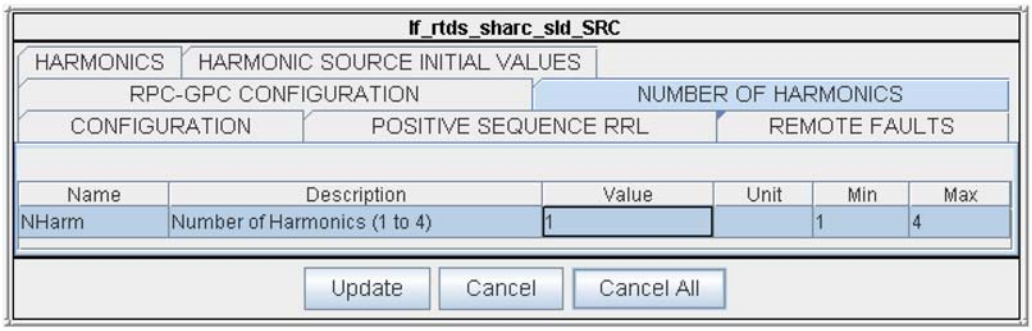
DynmImp – This option allows the user to specify whether or not the source impedance can be modified dynamically during RSCAD/Runtime. Seletion of *Static* implies that the source impedance should remain fixed for the duration of the simulation; selection of *Dynamic* implies that it can be changed. When a *Dynamic* source impedance is enabled the 'DYNAMIC IMPEDANCE' tab will become visible.

WvTyp – This option selects the type of waveform to be generated by the source model. For the three phase model, it is possible to toggle between *AC*, *DC*, *Har* (ie : ac with superimposed harmonics), *AC_Mod* (ie: ac with modulated frequency and/or magnitude) or *CC (controls component input)*. Note that if the Har option is not chosen then the Number of Harmonics and Harmonics tabs will not appear. In addition, the text in the Source Initial Values tab will be modified to reflect the type of source chosen.

Sctrl – This option allows the user to specify how the voltage magnitude, frequency and phase of the source are controlled. If *RunTime* is chosen then three sliders will automatically be available in RUNTIME to control these quantities after the case is successfully compiled. If *CC* is selected then the user can control the voltage magnitude, frequency and phase using any desired control logic. The necessary inputs will become visible on the icon.

PPVar – This option allows the source impedance to be modified from RunTime using a preprocessor slider. If *Yes* is chosen, the preprocessor variable name(s) should be entered in the POSITIVE SEQUENCE RRL menu. A DRAFT preprocessor slider will need to be created to define the initial value of the source impedance. Preprocessor variables can only be used to define the source impedance if RRL data entry is used. For more information regarding preprocessor variables, please refer to Chapter 19 of this manual.

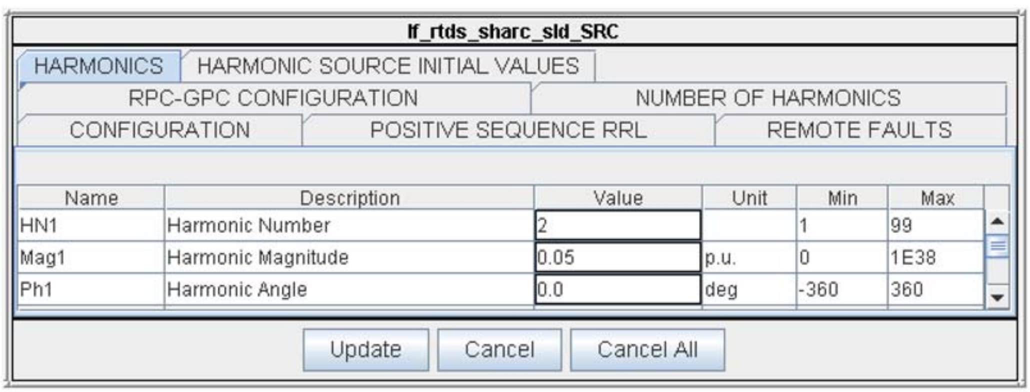
NUMBER OF HARMONICS MENU



This menu will appear only if the *Har* type of source is chosen in the Configuration Menu.

Nharm – In addition to the fundamental frequency component of source voltage the user can define up to 4 harmonics for the source in question.

HARMONICS MENU



This menu will exist only if the *Har* option is chosen in the Configuration menu. Depending on the value of Nharm entered in the Number Of Harmonics Menu, anywhere between 1 and 4 harmonics should be specified. The fundamental component of frequency is taken as the initial frequency F0 described under the Harmonic Source Initial Values menu. Harmonics are defined by their harmonic number (integer), harmonic magnitude, and harmonic phase angle.

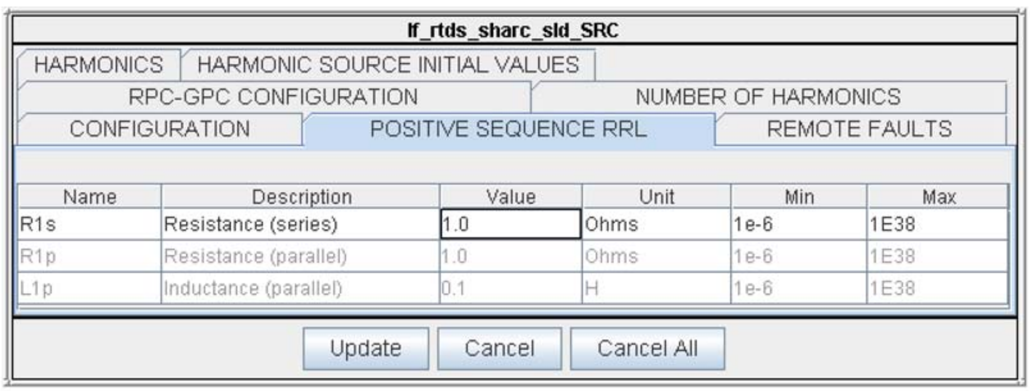
Hn1 – This is the harmonic number of interest, and can be any integer value. A value of 3 for example, would request the third harmonic component based on fundamental frequency ie: F0 = 60 Hz, harmonic = 3*60 = 180 Hz.

Mag1 – The magnitude of the harmonic is entered as a per unit multiplier of the fundamental frequency component's magnitude. Note that since a per unit multiplier is used, a change in source magnitude through a RunTime slider will result in an increase/decrease of both the fundamental and harmonic components in a proportional manner.

Ph1 – This is the relative phase angle of the harmonic with respect to the fundamental upon which it is being superimposed.

For each harmonic being defined, the three quantities described above must be supplied.

POSITIVE SEQUENCE RRL MENU



This menu will appear if *RRL Values* is selected in the Configuration menu and if the source impedance is 'Static'. Depending on the source type, the values of R's and L's defining the source (or equivalent system) impedance must be specified. The most complex case is the R–R//L type of source. The following values must be entered

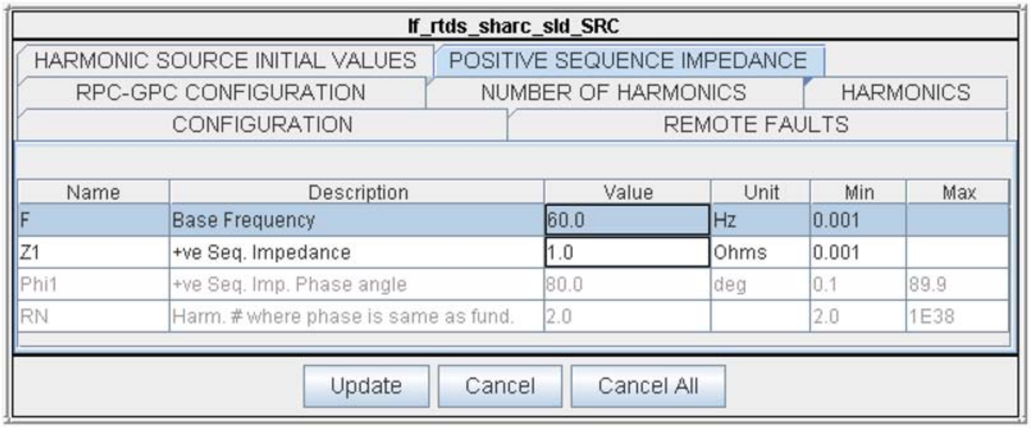
R1s – The series resistance in Ohms.

R1p – The resistance of the parallel R//L branch in Ohms.

L1p – The inductance of the parallel R//L branch in H.

For other source impedance types, one or more of the above lines will be greyed out and Draft will not allow values for the corresponding quantities to be entered.

POSITIVE SEQUENCE IMPEDANCE MENU



This menu will replace the Positive Sequence RRL menu when *Impedance* is chosen as the *Impedance Data Format* and if the source impedance is 'Static'.

F – The system base frequency must be provided in Hz. This quantity is used to internally compute the R,R,L component values if the impedance data is entered in terms of magnitude and angle. Even if the source is a DC type, the frequency to be used in the conversion equations outlined in section 3.1.1 of this chapter must be entered for F. In the case of a DC source, the initial and operating frequency is automatically made 0.0.

The following must be entered:

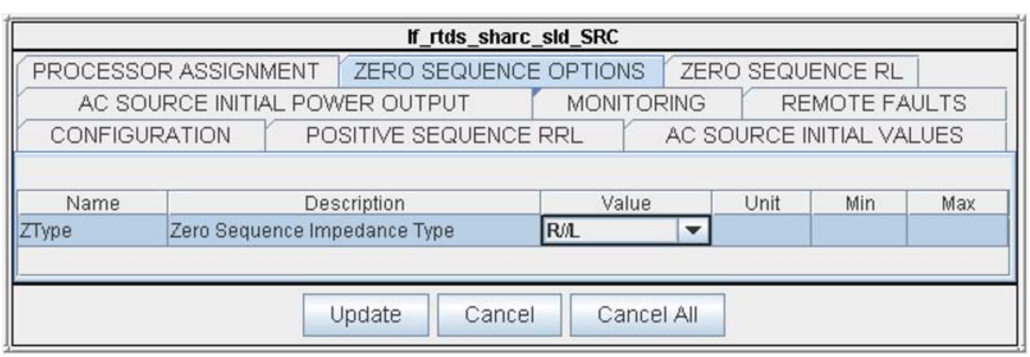
Z1 – The magnitude of the source impedance in Ohms.

Phi1 – The damping angle of the source impedance in electrical degrees.

RN – The harmonic number for which the impedance angle is also Phi1.

The F parameter is used to compute the R,R1 and L values corresponding to the Z1, RN and Phi1 entered.

ZERO SEQUENCE OPTIONS MENU

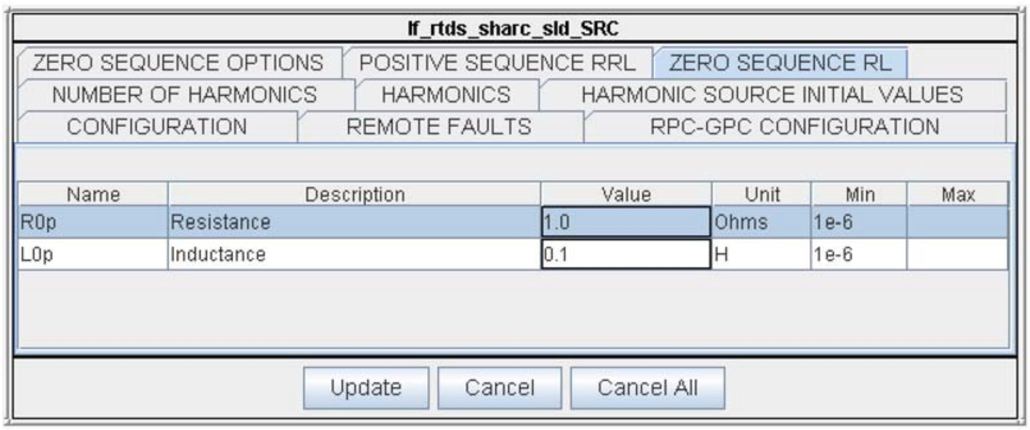


This menu will appear only if *Yes* is selected for ZSeq in the Configuration Menu. The following must be entered;

ZType – The configuration of the zero sequence impedance can be selected as either a parallel or series RL combination. (R//L or R–L).

ZERO SEQUENCE RL MENU

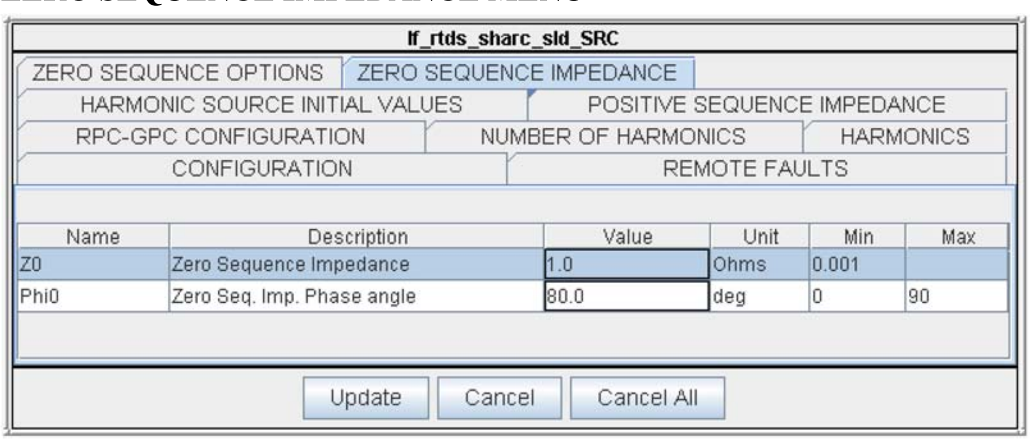
This menu will appear only if *Yes* is selected for ZSeq in the Configuration Menu, the source impedance is ’Static’ and if *RRL Values* is chosen instead of *Imp*. The following must be entered;



R0p – The parallel resistance in Ohms.

L0p – The parallel inductance in H.

ZERO SEQUENCE IMPEDANCE MENU

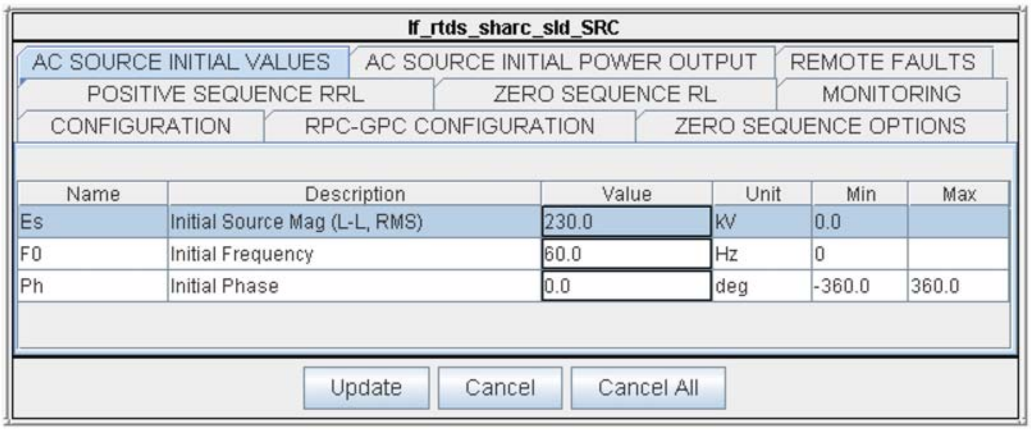


This menu will appear only if *Yes* is selected for ZSeq in the Configuration menu, the source impedance is 'Static' and and if *Impedance* is chosen instead of *RRL Values*. The following must be entered;

Z0 – The impedance magnitude in Ohms.

Phi0 – The impedance angle in electrical degrees.

SOURCE INITIAL VALUES MENU



Initial conditions are required to define the source. Depending on the waveform type, initial values for voltage magnitude, frequency and phase angle should be entered using this menu to define the initial settings for sliders created in the RunTime Operator's Console. It should be remembered that a simulation case always starts with sources at their initial condition settings. If a RunTime slider is created and modified before the case is started, a start–up transient may occur as the operating point changes from its initial condition to that defined by modified slider settings. The following values should be entered;

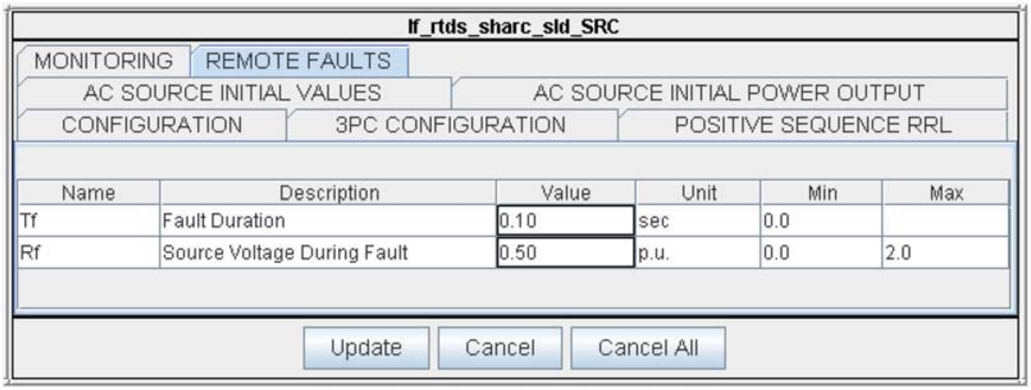
Es – The three phase source magnitude on start–up. This magnitude is reached through the user defined time constant once the simulation run is started.

F0 – The source frequency on start–up. The value can be anything greater than or equal to 0.0 Hz. Note that for a dc source type F0 is assumed to always be 0.0 and hence this information is not required.

Ph – The source initial phase angle. When more than one source is being simulated, this feature allows relative phase angles of the sources to be specified in order to get desired power flow conditions. Note that for a dc source type Ph has no real meaning and hence this information is not required.

REMOTE FAULTS MENU

This menu exists for all types of three phase source models, since this option exists for all sources. An internal or remote fault can be initiated within the equivalent system being represented by the source model, while the simulation is in progress. Faults are applied instantaneously and not through the voltage input time constant. Faults are always on all three phases. Application of the fault condition can be repeated as many times and as often as required by successive triggering through the Operator's Console. An internal timer prevents initiation of a second fault before removal of a previously applied fault. The following values must be supplied;



Tf – The fault duration in sec. Each time the fault is initiated during the simulation run the duration of the fault will be as defined through this parameter.

Rf – The level of voltage during the fault. For example, if the infinite source voltage behind the impedance is to drop to 20% of it's pre–fault value, Rf would be entered as 0.20 pu.

DYNAMIC IMPEDANCE MENU

This menu will appear only if *Dynamic* is selected for DynmImp parameter in the Configuration Menu. The following parameters can be specified;

R1s – Initial positive sequence series resistance.

R1p – Initial positive sequence parallel resistance.

L1p – Initial positive sequence parallel inductance.

R0p – Initial zero sequence resistance.

L0p – Initial zero sequence inductance.

ImpCtlSrc – Used to specify whether reference values for the dynamic source impedances originate from Runtime sliders or from CC signals.

R2signalCC – CC signal name used to control positive sequence series resistance.

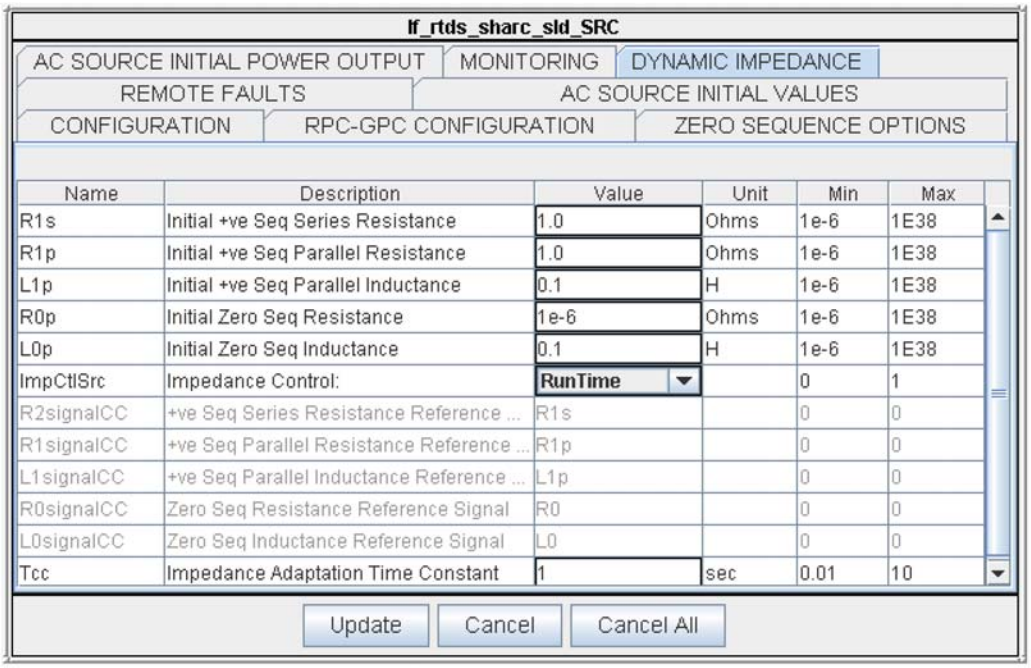
R1signalCC – CC signal name used to control positive sequence parallel resistance.

L1signalCC – CC signal name used to control positive sequence parallel inductance.

R0signalCC – CC signal name used to control zero sequence resistance.

L0signalCC – CC signal name used to control zero sequence inductance.

Tcc – Time constant of the real pole filters used to ensure smooth transition of source impedance parameter values.

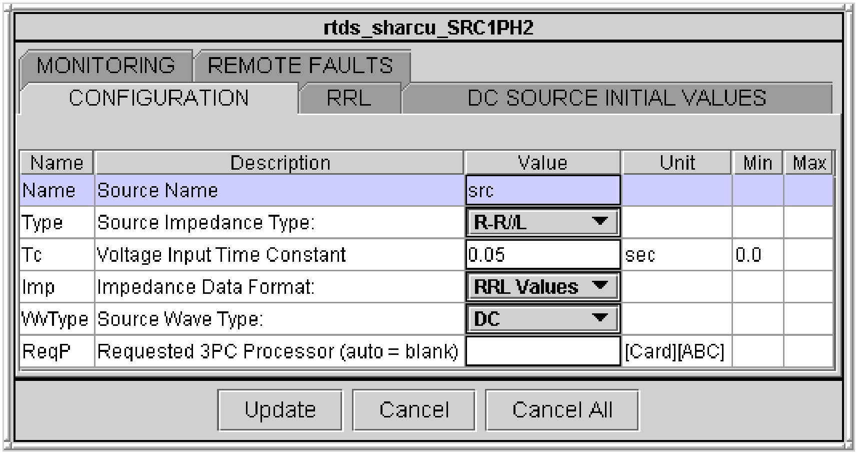


3.3.2 SINGLE PHASE SOURCE MODEL INPUT DATA

The menus associated with single sources are similar to that already explained with respect to the three phase model. Important differences however, include :

– magnitudes are entered in line–to–ground, rms kV for ac and ac with harmonics, and entered in dc kV for the case of a dc source.

– separate zero sequence network is not permitted.



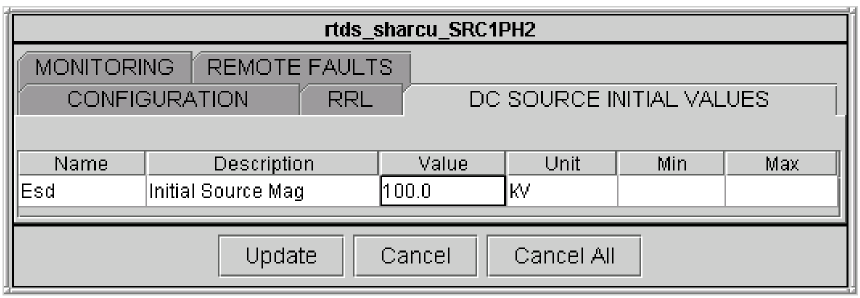
rtds_sharcu_SRC1PH2

MONITORING | REMOTE FAULTS

CONFIGURATION | RRL | DC SOURCE INITIAL VALUES

Name	Description	Value	Unit	Min	Max
Name	Source Name	src			
Type	Source Impedance Type:	R-R/L			
Tc	Voltage Input Time Constant	0.05	sec	0.0	
Imp	Impedance Data Format:	RRL Values			
WvType	Source Wave Type:	DC			
ReqP	Requested 3PC Processor (auto = blank)		[Card][ABC]		

Update | Cancel | Cancel All



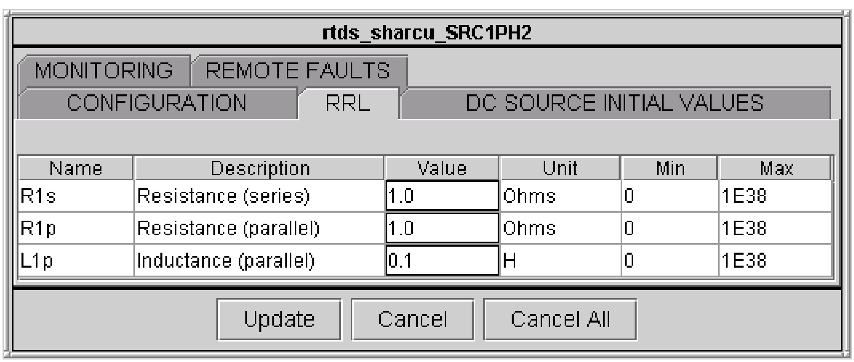
rtds_sharcu_SRC1PH2

MONITORING | REMOTE FAULTS

CONFIGURATION | RRL | DC SOURCE INITIAL VALUES

Name	Description	Value	Unit	Min	Max
Esd	Initial Source Mag	100.0	kV		

Update | Cancel | Cancel All



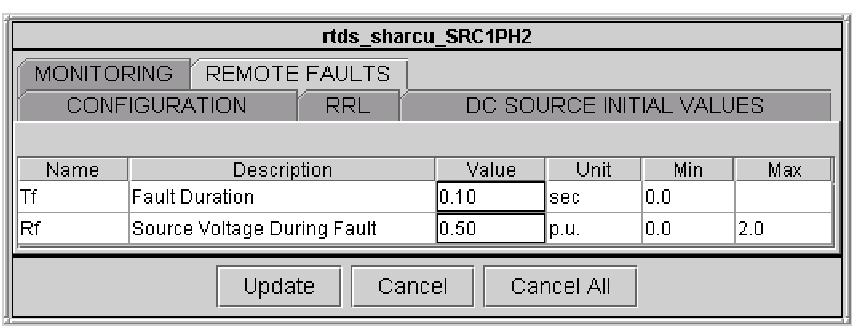
rtds_sharcu_SRC1PH2

MONITORING | REMOTE FAULTS

CONFIGURATION | RRL | DC SOURCE INITIAL VALUES

Name	Description	Value	Unit	Min	Max
R1s	Resistance (series)	1.0	Ohms	0	1E38
R1p	Resistance (parallel)	1.0	Ohms	0	1E38
L1p	Inductance (parallel)	0.1	H	0	1E38

Update | Cancel | Cancel All



rtds_sharcu_SRC1PH2

MONITORING | REMOTE FAULTS

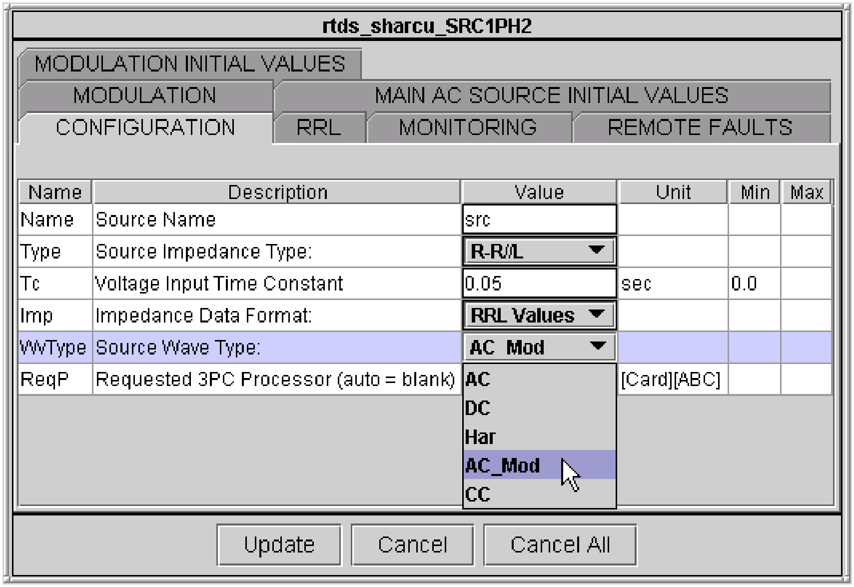
CONFIGURATION | RRL | DC SOURCE INITIAL VALUES

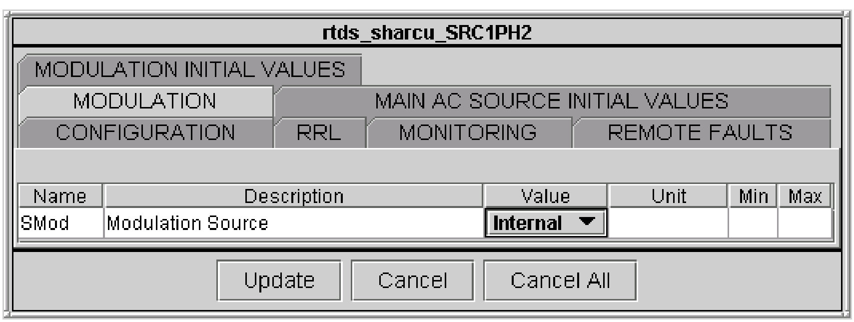
Name	Description	Value	Unit	Min	Max
Tf	Fault Duration	0.10	sec	0.0	
Rf	Source Voltage During Fault	0.50	p.u.	0.0	2.0

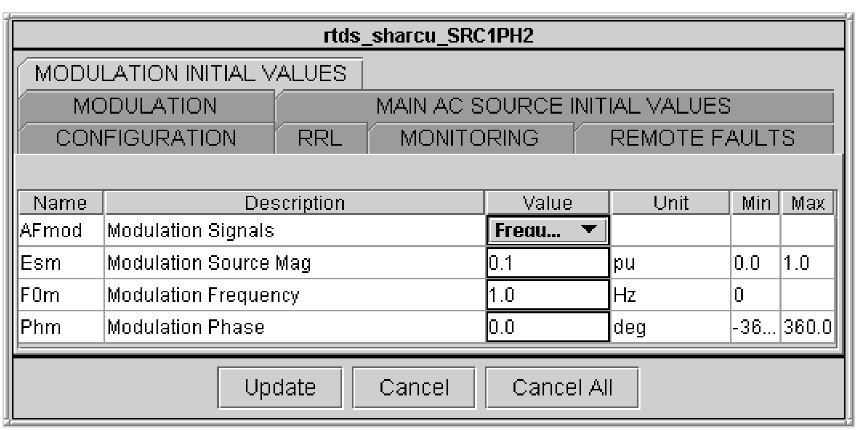
Update | Cancel | Cancel All

3.3.3 AC MODULATED SOURCE TYPE

A source model which permits modulation of both the source frequency and the source magnitude exists. The feature is enabled by setting the source wave type variable to 'AC_Mod' in the RSCAD/Draft component. The modulation signal may be derived from within the RTDS, or optionally from the RTDS Controls Compiler.







INTERNAL MODULATION SOURCE

Internal Modulation refers to the fact that the frequency modulation signal is generated internal to the RTDS. When internal modulation is selected, a modulation source is automatically created. The modulation source's magnitude, frequency and phase may be changed dynamically by creating RSCAD/RunTime sliders for the following variables –

Subsystem #N:Sources:Name:MOD_Mag
Subsystem #N:Sources:Name:MOD_Freq
Subsystem #N:Sources:Name:MOD_Phase

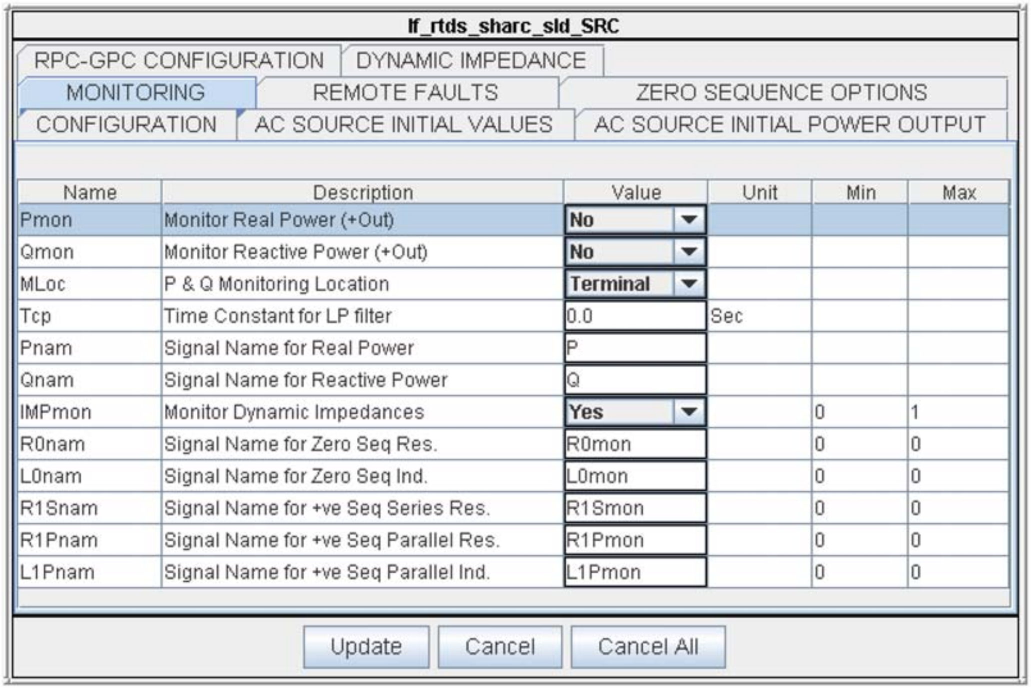
The signal produced by the modulation source is used to modulate the frequency of the main source.

CONTROLS COMPILER MODULATION SOURCE

Controls compiler signals may optionally be created which will permit modulation of both the main source's frequency and magnitude. See the RTDS Controls Compiler User's Manual for further information.

3.4 MONITORING OUTPUT VARIABLES

The single phase source includes an option to monitor the current flowing. The three phase source includes more extensive monitoring including the ability to monitor real and reactive power. If the 3Φ source's impedance is *Dynamic*, then the source resistances and inductances can also be monitored. Monitoring options are set in the 'MONITORING' tab for both the 1Φ and 3Φ source models.



Name	Description	Value	Unit	Min	Max
Pmon	Monitor Real Power (+Out)	No			
Qmon	Monitor Reactive Power (+Out)	No			
MLoc	P & Q Monitoring Location	Terminal			
Tcp	Time Constant for LP filter	0.0	Sec		
Pnam	Signal Name for Real Power	P			
Qnam	Signal Name for Reactive Power	Q			
IMPmon	Monitor Dynamic Impedances	Yes		0	1
R0nam	Signal Name for Zero Seq Res.	R0mon		0	0
L0nam	Signal Name for Zero Seq Ind.	L0mon		0	0
R1Snam	Signal Name for +ve Seq Series Res.	R1Smon		0	0
R1Pnam	Signal Name for +ve Seq Parallel Res.	R1Pmon		0	0
L1Pnam	Signal Name for +ve Seq Parallel Ind.	L1Pmon		0	0

The following values should be specified:

Pmon – ‘Yes’ if real power monitoring is required.

Qmon – ‘Yes’ if reactive power monitoring is required.

MLoc – The user can choose to monitor P and Q either at the source (ie: between the voltage source and the internal impedance) or at the terminals of the model (ie: the nodes to which the model is connected).

Tcp – Filtering time constant used to compute P and Q values

Pnam, Qnam – Signal names for the monitored real and reactive power.

IMPmon – ’Yes’ if monitoring of source impedance values is required.

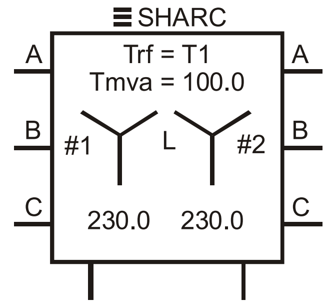
R0nam, L0nam, R1Snam, R1Pnam, L1Pnam – Signal names for the monitored dynamic resistances and inductances.

Both of the monitored P and Q values represent three phase quantities and are computed according to equations below.

$$P = Va*ia + Vb*ib + Vc*ic$$

$$Q = (1/3) * (ia*(Vb-Vc) + ib*(Vc-Va) + ic*(Va-Vb))$$

4 TRANSFORMER MODELS



Different types of transformers for various applications can be represented on the RTDS. The basic power or voltage transformer (ie: step−up or step−down) will be discussed in this chapter.

Presently, transformer models can represent two or three winding configurations on a single 2 limb core. Three phase transformers models have each winding connected in either wye−grounded, wye−ungrounded or delta. The user is free to choose the configuration through appropriate data entry during the DRAFT session. A single phase two winding transformer and three phase two and three winding auto transformers models are also available.

In general, transformer models are stackable, meaning that two or more components may be assigned to one Sharc processor. Computations of all stacked components will be performed on a single Sharc processor. If stacking is not being used, the transformer models are allocated one Sharc processor per component.

On line tap changers are presently available for use with the three phase two winding transformer model.

Ideal transformers can be defined and simulated by choosing the *Ideal* option in the transformer's CONFIGURATION menu, in the *type* menu item. An ideal transformer will have no magnetizing inductance and will therefore be represented by the specified leakage reactance only. Non−ideal transformers will involve a magnetizing branch (ie: reactance) along with the specified leakage reactance value. If core saturation effects are not modelled, the magnetizing reactance will be linear. If however the user chooses to represent non−linear saturation effects, the magnetizing branch representation changes from that of a simple inductance to a more complicated combination of inductance in parallel with a non−linear current source. Currently, hysteresis can only be modelled in the three phase two winding transformer model. Each transformer modelling option is dealt with and explained in more detail in subsequent sections of this chapter.

4.1 THEORY OF MUTUAL COUPLING

RTDS transformer modelling is based on the theory of mutual coupling. In order to illustrate the concepts involved, the case of two coupled windings can be considered. The same theory can then be extended to cases of three or more windings.

Figure 4.1 represents two mutually coupled windings. The first winding is connected between nodes 1 and 2 and has its self inductance designated as L_{11}. The second winding is connected between nodes 3 and 4 with a self inductance L_{22}. The mutual inductance between windings is designated as M_{12}.

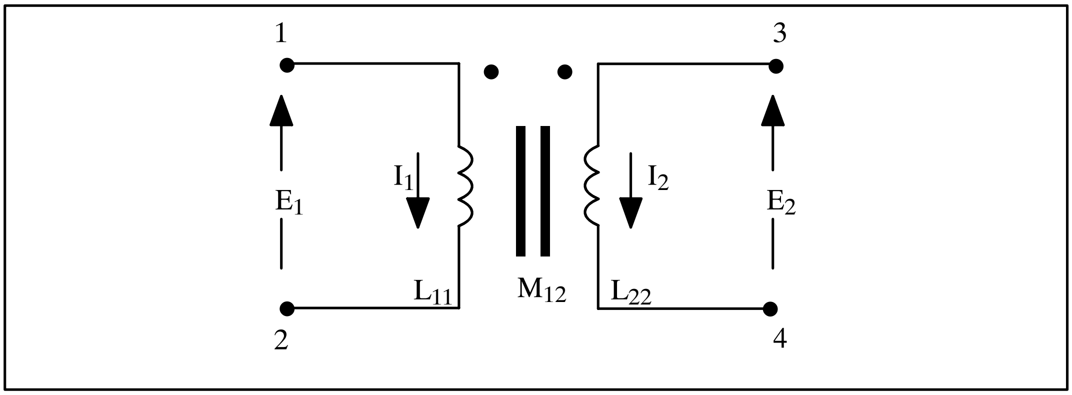


Figure 4.1 Two Mutually Coupled Windings

If the voltage across the first winding is E1 and the voltage across the second winding is E2 then the equation describing the electrical relationship of the circuit can be written in matrix form as :

$$\begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \begin{bmatrix} L_{11} & M_{12} \\ M_{12} & L_{22} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} \qquad \text{Eq. 4.1}$$

In order to solve for winding current, the inductance matrix must be inverted :

$$\frac{d}{dt} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} L_{22} & -M_{12} \\ -M_{12} & L_{11} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \end{bmatrix} \qquad \text{Eq. 4.2}$$

where :

$$D = L_{11} L_{22} - M_{12}$$
$$= L_{11} L_{22} (1 - K_{12}^2)$$

$$K_{12} = M_{12} / \sqrt{(L_{11} L_{22})} \quad \text{(coupling coefficient)}$$

For the case of ideally coupled windings, the coupling coefficient K would be one. Generally however, K is less than one hence resulting in a finite inverse inductance matrix (Equation 4.2).

For closely coupled coils wound on the same core, the turns ratio is defined as :

$$E_1 / E_2 \;\; = a = \sqrt{} \, (L_{11} / L_{22})$$

Making use of the turns ratio ‘a’, Equation 4.1 can be re–written as :

$$\begin{bmatrix} E_1 \\ aE_2 \end{bmatrix} = \begin{bmatrix} L_{11} & aM_{12} \\ aM_{12} & a^2L_{22} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_1 \\ i_2 /a \end{bmatrix} \qquad \text{Eq. 4.3}$$

An equivalent circuit, based on Equation 4.3 can then be drawn as shown in Figure 4.2. It should be noted that winding resistances have been ignored in all equations and equivalent circuits since the RTDS transformer models assume these to be zero.

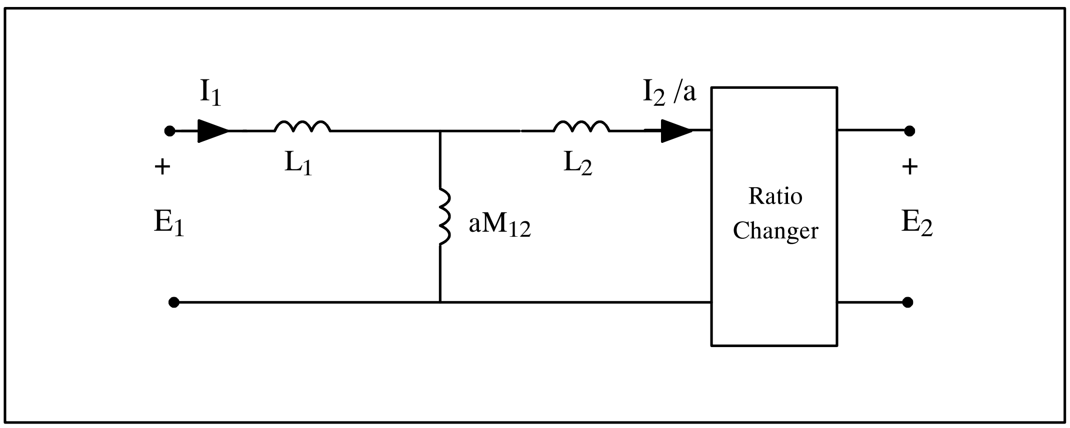


Figure 4.2 Equivalent Circuit for Two Mutually Coupled Windings

In Figure 4.2 the following definitions apply :

$$\begin{aligned} L_1 \quad &= L_{11} - aM_{12} \\ &= L_{11} - \sqrt{} \, (L_{11} / L_{22}) \;\; K_{12} \sqrt{} \, (L_{11}{*}L_{22}) \\ &= L_{11} \, (1 - K_{12}) \end{aligned}$$

$$\begin{aligned} L_2 \quad &= a^2 \, L_{22} - a \, M_{12} \\ &= (L_{11} / L_{22}) \, L_{22} - \sqrt{} \, (L_{11} / L_{22}) \, K_{12} \sqrt{} \, (L_{11} \, L_{22}) \\ &= L_{11} \, (1 - K_{12}) \end{aligned}$$

$$\begin{aligned} aM_{12} \quad &= / \, (L_{11} / L_{22}) \, K_{12} \, / \, (L_{11} \, L_{22}) \\ &= K_{12} \, L_{11} \end{aligned}$$

The parameters of the inductance matrix in Equation 4.1 can be determined from standard transformer tests assuming sinusoidal currents. The self inductance of any winding x is determined by applying rated rms voltage V_X to that winding and measuring the rms current I_X flowing in the winding with all other windings open circuit. This is the open circuit test and the current I_X is the magnetizing current. The self inductance L_{XX} is given as:

$$L_{XX} = V_X / (\omega I_X) \qquad \text{Eq. 4.4}$$

where : ω is the rated radian frequency at which the test was performed.

Similarly, the mutual inductance between any two coils x and y can be determined by shorting coil y and applying an rms voltage Vx to the coil such that rated rms current Ix flows in coil x. Then with reference to Figure 4.2, with x = 1 and y = 2:

$$\begin{aligned} V_1 / I_1 &= \omega (L_1 + L_2) \\ &= 2\omega L_{11} (1 - K_{12}) \\ &= XL_{12} \end{aligned}$$

$$\text{for } aM_{12} >> L_2$$

hence

$$K_{12} = 1.0 - XL_{12} / 2\omega L_{11}$$

or in general

$$K_{XY} = 1.0 - XL_{XY} / 2\omega L_{XX} \qquad \text{Eq. 4.5}$$

with winding y short circuited, and

$$M_{XY} = K_{XY} / (L_{XX} L_{YY}) \qquad \text{Eq. 4.6}$$

Providing the self inductances L_{XX} and L_{YY} are known, the mutual inductance M_{XY} between any two windings can be found using Equation 4.6.

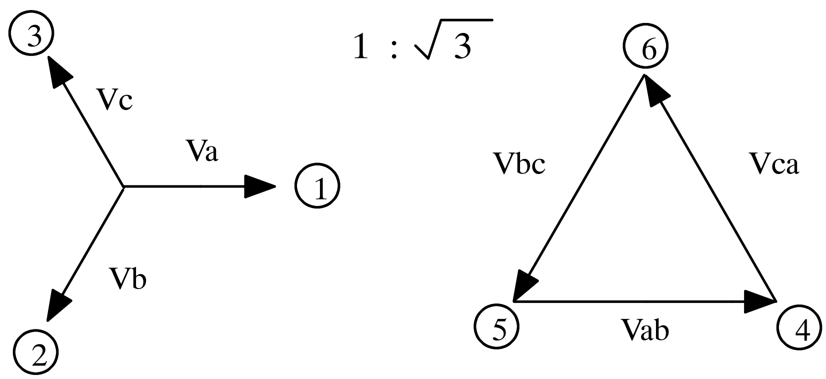
4.2 TRANSFORMER WINDING CONFIGURATIONS

As previously mentioned, transformer windings can be connected either between node and ground (as would be the case for a WYE–GROUNDED winding) or between two nodes (as would be the case for WYE–UNGROUNDED or DELTA windings). The desired winding configurations is specified by making the appropriate choices in the transformer's CONFIGURATION menu of DRAFT. In order to illustrate the effects of different winding configurations, a 2−winding transformer is considered in the following discussions. All discussions could however be extended to the case of 3−winding units.

When both sides of the transformer are WYE connected, the line to neutral voltages on the secondary will be in phase with the corresponding line to neutral voltages on the primary. Branch currents and current injection history terms of corresponding primary and secondary windings will then also be in phase.

If however, one side of the transformer is WYE connected while the other side is DELTA connected, a 30^{o} phase shift and a SQRT(3) change in magnitude are introduced between corresponding line to neutral quantities on the primary and secondary sides. For example, the line to ground voltage on the DELTA side will be 30^{o} out of phase and will have a magnitude which is SQRT(3) times less than that on the WYE side (assuming a 1:1 turns ratio). The 30^{o} phase shift can be either lagging or leading, depending on how the windings are connected. The DELTA winding must be specified in DRAFT to lead or lag the WYE winding.

A lagging DELTA phase shift can be explained with reference to the vector diagrams and equations shown in Figure 4.3 (note here a one−to SQRT(3) turns ratio has been assumed therefore resulting in line to ground voltages of equal magnitude on both sides).



$Va = 1.0 \angle 0.0^{o}$ $\quad$ $Vab = \sqrt{3.0} \angle 0.0^{o}$

$Vb = 1.0 \angle -120^{o}$ $\quad$ $Vbc = \sqrt{3.0} \angle -120^{o}$

$Vc = 1.0 \angle +120^{o}$ $\quad$ $Vca = \sqrt{3.0} \angle +120^{o}$

$Ia = 1.0 \angle -90^{o}$ $\quad$ $Iab = \sqrt{3.0} \angle -90^{o}$

$Ib = 1.0 \angle -210^{o}$ $\quad$ $Ibc = \sqrt{3.0} \angle -210^{o}$

$Ic = 1.0 \angle +30^{o}$ $\quad$ $Ica = \sqrt{3.0} \angle +30^{o}$

Figure 4.3 Vectors Representation For Lagging Delta Connection

If a leading DELTA is requested then the total current injections into nodes 4, 5 and 6 would require angles of $\angle -60^o$, $\angle -180^o$ and $\angle +60^o$ respectively.

The RTDS code together with DRAFT ensure that the appropriate coupling between windings, appropriate node numbering and appropriate injection summations are performed for the user defined winding configurations.

4.3 TRANSFORMER EQUIVALENT CIRCUIT OPTIONS

Transformers can be modelled in one of three ways :

i) ideal transformer
ii) linear transformer
iii) saturating transformer

Depending on the study application and upon operating conditions, any of the above modelling options may be chosen.

The ideal transformer option results in the simplified representation depicted in Figure 4.4.(one phase shown). Here the transformer is modelled as a simple series reactance (based on the user specified leakage reactance) together with a ratio changer. No magnetizing path is provided.

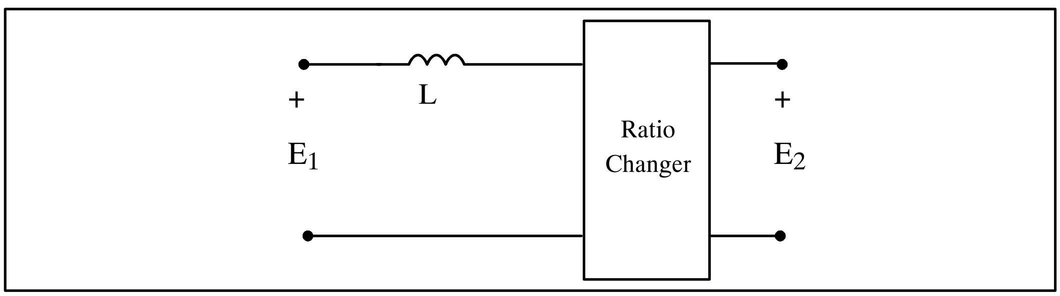


Figure 4.4 Ideal Transformer Representation

The linear transformer option results in the equivalent representation of Figure 4.5. In this case the magnetizing branch is included in the model as an inductive branch.

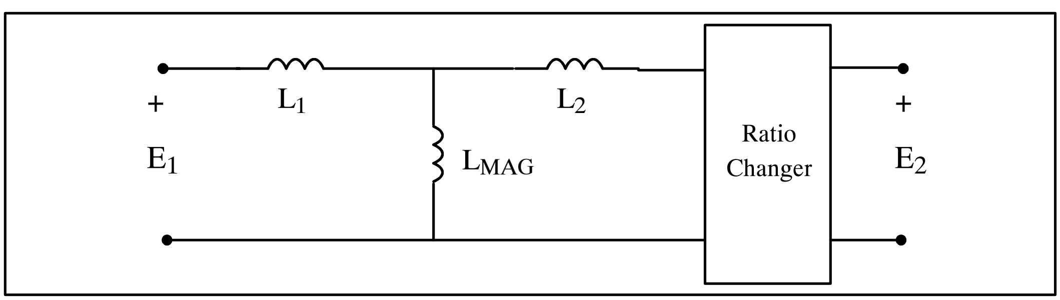


Figure 4.5 Linear Transformer Representation

The magnetizing branch inductance, L_{MAG}, is automatically computed by the RTDS compiler based on information supplied by the user during the DRAFT session. The desired level of magnetizing current at 1 p.u. voltage along with the MVA and voltage ratings of the transformer must be specified. Based on this information, the RTDS compiler determines and inserts the corresponding magnetizing branch inductance. Since the value of L_{MAG} is fixed, the magnetizing current increases linearly with increase in applied voltage. The effects of core saturation are therefore not represented when this version of transformer model is chosen.

The linear transformer model provides a more realistic representation than does the ideal transformer and can in fact be considered sufficiently accurate when winding voltages are maintained below saturating levels. For a better understanding, the linear transformer model may be verified by applying the standard open circuit test. With the secondary windings open circuited, 1 p.u. voltage can be applied to the primary winding. Measurement of the line current entering the transformer from the primary side should yield the specified '*magnetizing current at 1 p.u.*' level. In addition, the applied voltage may now be increased and the increase in current monitored. It should become clear that the non–linear increase in magnetizing current which results when winding voltages in a physical transformer unit approach and exceed the saturation knee point will not be reproduced in this model. Instead, the current will increase in a linear manner when the applied winding voltage is increased.

Non–linear magnetizing effects can normally be modelled in one of two ways, namely by modifying the conductance (ie: L_{MAG}) value which represents the transformer magnetizing branch, or by introducing an additional, changeable current source in parallel with a fixed conductance. For application on the RTDS the latter approach is preferable since it does not require change to, or re–inversion of the sub–system conductance matrix.

The equivalent representation of the saturating transformer model is shown in Figure 4.6. An important difference between this model and the non–saturating linear model is the placement of the magnetizing branch. In the linear model the magnetizing inductance can be placed between inductance L_1 and L_2, where the sum of L_1 and L_2 represent the leakage reactance. The relative magnitudes of L_1 and L_2 are user specified. From Figure 4.6 it can be seen that the magnetizing branch of the saturating transformer is placed at one end of the leakage reactance. This is an approximation which must be made in order to facilitate implementation of core saturation.

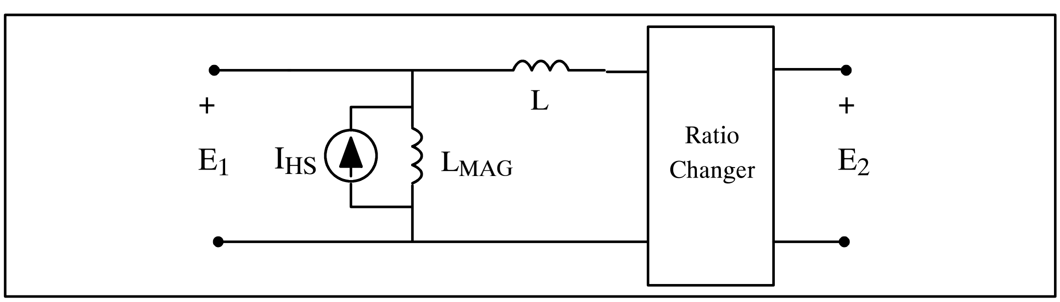


Figure 4.6 Saturating Transformer Representation

Remembering that the Dommel solution technique involves replacement of all inductances within a circuit by equivalent resistances and parallel current sources, the inductance L_{MAG} in Figure 4.6 can be converted to a resistance R_L in parallel with a current source I_H. The magnetizing branch can then be represented as shown in Figure 4.7.

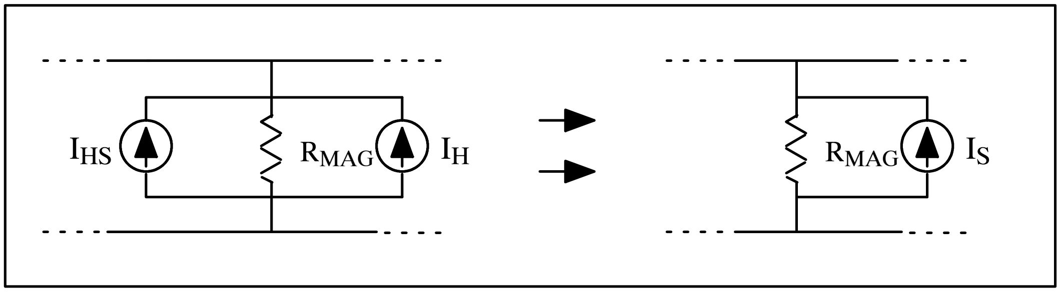


Figure 4.7 Magnetizing Branch Representation

In order to simplify implementation, the two current source components shown in Figure 4.7 have been combined to form a single current injection. The resultant current source (or current injection) represents both the effects of core saturation and the effects of core loss.

4.4 SATURATION AND HYSTERESIS MODEL

The algorithm developed for modelling of saturation and core loss is loosely based on a method described in the IEEE paper [REF1] " Hysteresis Model for System Studies ". With this model it is possible to represent minor loop travel within the flux–current (ie: ϕ vs I) plane, sustained and initial flux remenance and realistic inrush phenomena.

The model utilizes a look–up and interpolation method. A set of curves representing the major (or parent) loop of the ϕ vs I characteristic are generated off line and stored in the DSP's internal RAM by the RTDS compiler. These curves along with a second set of curves representing flux differences between the two paths of the parent loop are then used to determine the current to be injected for any given value of flux.

The the major loop of the ϕ vs I characteristic is generated by first solving Equation 4.7 for a single valued saturation curve and then shifting it in the horizontal plane to form the loop.

Equation 4.7 represents a curve which is asymptotic to the specified air core reactance line and to the vertical axis, passing through a point defined by the 1 pu. magnetizing current and flux. Figure 4.8 illustrates the curve defined by Eq. 4.7.

$$I_s = \frac{\left[\sqrt{(\phi_S - \phi_K)^2 + 4DL_A} + (\phi_S - \phi_K) \right]}{2L_A} - \frac{D}{\phi_K} \qquad \text{Eq. 4.7}$$

where : $D = \dfrac{-B - \sqrt{B^2 - 4AC}}{2A}$

$A = \dfrac{L_A}{\phi_K^2}$ $\qquad B = \dfrac{L_A I_M - \phi_M}{\phi_K}$

$C = I_M (I_M L_A - \phi_M + \phi_K)$

$\phi M = \dfrac{V_M}{2 \pi F}$ $\qquad \phi_K = K^* \phi_M$

and : ϕ_S is the winding flux obtained from integration of winding voltage, L_A is the air core reactance, I_M is the magnetizing current @ 1 pu. voltage, K is the pu. knee point value

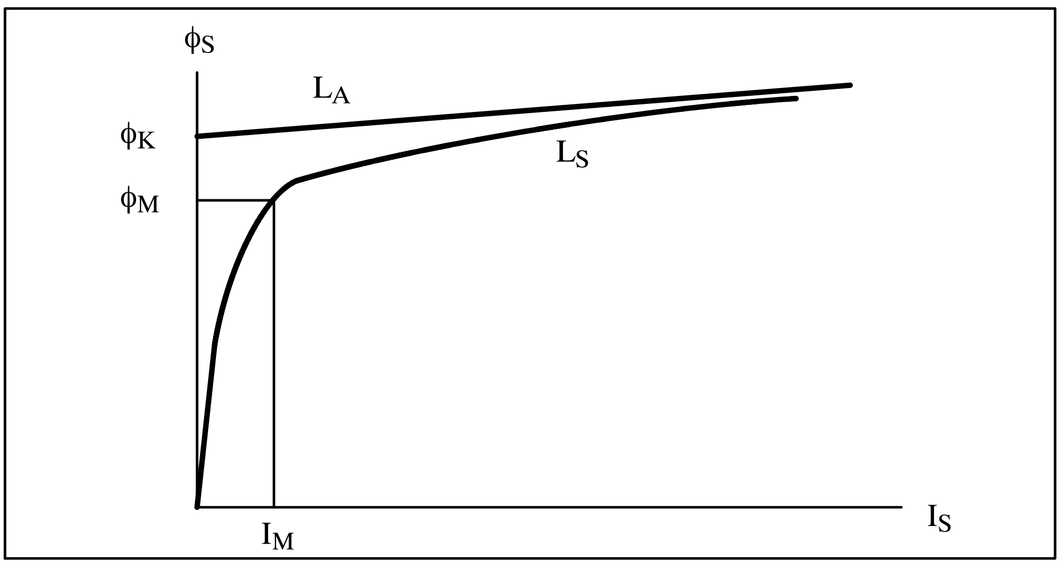


Figure 4.8 Single Valued Characteristic

This equation is solved as part of the off−line preprocessing. It is evaluated for flux values between plus and minus the specified knee point limits (ie : between $+/-\phi_K$). This single valued ϕ vs I characteristic is then shifted in the positive current direction (ie : horizontally) by an amount consistent with the user defined hysteresis loop width. The other side of the major loop is then generated as the negative of the negative function described by the positively offset curve, ie :

$$\text{if} \quad I_1 = F(\phi) \quad \text{then} \quad I_2 = -F(-\phi)$$

In this way the two extreme paths of the $\phi - I$ characteristic are defined.

Figure 4.9 illustrates a typical ϕ vs I characteristic with the parent or major loop shown.

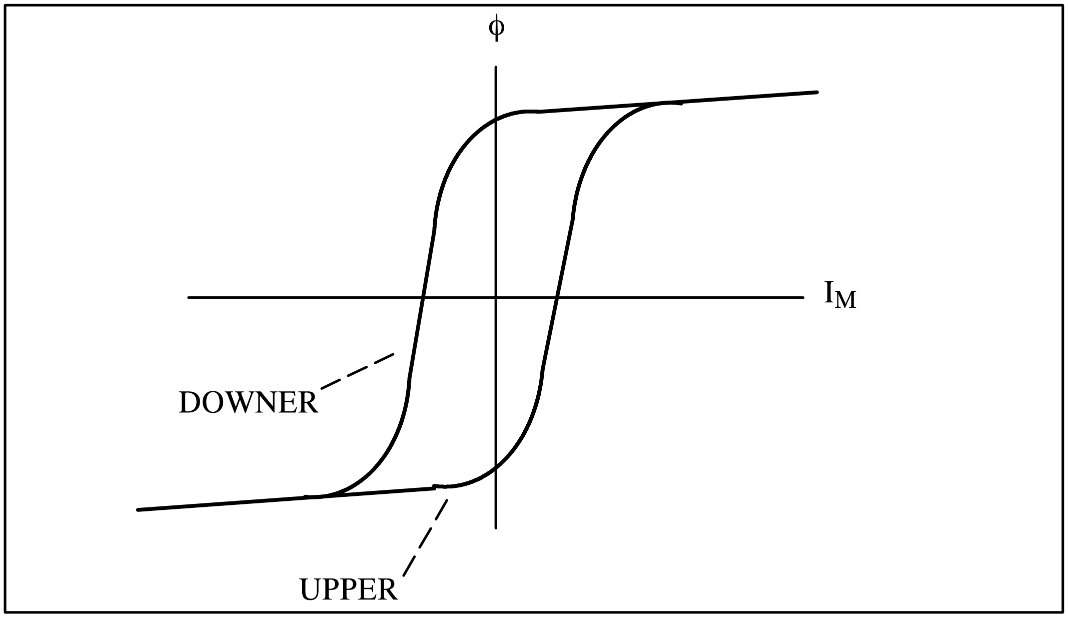


Figure 4.9 Typical $\phi - I$ Parent Loop

During saturated operation of the transformer, the normal path of travel in the flux–current plane would be along the positively offset portion of the curve for increasing flux (call this the UPPER curve) and along the negatively offset portion of the curve for decreasing flux (call this the DOWNER curve).

The points of confluence for the two curves making up the major loop are at the defined saturation knee point values (ie : $+/-\phi_{sat} = +/-\phi_K$). Both curves are forced to have the same value at these points. Beyond the points of confluence the characteristic is assumed to be single valued. The slope of the single valued curve extensions is equal to that of the last stored interval of the parent curve which matches the correct direction of travel towards the confluence point in question.

If a flux turn around point (ie : voltage zero crossing) occurs at any point in the non–saturated region, the path of travel must change along a trajectory which tends towards the confluence point associated with travel along the opposite parent curve. If a flux turn around point occurs in the saturated region (ie : outside the stored loop), then no action need be taken since only one path (ie : a straight line) exists there. Upon re–entry to the stored curve, the correct path is automatically chosen based on whether the flux is increasing or decreasing.

At a turn around point the trajectory leading from any present point on or within the stored loop toward the correct new point is defined by two quantities, namely ;

i) The difference in flux between the present point and the point directly above/below on the parent curve toward which we must travel (call this the turn around factor TAF).

ii) The point of confluence toward which we must move.

The quantity TAF is calculated only in the time steps where flux turn around points are detected and is then used in every sequent time step until a new turn around point occurs. TAF is multiplied by a function which reduces from 1.0 (for the time step in which the turn around point occurs) to 0.0 (for the time step in which the point of confluence is reached). This is the so called *reduction function*.

By applying the reduction function to the TAF, a trajectory is formed which takes the operating point from that at the turn around point toward the portion of the parent loop which represents the new direction of travel. If no new flux turn around point occurs before the reduction function becomes 0.0, the trajectory should take the operating point through the point of confluence and on to the single valued curve extensions.

This model may be used in conjunction with components that include transformers, but do not include saturation, such as the HVDC valve group transformers, and the synchronous machine.

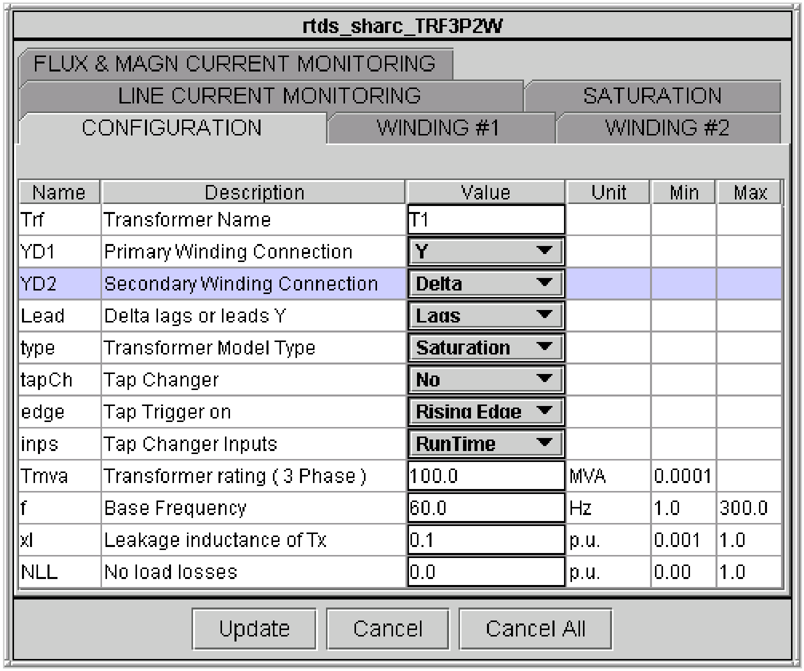
4.5 TRANSFORMER MODEL INPUT DATA

Data for the transformer models is entered through the RSCAD based DRAFT program. Required parameters are entered in the usual manner through various menus.

Many of the DRAFT parameters are common throughout all of the transformer models. All of the transformer parameters of the three phase two winding transformer will be discussed below. The three phase two winding transformer model may be used to represent an ideal, linear or saturation type transformer model. Hysteresis can be modelled and a dynamic tap changer are also available for use with this transformer model.

The three winding transformer model can be used to represent only ideal and saturation type transformers. A dynamic tap changer and hysteresis currently cannot be used with this model.

Two and three winding auto transformer models are also available. The data input is the same as the power transformer models, but the compiler computes the data as an auto transformer model. The two winding auto transformer model may represent a linear, ideal and saturation type transformer model. Currently hysteresis and a tap changer are not available. The three winding auto transformer model can be modelled as an ideal or saturation type transformer model. Saturation and hysteresis is placed across the entire high voltage winding.



The CONFIGURATION menu appears when the EDIT option on the transformer model is chosen. Note that the *SATURATION* menu tab appears only if the effects of core saturation and hysteresis are to be modeled, in which case the *type* menu item should be set to *Saturation*. If the desired transformer model is of type Saturation, another menu tab will appear labelled *FLUX & MAG CURRENT MONITORING,* as can be seen above.

Each of the menus is described in detail in the paragraphs which follow. The descriptions identify and explain the individual parameters which must be entered.

CONFIGURATION Menu:

– Name – The transformer name must begin with a letter. DRAFT will limit the number of characters to 10. The specified name is then used in all cross–referencing between DRAFT and the RunTime Operator's Console.

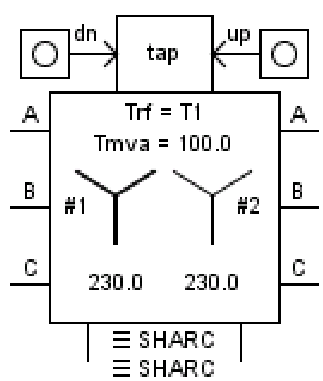
– YD1, YD2, YD3 – Winding configurations for the respective windings are defined using these parameters. YD3 is present only in the case of a 3–winding transformer.

– Lead – As previously explained in section 4.2 of this chapter, the 30 degree phase shift between the corresponding line quantities on the WYE and DELTA sides of a transformer can be either lagging or leading.

– type – The transformer model type must be selected. Three transformer types available are, linear, ideal and saturation. Upon selection of the transformer type, the graphical representation of the transformer icon in Draft will change. If the Linear type model is selected, a letter 'L' will appear in the transformer icon. Similarly, if an Ideal type model is chosen, a letter 'I' will appear in the transformer icon. If Saturation is selected, the winding that the saturation has been placed upon will appear drawn with a bold black line. Upon selection of the Saturation type transformer model, two additional menu tabs will appear: SATURATION and FLUX & MAGN CURRENT MONITORING.

– tapCh – A dynamic tap changer is available. The tap changer may only be used for transformer models of type "Ideal" or "Saturation". If a tap changer is enabled with the "Linear" type transformer model, an error message will be issued. The recommended tap range is 0.7 to 1.3 p.u. If the tap position is too extreme, it may cause numeric instabilities.

If a tap changer is not required, the tapCh toggle box should be set to "No". Two selections are available for setting the tap positions. A position table "POS Table" or a step table "Step/Limit". The position table requires all tap positions to be entered whereas the Step/Limit table requires an initial position, an increment and an upper limit. Selecting "POS Table" creates two new menu tabs, and the graphical appearance of the transformer model is modified.



2 Winding Transformer Model With Tap Changer

– edge – If Falling Edge is selected, the tap position increases or decreases by one when the tap position changes from 1 to 0. If Rising Edge is selected, the tap position increases or decreases by one when the tap position changes from 0 to 1.

inps – Tap changer inputs may originate from the controls compiler. If the tap changer is enabled, and the CC (controls compiler) option is selected to define the tap changer inputs, the transformer icon will change appearance as shown above. There are three inputs/output that need to be specified in Draft. These are down, up and position as shown on the tap changer of the transformer icon. The position wire is used for monitoring the current position of the tap in RunTime. The down and up inputs require an integer values such as a controls library pushbutton.

If the controls compiler is not selected to define tap inputs, the RunTime option should be chosen. This will prompt the compiler to automatically include UP/DOWN push buttons in the RunTime CREATE list. A POS signal is also created which can be selected in RunTime to monitor the current position of the tap.

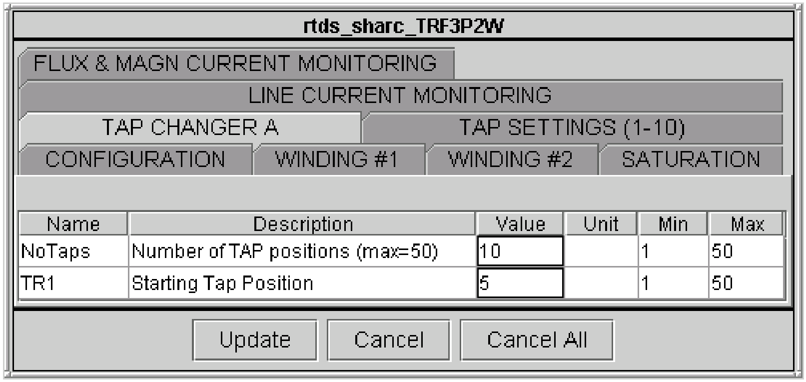
– Tmva – The 3–phase MVA rating of the transformer (in MVA) is used to convert pu quantities to kV, kA and Ω where required.

– f – The base frequency of the system is entered in Hz.

– Xl – The transformer positive sequence leakage reactance is required in pu.

– NLL – The no–load loss of the transformer is entered in pu. Since winding resistance is not included as part of the transformer model, provision has been made to specify and enter transformer no–load loss. This loss is realized by introducing resistances between the nodes to which the windings are connected and local ground. The presence of these resistance also helps eliminate numerical problems which may exist due to formation of inductive nodes when DELTA connected windings are involved.

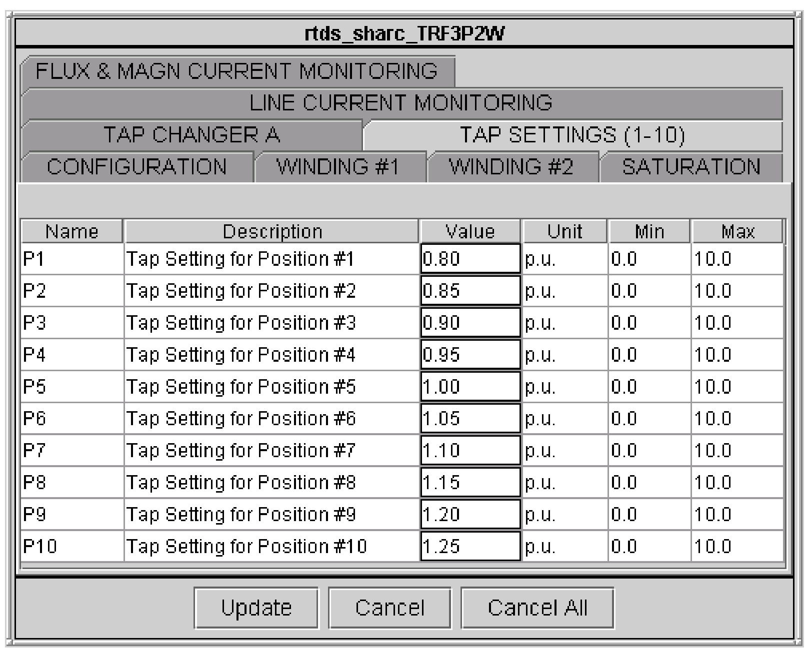
TAP CHANGER A MENU:



– NoTaps – The total number of tap positions is required. The maximum number of positions that can be used is 50.

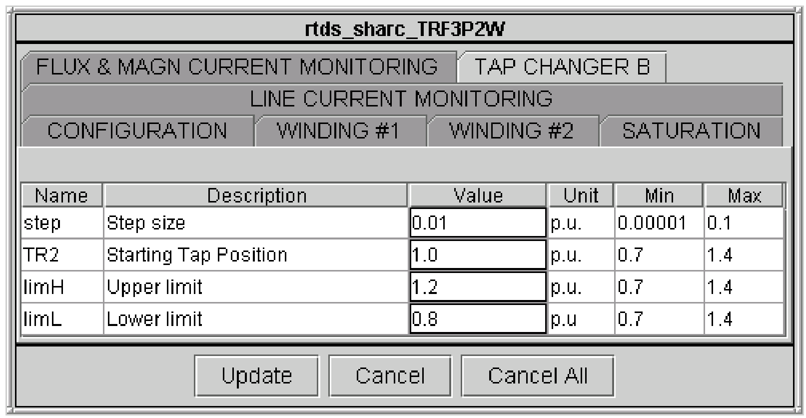
– TR1 – The initial tap position is also required. When the simulation is started in RunTime, the transformer tap position will be set to the starting position entered.

TAP SETTINGS MENU:



– P* – The number of tap setting parameters required is dependent upon the number of tap positions specified in the TAPCHANGER A menu. The tap positions are required as a per unit value. A tap position of 1.1 p.u. means that the rated voltage of the secondary winding is 1.1 times the value entered in Draft for the secondary base voltage.

If 'Step/Limit' option is selected for defining the tap changer positions in the CONFIGURATION menu, a new menu tab TAP-CHANGER B will appear. The tap positions are defined using a step size and an upper and lower limit. This menu is shown below.



– step – The Step size is required as a per unit value. The step size is the difference between two adjacent tap positions.

– TR2 – A starting tap position is required. When the simulation is started in RunTime, the transformer tap position will be set to the starting tap position specified.

– limH – An upper tap position limit is required. The tap position cannot exceed the upper limit.

– limL – A lower tap position limit is required. The tap position cannot be less than the lower limit value.

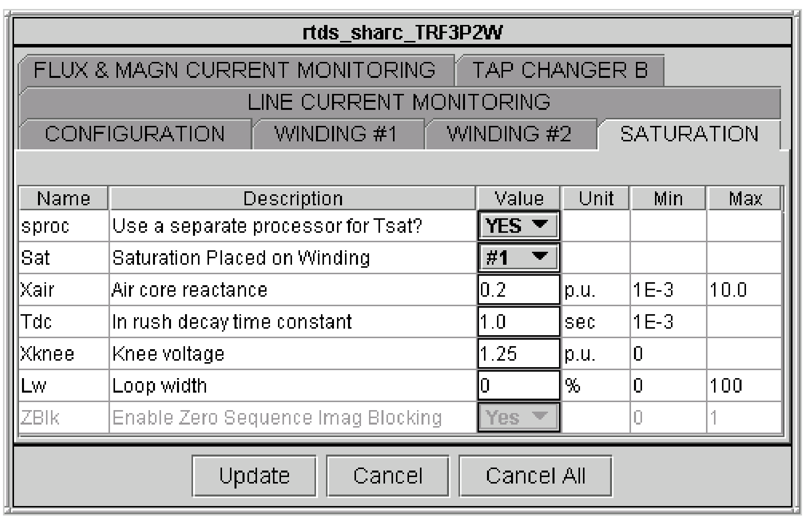
WINDING MENUS

Winding menus are identical for all windings. For the case of a 2–winding transformer two menus will exist, while for the 3–winding transformer three menus will exist.

– V1, V2 or V3 – Line to line rms voltage rating is entered for the winding in question. Voltage is defined in kV. The voltage entered here is not the winding voltage, but the line to line rms voltage on the appropriate side of the transformer.

– Im1, Im2 or Im3 – These entries define the level of magnetizing current which should flow in a particular winding, under 1 pu voltage conditions, if all other windings are open circuit. The 1 pu voltage referred to here is the winding voltage. From the leakage reactance, unit ratings and this magnetizing current level, the magnetizing branch inductance L_{MAG} is computed. In the case of the linear transformer model, the proportion of magnetizing current levels defines the proportion of the leakage reactance placed on each side of the magnetizing branch. For example, entering 1.0 % for Im1 and Im2 in a 2–winding transformer causes magnetizing branch placement in such that 50 % of the specified leakage reactance exists on each side of the magnetizing branch. In the case of the saturating transformer, the magnetizing branch is always placed at one end of the leakage reactance. Here the magnetizing current from the side of the transformer on which saturation is placed is used to determine the magnitude of L_{MAG}, and in addition, to define a point in the ϕ vs I plane through which the magnetizing characteristic must pass (see Eq. 4.7). In the case of the ideal transformer this parameter is ignored since no magnetizing branch if included (see Figure 4.4).

SATURATION MENU



Name	Description	Value	Unit	Min	Max
sproc	Use a separate processor for Tsat?	YES			
Sat	Saturation Placed on Winding	#1			
Xair	Air core reactance	0.2	p.u.	1E-3	10.0
Tdc	In rush decay time constant	1.0	sec	1E-3	
Xknee	Knee voltage	1.25	p.u.	0	
Lw	Loop width	0	%	0	100
ZBlk	Enable Zero Sequence Imag Blocking	Yes		0	1

The saturation menu can only be accessed if the type of transformer selected was a Saturation type.

– Sat – This parameter defines the placement of saturation. With respect to Figure 4.7 it was previously explained that the non–linear current source associated with the saturation algorithm and the conductance representing L_{MAG} are placed at one end of the leakage reactance. The parameter Sat is used to define at which winding (ie which side of the leakage reactance) these should be placed. Normally saturation would be placed on the lowest voltage winding since this winding is usually wound closest to the core. The user is however free to place saturation on any winding.

– Xair – The air core reactance is entered in pu. This quantity is used in Eq. 4.7 where the single valued flux – current characteristic is formulated. The characteristic is such that it becomes asymptotic to the air core reactance line in the saturated region. If the parameter is not readily available, an acceptable rule of thumb is to make Xair two times the leakage reactance value.

– Tdc – This is the so–called inrush decay time constant. This quantity is used in a feedback loop associated with flux calculation (ie: voltage integration). It's primary purpose is to remove numerical errors in the integration results which may be introduced when generated sine waves are not exactly symmetrical. The value should normally be chosen large (typically 50 to 100 sec.) so as to provide long term drift elimination but at the same time not cause unwanted removal or accelerated decay of sustained remnant flux phenomena. The parameters or properties of the connected power system, as well we the point on wave of initiation of the disturbance, will normally dictate the rate of decay of transformer inrush current. If the user wishes to accelerate the decay of inrush, this time constant could be made small to accomplish this.

– Xknee – The knee point voltage is entered in pu.. Xknee represents the level of applied voltage required to reach the knee point on the ϕ vs I characteristic. The saturation knee point is a commonly available parameter, and for voltage or power transformer is normally in the range of 1.2 to 1.5 pu..

– Lw – The loop width (Lw) parameter is used to represent transformer core loss. The core loss consists of both hysteresis and eddy current components. Normally the parameters associated with hysteresis and eddy current loss are not so readily available. Therefore, the total loss can be approximated by defining a loop as a percentage of the known 1.pu magnetizing current. If the loss is to be ignored, a loop width of 0.0 can be entered, in which case the parent loop becomes a single valued function (exactly that defined by Eq.4.7). It should however be noted that a loop width of 0.0 will take the ϕ vs I operating point through the origin. A path which passes through the origin implies that no sustained remnant flux will ever result.

4.6 TRANSFORMER MONITORING OPTIONS

A number of quantities associated with the transformer are available for monitoring. All winding currents, magnetizing current and flux computed during the simulation can be monitored on the RunTime Operator's Console. The quantities to be monitored can be chosen from the LINE CURRENT MONITORING and the FLUX and MAGN CURRENT MONITORING menus provided. Selecting YES to monitor any of the signals available will cause new menu tabs to appear which require the variable name of the signal to be entered.

Currently the monitored signals are not available for monitoring at the analogue output channels of the 3PC card. If it is required that a transformer signal be monitored at the D/A output channel, an analog output meter or an over sampling component could be used. Utilizing the above mentioned components will cause the signal in question to appear at the D/A output channel on the front of the 3PC card. Alternatively, using the over sampling component, signals could also be sent to an optional 16 bit D/A converter. The MAP file lists the 3PC card and channel to which the signal has been assigned for monitoring.

4.7 TRANSFORMER MODELS WITH INTERNAL FAULTS

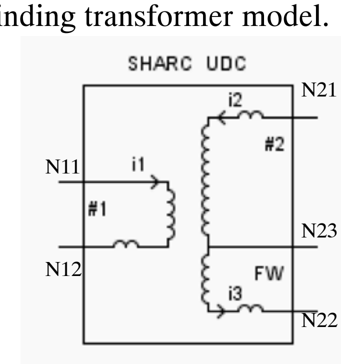
The transformer models described in this section have been developed for testing transformer protection. Currently only single phase models are available. However, single phase models can be inter–connected to form three phase transformers. Processing of three single phase models can be done on a single DSP using the stacking component (rtds_sharc_MPROC).

Each transformer model discussed below has a parameter menu named Internal Plot Selections. Monitoring of winding currents can be enabled using this menu.

4.7.1 TWO WINDING SINGLE PHASE TRANSFORMER MODEL WITH FAULT

component name: (rtds_sharc_TRF1Pflt)

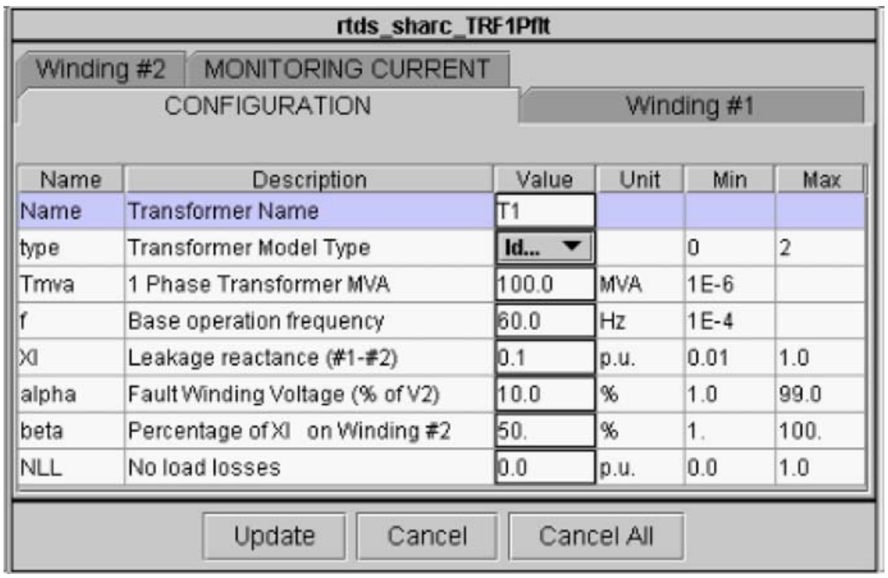
A single phase 2 winding transformer with internal fault can be simulated with a single phase 3 winding transformer model. The component icon is shown below.



Winding #1 is the primary winding. Winding #2 is the secondary winding. The fault winding (FW) is part of the secondary winding. If the fault winding (FW) is open circuited, the transformer will behave exactly the same as a two winding transformer model.

Since the model is based on a three winding transformer, three leakage parameters are needed to specify the transformer: x1, x2 and x3 (or x12, x13 and x23). For a normal transformer, however, only one leakage value (x12) is given. In order to compute x1, x2 and x3 from x12, two extra parameters are needed. These parameters are named *alpha* and *beta* and are specified in the component CONFIGURATION menu.

Configuration Menu



rtds_sharc_TRF1Pflt

Winding #2 | MONITORING CURRENT | CONFIGURATION | Winding #1

Name	Description	Value	Unit	Min	Max
Name	Transformer Name	T1			
type	Transformer Model Type	Id...		0	2
Tmva	1 Phase Transformer MVA	100.0	MVA	1E-6	
f	Base operation frequency	60.0	Hz	1E-4	
Xl	Leakage reactance (#1-#2)	0.1	p.u.	0.01	1.0
alpha	Fault Winding Voltage (% of V2)	10.0	%	1.0	99.0
beta	Percentage of Xl on Winding #2	50.	%	1.	100.
NLL	No load losses	0.0	p.u.	0.0	1.0

Update | Cancel | Cancel All

The first parameter *alpha* is the rated voltage of the fault winding (FW) and is entered as a percentage of the secondary winding rated voltage (V2). The second parameter *beta* is the percentage of the leakage x12 assigned to the secondary winding.

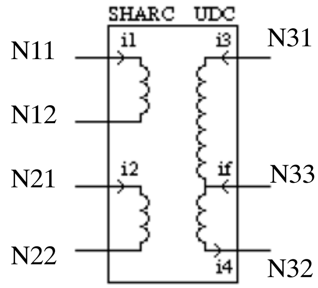
Node N23 can be connected to either N21 or N22 to simulate a fault on winding #2.

A three phase transformer model with internal faults can be built with three of the above single phase models.

4.7.2 THREE WINDING SINGLE PHASE TRANSFORMER MODEL WITH FAULT

component name: (rtds_sharcu_TRF1P3Wflt)

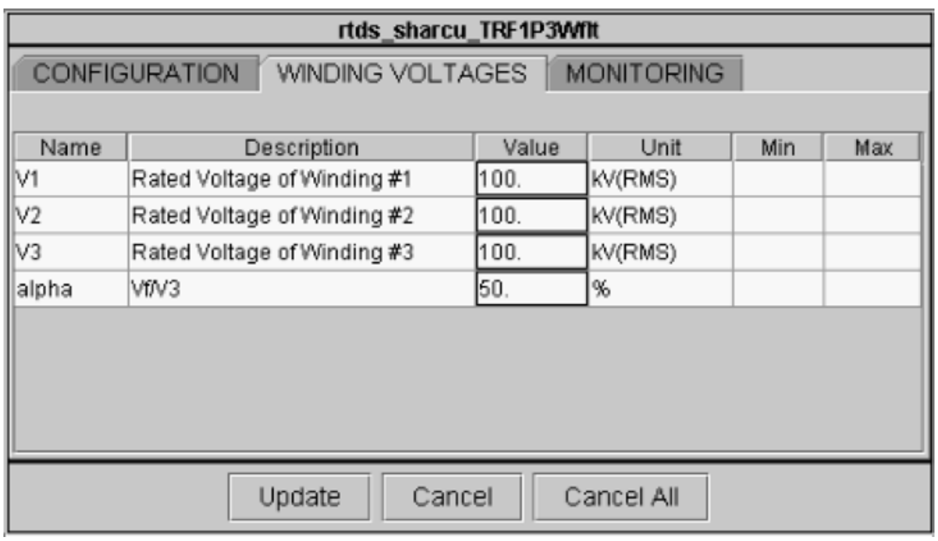
The three winding single phase transformer model with an internal fault winding is based on a single phase 4 winding transformer. The component icon is shown below.



Winding #1 is the primary winding. Winding #2 is the secondary winding. The fault winding (FW) is part of the tertiary winding. If the fault winding (FW) is open circuited, the transformer would behave exactly the same as a three winding transformer.

Since the model is based on a four winding transformer, four leakage parameters are needed to specify the transformer: *x1*, *x2, x3* and *x4*. For a regular three winding transformer, however, only three leakage values (*x12*, *x13* and *x23*) are given. In order to compute *x1*, *x2, x3* and *x4* from those parameters, an extra parameter named *alpha* is required. The parameter *alpha* is the rated voltage of the fault winding (FW) as is entered as percentage of the tertiary winding rated voltage (V3). This parameter can be entered in the winding voltages menu.

Winding Voltages Menu



Name	Description	Value	Unit	Min	Max
V1	Rated Voltage of Winding #1	100.	kV(RMS)		
V2	Rated Voltage of Winding #2	100.	kV(RMS)		
V3	Rated Voltage of Winding #3	100.	kV(RMS)		
alpha	Vf/V3	50.	%		

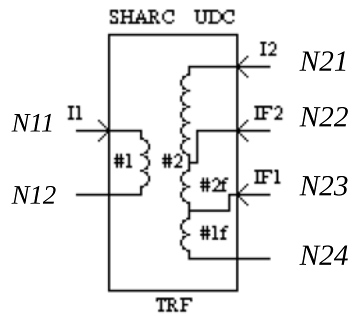
Node *N33* can be connected to either *N31* or *N32* to simulate a fault on winding #3.

A three phase transformer model with internal faults can be built with three of the above single phase models.

4.7.3 TWO WINDING SINGLE PHASE MODEL WITH TWO FAULT WINDINGS

component name: (rtds_sharcu_TRF1P2Wflt2)

A single phase two winding transformer model with two fault windings on winding #2 is shown below. This model is based on a single phase 4 winding transformer model.

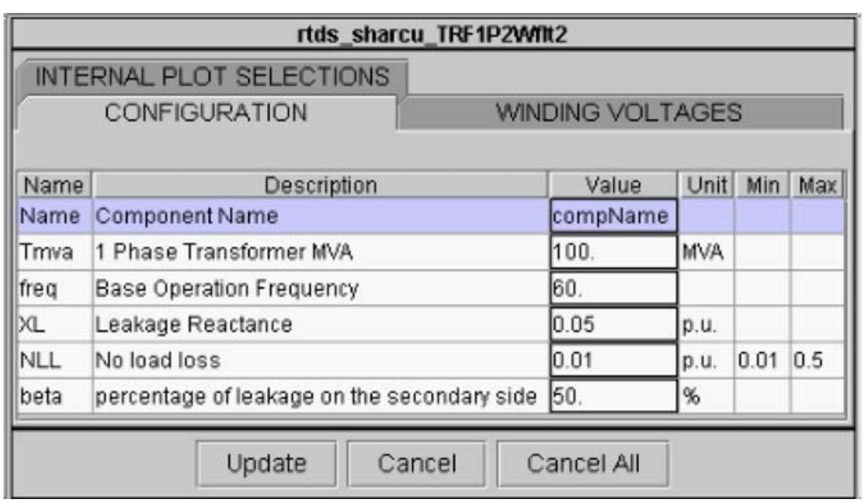


Winding #1 is the primary winding and winding #2 is the secondary winding. There are two fault terminals (N22 and N23) on the secondary winding. If both of the fault terminals are open circuited the transformer will behave as a two winding transformer model.

Since the model is based on a single phase 4 winding transformer model, four leakage parameters must be computed. The parameter *beta*, entered in the CONFIGURATION menu is used to compute the equivalent leakage of the single phase 4 winding transformer.

The parameter *beta* is entered as the percentage of the total leakage to be placed on the secondary side. *beta* is specified in the Configuration menu.

Configuration Menu

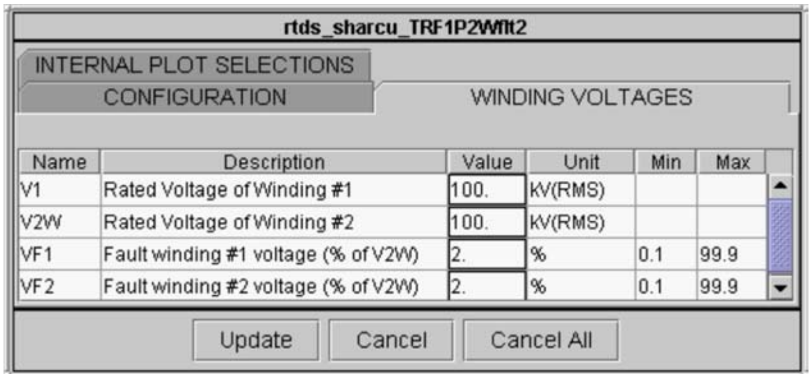

rtds_sharcu_TRF1P2Wflt2

INTERNAL PLOT SELECTIONS | CONFIGURATION | WINDING VOLTAGES

Name	Description	Value	Unit	Min	Max
Name	Component Name	compName			
Tmva	1 Phase Transformer MVA	100.	MVA		
freq	Base Operation Frequency	60.			
XL	Leakage Reactance	0.05	p.u.		
NLL	No load loss	0.01	p.u.	0.01	0.5
beta	percentage of leakage on the secondary side	50.	%		

Update | Cancel | Cancel All

Winding Voltages Menu


rtds_sharcu_TRF1P2Wflt2

INTERNAL PLOT SELECTIONS | CONFIGURATION | WINDING VOLTAGES

Name	Description	Value	Unit	Min	Max
V1	Rated Voltage of Winding #1	100.	kV(RMS)		
V2W	Rated Voltage of Winding #2	100.	kV(RMS)		
VF1	Fault winding #1 voltage (% of V2W)	2.	%	0.1	99.9
VF2	Fault winding #2 voltage (% of V2W)	2.	%	0.1	99.9

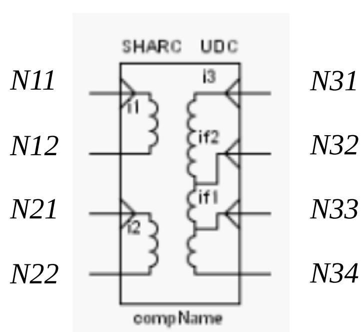
Update | Cancel | Cancel All

The parameter V2W is the voltage between node *N21* and *N24*, VF1 is the voltage between node *N23* and *N24*, and VF2 is the voltage between node *N22* and *N23*.

4.7.4 THREE WINDING SINGLE PHASE MODEL WITH TWO FAULT WINDINGS

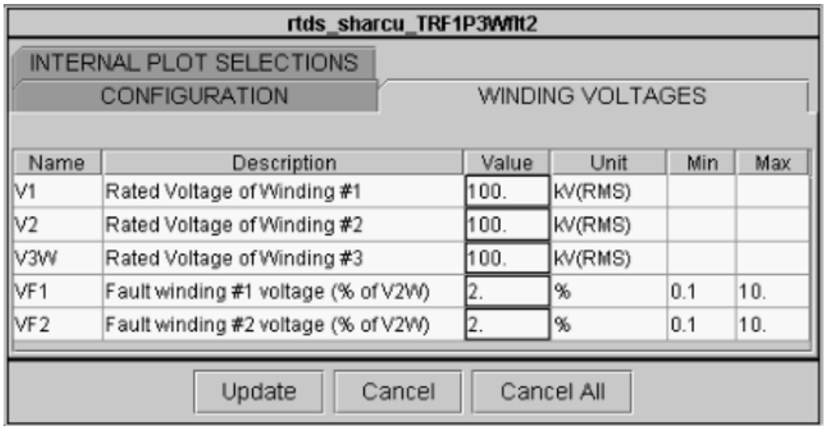
component name: (rtds_sharcu_TRF1P3Wflt2)

A single phase three winding transformer model with two fault windings on winding #3 is shown below.



Winding #1 is the primary winding. Winding #2 is the secondary winding. Winding #3 is the tertiary winding. There are two fault terminals (N32 and N33) on the tertiary winding. If both of the fault terminals are open circuited, the transformer would behave as a three winding transformer model.

Winding Voltages Menu



rtds_sharcu_TRF1P3Wflt2

INTERNAL PLOT SELECTIONS | CONFIGURATION | WINDING VOLTAGES

Name	Description	Value	Unit	Min	Max
V1	Rated Voltage of Winding #1	100.	kV(RMS)		
V2	Rated Voltage of Winding #2	100.	kV(RMS)		
V3W	Rated Voltage of Winding #3	100.	kV(RMS)		
VF1	Fault winding #1 voltage (% of V2W)	2.	%	0.1	10.
VF2	Fault winding #2 voltage (% of V2W)	2.	%	0.1	10.

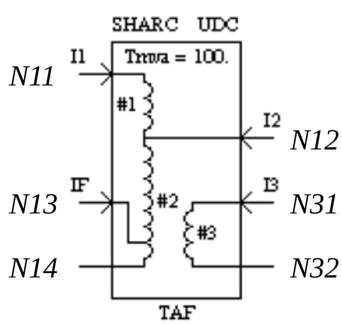
Update | Cancel | Cancel All

Please note that V3W is the voltage between node *N31* and *N34*, VF1 is the voltage between node *N33* and *N34*, VF2 is the voltage between node *N32* and *N33*. Both VF1 and VF2 are a percentage of V3W.

4.7.5 THREE WINDING SINGLE PHASE AUTO TRANSFORMER WITH FAULT WINDING

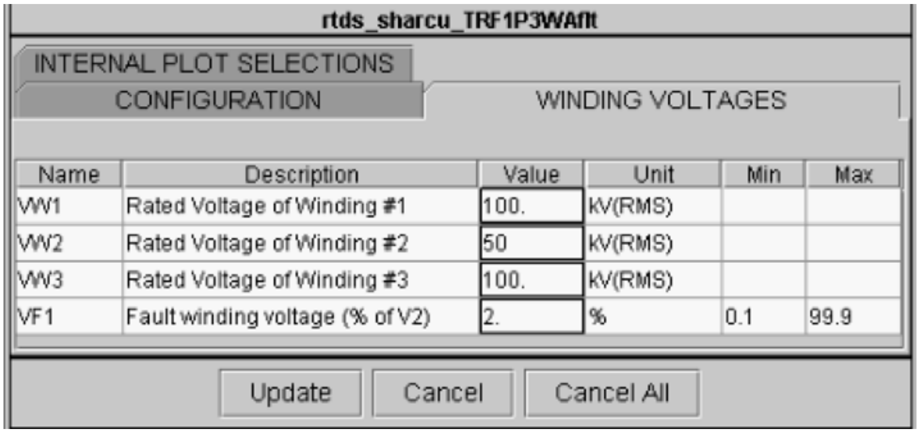
component name: (rtds_sharcu_TRF1P3WAflt)

A single phase three winding auto transformer model with a fault winding on winding #2 is shown below.



Winding #1 is the primary winding. Winding #2 is the secondary winding. Winding #3 is the tertiary winding. There is a fault terminal (N13) on the secondary winding. If the fault terminal is open circuited, the transformer would behave as a three winding auto transformer model.

Winding Voltages Menu



Please note that VW1 is the voltage between node *N11* and *N14,* VW2 is the voltage between node *N12* and *N14,* VW3 is the voltage between node *N31* and *N32*, VF1 is the voltage between node *N13* and *N14* and entered as a percentage of VW2. Since the model is an auto transformer, VW2 must not exceed VW1.

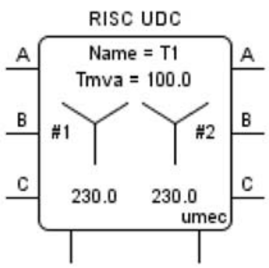
4.8 UMEC TRANSFORMER MODEL

component name: (lf_rtds_udc_sld_UMEC)

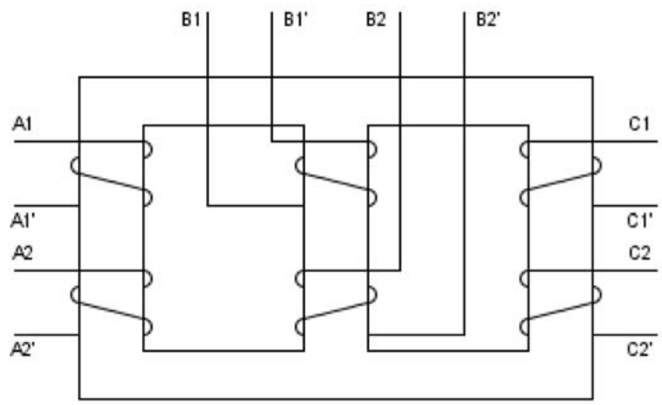
(rtds_UMEC_Windings)

The UMEC (Unified Magnetic Equivalent Circuit) transformer model is based primarily on core geometry. Unlike the classical transformer model, magnetic coupling between windings of different phases, and coupling between windings of the same phase are taken into account.

There are two UMEC transformer models available for use on an RPC or GPC processor. The transformer model named 'rtds_udc_UMEC' has the Y and delta winding connections embedded in the model. The transformer model named 'rtds_UMEC_Windings', on the other hand, provides an interface that allows access to the windings of the transformer directly. The algorithm used in both models is exactly the same. The two UMEC models are shown below;



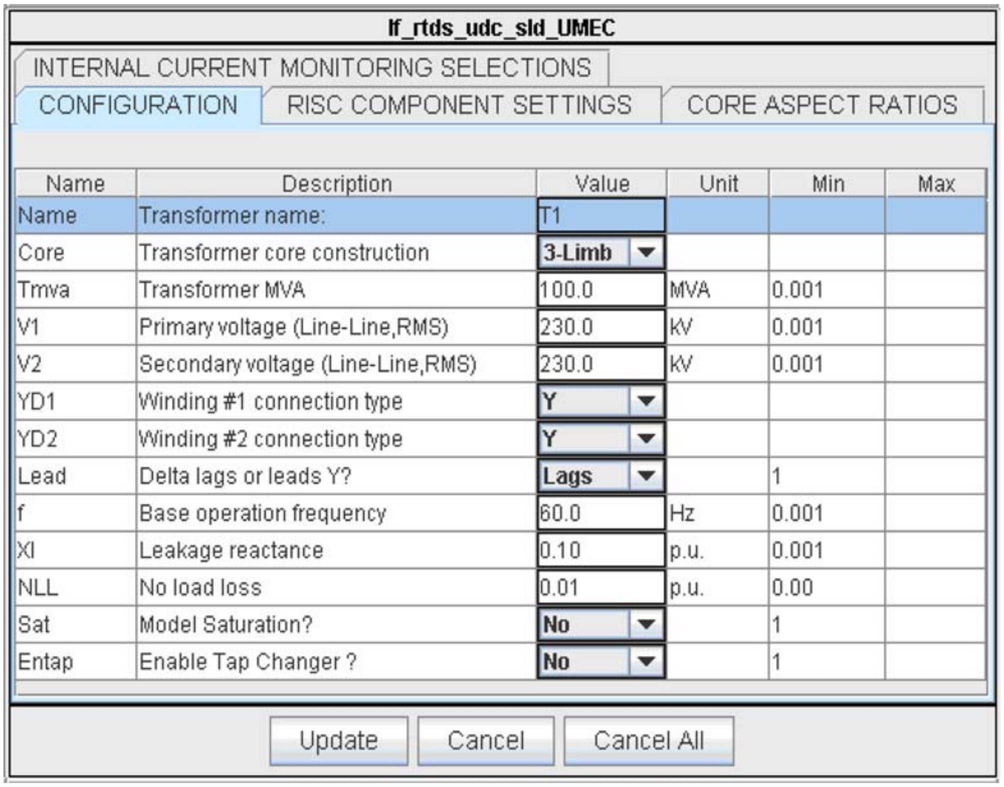
lf_rtds_udc_sld_UMEC



rtds_UMEC_Windings

The UMEC transformer model is based on the solution of magnetic circuits and requires a six by six matrix inversion every time step. As such, the model is quite heavy in computation. Although very careful work has been done to reduce the computation load, the model can only run on an RPC or GPC processor and requires 3 units of load, which is 30% of the total load for a RISC processor.

Configuration Menu



lf_rtds_udc_sld_UMEC

INTERNAL CURRENT MONITORING SELECTIONS

CONFIGURATION | RISC COMPONENT SETTINGS | CORE ASPECT RATIOS

Name	Description	Value	Unit	Min	Max
Name	Transformer name:	T1			
Core	Transformer core construction	3-Limb			
Tmva	Transformer MVA	100.0	MVA	0.001	
V1	Primary voltage (Line-Line,RMS)	230.0	kV	0.001	
V2	Secondary voltage (Line-Line,RMS)	230.0	kV	0.001	
YD1	Winding #1 connection type	Y			
YD2	Winding #2 connection type	Y			
Lead	Delta lags or leads Y?	Lags		1	
f	Base operation frequency	60.0	Hz	0.001	
Xl	Leakage reactance	0.10	p.u.	0.001	
NLL	No load loss	0.01	p.u.	0.00	
Sat	Model Saturation?	No		1	
Entap	Enable Tap Changer ?	No		1	

Update | Cancel | Cancel All

– Name – The transformer name must begin with a letter. DRAFT will limit the number of characters to 10. The specified name is then used in all cross–referencing between DRAFT and the RunTime Operator's Console.

– Core – A 3–Limb or 5–Limb core configuration can be selected.

– Tmva – The 3–phase MVA rating of the transformer (in MVA) is used to convert pu quantities to kV, kA and Ω where required.

– V1, V2 – Line to line rms voltage rating is entered for the winding in question. Voltage is defined in kV. The voltage entered here is not the winding voltage, but the line to line rms voltage on the appropriate side of the transformer.

– YD1, YD2 – Winding configurations for the respective windings are defined using these parameters.

– Lead – The 30 degree phase shift between the corresponding line quantities on the WYE and DELTA sides of a transformer can be either lagging or leading.

– f – The base frequency of the system is entered in Hz.

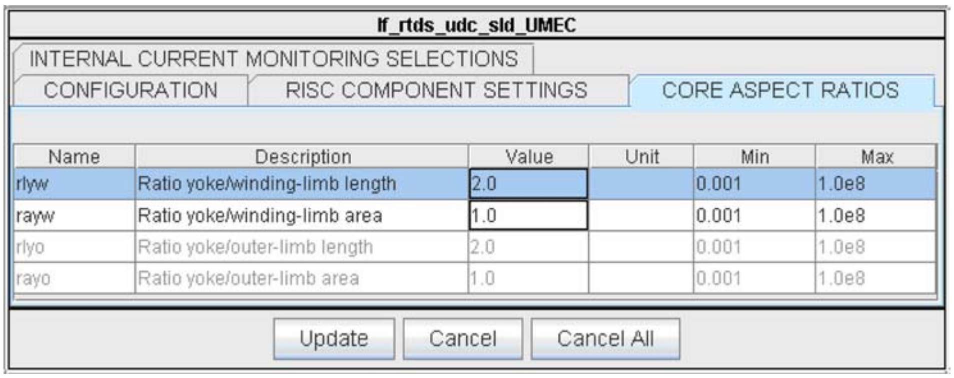
– Xl – The transformer positive sequence leakage reactance is required in pu.

– NLL – The no–load loss of the transformer is entered in pu. Since winding resistance is not included as part of the transformer model, provision has been made to specify and enter transformer no–load loss. This loss is realized by introducing resistances between the nodes to which the windings are connected and local ground. The presence of these resistance also helps eliminate numerical problems which may exist due to formation of inductive nodes when DELTA connected windings are involved.

– Sat – This parameter enables/disables saturation.

– Entap – A tap changer may be included in the model by setting this parameter to 'Yes'.

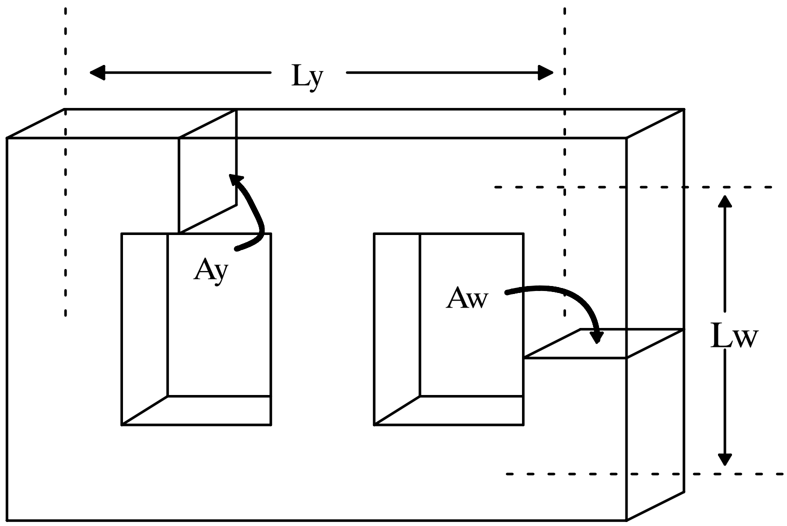
Core Aspect Ratios



Name	Description	Value	Unit	Min	Max
rlyw	Ratio yoke/winding-limb length	2.0		0.001	1.0e8
rayw	Ratio yoke/winding-limb area	1.0		0.001	1.0e8
rlyo	Ratio yoke/outer-limb length	2.0		0.001	1.0e8
rayo	Ratio yoke/outer-limb area	1.0		0.001	1.0e8

The UMEC transformer model is based on the magnetic circuits, so it needs the physical core structure parameters in the computation process. Normalized core parameters are used in the model so that requirements of physical data are minimized. Only 4 core aspect ratios are needed. If a three limb core is selected in the CONFIGURATION menu, two ratios are needed, the ratio of core yoke length (Ly) to the core winding–limb length (Lw), and the ratio of core yoke area (Ay) to the core winding–limb area (Aw). If the 5 limb core is selected, two additional parameters are required, the ratio of core yoke length (Ly) to the core outer –limb length (Lo) and the ratio of core yoke area (Ay) to the core outer–limb area (Ao). The core structures of 3 and 5 limb transformer as shown in the following figures.

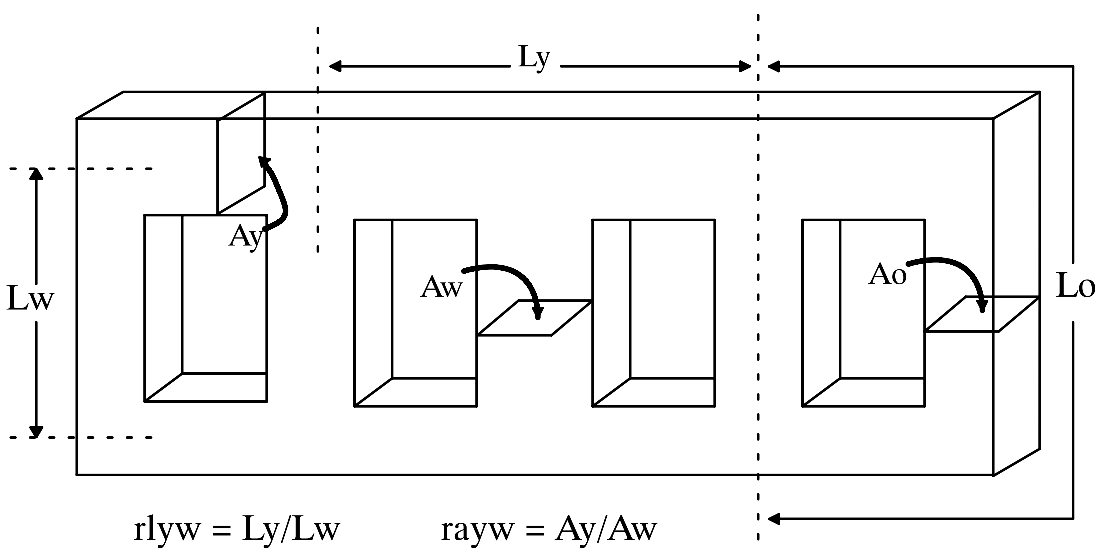
Three Limb Transformer



rlyw = Ly/Lw

rlyo = Ly/Lo

Five Limb Transformer



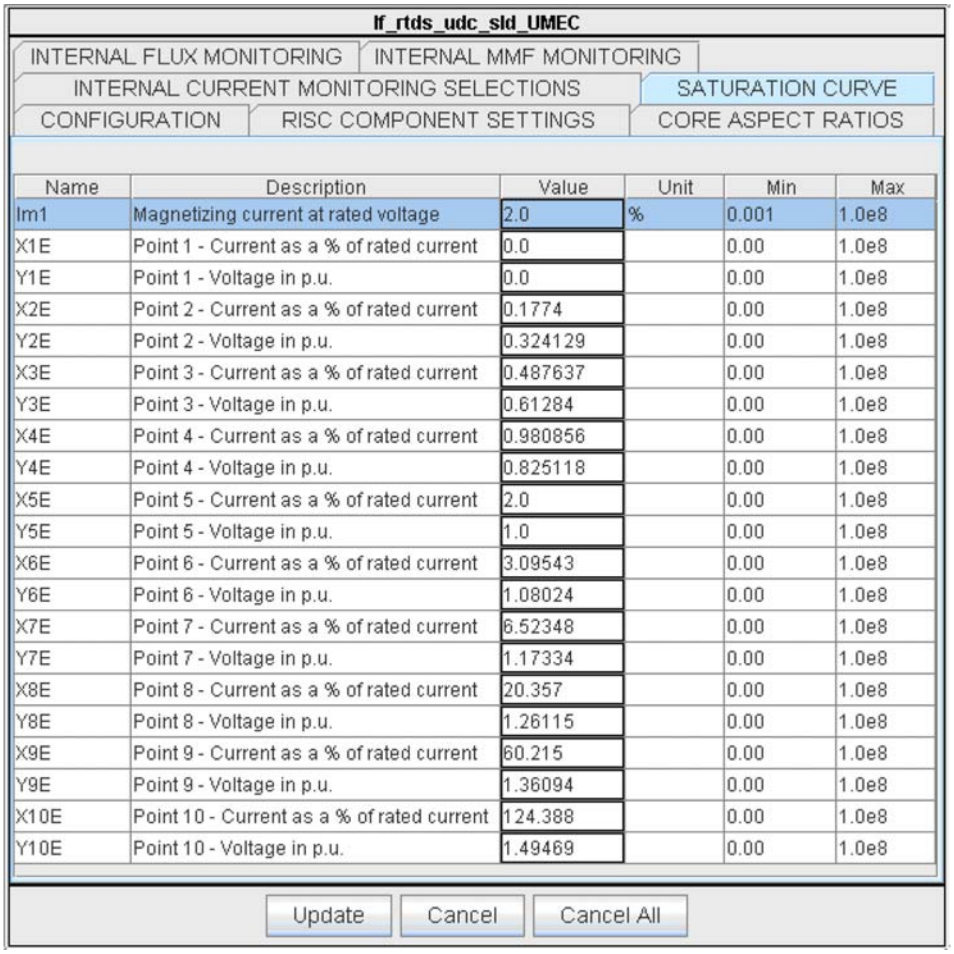
rlyw = Ly/Lw

rlyo = Ly/Lo

rayw = Ay/Aw

rayo = Ay/Ao

Saturation Curve

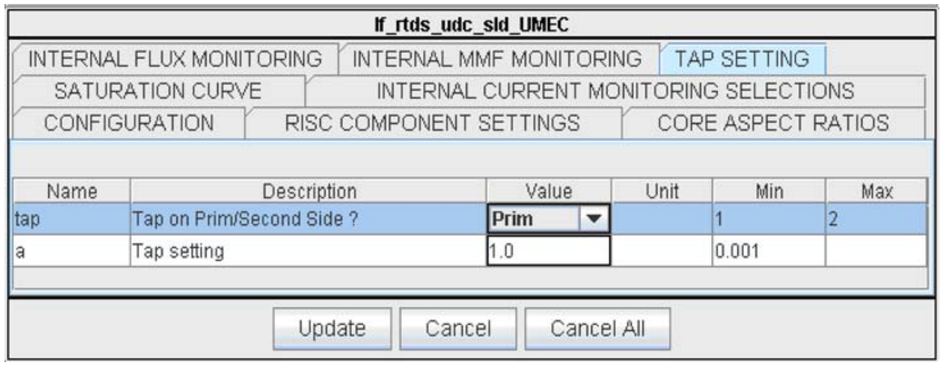


Name	Description	Value	Unit	Min	Max
Im1	Magnetizing current at rated voltage	2.0	%	0.001	1.0e8
X1E	Point 1 - Current as a % of rated current	0.0		0.00	1.0e8
Y1E	Point 1 - Voltage in p.u.	0.0		0.00	1.0e8
X2E	Point 2 - Current as a % of rated current	0.1774		0.00	1.0e8
Y2E	Point 2 - Voltage in p.u.	0.324129		0.00	1.0e8
X3E	Point 3 - Current as a % of rated current	0.487637		0.00	1.0e8
Y3E	Point 3 - Voltage in p.u.	0.61284		0.00	1.0e8
X4E	Point 4 - Current as a % of rated current	0.980856		0.00	1.0e8
Y4E	Point 4 - Voltage in p.u.	0.825118		0.00	1.0e8
X5E	Point 5 - Current as a % of rated current	2.0		0.00	1.0e8
Y5E	Point 5 - Voltage in p.u.	1.0		0.00	1.0e8
X6E	Point 6 - Current as a % of rated current	3.09543		0.00	1.0e8
Y6E	Point 6 - Voltage in p.u.	1.08024		0.00	1.0e8
X7E	Point 7 - Current as a % of rated current	6.52348		0.00	1.0e8
Y7E	Point 7 - Voltage in p.u.	1.17334		0.00	1.0e8
X8E	Point 8 - Current as a % of rated current	20.357		0.00	1.0e8
Y8E	Point 8 - Voltage in p.u.	1.26115		0.00	1.0e8
X9E	Point 9 - Current as a % of rated current	60.215		0.00	1.0e8
Y9E	Point 9 - Voltage in p.u.	1.36094		0.00	1.0e8
X10E	Point 10 - Current as a % of rated current	124.388		0.00	1.0e8
Y10E	Point 10 - Voltage in p.u.	1.49469		0.00	1.0e8

If saturation is enabled in the CONFIGURATON menu, the user can model the core saturation characteristic as a V−I curve. If desired however, the magnetizing branch can be eliminated altogether, by leaving the transformer in 'ideal' mode. In ideal mode, all that remains is a series leakage reactance.

The SATURATION CURVE menu allows users to input the magnetic parameters of the core. The first entry appears only when saturation is disabled. It is the magnetizing current at rated voltage, which will be used to calculate the linear permeance of the transformer. When the saturation is enabled, the user can input up to 10 points of the RMS V−I curve of the core, where I is entered in % and V in p.u.. The entered saturation data points will be converted to FLUX−MMF and define the core saturation curve. The maximum number of points is 10. NOTE: If a value of 0.0 is entered as any data point greater than point1, RTDS will ignore all points following the 0.0. This is useful in instances where the saturation curve has less then 10 points.

Tap Setting



The TAP SETTING menu only appears when the Tap Changer is enabled in CONFIGURATION menu. The TAP SETTING menu allows the user to input the tap value and specify which side of the transformer the tap should be applied on. The tap setting is specified as a constant. It cannot be dynamically adjusted in the RUNTIME. This feature is different with the tap changers in other RTDS transformer models. The tap was written in this format to be fully compatible with the UMEC model in PSCAD/EMTDC.

Monitoring

The UMEC Transformer model allows monitoring of a number of variables such as current, flux and MMF. If monitoring is enabled, a corresponding variable name should be given. The signal can then be monitored in RUNTIME. The monitoring available is listed below.

Internal Current Monitoring

- Enable monitoring of phase currents of winding #1 and/ or winding#2

Internal Current Monitoring Signal Names

- This menu will only appear if one or more winding currents are enabled for monitoring. A signal name is required for the current(s).

Internal Flux Monitoring

- Enable monitoring of the winding and/or leakage flux of either winding.

Internal Flux Monitoring Signal Names

- This menu will only appear if flux monitoring is enabled. Signal names are required for the flux.

Internal MMF Monitoring

- Enable monitoring of winding MMF.

Internal MMF Monitoring Signal Names

- This menu will only appear if MMF monitoring is enabled. Signal names are required for the MMF.

REFERENCES

[1] W. Enright, O.B. Nayak, G.D. Irwin, A. Arrillaga, "An Electromagnetic Transients Model of Multi–Limb Transformer Using Normalized Core Concept", IPST'97 – International Conference on Power System Transients, Seattle, June 22–26, 1997, pp.93–98.

[2] W. Enright, N. Waston and O.B. Nayak, "Three Phase five–Limb Unified Magnetic Equivalent Circuit Transformer Models for PSCAD V3", IPST'99 – International Conference on Power System Transients, July 20–24, 1999, Budapest, Hungary, pp.462–467.

[3] J. Arrillaga, W. Enright, N. Watson and A. Wood, "Improved Simulation of HVDC Converter Transformers in Electromagnetic Transient Programs", IEE Proc. – Generation. Transmission and Distribution, Vol. 144, No.2, March 1997, pp100–106.

5 TRANSMISSION LINE MODELS

5.1 INTRODUCTION

Travelling wave transmission line models and PI section models are both available to represent transmission lines on the RTDS. However, travelling wave models are generally preferred unless the line in question is very short, in which case a PI section model must be used. Travelling wave models are preferred for several reasons.

Travelling wave models are distributed parameter representations of transmission lines and are much more accurate for modelling long lines than the lumped parameter representation inherent in PI section models.

Travelling wave models can represent the entire line using one instance of the model. PI section models tend to use more simulator hardware because of the need to cascade several PI sections to represent the line and also because of the need to model the network nodes between the individual sections. On this point, travelling wave models require only one or two processors to model a complete line containing as many as 12 mutually coupled conductors.

Furthermore, travelling wave line models provide a means for separating the power system into mathematically isolated sub−systems which can be run on separate RTDS Racks if required.

The TLINE program, a member of the RSCAD family of tools is used to lay out and define the geometry and parameters of an N−conductor travelling wave transmission line. The output of the TLINE program is used by DRAFT when a case involving the line is compiled.

The CABLE program, another member of the RSCAD family of tools is used to define the geometry and parameters of the core and layers of a single phase cable.

Since the accurate modelling of transmission lines is of upmost importance when studying transient phenomena, the theory of the frequency dependant (F−Dep) modal travelling wave line model has been presented in some detail in Appendix 5A, located at the end of this chapter. The special case of the so−called Bergeron model is also discussed.

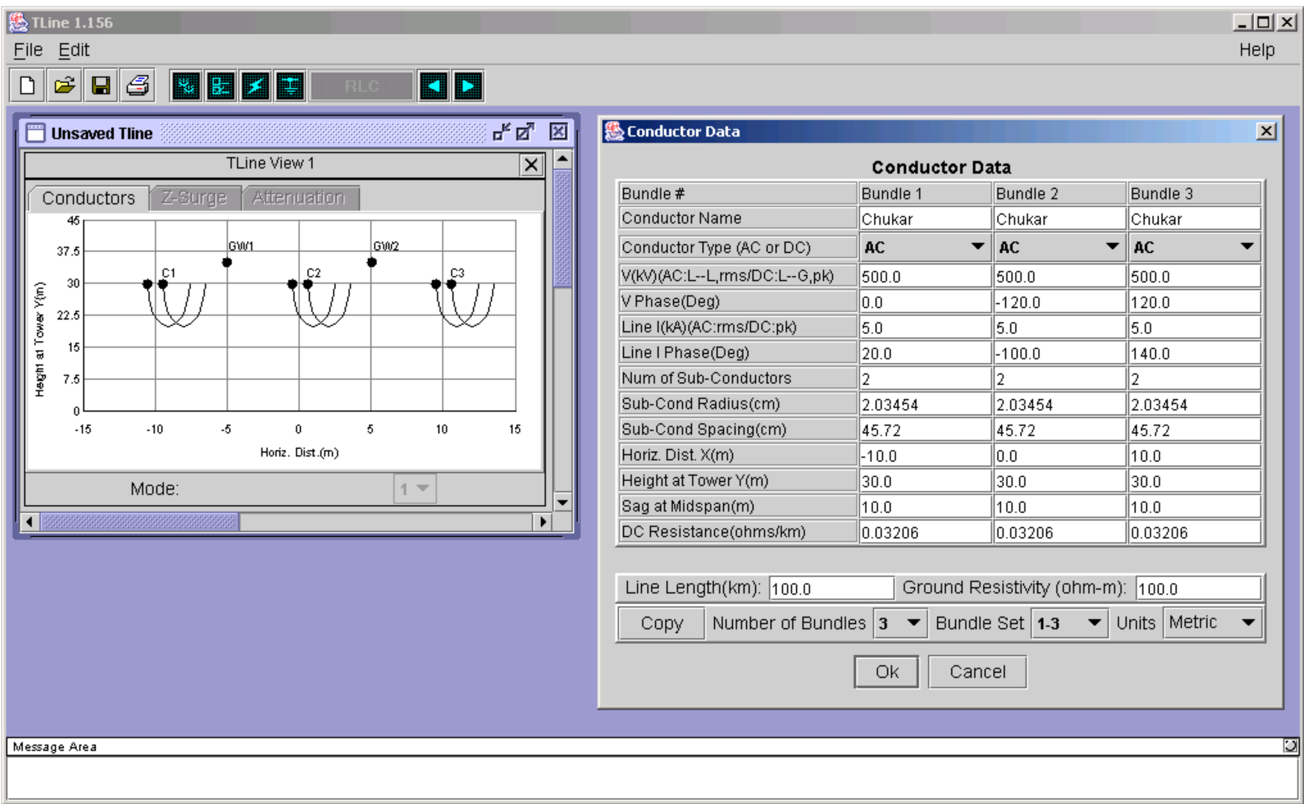
Sections 5.2 and 5.3 provide a general discussion of modelling transmission lines in the RTDS using travelling wave and PI section models. Section 5.4 briefly describes three groups of transmission line models available on the RTDS. Section 5.5 describes the Unified T−Line and Cable model. Section 5.6 describes the UDC Group of T−Lines models. Section 5.7 describes UDC PI section models.

Chapter 18 describes the faulted line model, a Preprocessor components.

5.2 TRAVELLING WAVE T–LINE MODELS

Generally, transmission lines consist of several mutually coupled phases or conductors. The extent of coupling depends on the geometry of the line and the proximity of the individual phase conductors to one another and to ground. The TLINE program in RSCAD, is used to define the line, its geometrical configuration and other parameter data for travelling wave line models. Both the Frequency Dependent and Bergeron lines are defined in this manner. PI section models are also available which can use the Bergeron output from the T–Line program. The user is referred to the TLINE manual of the RSCAD documentation set for details regarding detailed use of the TLINE program.

A screen dump of the main TLINE parameter input menu is shown in the figure below.



5.2.1 REPRESENTATION OF MODE/PHASE TRANSFORMATIONS AT ONE FREQUENCY ONLY

The theory of the Frequency Dependant model is discussed in Appendix 5A. The use of the model is discussed in Section 5.5.

In the RTDS, travelling wave transmission line models are solved in the modal domain. That is, a transformation matrix is used to convert the line admittance and impedance matrices from the phase domain into the modal domain. Phase domain voltages and currents are converted into the modal domain and back into the phase domain at each end of the line, as required.

In theory, the transformation matrix is frequency dependent. Due to various difficulties however, it is solved at only one frequency. For the Bergeron line model, this limitation is not a problem, as the model is meant to be accurate at only one frequency in any case.

For the Frequency–dependent model, the 3 phase line model is affected very little over a wide frequency range. However in the six conductor line, mutual coupling at various frequencies must be carefully checked. More conductors than 6 are not supported.

For the Frequency–dependent model, the transformation frequency is generally chosen to be higher than fundamental frequency (50 or 60 Hertz). Therefore, coupling of DC components of current in conductors tends to contain some error. The DC current coupling problem can be reduced somewhat by using the “Ideally Transposed” option in the TLINE program. Research is underway to include a Frequency–Dependant Phase Domain T–Line model which should help eliminate this problem.

5.2.2 MINIMUM TIME STEP FOR BERGERON AND FREQUENCY DEPENDANT T–LINE MODELS

One of the constraints in using the Bergeron and Frequency–Dependant line models relates to the overall length of the line being represented. When the modal propagation time (or “travel time”) of a line is less than the chosen simulation time–step Δt, the line cannot be represented using these general travelling wave models. This limitation is a result of the calculation algorithm. The travel time of the line is directly related to the line length, and hence it may found that, for short transmission lines, PI section representation will be required to represent length accurately.

Normally as lines become shorter, the approximations resulting from using PI section modelling become less significant.

If requested, both Bergeron and Frequency–Dependant line models make use of the “interpolation of line length” feature mentioned in the *RSCAD/RTDS T–Line and Cable Manual* to interpolate all modes. 3PC–based line models are capable of interpolating down to travel times as small as 1 simulation time–step.

A travel time of 50 microseconds corresponds to 15 km at the speed of light.

It should be noted that the interpolation function does tend to damp higher frequency components in all models including the Frequency–Dependant models. However, interpolation is very useful where accurate representation of line impedance is important, such as in line models for testing distance relays, and where high frequency accuracy is less important.

Interpolation is not performed on any of the modes associated with a particular transmission line if it is not requested in the T−Line program.

One of the features inherent in the travelling wave line model is its ability to mathematically partition (split) the overall power system into so−called subsystems. The RTDS computes conditions in each subsystem using nodal analysis and hence a system conductance matrix is used. Splitting the overall system into subsystems keeps the conductance matrices within manageable dimensions. The mathematical splitting of the conductance matrix into subsystems using travelling wave line models is therefore an important element in providing the real−time performance of the RTDS.

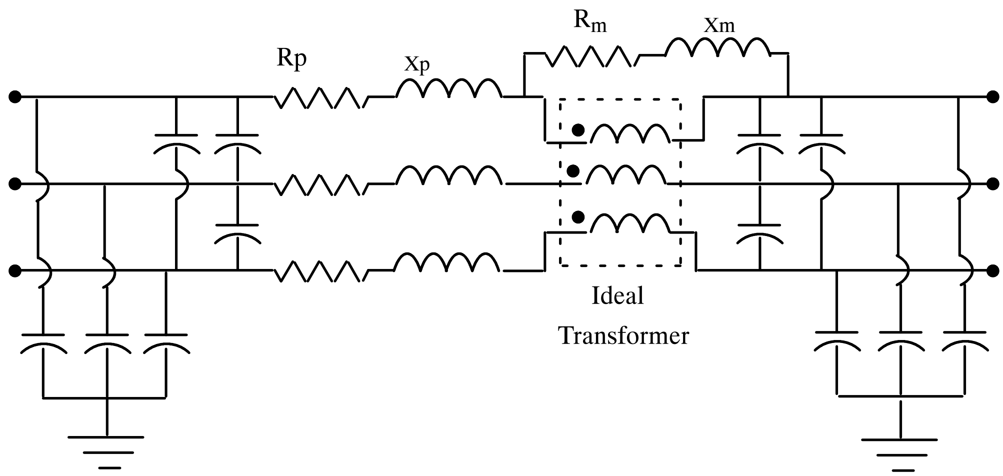
When larger and larger power systems are to be studied, the simulation must be spread over many RTDS hardware racks. The nature of the RTDS hardware design is such that it conveniently mimics the layout of real power systems. The travelling wave line is one of the principle elements used to span between racks on the RTDS. Separate subsystems can be thought of as separate stations scattered around the power system with interconnection between stations (or racks) over transmission lines. In this way the mathematical solution within one subsystem (rack) can be performed independently from the conditions which exist in neighboring racks during the current time step. Please refer to Chapter 2 for more details on the concept of subsystems.

Unlike the travelling wave models, the PI section line model does not provide mathematical isolation or splitting into subsystems and hence cannot be used to span between networks.

5.3 MODELLING TRANSMISSION LINES USING PI SECTIONS

Although using PI sections made up of R,L and C components is not normally the recommended method for line representation on the RTDS, there are instances where length of the line dictates that such modelling techniques must be used. As was already mentioned, if the travel time of the line in question is less than the simulation time step Δt, the general travelling wave model cannot be used. Assuming propagation velocity is equivalent to the speed of light, a 50 usec time step would see the waveform travel a total distance of approximately 15 km. This means that if the chosen simulation time step Δt is 50 usec, any line of length less than about 15 km would have to be represented using a PI section.

For a balanced line all self and all mutual impedances are the same. This type of line can be represented quite accurately (particularly if fairly short) using the circuit configuration illustrated in the following Figure. The transformer shown inside of the dashed line is a 3−winding single−phase ideal transformer.



Self resistance, reactance and susceptance

Rs = (Rz + 2 • Rp) / 3

Xs = (Xz + 2 • Xp) / 3

Bs = (Bz + 2 • Bp) / 3

Mutual resistance, reactance and susceptance

Rm = (Rz – Rp) / 3

Xm = (Xz – Xp) / 3

Bm = (Bz – Bp) / 3

PI–section models are also provided for the 3PC which use the Bergeron line output of the T–LINE program (a Bergeron .tlb or .cbl file) in order to specify line parameters.

5.4 THREE GROUPS OF T–LINE MODELS

There are three distinct groups of T–Line models for the 3PC processors.

1. The Unified T–Line and Cable Model (Section 5.5)

The first group of T–Line models is referred to as the “Unified T–Line and Cable Model”. As suggested by the term “Unified”, one set of icons can be used in DRAFT to specify either an instance of a Frequency–Dependant Modal (Fre–Dep) line model; a travelling–wave line model based on Bergeron data; or a PI section model based on Bergeron data.

The set of DRAFT icons to represent a line includes a “Calculation Block” and either two T−Line Terminal icons or two Cable Terminal icons.

The 3PC−based Frequency−Dependant Modal (Fre−Dep) T−Line models require the use of either one or two DSPs. One or two DSPs can be selected for Fre−Dep lines with 3 or less conductors. Two DSPs must be used for Fre−Dep lines with more than 3 conductors. Frequency−Dependant models with more than 6 conductors are not supported.

The 3PC−based Bergeron T−Line models require either one or two DSPs. One or two DSPs can be selected for Bergeron lines with 6 or less conductors. Two DSPs must be selected for Bergeron lines with more than 6 conductors. Bergeron models with more than 12 conductors are not supported. The same rules for processor usage apply to the travelling−wave and PI section models based on Bergeron line data. Where using either one or two DSPs is allowed, using two DSPs will reduce the time−step size required by the model.

The main limitation of this model is that one or two 3PC processors must be used exclusively for each instance of the model.

2. The UDC T−Line Models (Section 5.6)

The UDC T−Line models, implemented based on User Defined Component methods, are limited to calculations based on Bergeron or PI section methods. These models do not support the frequency dependant modelling methods discussed above.

However, the UDC models have been prepared to permit “Stacking” with other UDC models on a processor. The term “Stacking” of models on a processor means that more than one model is calculated on the particular processor. “Stacking” of models is an important feature because it allows efficient utilization of processors when the models are small and do not require heavy computational effort.

For Bergeron line models with a small number of conductors (< 4), the computational burden is fairly light and “Stacking” is a very useful feature.

3. The UDC PI Section Models (Section 5.7)

PI Section models are required when the modal travel time of a line is less than one time−step in duration.

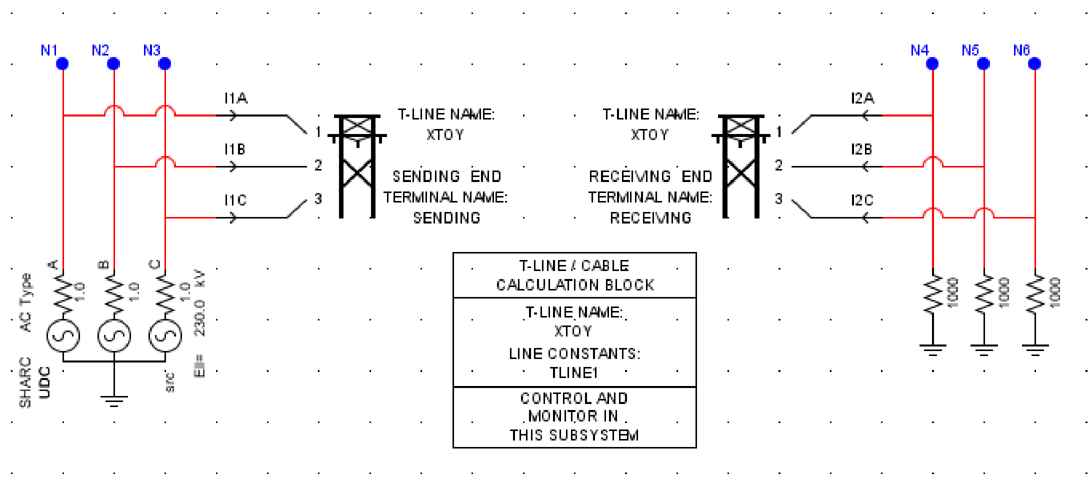
Dedicated PI section models are provided for 3 and 6 conductor PI sections which allow the specification of positive and zero sequence data directly in DRAFT without the use of the TLINE program. A stackable PI section model is also available for a two conductor line.

5.5 THE UNIFIED T−LINE AND CABLE MODEL

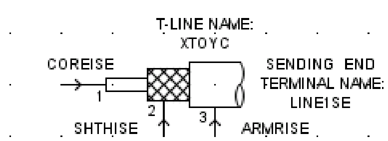
The Unified T−Line and Cable model may be connected to the defined power system network in RSCAD / Draft.

5.5.1 ICONS FOR THE UNIFIED T–LINE AND CABLE MODEL

The basic components of the Unified T–line and Cable model include a T–Line/ Cable Calculation Block (**rtds_sharc_TL16CAL**) and either two T–Line Terminal components (**rtds_sharc_TL16TRM**) or two Cable Terminal components (**rtds_sharc_TL16TRMC**). An example connection for a T–Line is as shown in the following figure.

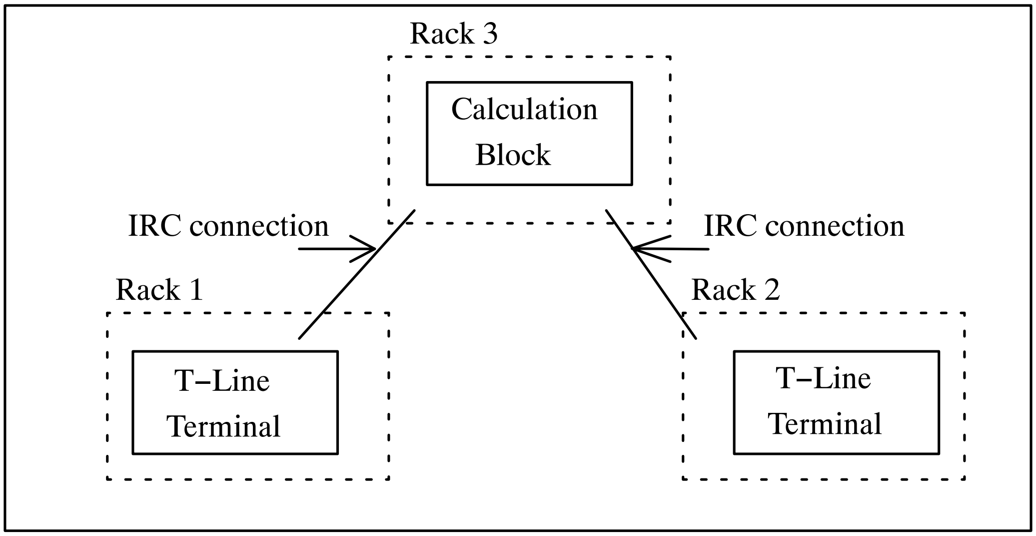


The Terminal icon (**rtds_sharc_TL16TRMC**) for a Cable is as shown in the following figure. The appearance of the Cable Terminal icon varies depending on the **number of insulated conductive cable layers** that are being modelled, as well as the choices for monitoring in RunTime. The icon of the Cable Terminal component appears as follows when three **insulated** conductive layers are modelled, with monitoring in RunTime enabled for all three currents:



The Terminal icon for the Cable causes the same model calculations as the Terminal icon for the T–Line except that data for the line is obtained from a .cbl file rather than from a .tlb file. In addition, the Cable Terminal icon provides different options for monitoring.

5.5.2 SPANNING BETWEEN NETWORK SOLUTIONS WITH THE UNIFIED T–LINE / CABLE MODEL



In large simulators, there may not be an IRC channel connecting each pair of racks in the simulator. This T–Line model supports the connection of a T–Line between racks that are not connected by an IRC channel. In this case, all that is required is that each of the two racks has an IRC channel to a third rack. The calculation block is then placed in the third rack and a terminal is placed in each of the two unconnected racks. The connection would appear as shown above.

Each terminal block component communicates only with the T–Line/Cable calculation block component. There is no need for direct communication between two terminal block components during the calculations. Of course, all three components can be positioned in one subsystem. Alternatively, each of the three components may be positioned in a separate subsystem, provided there are two inter–rack communication (IRC) channels for connecting the terminal components with the calculation block component.

The processors used by the model are always located in the rack where the Calculation Block is placed. Therefore, for a T–Line spanning between two IRC–connected racks, the Calculation Block would normally be placed in the rack with the largest number of available 3PC processors.

5.5.3 DETAILS ABOUT USING FREQUENCY DEPENDANT MODAL LINE CONSTANTS

The Frequency Dependant Modal (Fre–Dep) T–line model can support up to 6 conductors. At least one DSP on a 3PC card must be selected exclusively for each instance of the model. For more than 3 conductors, 2 processors on a 3PC card must be selected. Using 2 processors for a line with less than 4 conductors will shorten the time−step required by the model. For advanced users, every instance of the model writes the pre−T0 and post−T0 execution time in the time−step to the .map file when the case is compiled.

5.5.3.1 MAXIMUM NUMBER OF POLES AND ZEROS FOR FREQUENCY DEPENDENT T−LINES

The T−Lines constants data is prepared using the RSCAD T−Lines program. The present 3PC model is dimensioned to support up to 10 poles for attenuation and 10 poles for characteristic impedance per mode.

NEVER specify "A max # of Poles:" to be greater than 10. Similarly, "Z max # of Poles:" must NEVER be specified to be greater than 10.

Also, in order to maintain a short time−step length, it is recommended to limit the number of poles to 5 for attenuation and 5 for characteristic impedance in the T−Line program.

5.5.4 DETAILS ABOUT USING BERGERON MODAL LINE CONSTANTS

Alternatively, the model will use calculations based on Bergeron T−Line data. In that case, from 1 to 12 conductors can be modelled for T−Lines (up to 3 layers for cables). If more than 6 conductors are modelled, two processors must be selected. Accordingly, if less than 7 conductors are modelled, then one or two processors may be selected. Using two processors will shorten the time−step compared to using one processor.

When using Bergeron line constants, the model may optionally be "forced" to substitute PI section calculations for travelling wave calculations when splitting of subsystems is not a required feature. PI sections calculations may also be "allowed" to be substituted depending on whether the travel time of any mode is less than one time−step.

5.5.4.1 CONNECTION OF LINES WHICH MAY USE PI SECTION ALGORITHM

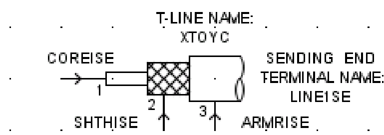
A PI section model, like a transformer, cannot be connected between separate network solutions. Therefore, if a PI section algorithm is "forced" or "allowed" for Bergeron line constants, the RTDS compiler will check to make certain that the nodal connections are permitted. PI section models must be connected in a single network solution according to the same rules that apply to general models such as transformers.

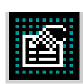
If a PI section algorithm is **not** either “forced” or “permitted” , and the minimum modal travel time is less than 1 time−step, then the compiler will apply a lower limit on the modal travel times (and associated modal resistances) of 1 time−step. Of course, in that case, the usual Bergeron line calculations will be used.

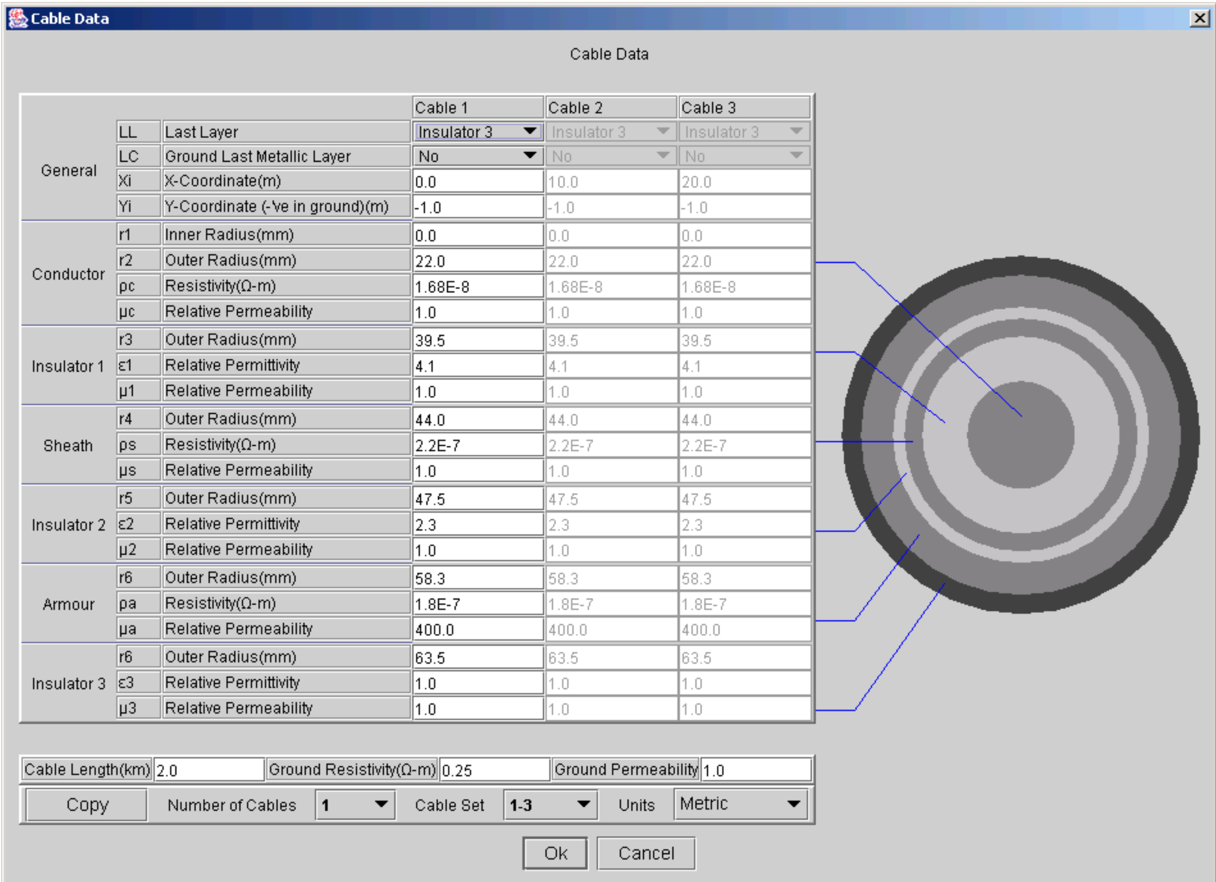
5.5.5 DETAILS ABOUT USING CABLE TERMINAL ICON

The same calculation block (**rtds_sharc_TL16CAL**) is used for the Cable Terminals as was used by the T−Line Terminals. However, the terminal component for the cable **(rtds_sharc_TL16TRMC**) is different from the terminal component of the T−Line.

As noted above, the appearance of the Cable Terminal component varies depending on the **number of insulated conductive cable layers** that are being modelled. The icon of the Cable Terminal component appears as follows when three **insulated** conductive layers are modelled, and all three are set to be available for monitoring in RunTime:



The data for the Cable model is prepared using the RSCAD CABLE program. The CABLE program is started by clicking on the “CABLE” button in the FileManager program. When the main window of the CABLE program appears, the Edit Parameters button:  near the top of the window should be clicked. This will cause the main cable editing window to appear as shown here:



			Cable 1	Cable 2	Cable 3
General	LL	Last Layer	Insulator 3	Insulator 3	Insulator 3
	LC	Ground Last Metallic Layer	No	No	No
	Xi	X-Coordinate(m)	0.0	10.0	20.0
	Yi	Y-Coordinate (-'ve in ground)(m)	-1.0	-1.0	-1.0
Conductor	r1	Inner Radius(mm)	0.0	0.0	0.0
	r2	Outer Radius(mm)	22.0	22.0	22.0
	ρc	Resistivity(Ω-m)	1.68E-8	1.68E-8	1.68E-8
	μc	Relative Permeability	1.0	1.0	1.0
Insulator 1	r3	Outer Radius(mm)	39.5	39.5	39.5
	ε1	Relative Permittivity	4.1	4.1	4.1
	μ1	Relative Permeability	1.0	1.0	1.0
Sheath	r4	Outer Radius(mm)	44.0	44.0	44.0
	ρs	Resistivity(Ω-m)	2.2E-7	2.2E-7	2.2E-7
	μs	Relative Permeability	1.0	1.0	1.0
Insulator 2	r5	Outer Radius(mm)	47.5	47.5	47.5
	ε2	Relative Permittivity	2.3	2.3	2.3
	μ2	Relative Permeability	1.0	1.0	1.0
Armour	r6	Outer Radius(mm)	58.3	58.3	58.3
	ρa	Resistivity(Ω-m)	1.8E-7	1.8E-7	1.8E-7
	μa	Relative Permeability	400.0	400.0	400.0
Insulator 3	r6	Outer Radius(mm)	63.5	63.5	63.5
	ε3	Relative Permittivity	1.0	1.0	1.0
	μ3	Relative Permeability	1.0	1.0	1.0

The RTDS Cable model is limited to modelling the capacitive and inductive coupling within one single–phase concentric cable. Modelling of the electromagnetic coupling between parallel cables is not supported. Therefore, one should be specified in response to the “Number of Cables” item located near the bottom of the main cable editing window.

In the main cable editing window, the “LL” (Last Layer) menu item determines the number of layers in the single–phase cable. The default is “Insulator3”. In that case the cable contains a conductive core, a non–porous insulating layer over the core, a metallic sheath layer, an insulating layer over the sheath, a metallic armour layer, and an insulating layer over the armour. A mouse right–click will remove an outer layer. At the minimum, the cable must include the conductive core plus the non–porous insulating layer over the core. A mouse left–click will add an outer layer providing that the limit of “Insulator3” has not been reached. The existence of a layer implies that all underlying layers exist.

If the last layer is “Insulator2” or “Insulator3”, then that last insulating layer may be porous. In that case, the “LC” menu item specifies that the last underlying metallic layer is effectively in contact with the surrounding ground.

The menu item “numc” in the Draft cable terminal CONFIGURATION menu prompts for the number of insulated conductor or conductive layers in the cable model.

“numc” should be set to the number of non−porous insulating layers.

For example, if the cable contains only a conductive core, a non−porous insulating layer over the core, and a metallic sheath layer, then “numc” should be set equal to 1. Similarly, if the cable contains a conductive core, a non−porous insulating layer over the core, a metallic sheath layer, and a porous layer over the metallic sheath layer, then “numc” should still be set equal to 1. The existence of the last porous insulating layer makes no difference to the number of insulated conductors/conductive layers.

The main cable editing window also requires the specification of the physical dimensions as well as relative permittivity and relative permeability for each layer of the cable. Ground resistivity, ground permeability and length of the line are also required.

The Compile button: in the main window of the CABLE program can be used to initiate the actual calculation of the line constants for the cable. Clicking on the Options button: causes an options menu to appear. The options menu can be used to select whether line constants should be produced for a “Frequency Dependant” or “Bergeron” cable model.

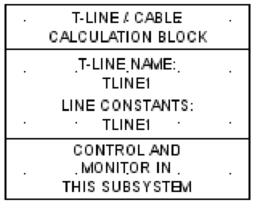
When specifying a Frequency Dependant (“Fre−Dep”) model in DRAFT, the present T−Line/Cable model is dimensioned to support up to 10 poles for attenuation and 10 poles for characteristic impedance per mode.

NEVER specify “A max # of Poles:” to be greater than 10. Similarly, “Z max # of Poles:” should NEVER be specified to be greater than 10.

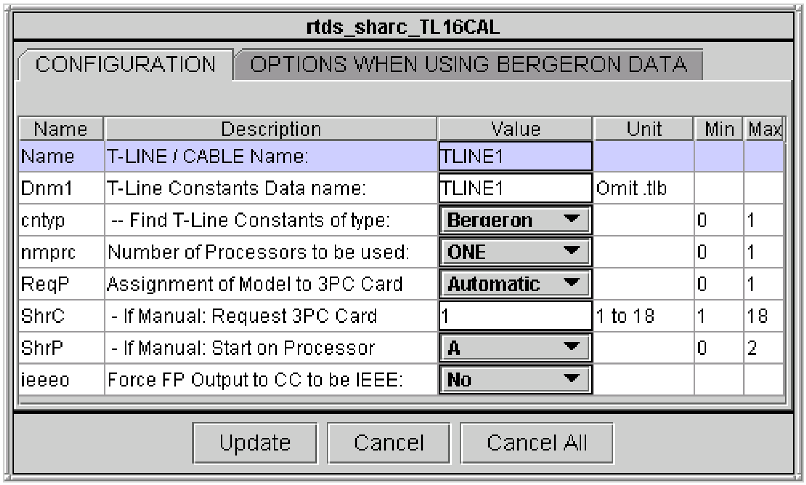
Moreover, in order to maintain a short time−step length, it is recommended to limit the number of poles to 5 for attenuation and 5 for characteristic impedance in the Cable program. This limitation is particularly recommended when only one processor is to be used for a simulating a three conductor/layer Frequency Dependant cable model.

5.5.6 THE T−LINE/CABLE CALCULATION BLOCK ICON

The Unified T−Line and Cable models in Draft both use the T−Line/Cable Calculation Block (**rtds_sharc_TL16CAL**). The Calculation Block appears in the following figure:



The CONFIGURATION menu appears as follows:



Name	Description	Value	Unit	Min	Max
Name	T-LINE / CABLE Name:	TLINE1			
Dnm1	T-Line Constants Data name:	TLINE1	Omit .tlb		
cntyp	-- Find T-Line Constants of type:	Bergeron		0	1
nmprc	Number of Processors to be used:	ONE		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	- If Manual: Request 3PC Card	1	1 to 18	1	18
ShrP	- If Manual: Start on Processor	A		0	2
ieeeo	Force FP Output to CC to be IEEE:	No			

The first line in the CONFIGURATION menu of the Calculation Block (“Name”) contains the Name of the T−Line/Cable being specified. Terminal Blocks also requires the name (“Tnam1”) of the T−Line or Cable. The responses to these entries are used to connect the Calculation Block with two Terminal components. Therefore, a unique Name must be specified in each Calculation Block. Also, for each Calculation Block, there must be precisely two T−Line Terminal components or two Cable Terminal components that have the same T−Line name. If there are not precisely two terminals of the same type for a T−Line/Cable name, then an Error message will be given upon compiling. If the two terminals do not have the same number of conductors, then an Error message for this will also be given.

The second menu line (“Dnm1”) prompts for the name of the T−Line or Cable constants prepared by the T−Line or Cable program for the line. Do not include the suffix .tlb or .cbl when specifying the name of the line constants.

The third line (“cntyp”) prompts for the type of line constants which should be sought by the RTDSPC compiler. The two choices are “Bergeron” and “Fre−Dep”. “Fre−Dep” is an abbreviation for Frequency Dependant Modal constants data. The RTDSPC compiler will attempt to find the specified type of line constants with the “Dnm1” name in a .tlb or .cbl file. An Error message will be given if the RTDSPC compiler encounters transmission line data of the specified name that is of the wrong constants type or is for the wrong number of conductors. The RTDSPC compiler obtains the number of conductors from the T−Line/Cable terminal components.

The appropriate response to the number of processors item (“nmprc”) varies depending upon the type of constants (“Bergeron/Fre−Dep”); the number of conductors; and the preference for maintaining a short time−step. First of all, “TWO” must be selected if a Frequency Dependant type line has more than 3 conductors, or if a Bergeron line has more than 6 conductors. An Error message will be given if this rule is not followed. Otherwise, “ONE” or “TWO” can be chosen depending on need to maintain a short time–step, as “TWO” processors will shorten the time–step requirement of the model. The time–step usage of the model is recorded in the .map file when RTDSPC compiles the case.

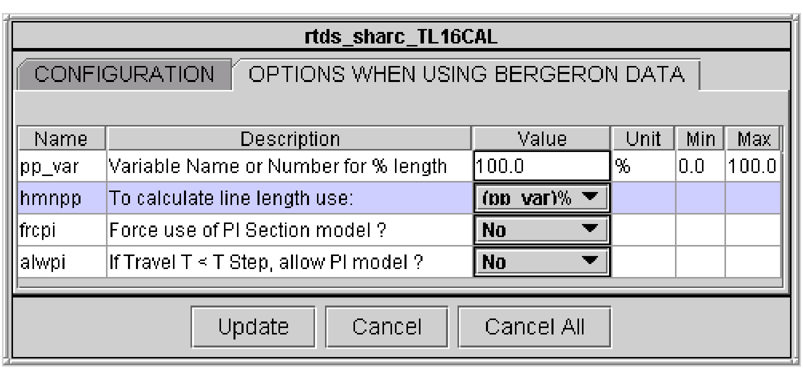
The next 3 entries in the PARAMETERS menu (ReqP, ShrC and ShrP) allow the model to be Automatically or Manually assigned to a specified processor. If automatic assignment is requested, the subsequent two entries in the menu are ignored. If manual assignment is requested, a specific processor can be requested by indicating 3PC card number and processor A, B, or C. If “TWO” processors are requested for the model, then an Error message will be given if the request is to manually place a processor beginning on C.

The final menu item in the PARAMETERS menu, labelled “ieeeo”, checks if floating point numbers passed to the backplane from the model should be forced to IEEE floating point format. In simulators containing only 3PC processors this line is ignored. In mixed 3PC/TPC simulators, the usual choice is “No” to this line. Some explanation is required.

When the simulation hardware contains only 3PC cards (that is, no TPC cards), then the IEEE floating point format is always used on the rack backplane. In that case, the response to the “ieeeo” item is ignored by the compiler.

The item “ieeeo” becomes relevant when the simulation hardware contains at least one “mixed rack” of simulation hardware (that is, both TPC and 3PC cards). In that case, the format of floating point numbers passed on all of the backplanes is generally the NEC processor floating point format rather than the IEEE floating point format. However, some 3PC models can be forced to expect floating point numbers from the backplane in IEEE format in mixed racks even though the default is NEC. Accordingly, the “ieeeo” item in this model gives the option to pass floating point numbers to the backplane in IEEE format in mixed racks. The User should exercise diligence when choosing to pass floating point numbers in IEEE format in mixed racks.

The OPTIONS WHEN USING BERGERON DATA menu appears as follows:



The above menu is available only when “Bergeron” type line constants data has been specified in the CONFIGURATION menu.

The first entry (pp_var) in the OPTIONS menu can accept a numerical percentage entry for modifying length as shown above.

Alternatively, the first entry (pp_var) can accept a Pre−Processor Variable name which can be used to acquire numerical percentage input from a Pre−Processor slider. The Pre−Processor slider icon is named "rtds_pp_var" in the DRAFT components library. In order to use a Pre−Processor slider, an instance of the "rtds_pp_var" icon must be placed in the DRAFT circuit diagram and the slider icon given the name specified in the first entry (pp_var). The initial value and permitted range of the slider may also be specified. Once compiled, a Pre−Processor slider becomes available in RunTime for changing prior to starting the simulation in RunTime. Please refer to section 3.15 of the RunTime RSCAD manual concerning Pre−Processor sliders and Chapter 18 of this manual for more information.

As noted above, the percentage obtained through the first entry (pp_var) is used to modify the length of the line described in the .tlb, .cbl or tlines file. The second entry is a toggle which gives the choice of how the percentage input is used to calculate line length.

If "(pp_var)%" is selected for the second entry, then the percentage is used directly to modify the length of line specified in the t−line constants files (.tlb, .cbl, or tlines). In that case, if a .tlb file has been prepared for a Bergeron line that is 100 kilometers long, then the percentage input will correspond with the simulation length in kilometers.

If "(100−pp_var)%" has been selected for the second entry, then the simulation length of the line will be the length of the line as defined in the line constants file times the factor:

(100 − percentage input) / 100

The 3rd and 4th entries ("frcpi" and "alwpi") in the OPTIONS WHEN USING BERGERON DATA menu, enable the specification that the use of a PI section algorithm is to be forced ("frcpi") or alternatively permitted only when a modal travel time is less than one simulation time−step in length ("alwpi").

A travelling wave line model can be used to span between different network solutions. This capability exists because a travelling wave line model provides a separate contribution to the conductance matrix at each end of the line. There is no mutual conductance contributions which span between the two ends.

5.5.6.1 CONNECTION OF LINES WHICH MAY USE PI SECTION ALGORITHM

The PI section algorithm cannot be used to span between network solutions in the way that a travelling wave line model can. This limitation exists because a PI section algorithm creates one connected conductance matrix for contributing to the main network conductance matrix. There are mutual elements of conductance in the matrix contribution connecting nodes at one end of the PI section to nodes at the other end. Therefore, if use of the PI section model is either to be forced or permitted (according to entries “fcrpi” or “alwpi”), then the model must be connected in one network solution in the manner of a general model (such as a transformer).

If a PI section algorithm is either forced or allowed, then the RTDSPC compiler will issue an error message if the transmission line is connected so as to span between network solutions in an unsupported manner.

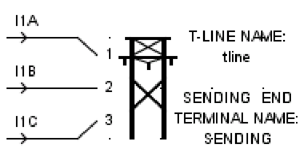
If “Yes” is given to the “frcpi” (force PI) item for a properly connected T–Line, then the PI section algorithm will be used regardless of whether a modal travel time is longer or shorter than one time–step.

If “No” is given to the “frcpi” (force PI) item but “Yes” to the “alwpi” (allow PI) item for a properly connected T–Line, then the PI section algorithm will be used only if a modal travel time is shorter than one time–step.

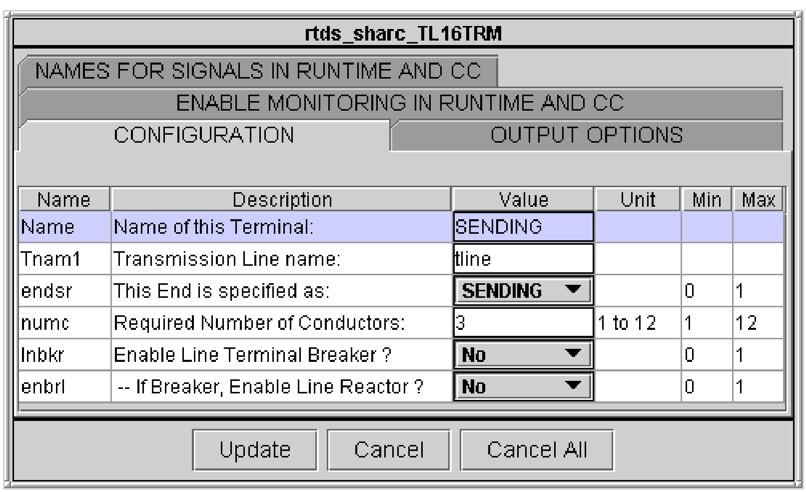
If “No” is given to both “fcrpi” (force PI) and “alwpi” (allow PI), then a lower limit of one time–step is placed on all modal travel times and the Bergeron travelling wave algorithm will be used.

5.5.7 THE T–LINE TERMINAL COMPONENT ICON

A single T–Line Terminal component (**rtds_sharc_TL16TRM**) specified as containing 3 conductors is illustrated in the following figure.



The CONFIGURATION menu appears as follows:



Name	Description	Value	Unit	Min	Max
Name	Name of this Terminal:	SENDING			
Tnam1	Transmission Line name:	tline			
endsr	This End is specified as:	SENDING		0	1
numc	Required Number of Conductors:	3	1 to 12	1	12
lnbkr	Enable Line Terminal Breaker ?	No		0	1
enbrl	-- If Breaker, Enable Line Reactor ?	No		0	1

The first entry in the CONFIGURATION menu (Name) requires a unique terminal name. If every terminal in a simulation does not have a unique name, then an error message will be given.

The second entry in the CONFIGURATION menu (Tnam1) requires the "Transmission Line" name corresponding to the name of a T−Line/Cable Calculation block. If there is no Calculation Block with the same name as "Transmission Line name" then an error will be issued by the compiler. Also, if not exactly two terminals exist for each Calculation Block there will also be an error message issued by the compiler.

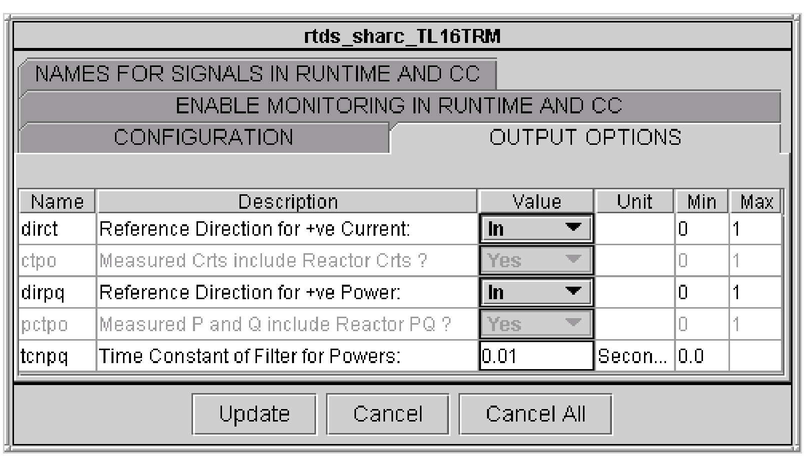
The third entry in the CONFIGURATION menu (endsr) requires one terminal of the line to be the SENDING end and the other terminal to be the RECEIVING end. The choice of which end is the SENDING end and which is the RECEIVING end is generally not important. However, in the case where two processors (say A and B on a 3PC card) are used to calculate the model, the SENDING end is calculated on the first processor (A) and the RECEIVING end is calculated on the second (B) processor.

The fourth entry in the CONFIGURATION menu (numc) prompts for the number of conductors in the line. Up to 6 conductors are supported by the frequency dependant line models. Up to 12 conductors are supported when using Bergeron data in Bergeron travelling wave models or PI section models. When using more than 3 conductors in a frequency−dependant line model, 2 processors must be specified in the T−Line/Cable Calculation Block. When using more than 6 conductors in a Bergeron line model (or PI model), 2 processors must be specified. Two processors can always be specified for any line in order to reduce the time−step requirement of the model. Error messages will be given by the compiler if the rules are not followed.

The final two entries in the CONFIGURATION menu are for the inclusion of an optional circuit breaker with three embedded nodes, and a line reactor.

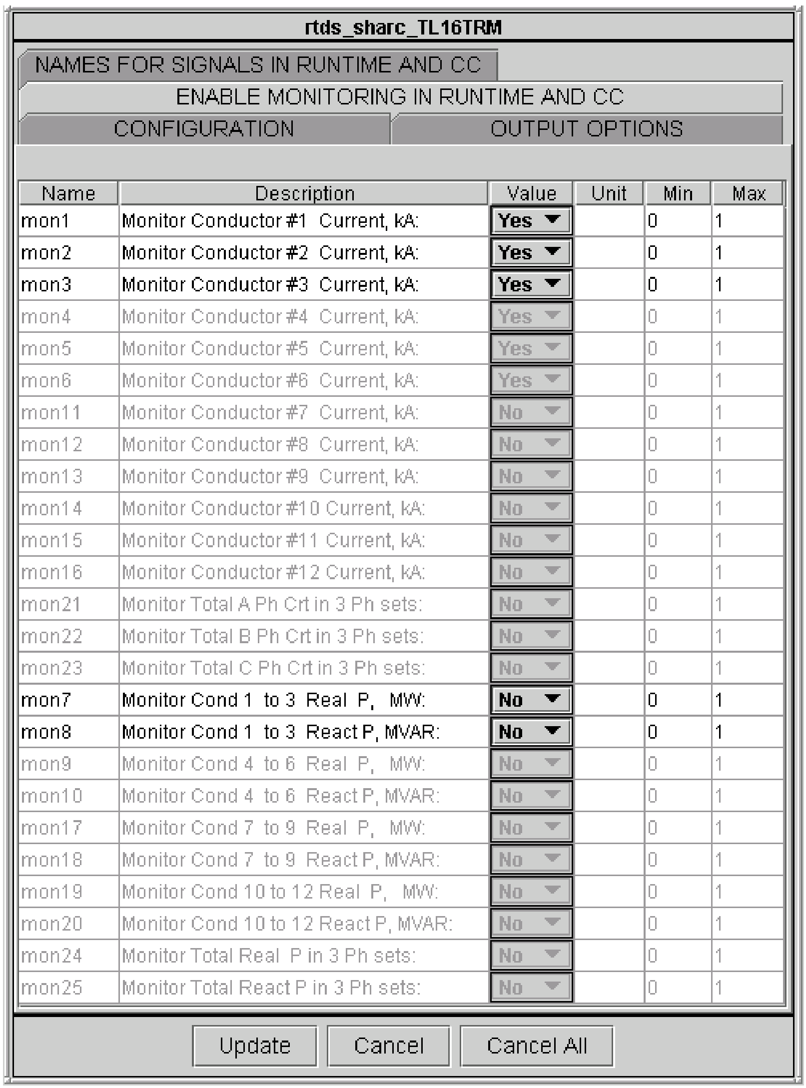
The other 3 menus in the PARAMETERS menu allow specification of output for monitoring in RunTime and the CC.

The OUTPUT OPTIONS menu appears as follows:



The currents and powers at the terminal output are both available for monitoring. The OUTPUT OPTIONS menu allows a reference direction to be specified for the monitored currents and powers. Power and Current may be monitored with reference direction either into or out of the line. If real or reactive power is monitored, then the monitored power signals may be passed through first−order lag filters with a time constant “tcnpq” as specified in the OUTPUT OPTIONS menu. If no filter is desired, then a 0.0 may be entered for “tcnpq”.

The ENABLE MONITORING IN RUNTIME AND CC menu contains toggle boxes that enable output for monitoring. The output which is available depends upon the number of conductors. The menu shown below shows illustrates the 5 signals that may be monitored at one end of a 3 conductor line.



Name	Description	Value	Unit	Min	Max
mon1	Monitor Conductor #1 Current, kA:	Yes		0	1
mon2	Monitor Conductor #2 Current, kA:	Yes		0	1
mon3	Monitor Conductor #3 Current, kA:	Yes		0	1
mon4	Monitor Conductor #4 Current, kA:	Yes		0	1
mon5	Monitor Conductor #5 Current, kA:	Yes		0	1
mon6	Monitor Conductor #6 Current, kA:	Yes		0	1
mon11	Monitor Conductor #7 Current, kA:	No		0	1
mon12	Monitor Conductor #8 Current, kA:	No		0	1
mon13	Monitor Conductor #9 Current, kA:	No		0	1
mon14	Monitor Conductor #10 Current, kA:	No		0	1
mon15	Monitor Conductor #11 Current, kA:	No		0	1
mon16	Monitor Conductor #12 Current, kA:	No		0	1
mon21	Monitor Total A Ph Crt in 3 Ph sets:	No		0	1
mon22	Monitor Total B Ph Crt in 3 Ph sets:	No		0	1
mon23	Monitor Total C Ph Crt in 3 Ph sets:	No		0	1
mon7	Monitor Cond 1 to 3 Real P, MW:	No		0	1
mon8	Monitor Cond 1 to 3 React P, MVAR:	No		0	1
mon9	Monitor Cond 4 to 6 Real P, MW:	No		0	1
mon10	Monitor Cond 4 to 6 React P, MVAR:	No		0	1
mon17	Monitor Cond 7 to 9 Real P, MW:	No		0	1
mon18	Monitor Cond 7 to 9 React P, MVAR:	No		0	1
mon19	Monitor Cond 10 to 12 Real P, MW:	No		0	1
mon20	Monitor Cond 10 to 12 React P, MVAR:	No		0	1
mon24	Monitor Total Real P in 3 Ph sets:	No		0	1
mon25	Monitor Total React P in 3 Ph sets:	No		0	1

In the above figure, only the signals that are available for monitoring are not “greyed” out. As the number of conductors in the line is increased, the signals available for monitoring also increase.

As the number of conductors is increased, the additional conductor currents (up to 12) become available for monitoring in the above menu.

Conductors numbered 1,2,3 form a three−phase set for monitoring purposes if there are 3 or more conductors. Conductors numbered 4,5,6 form a three−phase set for monitoring purposes if there are 6 or more conductors. Similarly, conductors numbered 7,8,9 and 10,11,12 can form three−phase sets for monitoring purposes.

Menu items “mon21”, “mon22”, and “mon23” in the above menu become available for monitoring summed phase currents in complete three−phase sets when there are 6 or more conductors in the T−Line. As an example, if there are 11 conductors, “mon21” enables the monitoring of the sum of A phase currents in the complete sets (1,2,3 4,5,6 7,8,9). The current monitored for “mon21” would be the sum of currents in conductors 1, 4, and 7. Conductor 10 would not be included in the sum because it does not form part of a complete three−phase set. Similarly, “mon22” would form a signal based on the sum of currents in conductors 2, 5, and 8.

Real and reactive power is available for monitored according to three−phase sets.

For real power, a three−phase set does not need to be complete. Therefore, “mon7” is always available for monitoring power into the first set even if there is only 1 conductor in the line. Similarly, “mon9” becomes available when there are 4 conductors or more; “mon17” becomes available when there are 7 conductors or more; and “mon19” becomes available when there are 10 conductors or more.

However, for reactive power, each three−phase set must be complete before reactive power can be monitored in the set, because reactive power is only defined according to three conductor systems. Therefore, “mon8” in the above menu would not be available until there are 3 or more conductors in the line. Similarly, “mon10” becomes available when there are 6 or more conductors; “mon18” becomes available when there are 9 or more conductors; and “mon20” becomes available when there are 12 or more conductors.

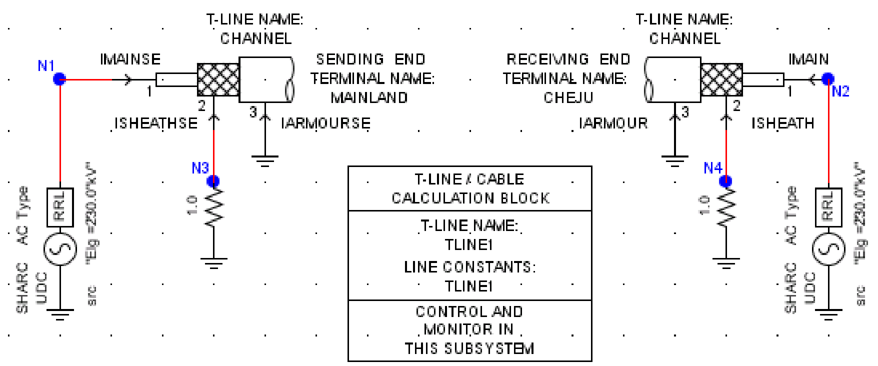
Menu item “mon24” allows monitoring of the sum of real power in complete three phase sets. As an example, for an 11 conductor line, only the first 9 conductors would be considered.

Menu item “mon25” allows monitoring of the sum of reactive power in complete three phase sets. As an example, for an 11 conductor line only the first 9 conductors would be considered.

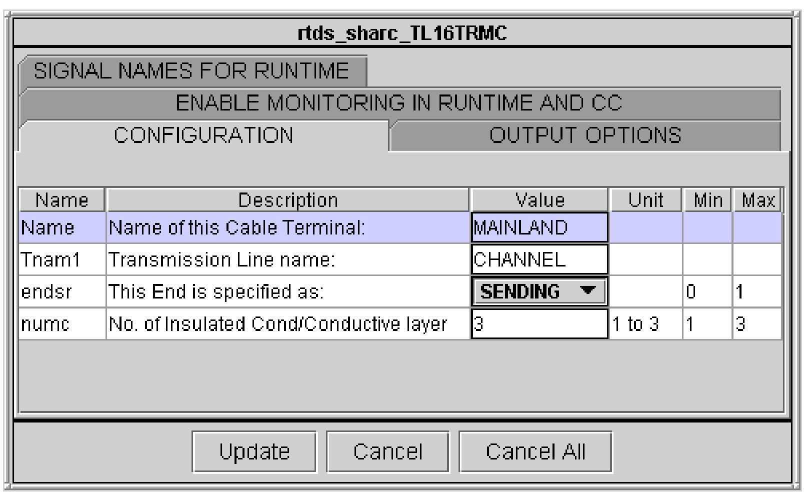
The NAMES FOR SIGNALS IN RUNTIME AND CC menu allows unique names for signals to be made available for monitoring in RunTime and the Controls Compiler (CC). The menu items become available (not “greyed” out) in the menu according to the signals enabled in the ENABLE MONITORING IN RUNTIME AND CC menu described above.

5.5.8 THE CABLE TERMINAL COMPONENT ICON

A Cable model is illustrated below in a simple DRAFT schematic including two Cable Terminal components (**rtds_sharc_TL16TRMC**). The Cable Terminal icon, as shown, is for a cable with 3 insulated layers (including the core). The outer layer (armour) is directly bonded to ground. The middle layer (sheath) is grounded through a 1.0 Ohms resistance. This connection is for illustrative purposes only and does not represent typical parameters.



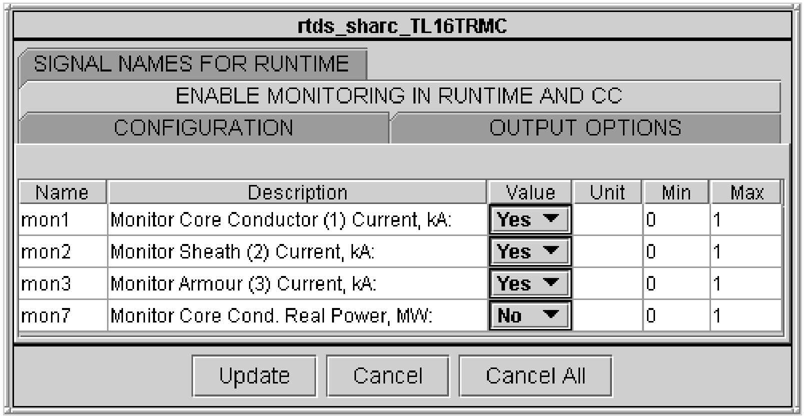
The CONFIGURATION menu appears as follows:



The CONFIGURATION menu is the same as that for the T–Line Terminal except that the Cable Terminal model asks for the number of Insulated Conductors/Conductive Layers in the Cable. The count entered for the "numc" menu item should include the core conductor plus any conductive layers that are surrounded by a non–porous insulating layers.

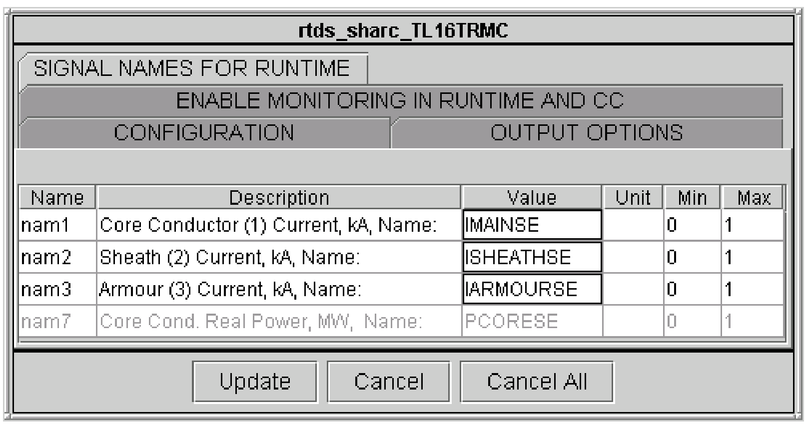
The OUTPUT OPTIONS menu for the Cable Terminal model is exactly the same as for the T–Line Terminal model.

The ENABLE MONITORING IN RUNTIME AND CC menu for the Cable Terminal model appears as follows:



The ENABLE MONITORING IN RUNTIME AND CC menu allows currents to be monitored in the core and insulated layers of the cable at the terminal. The menu also allows monitoring of the power in the core conductor at the terminal.

The SIGNAL NAMES FOR RUNTIME menu allows unique names to be specified for the monitored signals. The menu appears as follows:

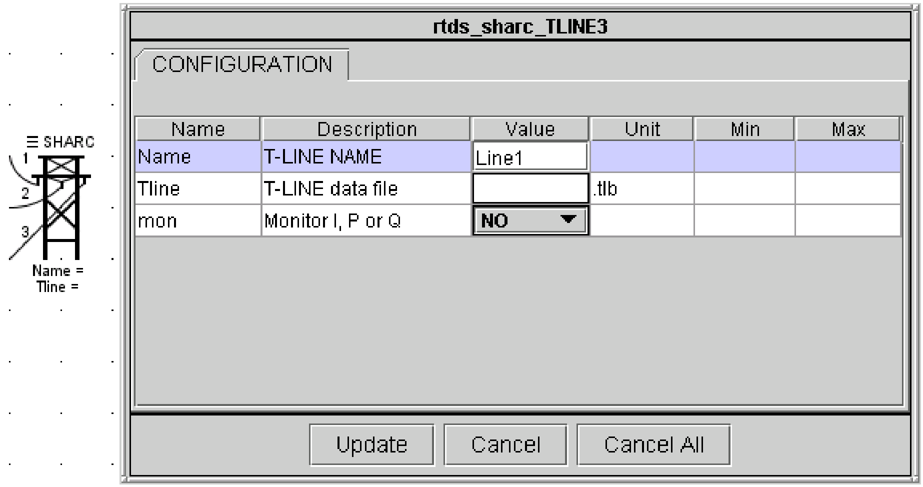


5.6 THE UDC GROUP OF TRAVELLING WAVE T–LINE MODELS

A transmission line model for a line with 3 or fewer conductors is not computationally heavy for a 3PC processor. Therefore, UDC line models have been prepared which can be “stacked” on one 3PC processor with another UDC model such as a source model or generator model. This efficient use of processors is an important feature of the UDC models. The UDC models are based on either Bergeron travelling wave line models or PI section models. Frequency Dependant line model algorithms are not available in UDC models.

5.6.1 DATA FOR UDC TRAVELLING WAVE MODELS

Entering data in the DRAFT module for traveling wave line models requires only a name to be entered for the line in question. The transmission line icon is placed in the circuit and connected to the appropriate nodes. When the edit option is chosen, DRAFT prompts for the line name. The icon and associated menu are depicted below.

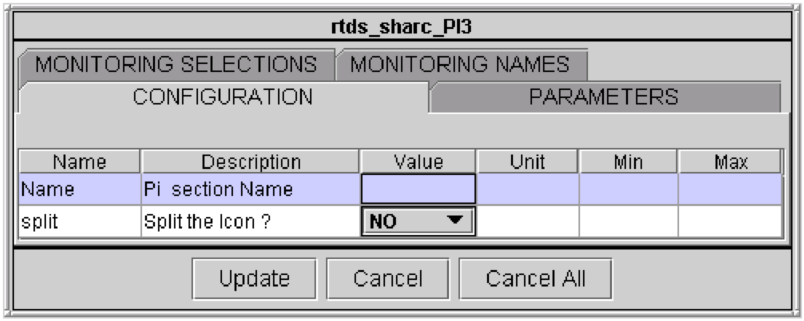


In order to define the line, the RSCAD based TLINE program must be invoked from the FILEMANAGER level of RSCAD. The geometry and parameters of the conductors and associated ground wires are defined as well as options relating to the type of line modelling (ie : transposed, etc.). Again, refer to the TLINE manual of the RSCAD documentation set for specific details regarding use of the TLINE program.

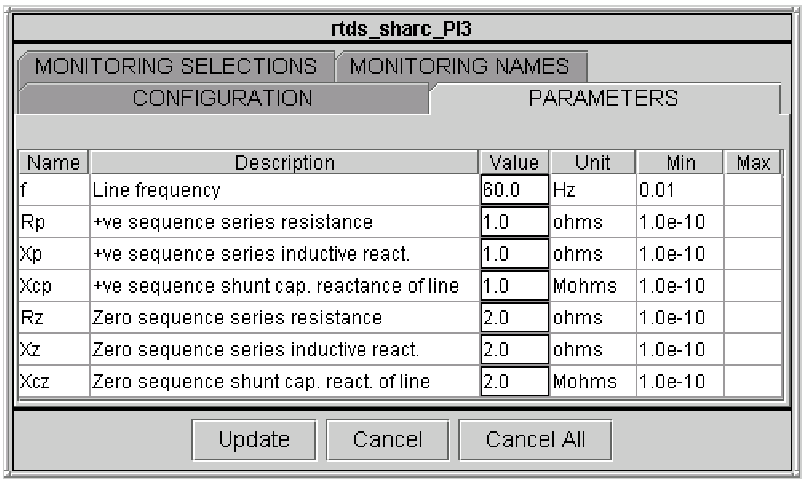
The transmission line icon shown above is used to define either end of a line. In order to fully define the line one such icon must be connected to the nodes representing the connection point at one end of the line (call this the sending end) and one such icon to the nodes representing the connection point at the other end of the line (call this the receiving end). The sending and receiving end icons of any one line section must be given the same name. The DRAFT compiler uses the common line names to distinguish which sending end line icons correspond to which receiving end icons. If a travelling wave line model is to be used to span between racks (ie to provide connection path between two racks of RTDS hardware) then one of the line icons must be placed on one subsystem of the DRAFT canvas and the other corresponding line icon on another subsystem of the canvas. DRAFT is arranged in such a way that different subsystems are assigned to different RTDS racks. Racks are assigned one per subsystem, with the lowest numbered rack (as defined in the PARAMETERS menu of DRAFT) being assigned to the first subsystem, followed in ascending order to subsequent subsystems. From the MAP file it can be noted that in any multi–rack simulation case, the transmission line auxiliary processor (ie the processor in which the travelling wave equations are solved) always resides in the lower numbered rack (ie: on the sending end rack).

5.7 THE UDC GROUP OF PI SECTION MODELS

Data required for a PI section line is summarized in Figure 5.12 below. It can be seen that DRAFT must be provided with positive and zero sequence quantities of the line which the PI section is representing and the line base frequency. Parameters are entered as the total impedance of the PI section in each of the boxes.



Name	Description	Value	Unit	Min	Max
Name	Pi section Name				
split	Split the Icon ?	NO			



Name	Description	Value	Unit	Min	Max
f	Line frequency	60.0	Hz	0.01	
Rp	+ve sequence series resistance	1.0	ohms	1.0e-10	
Xp	+ve sequence series inductive react.	1.0	ohms	1.0e-10	
Xcp	+ve sequence shunt cap. reactance of line	1.0	Mohms	1.0e-10	
Rz	Zero sequence series resistance	2.0	ohms	1.0e-10	
Xz	Zero sequence series inductive react.	2.0	ohms	1.0e-10	
Xcz	Zero sequence shunt cap. react. of line	2.0	Mohms	1.0e-10	

Based on the circuit configuration of Figure 5.11, the user−entered positive and zero sequence data must be appropriately converted to self and mutual resistances, inductances and susceptances. This is done internally by the DRAFT compiler based on the specified positive and zero sequence components according to the equations shown below.

Self resistance, reactance susceptance

$$R_S = (R_Z + 2 * R_P) / 3$$

$$X_S = (X_Z + 2 * X_P) / 3$$

$$B_S = (B_Z + 2 * B_P) / 3$$

Self resistance, reactance susceptance

$$R_M = (R_Z - R_P) / 3$$

$$X_M = (X_Z - X_P) / 3$$

$$B_M = (B_Z - B_P) / 3$$

5.8 **REFERENCES**

1) "Accurate Modelling of Frequency−Dependent Transmission Lines in Electromagnetic Transients Simulations",J.R. Marti, IEEE Trans., PAS−101, pp.147−157, January 1982

2) "Fast and Accurate Switching Transients Calculations on Transmission Lines with Ground Return Using Recursive Convolutions",A. Semlyen and A. Dabuleanu, IEEE Trans., PAS−94, pp.561−571, March/April 1975

3) "Transient Analysis of Underground Power−Transmission Systems",L.M. Wedepohl, D.J. Wilcox, Proc IEE, Vol.120, No.2, February 1973

4) "Simulation of Transients in Underground Cables with Frequency−Dependent Modal Transformation Matrices",L. Marti, Ph.D Dissertation, University of British Columbia, November 1986

5) "Rational Approximation of Frequency Domain Responses by Vector Fitting",B. Gustavsen, A. Semlyen, IEEE Trans., PE−194, PWRD−0−11−1997

6) "Transmission Line Models for the Simulation of Interaction Phenomena Between Parallel AC and DC Overhead Lines",B. Gustavsen, G. Irwin, R. Mangelrod, D. Brandt, K. Kent, Proceedings of the International Conference on Power Systems Transients, IPST99, Budapest, Hungary, June 20−24, 1999, pp. 37−42.

APPENDIX 5A: BASIC TRANSMISSION LINE THEORY

5A.1 TRANSMISSION LINE EQUATIONS

For a transmission line with distributed parameters there are two independent variables, time t and distance x. The dependent variables, voltage u and current i, are both functions of t and x. The relationship between these variables is governed by the following transmission line equations

$$-\frac{\partial u}{\partial x} = L\frac{\partial i}{\partial t} + Ri \qquad (1)$$

$$-\frac{\partial i}{\partial x} = C\frac{\partial u}{\partial t} + Gu \qquad (2)$$

where u and i are voltage and current on the line at a distance x and
R = line series resistance per unit length
L = Series inductance per unit length
G = Shunt conductance per unit length
C = Shunt capacitance per unit length

Because of the distributed nature of the line parameters and because of their frequency dependance, it is difficult to obtain a general analytical solution.

5A.2 THE SOLUTION OF LINE EQUATION IN FREQUENCY DOMAIN

It is difficult to write the solution of the line equation directly in the time domain when the frequency dependence of the parameters and the distributed nature of the losses are taken into account. However, the solution can be easily obtained in frequency domain as illustrated below ;

$$U_k(w) = \cosh[\gamma(\omega)\, l\,]\, U_m(\omega) - Zc(\omega)\sinh[\gamma(\omega)\, l\,]\, I_m(\omega) \qquad (3)$$
$$I_k(w) = \sinh[\gamma(\omega)\, l\,]\, U_m(\omega)/Zc(\omega) - \cosh[\gamma(\omega)\, l\,]\, I_m(\omega) \qquad (4)$$

where the subscripts k and m represent the sending and receiving ends respectively and l is the length of the line. $Zc(\omega)$ and $\gamma(\omega)$ are the complex characteristic impedance and propagation constant as defined by ;

$$Zc(\omega) = \sqrt{\frac{R + j\,\omega L}{G + j\,\omega C}} \qquad (5)$$

$$\gamma(\omega) = \sqrt{(R + j\,\omega L)(G + j\,\omega C)} \qquad (6)$$

The forward and backward voltage travelling wave functions are introduced to relate currents and voltages in frequency domain as follows ;

$$F_k(\omega) = U_k(\omega) + Zc(\omega)\, I_k(\omega) \quad (7)$$
$$F_m(\omega) = U_m(\omega) + Zc(\omega)\, I_m(\omega) \quad (8)$$

$$B_k(\omega) = U_k(\omega) - Zc(\omega)\, I_k(\omega) \quad (9)$$
$$B_m(\omega) = U_m(\omega) - Zc(\omega)\, I_m(\omega) \quad (10)$$

where F denotes forward and B denotes backward.

Eliminating $U_k(\omega)$ and $U_m(\omega)$ from (9) and (10) gives

$$B_k(\omega) = A_1(\omega)\, F_m(\omega) \quad (11)$$
$$B_m(\omega) = A_1(\omega)\, F_k(\omega) \quad (12)$$

where $$A_1(\omega) = e^{-\gamma(\omega)\, l} = 1/\{\cosh[\gamma(\omega)\, l] + \sinh[\gamma(\omega)\, l]\} \quad (13)$$

Equations (9) and (10) imply a time domain equivalent circuit for the frequency dependent transmission line to be that shown in Figure 5A.1 below.

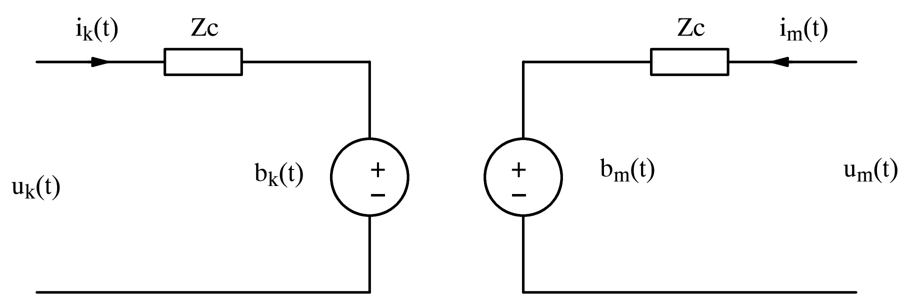


Figure 5A.1 Frequency dependent line model

If $b_k(t)$,$b_m(t)$ and Zc can be determined then the above circuit can be solved.

5A.3 DETERMINATION OF ZC

The characteristic impedance $Zc(\omega)$ is a function of frequency and cannot be directly used in Figure 5A.1 since it is normally a tabular function of frequency. Also, it is not reasonable to use a single impedance at a specified frequency (even a high frequency). If we can find an equivalent network Zeq whose frequency response is the same as the characteristic impedance of the line, then $Zc(\omega)$ can be replaced by the equivalent network Zeq. The Zeq developed by J. Marti[1] consists of passive circuit elements (R and C) which are frequency independent. The asymptotic technique is used to develop the Zeq network which is made up of a series of resistance−capacitance parallel block as shown in Figure 5A.2.

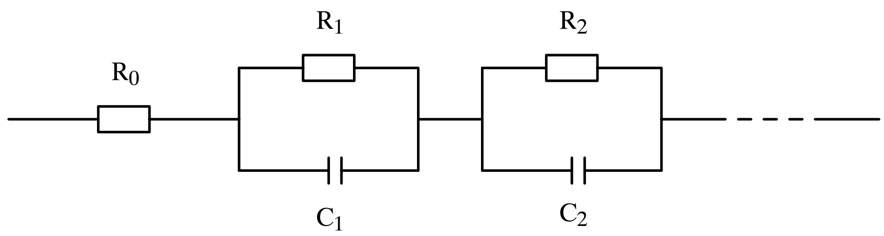


Figure 5A.2 Zeq realization

Bode's asymptotic technique can be used in the frequency domain to approximate Zc(ω) with a rational transfer function having the general form ;

$$H(s) = \frac{H\,(1+s/Z_1)\,(1+s/Z_2)\,...\,(1+s/Z_n)}{(1+s/p_1)\,(1+s/p_2)\,...\,(1+s/p_n)} \qquad (14)$$

All poles and zeros of H(s) are real and lie on the left hand side of the complex plane. The function to be approximated can be traced with magnitude |H(ω)| in asymptotic form. |H(ω)| lies within the boundaries defined by its asymptote. Then straight line segments with a slope of either zero or +/− 20 db/decade will constitute an envelope for the rational function.

The rational function Zeq (dotted line) is contained between Zc(ω) and the asymptotes. The corner of the asymptotic envelope defines the zeros and poles of the rational function. The routine starts from a horizontal reference level (0db). Every time a pole corner is added, the slope decreases by 20 db/dec. When a zero corner is added, the slope will increase by 20 db/dec. The number of poles and zeros depends on how far the asymptote is allowed to separate from the data before the next corner is added. The differences are kept below a specified value.

The rational function Zeq is further developed into a partial fraction expression

$$H(s) = A_0 + \frac{A_1}{s + p_1} + \frac{A_2}{s + p_2} + \;...\; \frac{A_n}{s + p_n} \qquad (15)$$

where in Figure 5A.2
Ro = Ao
Ri = Ai/Pi
Ci = 1/Ai for i=1,2,3,...n (16)

Expression (15) directly produces the values of R and C in the R−C network of Figure 5A.2.

5A.4 DETERMINATION OF $B_K(T)$ AND $B_M(T)$

The functions $b_k(t)$ and $b_m(t)$ are the time domain backward voltage travelling wave functions. Their corresponding frequency domain functions are defined by equations (11) and (12). Functions $b_k(t)$ and $b_m(t)$ are defined by the convolution integrals

$$b_k(t) = \int_{-\infty}^{\infty} f_m(t-u)a_1(u)du \tag{17}$$

$$b_m(t) = \int_{-\infty}^{\infty} f_k(t-u)a_1(u)du \tag{18}$$

where $f_m(t) = 2\,u_m(t) - b_m(t)$ (19)

$f_k(t) = 2\,u_k(t) - b_k(t)$ (20)

and $a_1(t)$ is the inverse Fourier Transformation of $A_1(\omega)$, also known as attenuation function or weighting function.

5A.5 NUMERICAL EVALUATION OF CONVOLUTION

The convolution integrals defined by (17) and (18) are re–written as

$$b_k(t) = \int_{\tau}^{t} f_m(t-u)a_1(u)du \tag{21}$$

$$b_m(t) = \int_{\tau}^{t} f_k(t-u)a_1(u)du \tag{22}$$

Note that the general convolution integration limits of $-\infty \rightarrow +\infty$ become $\tau \rightarrow t$ for the given functions. The lower limit of the integrals is τ because $a1(t) = 0$ for $t<\tau$.

The numerical evaluation of the convolution integral is the most time consuming part of transmission line transient calculation by travelling wave technique. As noted by Semlyn [2] it can be greatly reduced if one of the two functions to be convoluted can be expressed as a sum of exponential terms. That is, if the convolution integral at time t has the form ;

$$s(t) = \int_{\tau}^{t} b e^{-a\bullet(u-\tau)} f(t-u)du \tag{23}$$

S(t) can then be directly obtained from the value $S(t-\Delta t)$ (from the previous time step) and the known history of f at τ and $(\tau+\Delta t)$ earlier

$$s(t) = \alpha\, s(t-\Delta t) + \lambda\, f(t-\tau) + \mu\, f(t-\tau-\Delta t) \tag{24}$$

where α, λ and μ are known constants depending on b,a, the integration step Δt, and the numerical interpolation technique. With a first order approximation of function f (liner interpolation) α, λ and μ are defined as

$$\alpha = e^{-a\Delta t} \tag{25}$$

$$\lambda = \frac{b}{a}\left(1 - \frac{1-\alpha}{a\,\Delta t}\right) \tag{26}$$

$$\mu = \frac{b}{a}\left(\frac{1-\alpha}{a\,\Delta t} - \alpha\right) \tag{27}$$

This method is known as recursive evaluation of the convolution integral.

Unfortunately the weighting function a1(t) is not a exponential function. However, by using the same asymptotic technique as used for Zc(ω), a1(t) can be approximated by a sum of exponential terms. This means the recursive evaluation of convolution can be applied to it.

5A.6 APPROXIMATION OF WEIGHTING FUNCTION $A_1(\Omega)$

$A_1(\omega)$ can be approximated by a rational function

$$A_{approx}(s) = e^{-s\tau}\; H\; \frac{(1+s/Z_1)\,(1+s/Z_2)\,...\,(1+s/Z_n)}{(1+s/p_1)\,(1+s/p_2)\,...\,(1+s/p_n)}$$

with $s=j\omega$ and $n<m$. Note that $A_1(\omega) = e^{-\gamma l}$ starts from 1.0 and becomes less than 1.0 as the line length (or frequency) increases.

With $n<m$, the rational function $A_{approx}(s)$ can be expanded into partial fractions (with $A_o = 0.0$ since $n<m$).

$$A_0 + \frac{A_1}{s+p_1} + \frac{A_2}{s+p_2} + \;...\; \frac{A_n}{s+p_n}$$

The corresponding time−domain form of the above expression becomes
Now the weighting function $a_1(t)$ has been approximated by a sum of exponentials. Therefore, the recursive convolution method can be used to find $b_k(t)$ and $b_m(t)$.

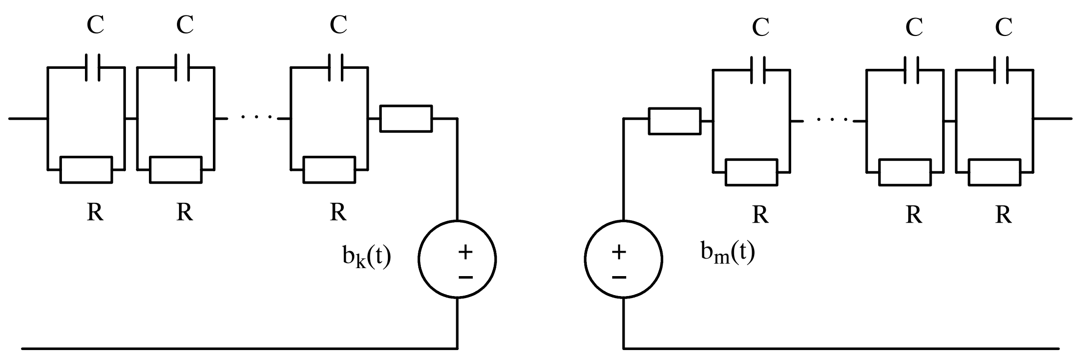
$$a_1(t) = A_1 e^{-p1 \bullet (t-\tau)} + A_2 e^{-p2 \bullet (t-\tau)} + \ . \ . \ .$$

5A.7 DEVELOPMENT OF EQUIVALENT CIRCUIT

The following diagrams illustrate how the equivalent circuits of the frequency dependent line model are developed, step by step.

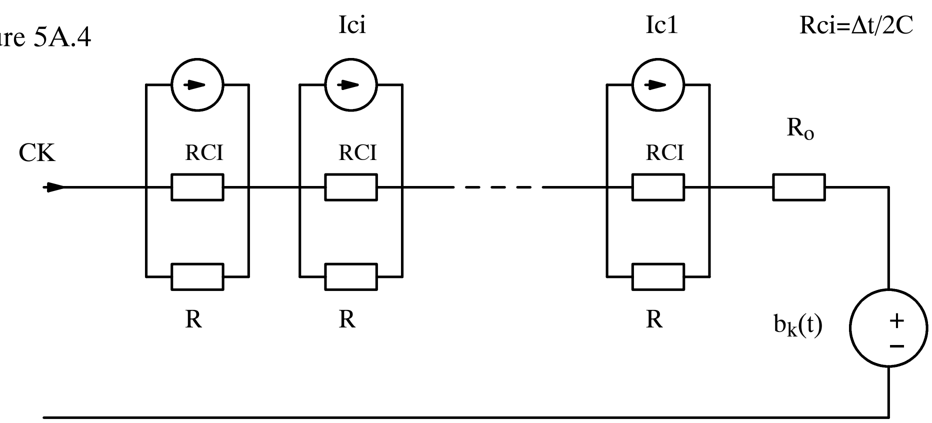
Beginning with Figure 5A.1, Zc is replaced by the R−C blocks of Figure 5A.2 to yield Figure 5A.3

Figure 5A.3



In each end of Figure 5A.3, the parallel RC elements can each be represented with resistances and a parallel current source as shown in Figure 5A.4

Figure 5A.4



We can define $R_{paralleli} = R_i//R_{ci}$, where // means parallel, to yield Figure 5A.5

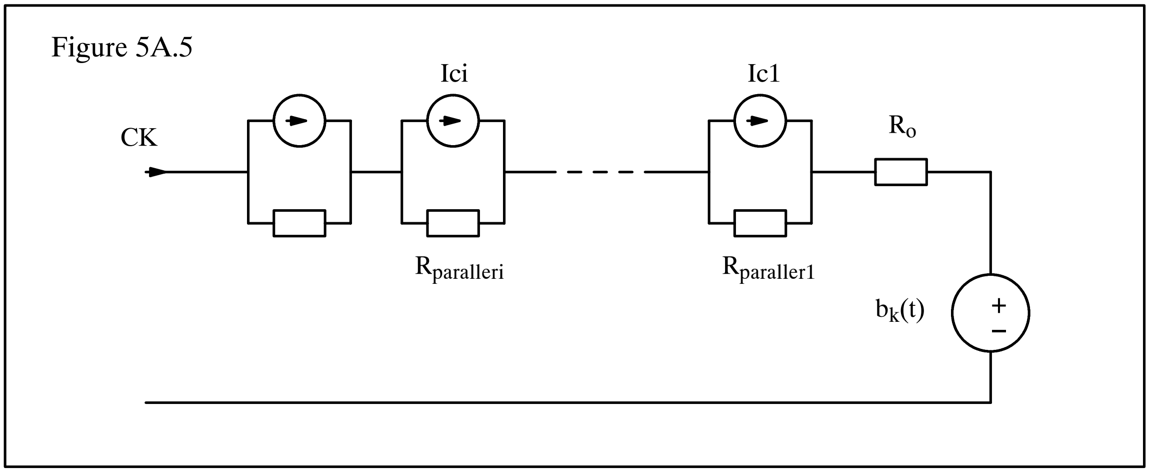


Figure 5A.5

Converting Norton sources to Thevenin sources yields Figure 5A.6

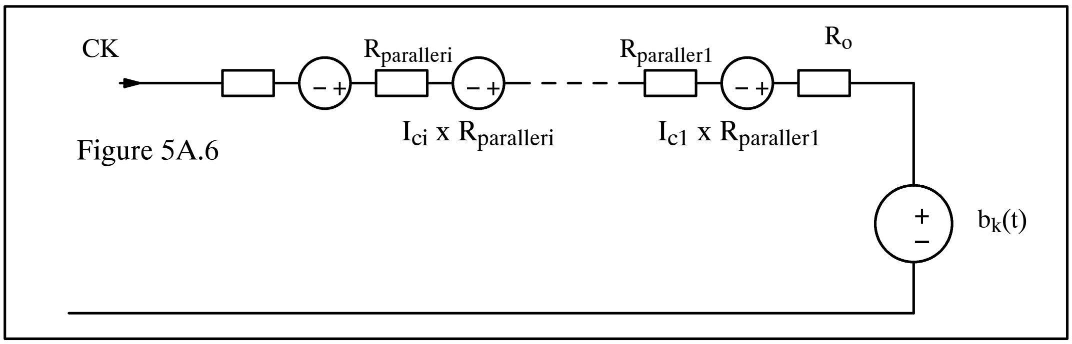


Figure 5A.6

In Figure 5A.6 the series resistances and voltage sources can be combined and defined according to:

$$R_{eq} = R_o + R_1//R_{c1} + R_2//R_{c2} + ... + R_i//R_{ci}$$

$$E_{eq}(t) = I_{c1} \times R_{paraller1} + I_{c2} \times R_{paraller2} + ... + I_{ci} \times R_{paralleri}$$

to yield Figure 5A.7.

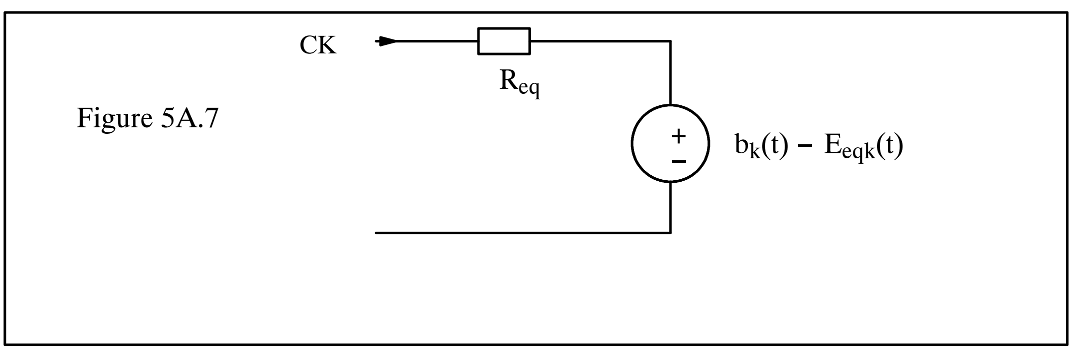


Figure 5A.7

Finally, the Thevenin sources at each end of the line can be converted to Norton sources to yield Figure 5A.8.

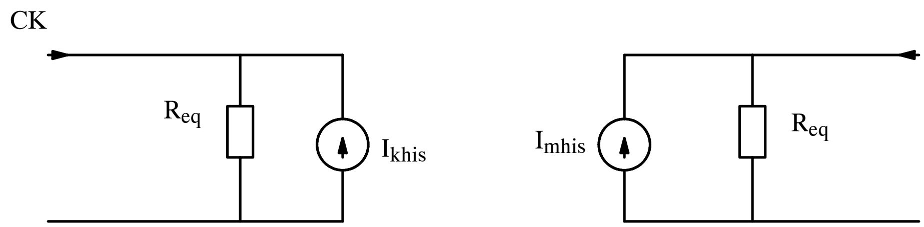


Figure 5A.8

where

$$I_{khis} = \frac{b_k(t) - E_{eqk}(t)}{R_{eq}} = Itw + Irc \tag{28}$$

$$I_{mhis} = \frac{b_m(t) - E_{eqm}(t)}{R_{eq}} \tag{29}$$

where $Itw = \frac{b_k(t)}{R_{eq}}$ is the current injection from travelling wave

$Irc = \frac{-E_{eqm}(t)}{R_{eq}}$ is the current injection from surge impedance

5A.8 BERGERON'S MODEL −−A SPECIAL CASE OF THE FREQUENCY DEPENDENT LINE MODEL

Bergeron's model is a special case of the frequency dependent line model when the number of poles and zeros are both set to zero and the lower frequency is set to the power frequency (say 60 Hz). The line model can be used either with or without frequency dependence without changing the general formulas.

Based on equation (9)

$$B_k(\omega) = U_k(\omega) - Zc(\omega)I_k(\omega) \tag{9}$$

we get

$$I_k(\omega) = U_k(\omega)/Zc(\omega) - B_k(\omega)/Zc(\omega) \tag{30}$$

In time domain $i_k(t) = u_k(t)/Zc - b_k(t)/Zc$ (31)

$$= u_k(t)/Zc - I_{khis} \tag{32}$$

where $I_{khis} = b_k(t)/Zc$

Equation (32) implies the following equivalent circuit,

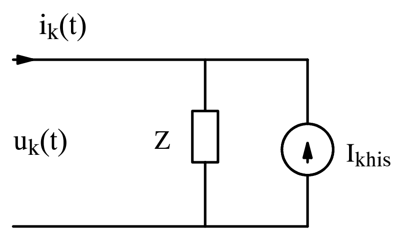


Figure 5A.9

Recalling the general relationship of (11) and (12),

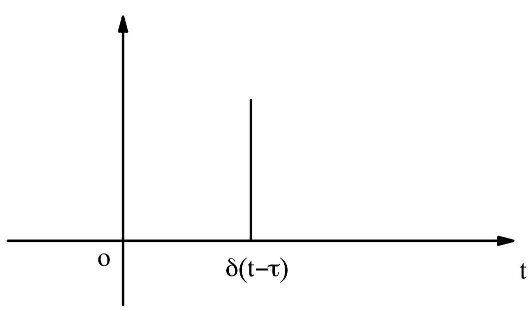
$$Bk(\omega) = A_1(\omega)\, Fm(\omega) \tag{11}$$
$$Bm(\omega) = A_1(\omega)\, Fk(\omega) \tag{12}$$

and in time domain equivalent equations (20) and (21)

$$b_k(t) = \int_{\tau}^{t} f_m(t-u)a_1(u)du \tag{20}$$

$$b_m(t) = \int_{\tau}^{t} f_k(t-u)a_1(u)du \tag{21}$$

By curve fitting, the attenuation function $a_1(t)$ (or weighting function) can be expressed as a sum of exponential functions. Recursive convolution can then be used to solve $b_k(t)$ and $b_m(t)$. If the number of poles = 0 in the curve−fitting, $a_1(t)$ is constant in the frequency domain. This corresponds to an impulse function in time domain with a delay of travel time τ .



Then equations (11) and (12) in time domain become simply

$$b_k(t) = \delta(t-\tau)f_m(t) = f_m(t-\tau) \quad (33)$$
$$b_m(t) = \delta(t-\tau)f_k(t) = f_k(t-\tau) \quad (34)$$

From (28) and (29)

$$I_{khis} = \frac{b_k(t) - E_{eqk}(t)}{R_{eq}} \quad (28)$$

$$I_{mhis} = \frac{b_m(t) - E_{eqm}(t)}{R_{eq}} \quad (29)$$

when $E_{eqk}(t) = 0.0$ and $E_{eqm}(t) = 0.0$ (without frequency dependence of $Zc(\omega)$)

$$I_{khis} = \frac{b_k(t)}{Z} = \frac{f_m(t-\tau)}{Z} = \frac{1}{Z}\,(u_m(t-\tau) + Z\, i_m(t-\tau)) = \frac{1}{Z}\, u_m(t-\tau) + i_m(t-\tau) \quad (35)$$

then (32) changes to

$$i_k(t) = \frac{1}{Z}\, u_k(t) - \frac{1}{Z}\, u_m(t-\tau) - i_m(t-\tau) \quad (36)$$

Similarly at node m

$$i_m(t) = \frac{1}{Z}\, u_m(t) - \frac{1}{Z}\, u_k(t-\tau) - i_k(t-\tau) \quad (37)$$

(36) and (37) are the typical Bergeron's expression.

The attenuation function $A_1(\omega) = e^{-\gamma l}$ starts from 1.0 and becomes less than 1.0 as the line length (or frequency) increases. Curve fitting does not start from 0 Hz (pure dc) however, but normally starts from some low frequency. Therefore, the magnitude of the starting point of the curve is not exactly 1.0, but some lesser value such 0.9963.

In the off–line EMTDC program, the value less than 1.0 in the frequency dependent line model is also used for the special case of Bergeron's model. So the resulting I_{kis} in equation (35) is

$$I_{khis} = \frac{b_k(t)}{Z} = \frac{f_m(t-\tau)}{Z} = \frac{0.9963}{Z}\, u_m(t-\tau) + i_m(t-\tau)$$

which is an approximation to the original Bergeron model.

In RTDS, for this special case, the original Bergeron expression (37) is used. No approximation is involved.

6 ELECTRIC MACHINE MODELS

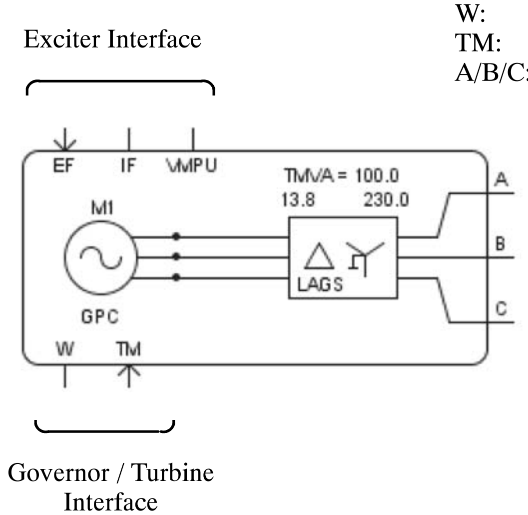
6.1 INTRODUCTION

The AC Machine models covered in this chapter include two versions of the synchronous machine followed by the induction machine. The synchronous machine model discussed first is the newest one and has numerous advantages over the second. New users are encouraged to use this model. The second synchronous machine is included for users who prefer not to upgrade their existing models. Note that the multi−mass model is described after the second synchronous machine and is applicable to both machine types. The induction machine is described in the section following. Finally, the permanent magnet synchronous machine is described in the last sections.

This chapter makes extensive use of control components and RunTime concepts. Users who are unfamiliar with this material are encouraged to consult the appropriate chapters of this manual, as well as the RSCAD RunTime Manual and the CONTROL SYSTEMS manual.

6.2 SYNCHRONOUS MACHINE MODEL WITH TRANSFORMER AND LOADS (RTDS_SHARC_MAC_V3)

EF: Field Voltage (norm)
IF: Field Current (norm)
VMPU: Machine Voltage (P.U.)
W: Machine speed (Rad./sec.)
TM: Mechanical Torque (P.U.)
A/B/C: Bus Connection Terminals



A synchronous machine model for the 3PC card, based on generalized machine theory, may be connected to the user defined power system network in RSCAD / Draft. This model can be connected to network nodes modelled with the 3PC Real−time Network solution.

The default icon (rtds_sharc_MAC_V3) for the model appears as shown above.

The Exciter and Governor/Turbine Interfaces in the above icon are standard Controls Compiler (CC) interconnection points.

The new 3PC based machine model includes a number of improvements with respect to the rtds_sharc_MAC machine model described in the next section. Briefly these improvements are as follows:

1. The model includes an optional Y−Δ generator unit transformer with separately specifiable zero sequence parameters. If the transformer option is enabled, then the model also simulates the three nodes between the transformer and the generator. This effectively increases the number of nodes than can be modelled in a single lumped network.

2. The model supports two optional R, RL, or RC shunt load banks which may be placed on the terminals of the machine.

3. The model now accepts SE(1.0) and SE(1.2) saturation factors for specifying the machine saturation curve. This is in addition to the previous method of defining the saturation curve with 10 points. The SE(1.0) and SE(1.2) factors are explained below.

4. There has been a large increase in the number of internal variables which may be monitored in RunTime or the CC and/or passed out through the D/A channels for external monitoring. The newly observable variables include: the load angle (in Radians), the phase currents out of the machine (in kA); Machine terminal voltage (in p.u.), ED and EQ (in p.u.), ID and IQ (in p.u.), and rotor mechanical angle (in Radians). The User may now also monitor the real and reactive power and currents out of the primary of the transformer when the transformer option is enabled. The list of output variables contained within the “SIGNAL MONITORING” menus.

5. The model uses fluxes as state variables rather than currents. A new method of calculating winding currents based on winding fluxes has allowed the resistance drop in the windings to be applied in the integration of fluxes without a one step delay. This will enhance accuracy of damping at higher frequencies.

6. Voltage projection techniques are applied in order to effectively remove delay in the closed loop created between the machine and the main network.

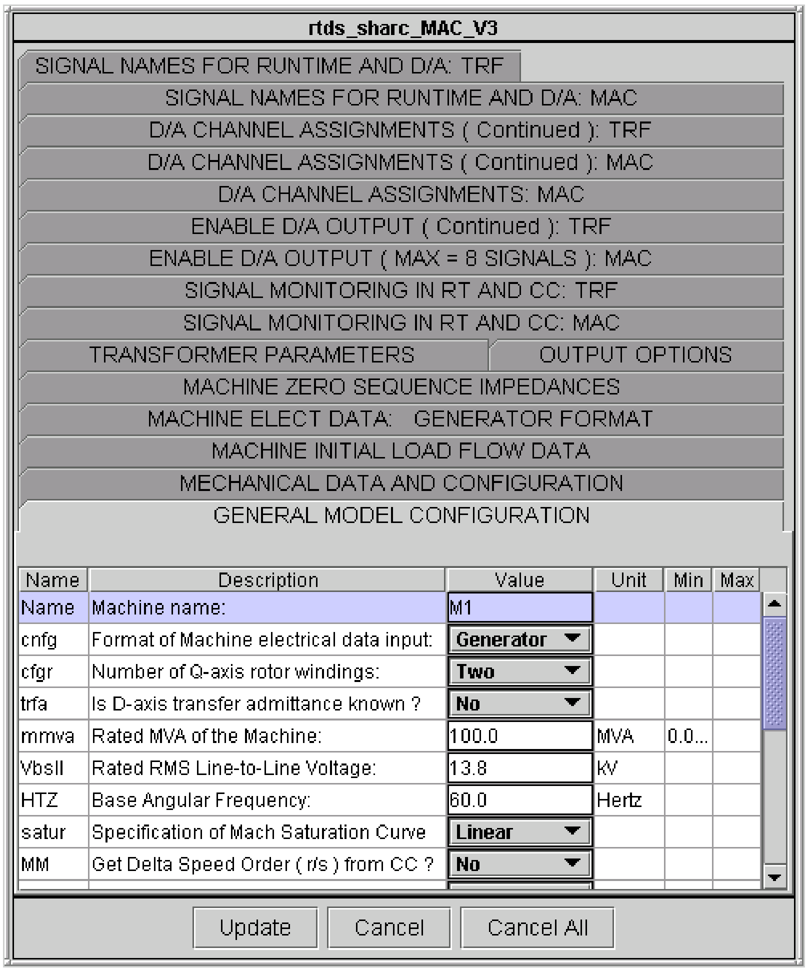
7. A new approach to initializing large networks has been facilitated by additions to the model. This approach will be discussed below.

8. New optional Controls Compiler inputs have been provided for temporarily: adding external inertia to the machine (EX_H in p.u.); adding external synchronous

damping (EX_D in p.u.); and providing a reference speed (EX_W in rad./sec.) for the external synchronous damping.

6.2.1 THE MENU TABS

Due to the large number of menu tabs for the Synchronous Machine Model, images of the its various menus throughout this chapter will not show all of the menu tabs. The partial GENERAL MODEL CONFIGURATION menu, and all of the tabs which are available by default appears below.

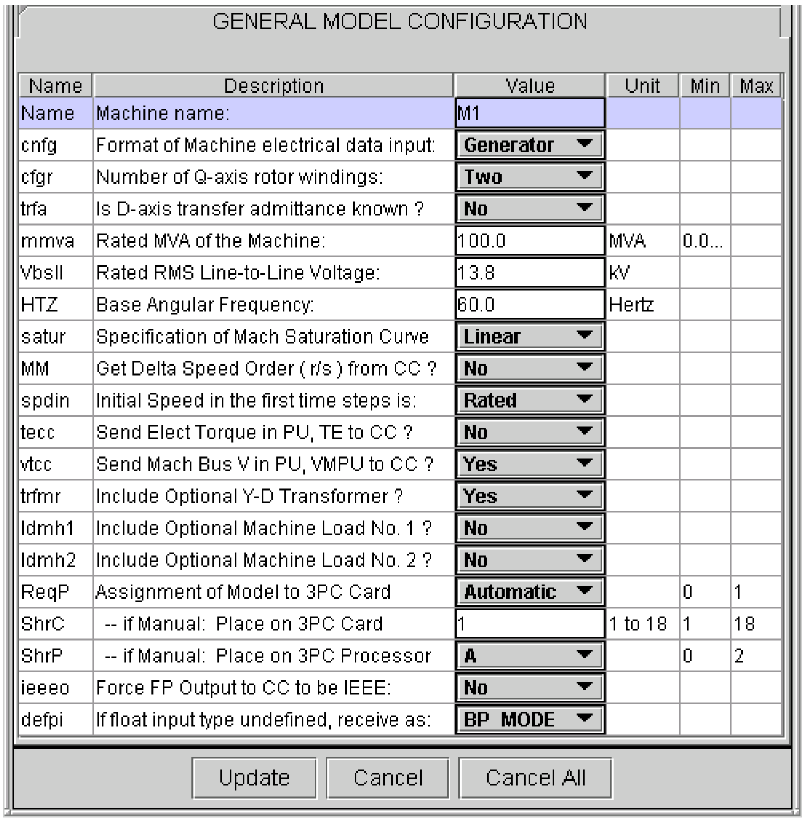


In the above menu, the “MACHINE ELECT DATA: GENERATOR FORMAT” menu tab may be replaced with the alternative “MACHINE ELECT DATA: R AND X FORMAT” menu tab depending on the selection made in the GENERAL MODEL CONFIGURATION menu.

In general, the lowest five (5) menu tabs (excluding “Output Options) relate to configuring the model and entering the machine and transformer data. The other menu tabs relate to providing output for monitoring or for use in the Controls Compiler (CC) and also to assigning output to the D/A channels on the front of the 3PC card.

6.2.2 THE GENERAL MODEL CONFIGURATION MENU

The GENERAL MODEL CONFIGURATION menu appears as follows:



GENERAL MODEL CONFIGURATION

Name	Description	Value	Unit	Min	Max
Name	Machine name:	M1			
cnfg	Format of Machine electrical data input:	Generator			
cfgr	Number of Q-axis rotor windings:	Two			
trfa	Is D-axis transfer admittance known ?	No			
mmva	Rated MVA of the Machine:	100.0	MVA	0.0...	
Vbsll	Rated RMS Line-to-Line Voltage:	13.8	kV		
HTZ	Base Angular Frequency:	60.0	Hertz		
satur	Specification of Mach Saturation Curve	Linear			
MM	Get Delta Speed Order (r/s) from CC ?	No			
spdin	Initial Speed in the first time steps is:	Rated			
tecc	Send Elect Torque in PU, TE to CC ?	No			
vtcc	Send Mach Bus V in PU, VMPU to CC ?	Yes			
trfmr	Include Optional Y-D Transformer ?	Yes			
ldmh1	Include Optional Machine Load No. 1 ?	No			
ldmh2	Include Optional Machine Load No. 2 ?	No			
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- if Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- if Manual: Place on 3PC Processor	A		0	2
ieeeo	Force FP Output to CC to be IEEE:	No			
defpi	If float input type undefined, receive as:	BP MODE			

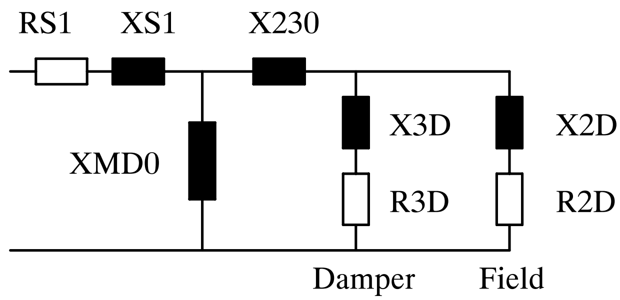
Update Cancel Cancel All

The “cnfg” entry in the GENERAL MODEL CONFIGURATION menu permits the the choice between entering the machine data in “Generator” format or alternatively in “R and X” format. “R and X” format is sometimes referred to as Motor format. In the “R and X” format case, the R AND X FORMAT menu tab replaces the GENERATOR FORMAT menu tab.

The “cfgr” option allows the choice between modelling one damper winding or two damper windings on the Q−axis of the rotor. If “One” is selected, then the unnecessary menu items will become grey in the GENERATOR FORMAT and R and X FORMAT menus. In the GENERATOR FORMAT menu Xq’ and Tqo’ will become grey. In the R and X FORMAT menus R3Q (2^{nd} Q−axis Damper Resistance) and X3Q (2^{nd} Q−axis Damper Leakage Reactance) will become grey. Very often, for Salient machines, there is only data available for modelling one Q−axis rotor winding.

The “trfa” option allows the optional modelling of a mutual flux linkage path which links the damper and field windings on the D−axis but which does not link the armature winding on the D−axis. Prompts for additional data in the GENERATOR

FORMAT menu will be given when this option is selected. The “trfa” menu item does not have any effect when using the R AND X FORMAT menu. In that case, enter X230 directly. When the required additional data is available, the representation of this extra flux linkage path can improve the modelling of the machine as seen from the field terminals. A paper [1] by Dr. I. M. Canay discusses the modelling of this additional flux linkage path. The representation of the D−axis with the additional mutual flux linkage path (X230) included is as shown in the following figure:



Discussion of the data required for the “trfa” option is included in section 16.6 which discusses the MACHINE ELECT DATA menu.

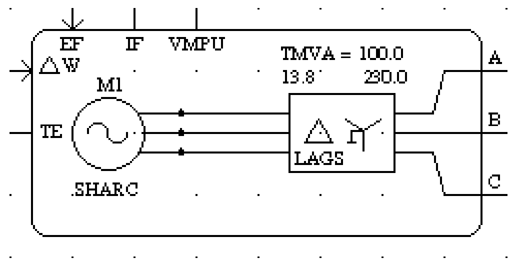
The Machine MVA is entered in response to the “mmva” menu item. Transformer MVA is specified in the TRANSFORMER PARAMETERS menu, independent of machine MVA.

The “Vbsll” menu item prompts for the rated root−mean−squared (RMS) line−to−line (L−L) voltage of the machine. Rated voltages for the optional transformer are specified independently in the TRANSFORMER PARAMETERS menu.

The “HTZ” menu item in the GENERAL MODEL CONFIGURATION menu prompts for the rated machine frequency in Hertz.

The “satur” menu item prompts for an indication of whether D−axis saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2).

The “MM” menu item prompts for an indication of whether the machine speed calculation is internal to the model or, alternatively, whether the speed is to be calculated externally and provided to the machine model through an optional CC input (ΔW). ΔW is speed deviation in units of radians / second with respect to rated speed. For example, when the machine is operating at rated speed, as specified by the HTZ item, then ΔW = 0.0 radians / second.



Choosing "Yes" in the "MM" menu item causes the MECHANICAL DATA AND CONFIGURATION menu tab to disappear. This corresponds with the fact that the machine speed is calculated external to the model when a "Yes" response is given for the "MM" item. Conversely, the CC input of mechanical torque TM per unit, and the CC output of machine speed W radians / second are also removed from the icon when a "Yes" response is given for the "MM" item.

In the case of a "No" response to the "MM" item, the reference direction for the mechanical torque CC input (TM) is positive torque when the machine is generating positive power into the electrical system. Also, in the case of a "No" response to the "MM" item, the CC output for machine speed (W) is in units of radians / second.

The "spdin" menu item prompts for information concerning the speed of the model in the first time−steps. The two choices are: "Zero" and "Rated". When initializing the machine according to a load flow it is important that the User select "Rated". When the response of "Zero" is given, then the MACHINE INITIAL LOAD FLOW DATA menu tab will disappear. In that case, all currents in the stator and the rotor of the machine will be initially set to 0.0 in addition to setting initial speed to 0.0.

The "tecc" item prompts for a request that Machine Electrical Torque in p.u. should be provided through an optional CC output point on the icon (TE), as shown on the above icon. This is required when the speed of the machine is calculated external to the model, such as when speed is calculated in an external multi−mass model (see item MM above). The TE output is in P.U. torque as determined by the machine MVA (item "mmva") and rated speed in radians / second (item "HTZ" in Hertz). The reference direction for TE is positive torque when the machine is generating positive power into the electrical system.

The "vtcc" item prompts for a request that the machine p.u. terminal voltage should be provided through an optional CC output point on the icon (VMPU). The VMPU output is calculated by taking the square root of the sum of the line−to−line voltages squared and then scaling to per unit. The per unit base comes from the item "Vbsll" noted above. The OUTPUT OPTIONS menu, described below, allows the User to specify that the VMPU signal should be passed through a first order lag filter before output.

The "trfmr" item prompts for a request that a generator unit transformer should be included in the model, as shown in the above icons. When the transformer is requested, then the transformer parameters are entered into the TRANSFORMER PARAMETERS menu.

The “ldmh1” item enables a request that a shunt connected bank of R, series RL or series RC loads on the terminals of the machine. When a bank is requested, the OPTIONAL LOADS ON MACHINE BUS menu tab will appear. Similarly, the “ldmh2” item can be used to enable a second load bank on the machine terminals.

The next 3 entries in the GENERAL MODEL CONFIGURATION menu (ReqP, ShrC and ShrP) allow the the specification either that the model will be automatically assigned to a processor (Automatic) or manually assigned (Manual) to a user specified processor. If automatic assignment of the model to a 3PC processor is requested using the ReqP item, then the subsequent two entries in the menu are ignored. If manual assignment of the model to a processor is requested, then a specific processor can be requested by indicating a 3PC card number (beginning with 1) and whether the model will be on processor A, B, or C on the card. A 3PC card number of 1 means the first 3PC card in a rack.

The final two items, “ieeeo” and “defpi”, force floating point numbers to be transmitted and received over the backplane in IEEE floating point format, when the numbers normally would be passed in NEC format.

Of course, when the simulation hardware contains only 3PC cards (that is, no TPC cards), then the IEEE floating point format is always used on the rack backplanes. In that case, the responses to the final two items are ignored by the compiler.

Conversely, when the simulation hardware contains at least one “mixed rack” of simulation hardware (that is, both TPC and 3PC cards), then the default format of floating point numbers passed on all of the the backplanes is the NEC floating point format rather than the IEEE format. However, regardless of the NEC default, the User may still wish to pass some numbers on IEEE format. The “ieeeo” and “defpi” items facilitate this possibility.

Always be very careful when choosing to pass floating point numbers in IEEE format in mixed racks and make certain that both the source and all destinations for the floating point number are set to use the IEEE format.

The final menu item in the GENERAL MODEL CONFIGURATION menu, labelled “defpi”, prompts for the specification of whether or not floating point numbers <u>received from the backplane</u> should be received in IEEE format when the default would be NEC.

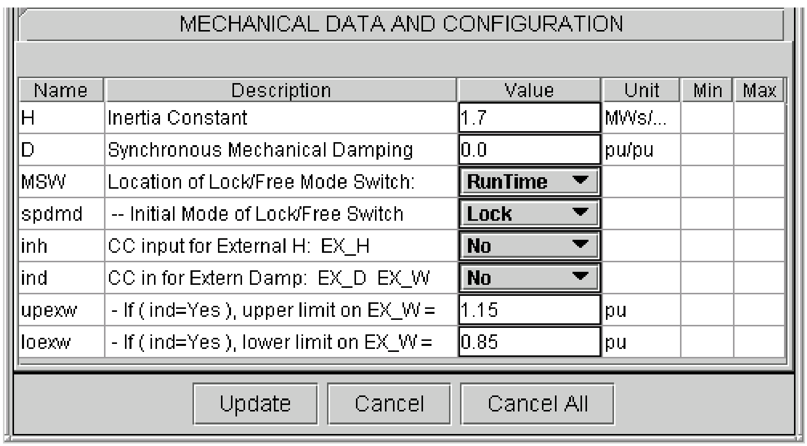
In general, the selection in the “ieeeo” item should be “No”. Similarly, the selection in the “defpi” item should usually be selected as “BP_MODE”. In that case the default floating point type, “NEC” or “IEEE” will be used depending on whether the simulation hardware is all 3PC cards.

It should be noted that the compiler will ignore the selection in the “defpi” item if the compiler can explicitly identify the type of a particular input and determine that the “defpi” selection is wrong. However, the compiler cannot always provide this back-up support. Be highly diligent when choosing to pass and receive floating point numbers in IEEE format in mixed racks.

6.2.3 THE MECHANICAL DATA AND CONFIGURATION MENU

This menu is needed when the model is configured to internally calculate the speed of the machine. This menu is only available if the “MM” item in the GENERAL MODEL CONFIGURATION menu has been set to “No”. Responding with a “Yes” to the “MM” item configures the model to receive a speed order from the CC.

Therefore, when the “MM” item is specified as “No” in the GENERAL MODEL CONFIGURATION menu, then the MECHANICAL DATA AND CONFIGURATION menu is made available for specifying the required mechanical data. The MECHANICAL DATA AND CONFIGURATION menu appears as follows:



The “H” menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speedper MVA of machine rating. The MVA rating of the machine is as entered in the GENERAL MODEL CONFIGURATION menu in response to the “mmva” item.

The “D” menu item prompts for a synchronous damping torque factor. The resulting damping torque tends to resist over−speed or under−speed operation. The damping torque factor “D” is in units of per−unit torque over per−unit speed deviation.

When the machine model is responsible for calculating the machine speed (MM = “No” in the GENERAL MODEL CONFIGURATION menu), then the machine can be run in locked speed mode or in free speed mode.

In locked speed mode, the speed of the machine is determined by a machine slider (CONSPD) in RunTime which has a default value of synchronous speed. It is usually not necessary to change the default value of the CONSPD slider. Therefore, it is usually not necessary to create or use the CONSPD slider.

In the free speed mode, the machine speed is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (TM), electrical torque (TE), and the damping torque.

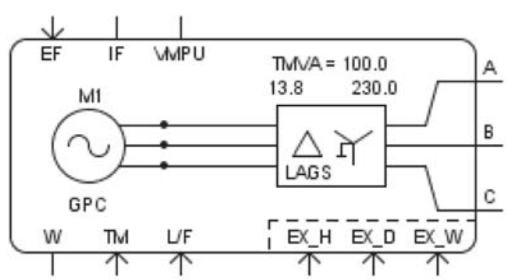
It is possible to switch from the locked speed mode (the usual start−up mode) to the free speed mode using a Lock/Free (L/F) input.

If the “Location of the Lock/Free Mode Switch” is specified as RunTime using the “MSW” item in the above menu, then a switch labelled “LockFree” will appear in the CREATE−>SWITCH menu in RunTime for the machine. This RunTime switch will have the initial value (Lock or Free) specified by the “spdmd” item in the above menu.

If the “Location of the Lock/Free Mode Switch” is specified as CC (Controls Compiler) using the “MSW” item in the above menu, then a CC integer input labelled “L/F” will appear on the lower edge of the icon. If an integer 0 is supplied to the L/F input, then the machine will run in locked speed mode. If an integer 1 is supplied to the L/F input, then the machine will run in free speed mode.

A simulation which is begun with a machine in “Lock” speed mode must be switched to “Free” speed mode to enable the proper modelling of mechanical dynamics.

The next two items in the MECHANICAL DATA AND CONFIGURATION menu, labelled “inh” and “ind”, enable the specification that there will be Controls Compiler inputs for external inertia H (EX_H) and an external damping factor (EX_D). The units of the signal to EX_H must be MWs/MVA on the machine MVA base. The units of the signal to EX_D must be pu torque / pu speed based on machine base speed and MVA. When an external damping factor CC input is enabled, then an additional CC input EX_W is provided on the icon to receive a speed input (EX_W). The units of the signal to EX_W must be radians / second. The EX_D and EX_W inputs cause an acceleration torque (in pu) which is equal to −EX_D times (ω −EX_W)/ ω_o where ω is the speed of the machine in radians per second and ω_o is the base speed of the machine in radians per second. Therefore, if EX_W is set equal to ω_o, then the external damping is synchronous damping.



Alternatively, the EX_W and EX_D inputs can be used to provide a simple load for a synchronous motor by creating a CC input for EX_W of 0.0 and controlling the EX_D input according to the load level desired.

The next two items in the MECHANICAL DATA AND CONFIGURATION menu, labelled “upexw” and “loexw”, enable specification of internal upper and lower limits to be placed upon the EX_W speed signal received from the CC input. The limits are specified in units of per unit speed. Of course, these two menu items are ignored if the EX_W input is not enabled.

6.2.4 THE MACHINE INITIAL LOAD FLOW DATA MENU

It is only possible to accurately initialize the machine model according to a load flow when the machine is to begin running at synchronous speed ("HTZ" in the GENERAL MODEL CONFIGURATION menu). Therefore, the MACHINE INITIAL LOAD FLOW menu tab will only appear when the initial speed (the "spdin" menu item in the GENERAL MODEL CONFIGURATION menu) is set to be "Rated". The MACHINE INITIAL LOAD FLOW menu appears as follows:

MACHINE INITIAL LOAD FLOW DATA

Name	Description	Value	Unit	Min	Max
Vmagn	Load Flow: Voltage Magn. at t=0-	1.0	p.u.	0.5	
Vangl	Load Flow: Voltage Phase A sine at t=0-	0.0	Degrees		
P0	Load Flow: Real P at t=0- (+ is Out)	0.0	MW		
Q0	Load Flow: React. P at t=0- (+ is Out)	0.0	MVAr		
rmpc	Start Up as Ramped Current Sources:	...			
rmptc	--- Time Constant for Ramping Up:	0.05	Sec	0.0005	0.4
iszro	Force initial stator currents to zero ?	...			
izro	Force all initial currents to zero ?	...			

Update | Cancel | Cancel All

When the response is a "Zero" to the "spdin" menu item, then the machine will begin at zero speed and all currents in the machine will also be initialized as zero.

Of course, it may not be possible to bring a large network to a stable operating condition unless the stable operating condition has been defined by a **correct load flow result**. It is clear that only certain operating conditions of a network are stable. If machines or lines are initially too heavily overloaded, then the network will immediately collapse and never reach a steady operating point.

The four menu items at the top of the above menu allow initial terminal conditions of the machine to be specified which are sufficient for initializing the machine. These initial terminal conditions are available from the output of the load flow program.

The angle "Vangl" defines the angle of the "A" phase terminal voltage sine wave in Degrees at time = 0. The effects of loading and saturation are included in the initialization calculations. The initialization feature calculates and initializes the initial stator and field currents and also the initial angular position of the rotor. The initialization also pre−calculates the mechanical torque and normalized field voltage which would be required to provide the desired real and reactive power (P0 and Q0) out of the machine for the specified machine terminal voltage (Vmagn). The calculated field voltage and torque are useful in initializing the exciter and governor models prior to the start of a simulation.

Menu Items: rmpc and rmptc

The “rmpc” menu item in the above menu prompts whether the machine should begin with zero output currents and then ramp to the pre−calculated initial output currents according to an exponential time constant. Alternatively, the machine can begin with the full calculated initial output currents in the first time−step.

If the load flow input specified in the first four menu items is accurate **for all machines** in the simulation, then it is usually better to choose “Yes” for the “rmpc” item **for all machines**, particularly when starting a case with many machines. If choosing to use the ramp feature, then the **same ramp exponential time constant “rmptc” for all machines and sources should be specified**.

If the load flow input is not accurate (or if there are significant differences between the load flow network and the network defined in DRAFT), then it is usually better to choose “No” for the “rmpc” item. If the case is very small, then it also may be acceptable to answer “No” to this item.

At this point, some explanation of the ramp start−up method is given to support the best answer for the “rmpc” item discussed above.

The initial direct (D) and quadrature (Q) axis voltages and currents for the stator are pre−calculated when calculating the initial currents for the machine model, as noted above. In steady operation, the D and Q axis currents and voltages are constant DC values.

When the selection is “No” in the “rmpc” menu item, then the model begins to produce and use D and Q axis stator voltages immediately in the first time−step based upon the ABC terminal voltages and the ABC to DQ0 transformation. The full initial stator currents flow to the network beginning in the first time−step based on the pre−calculated initial D and Q−axis currents. After the first time−step, the currents change depending on the stator voltages.

When the selection is “Yes” in the “rmpc” menu item, then the model initially uses the pre−calculated initial D and Q axis stator voltages without change for a period equal to 10 times the exponential ramp time constant “rmptc”. Therefore, during that period, the machine currents will NOT be affected by the fact that elements in the network (such as transmission lines) are in the process of being initialized. Also, during that period, the D and Q−axis currents used in calculating terminal current injections to the network are ramped from 0.0 to the pre−calculated initial values. Of course, after 10 time constants, the injections made by the machine model will be essentially according to the load flow. Consequently, if the network impedances defined in Draft are the same as those used in the load flow program, then the voltages on the terminals of the machine will have risen to the “Vmagn” and “Vangl” values entered in the menu. Of course, it is the responsibility of the User to assure that the impedances of the network defined in Draft are in fact the same as those used in the load flow program.

Beginning after the period of 10 time constants, described above, a transition is made to closed loop operation for the machine model. During the transition period the machine model changes from using the pre−calculated initial D and Q−axis voltages to using actual D and Q−axis voltages based upon the actual ABC terminal voltages and the ABC to DQ0 transformation. The transition is made using an exponential time constant equal to “rmptc”. If the load flow input is accurate, the transition is very smooth because the transition will actually occur between pre−calculated initial D and Q−axis voltages which are exactly equal to actual calculated D and Q−axis voltages. However, if there is some unbalance in the system, such as one produced by using non−transposed lines, then there will be some small adjustments as the model transitions to closed loop operation.

During the 10 time constant current ramp period described above, the CC output VMPU (in p.u.) for measured machine terminal voltage will be set equal to the specified “Vmagn” value. The machine model begins to provide actual machine terminal voltage through the CC output VMPU only after the current ramp period.

Also, the field voltage (normalized) provided to the CC input EF is not used during the current ramp period of 10 time constants. The input is replaced in the period by a constant pre−calculated field voltage as required by the load flow data. The machine model begins to use the EF input from the CC only after the end of the current ramp period.

The “rmpc” current ramping option may be used when the machine model is started either in “Lock” speed mode; in “Free” speed mode; or if the model is receiving an external speed order. “Lock” and “Free” speed mode are discussed in section 6.2.3 above.

If the machine is run in “Lock” speed mode during the current ramping period, then the machine is running in completely open−loop mode during the period. This includes the mechanical input, field voltage input and terminal voltage input interconnections. In this circumstance, if the CC output for electrically generated torque TE pu (air gap torque resisting mechanical torque) is enabled, then the TE output will be the constant p.u. value required by the load flow (plus some small additional torque to supply electrical losses in the stator of the machine). Only when the machine is switched to “Free” speed mode will the machine speed respond to mechanical torque input TM.

If the machine is run in “Free” speed mode during the current ramp period, then the machine will respond to mechanical torque TM input from the beginning. In this circumstance, the mechanical torque signal supplied to the TM input should be equal to the pre−calculated required initial mechanical torque according to the load flow.

The pre−calculated required initial mechanical torque and the pre−calculated required initial field voltage are both always written to the “case_name.map” file and to “Messages” by the machine data preparation function when a machine case is compiled in Draft. They are also passed to various exciter and governor models for initializing the exciter and governor models.

If the machine receives an externally generated speed deviation signal (such as from the Multi−mass model) through icon CC input ΔW (discussed above), then the machine will respond to that input immediately in all cases. During initialization it is usual that the speed deviation signal is 0.0 or close to it. This can be accomplished in the Multi−mass model by starting the multi−mass model in “Lock” speed model.

To reiterate, a simulation which is begun with a machine or Multi−mass in “Lock” speed mode must be switched to “Free” speed mode to enable the proper modelling of mechanical dynamics.

Menu Items: iszro and izro

Generally, select “No” when the “iszro” item prompts for whether or not the compiler should “force initial stator currents to zero”. This feature is carried over from very early versions of the machine model.

The “iszro” menu item allows all initial stator currents to be forced to zero. The initial mechanical angle of the rotor will continue to be initialized according to the load flow data. The main magnetizing current on the D and Q−axis is maintained when the feature is enabled. This is done by increasing the field current on the D−axis and the first damper winding current on the Q−axis when the stator currents are set to zero current. Enabling the feature establishes the correct main magnetizing flux at start−up with zero initial stator currents. Again this feature is rarely used.

The “izro” menu item can be used to start the machine with rotor or stator currents set to zero regardless of the load flow data. The initial mechanical rotor position, THETA, will continue to be initialized according to the load flow data.

THETA is the angle of the D−axis of the rotor with respect to the A−axis of the stator. THETA is positive when the D−axis of the rotor is ahead of the A−axis toward the B−axis of the stator.

The “izro” feature is sometimes used during testing of the machine model. For example, to confirm the open−circuit unsaturated transient time constant, T'_{do}, a field voltage is applied to an open−circuit machine model running at synchronous speed which has no current flowing in any winding. The terminal voltage of the machine then rises from zero according to the open−circuit unsaturated transient time constant, T'_{do}.

Additional Notes on Initialization

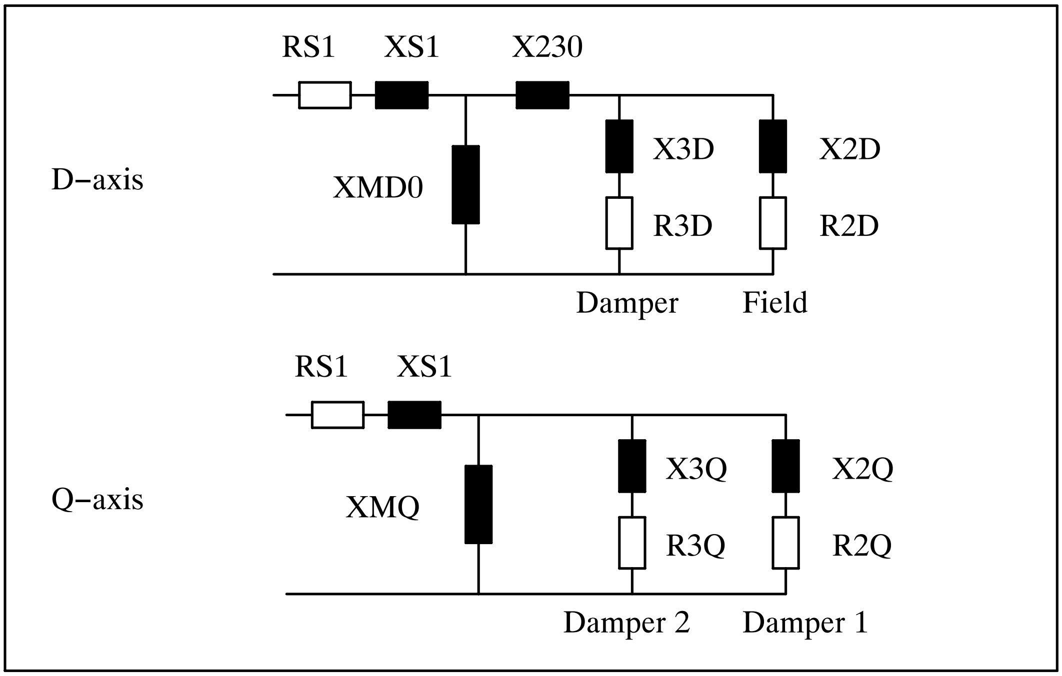
A machine which is started in “Lock” speed mode and a voltage source model can both be specified as having the same rated frequency in Draft. In that case, the machine and the voltage source model will operate for an extended period without change in their relative phase. However, the relative angular position of the rotor can be shifted with respect to the voltage source during initial “Lock” speed operation. This can be accomplished using an “A_shift” Slider which may be created in RunTime using the CREATE−>SLIDER pull−down menu for the machine. It is very rare that the “A_shift” slider will be used.

The load flow initialization feature, discussed above, presets the “A_shift” Slider with an angle (in Degrees) which is the sum of the angle specified for the machine terminal voltage A phase sine wave “Vangl” plus the initial generator load angle. Therefore, creation and adjustment of the “A_shift” Slider is usually unnecessary. However, the “A_shift” Slider can be used during “Lock” speed operation to modify the real power flow. In that regard, it is generally true that increasing the “A_shift” Slider angle during “Lock” speed operation causes more real power to flow out of the machine.

In the unusual event that the “A_shift” Slider is used in RunTime, then it should be removed and re−created in RunTime after new load flow information is compiled for a machine in Draft. Draft cannot override the setting of a Slider which already exists in RunTime.

6.2.5 THE MACHINE ELECT DATA MENUS

The machine electrical data parameters are used for determining the per unit resistances and reactances on the D and Q axes of the machine model. The resistances and reactances are as shown in the following figure. These resistances and reactances can be entered directly or converted from “Generator” type data.



The diagram for the Q–axis does not contain a X230 reactance entry. In addition, the R3Q and X3Q branches are eliminated from the Q–axis if the User has specified that the "Number of Q–axis rotor windings" will be "One" in the GENERAL MODEL CONFIGURATION menu.

There are two alternative menus for specifying the main machine electrical data parameters. If the default "Generator" is selected as the "Format of Machine electrical data" in the GENERAL MODEL CONFIGURATION menu, then the menu MACHINE ELECT DATA: GENERATOR FORMAT menu becomes available. Alternatively, the MACHINE ELECT DATA: R AND X FORMAT menu becomes available.

THE MACHINE ELECT DATA: GENERATOR FORMAT MENU

The MACHINE ELECT DATA: GENERATOR FORMAT menu appears as follows:

MACHINE ELECT DATA: GENERATOR FORMAT

Name	Description	Value	Unit	Min	Max
Xa	Stator Leakage Reactance	0.130	p.u.	0.01	
Xd	D-axis: Unsaturated Reactance	1.79	p.u.	0.1	
Xd'	D: Unsaturated Transient Reactance	0.169	p.u.	0.05	
Xd"	D: Unsaturated Sub-Trans. Reactance	0.135	p.u.	0.02	
Gfld	D: Real Component of Transfer Admit.	100.0	p.u.	0.0	100.0
Bfld	D: Imag Component of Transfer Admit.	100.0	p.u.	0.0	100.0
Xq	Q-axis Unsaturated Reactance	1.71	p.u.	0.1	
Xq'	Q: Unsaturated Transient Reactance	0.228	p.u.	0.05	1.0
Xq"	Q: Unsaturated Sub-Trans. Reactance	0.2	p.u.	0.02	
Ra	Stator Resistance	0.002	p.u.	0.00125	
Tdo'	D: Unsat. Transient Open T Const.	4.3	sec	0.001	
Tdo"	D: Unsat. Sub-Trans. Open T Const.	0.032	sec	0.001	
Tqo'	Q: Unsat. Transient Open T Const.	0.85	sec	0.001	3.0
Tqo"	Q: Unsat. Sub-Trans. Open T Const.	0.05	sec	0.001	

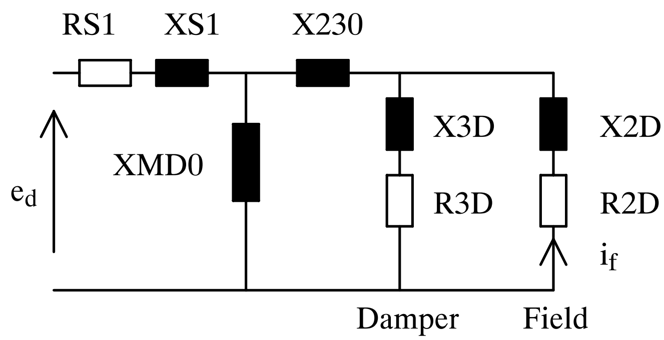
Update | Cancel | Cancel All

The reactances in the GENERATOR FORMAT menu are unsaturated reactances in per unit. The time constants contained in the menu are open−circuited unsaturated time constants in seconds.

The Xq’ and Tqo’ menu items will appear “greyed out” in this menu if the “Number of Q−axis rotor windings” is specified as “One” in the GENERAL MODEL CONFIGURATION menu.

Background for the Transfer Admittance Item: "trfa"

The "Gfld" and "Bfld" items will appear "greyed out" in this menu if in the GENERAL MODEL CONFIGURATION menu if it is specified that the D−axis transfer admittance is not known. The D−axis transfer admittance, when known, can be used to improve the modelling of the machine as seen from the field terminals as discussed in the reference [1]. For that purpose, a mutual flux linkage path X230 is included in the model when the transfer admittance is provided.



$$G_{fld} + J\,B_{fld} \;=\; \frac{-i_f\ (\text{p.u.})}{e_d\ (\text{p.u.})}$$

The D−axis transfer admittance ($G_{fld} + j\,B_{fld}$ p.u.) is the result of a test done on the D−axis to measure the transfer admittance between the armature winding and the field winding. The test is done with the rotor locked and with the field short circuited. The transfer admittance is as defined by the equation in the above figure. A fundamental−frequency voltage of reduced magnitude is applied to the stator windings so as to cause a reduced−magnitude fundamental−frequency D−axis armature voltage e_d and a zero q−axis armature voltage e_q. (Note: Reduction of stator voltages is required in order to limit currents during the test.) The resulting fundamental−frequency current i_f is measured in the field−winding with the normal reference direction shown in the above figure.

One method for producing a sinusoidal e_d with zero e_q would be to lock the D−axis in alignment with the A−axis; connect the terminals of the B and C phases together; and then apply a single−phase voltage to the two−port consisting of the A terminal and the combined BC terminal.

Practical use of the equation in the above figure requires some background on the per−unit system for e_d and i_f .

Deep within the machine model, the base voltage in the DQ armature system is equal to the base voltage in the ABC stator system namely the root−mean−squared(RMS) line−to−neutral voltage. This is obtained by dividing the rated machine line−to−line voltage by the square root of three. The transformation of p.u. voltages is then accomplished using the following transformation:

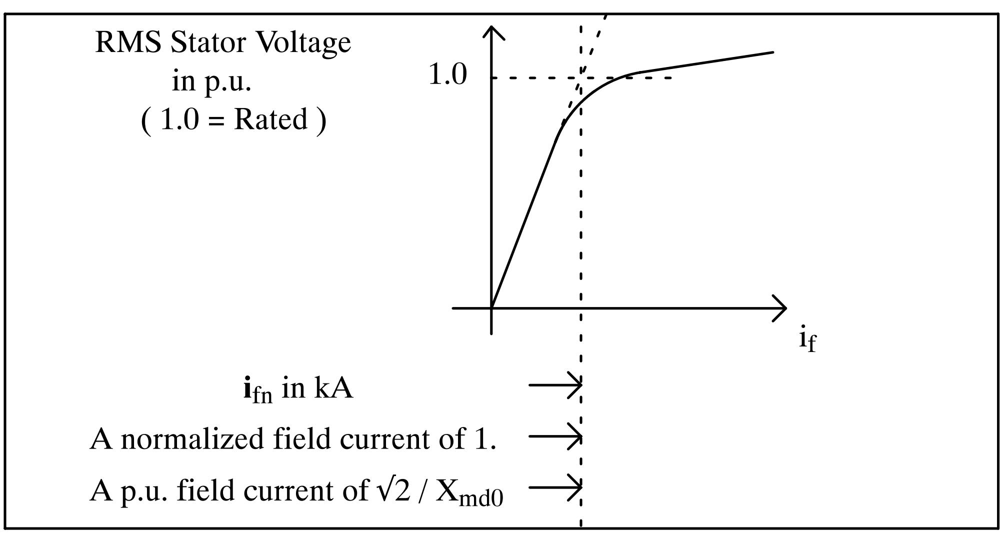
$$\begin{bmatrix} e_d \\ e_q \\ e_0 \end{bmatrix} = \begin{bmatrix} T_{dq0} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

where

$$\begin{bmatrix} T_{dq0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 120) & \cos(\theta - 240) \\ \sin\theta & \sin(\theta - 120) & \sin(\theta - 240) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

Balanced stator voltages Va, Vb and Vc at rated magnitudes are sinusoidal voltage waves having peak magnitudes equal to √2 per−unit (root 2). With the rotor locked, the corresponding transformed D−axis voltage e_d would also be a sinusoidal wave having a peak magnitude equal to √2 per−unit. This comparison is given only as an example to explain the per unit system.

The base value for the p.u. field current can be explained with reference to the following figure. The curve in the figure describes open−circuit stator voltage versus field current during synchronous speed operation.



The current $\mathbf{i}_{fn}$ (in kA) is that field current which would be required to cause rated

RMS stator voltage during the open−circuit test with no saturation. $\mathbf{i}_{fn}$ kA corresponds to a per−unit field current of $\sqrt{2} / X_{mdo}$ per−unit. Therefore, the base value for the field current is given by the following equation:

$$i_{fo} = \frac{\mathbf{i}_{fn}}{\dfrac{\sqrt{2}}{X_{md0}}} \quad kA$$

It is suggested to use the peak values of the sinusoidal waves of i_f and e_d expressed in per unit when evaluating the equation for the transfer admittance.

The MACHINE ELECT DATA: R AND X FORMAT Menu

The alternative R AND X FORMAT menu appears as follows:

MACHINE ELECT DATA: R AND X FORMAT

Name	Description	Value	Unit	Min	Max
XS1	Stator Leakage Reactance	0.13	p.u.		
XMD0	D-axis Unsaturated Magnet. React.	1.66	p.u.		
X230	D: Field-Damper Mutual Leak. React.	0.0	p.u.		
X2D	D: Field Leakage Reactance	0.0618	p.u.		
X3D	D: Damper Leakage Reactance	0.00546	p.u.		
XMQ	Q-axis Magnetizing Reactance	1.58	p.u.		
X2Q	1st Q-axis Damper Leakage React.	0.3293	p.u.		
X3Q	2nd Q-axis Damper Leakage React.	0.0942	p.u.	0.001	2.0
RS1	Stator Resistance	0.002	p.u.	0.00125	
R2D	Field Resistance	0.001407	p.u.		
R3D	Direct-Axis Damper Resistance	0.00407	p.u.		
R2Q	1st Q-axis Damper Resistance	0.01415	p.u.		
R3Q	2nd Q-axis Damper Resistance	0.0082	p.u.	0.001	2.0

Update | Cancel | Cancel All

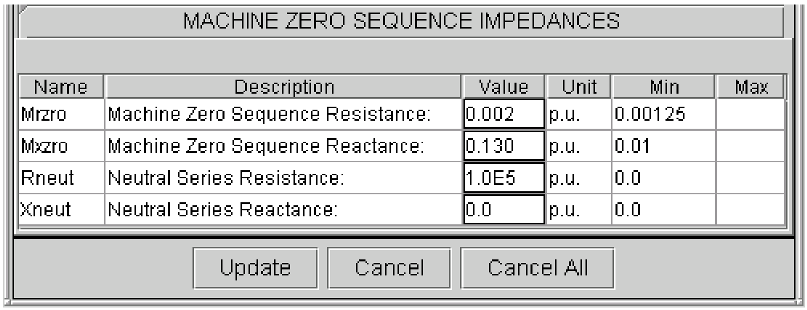
The R3Q and X3Q menu items will appear “greyed out” in this menu if the “Number of Q−axis rotor windings” is specified as “One” in the GENERAL MODEL CONFIGURATION menu.

If the X230 reactance is not to be used in the D−axis of the User’s model, then enter 0.0 for the X230 parameter.

The D−axis and Q−axis quantities in the R AND X FORMAT menu correspond to p.u. resistances and reactances in the above figure.

6.2.6 THE MACHINE ZERO SEQUENCE IMPEDANCES MENU

The MACHINE ZERO SEQUENCE IMPEDANCES menu appears as follows:


MACHINE ZERO SEQUENCE IMPEDANCES

Name	Description	Value	Unit	Min	Max
Mrzro	Machine Zero Sequence Resistance:	0.002	p.u.	0.00125	
Mxzro	Machine Zero Sequence Reactance:	0.130	p.u.	0.01	
Rneut	Neutral Series Resistance:	1.0E5	p.u.	0.0	
Xneut	Neutral Series Reactance:	0.0	p.u.	0.0	

The first two entries in the above menu specify the per unit zero sequence impedance of the machine. The final two entries in the above menu specify the per unit impedance of the neutral reactor. The zero sequence path of the machine is in series with the zero sequence path of the neutral reactor.

The zero sequence current from all three phases of the machine must flow through the neutral reactor. Therefore, the neutral reactor impedance has three times the weight in determining the total zero sequence impedance as compared to the machine zero sequence impedance specified in the first two items. If there is no neutral connection, then it is necessary to specify “Rneut” as being large as illustrated in the above menu.

The neutral current and the neutral point voltage cab be monitored in RunTime; in the Controls Compiler; or through D/A output on the front of the 3PC card. For interfacing to external equipment for purposes more than monitoring, it is recommended that FDAC or DDAC optically isolated D/A cards be used.

6.2.7 THE MACHINE SATURATION CURVE MENUS

The GENERAL MODEL CONFIGURATION menu contains an item labelled “satur” which allows the method of specifying machine D−axis saturation to be chosen. The choices are “Linear”, “Points”, and “Factors. If “Linear” is chosen, then the D−axis will not saturate. The other two choices are explained below.

The MACHINE SATURATION CURVE BY POINTS MENU

This method requires a saturation curve for the D−axis of the machine to be entered using points on the curve. The required curve can be obtained during synchronous−speed open−circuit operation by varying the field current and monitoring the stator voltage. The curve is a plot of stator voltage in per−unit versus magnetizing current specified in units of the User’s choice. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point allows it to provide scaling information for magnetizing currents entered in the menu. If fewer than 10 points are known for the curve, then enter −1.0 for the currents following the known points. An unsaturated machine can be represented by entering a straight line in the menu.

The MACHINE SATURATION CURVE BY FACTORS MENU

The required saturation curve is the curve which can be obtained during synchronous−speed open−circuit operation by varying the field current and monitoring the stator voltage.

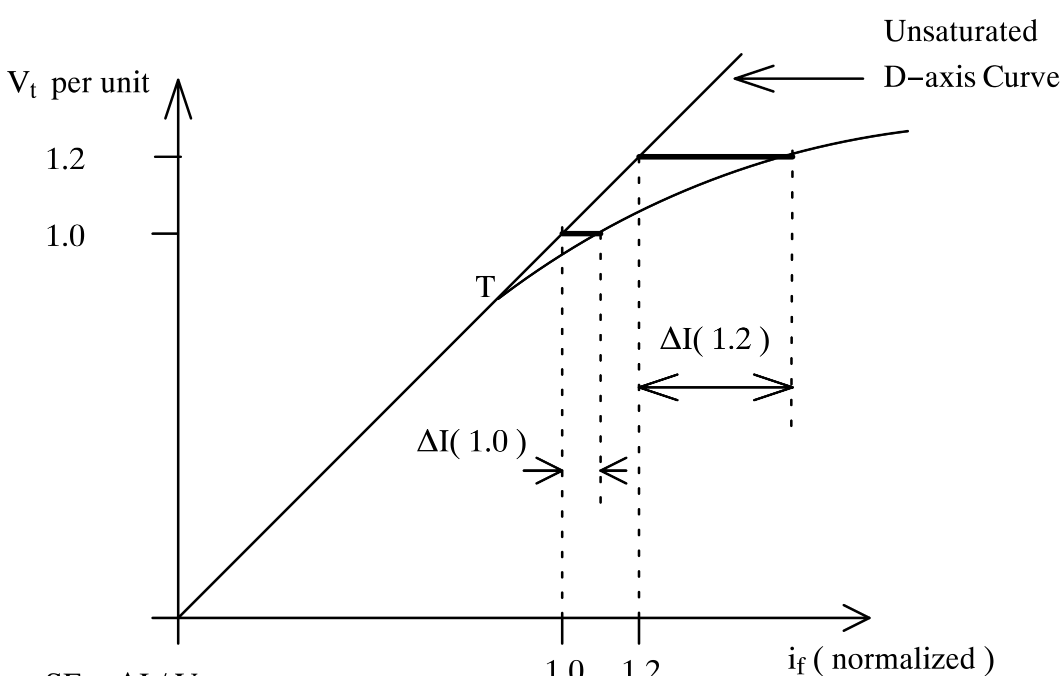
The MACHINE SATURATION CURVE BY POINTS menu appears as follows:

MACHINE SATURATION CURVE BY FACTORS

Name	Description	Value	Unit	Min	Max
SE10	Sat. Factor at 1.0 pu open-circuit V	0.0609		0.01	
SE12	Sat. Factor at 1.2 pu open-circuit V	0.1292		0.02	

Update | Cancel | Cancel All

The two factors to be specified in the above menu are defined in the following figure.



$SE = \Delta I / V_t$

$SE(1.0) = \Delta I(1.0) / 1.0$

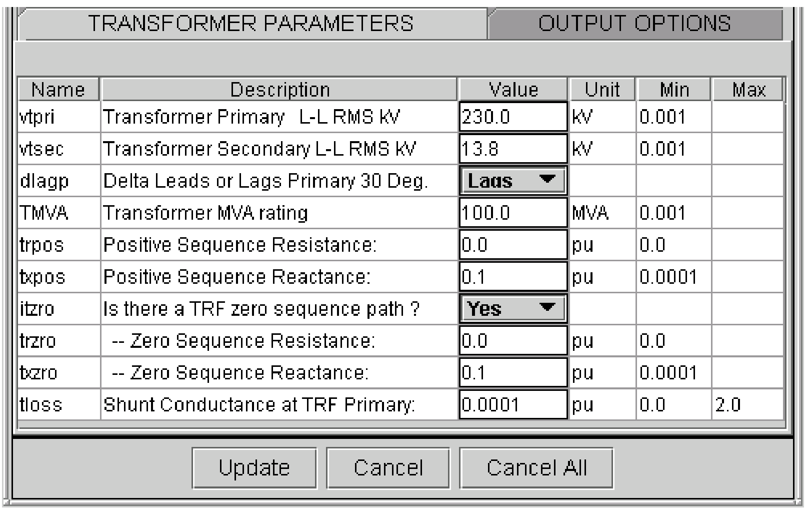
$SE(1.2) = \Delta I(1.2) / 1.2$

The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.

6.2.8 THE TRANSFORMER PARAMETERS MENU

The GENERAL MODEL CONFIGURATION contains an item “trfmr” which enables an optional Y−Δ generator transformer. When the request is made, the TRANSFORMER PARAMETERS menu is made available.

The TRANSFORMER PARAMETERS menu appears as follows:



TRANSFORMER PARAMETERS | OUTPUT OPTIONS

Name	Description	Value	Unit	Min	Max
vtpri	Transformer Primary L-L RMS kV	230.0	kV	0.001	
vtsec	Transformer Secondary L-L RMS kV	13.8	kV	0.001	
dlagp	Delta Leads or Lags Primary 30 Deg.	Lags			
TMVA	Transformer MVA rating	100.0	MVA	0.001	
trpos	Positive Sequence Resistance:	0.0	pu	0.0	
txpos	Positive Sequence Reactance:	0.1	pu	0.0001	
itzro	Is there a TRF zero sequence path ?	Yes			
trzro	-- Zero Sequence Resistance:	0.0	pu	0.0	
txzro	-- Zero Sequence Reactance:	0.1	pu	0.0001	
tloss	Shunt Conductance at TRF Primary:	0.0001	pu	0.0	2.0

Update | Cancel | Cancel All

When enabled, the transformer appears as shown above. The icon also displays the main ratings of the transformer and whether the Delta−side voltage lags the primary or leads the primary by 30 Degrees. Also, if the transformer is grounded on the Y side, then a ground symbol is shown.

The last entry in the menu allows the connection of an optional shunt conductance at the primary side terminals of the machine.

6.2.9 THE OPTIONAL LOADS ON MACHINE BUS MENU

The “ldmh1” item of the GENERAL MODEL CONFIGURATION menu enables a shunt connected bank of R, series RL or series RC load on the terminals of the machine. When a bank is requested, then the OPTIONAL LOADS ON MACHINE BUS menu tab will appear. Similarly, the “ldmh2” item can be used to enable a second load bank on the machine terminals.

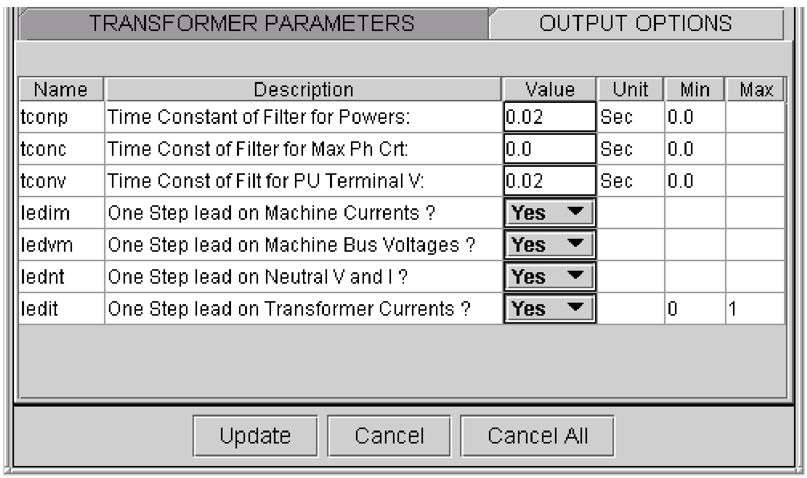
The OPTIONAL LOADS ON MACHINE BUS menu can be used to enter any reasonable loads on the machine bus.

6.2.10 THE OUTPUT OPTIONS MENU

There are about 25 different quantities that can be monitored in the machine model, either in RunTime or through D/A output. The selections of the quantities to be monitored can be made using the menus described in subsequent sections.

The OUTPUT OPTIONS menu provides some optional conditioning of certain selected signals.

The OUTPUT OPTIONS menu appears as follows:



Name	Description	Value	Unit	Min	Max
tconp	Time Constant of Filter for Powers:	0.02	Sec	0.0	
tconc	Time Const of Filter for Max Ph Crt:	0.0	Sec	0.0	
tconv	Time Const of Filt for PU Terminal V:	0.02	Sec	0.0	
ledim	One Step lead on Machine Currents ?	Yes			
ledvm	One Step lead on Machine Bus Voltages ?	Yes			
lednt	One Step lead on Neutral V and I ?	Yes			
ledit	One Step lead on Transformer Currents ?	Yes		0	1

The first menu item (“tconp”) specifies the time constant that the first order low pass filter will use on the signals for real and reactive power going out of the generator and transformer.

The second menu item (“tconc”) specifies the time constant that the first order low pass filter will use on the signal for maximum instantaneous phase current flowing out of the machine.

The next menu item (“tconv”) specifies the time constant that the first order low pass filter will use on the signal VMPU for the per unit terminal voltage of the machine.

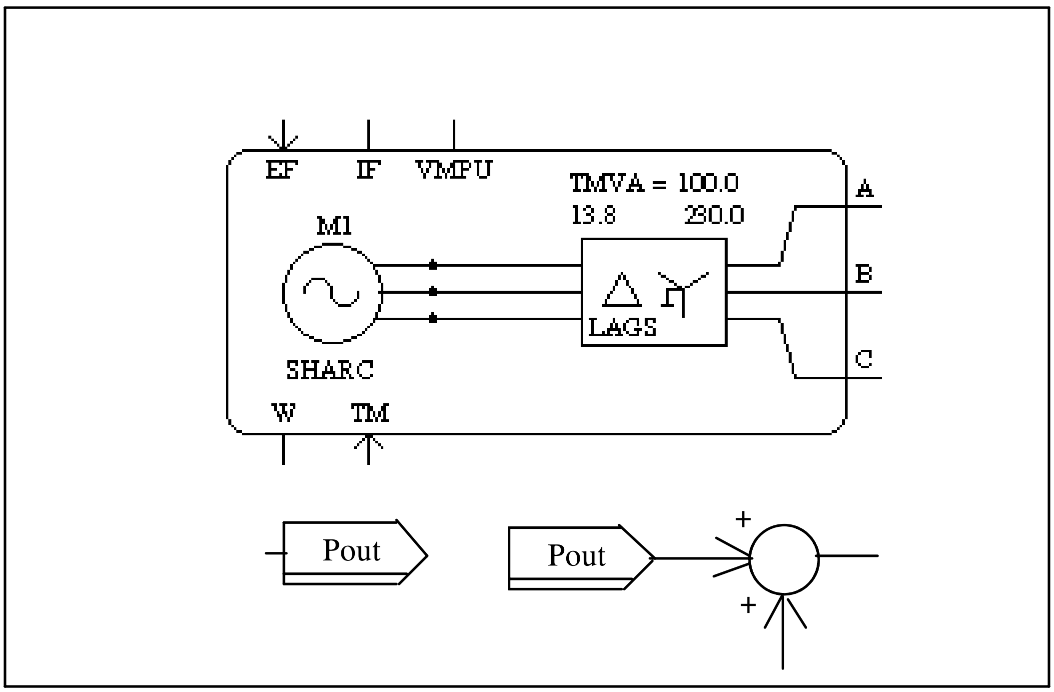
The model also allows machine terminal currents, machine terminal voltages (when the transformer is enabled), machine neutral point voltage and current, and the transformer currents (when the transformer is enabled) to be monitored. The above signals can only be calculated after the end of the time−step when new voltages become available for the network bus. The above quantities would normally lag one time−step behind the bus voltages when monitored in RunTime or viewed on D/A channels. Therefore, an optional feature has been provided which projects the delayed signals by one time−step to bring them back into time alignment with the network bus voltage.

6.2.11 SIGNAL MONITORING IN RT AND CC: MAC MENU

The number of different signals which can be monitored in this machine model has been increased significantly compared to previous machine models. Also, some signals may be monitored through CC output connection points on the icon as shown in above icons.

In particular, the machine terminal voltage (pu), machine speed (rad/sec) and machine electrical torque (pu) through CC output connections can all be accessed. Machine speed “W” is in radians/second corresponding to a 2 pole machine. However, machines of any pole count may be modelled.

Other quantities listed in this menu may be monitored by choosing “Yes” for the desired signal and then using the SIGNAL NAMES FOR RUNTIME AND D/A: MAC menu to provide a name for the signal. Having enabled and named the signal (“Pout” for example), the signal is available for monitoring in RunTime. A named signal can be passed to a control block in the CC as shown in the following figure using CC Import and Export icons (or a combined Import/Export symbol).



In total, there are presently 17 signals which can be accessed through this menu and the NAMES FOR RUNTIME AND D/A: MAC menu. Most signals such as the P and Q out of the machine in MWs and MVARs need no explanation. However, some details will be provided concerning certain signals.

The “Max Mach. Phase Crt kA” is the maximum of the three phase currents in the direction of out of the machine. This means the most positive of the three output terminal currents at any instant is provided as the signal.

The Load Angle δ for the machine is given by:

$$\delta = \tan^{-1}\left[\frac{E_d}{-E_q}\right]$$

The negative sign in the above equation for δ occurs because the Q−axis of the rotor lags the D−axis of the rotor by 90 degrees in this model. In some other models, the Q−axis leads the D−axis and the negative sign is omitted. Because of the opposite orientation, E_q is equal to $-\sqrt{2}$ during open−circuit operation at rated frequency and rated stator voltage. As the generator is loaded, E_d changes from a zero value to a positive value.

In order to compare the EQ and IQ signals from this model with the EQ and IQ signals from another model, it may be necessary to change the sign of the signals depending on the position of the Q−axis with respect to the D−axis in the other model.

The rotor mechanical angle is the instantaneous angle in radians that the D−axis is ahead of the A−axis toward the B−axis of the stator. As the machine turns this signal repeatedly increases from 0.0 to 2π radians and then resets to 0.0 radians. The reset occurs as the D−axis passes alignment with the A−axis.

The machine Neutral Current is equal to three times the machine zero sequence current because the neutral carries the zero sequence current of all three stator windings.

When the transformer option is enabled, the voltages of the A, B and C nodes between the machine and the transformer may be monitored.

6.2.12 SIGNAL MONITORING IN RT AND CC: TRF MENU

This menu is similar to the SIGNAL MONITORING IN RT AND CC: MAC menu, except that it contains signals exclusively for the transformer model. Consequently, this menu is not available unless the transformer option has been enabled.

The menu allows monitoring for real and reactive power out of the transformer into the network to be enabled. It also enables the monitoring of primary currents flowing out of the transformer into the network.

Names are given to the transformer signals using the SIGNAL NAMES FOR RUNTIME AND D/A: TRF menu.

6.2.13 THE ENABLE D/A OUTPUT MENUS

A maximum of 8 output signals may be requested to be sent to D/A channels on the front of the 3PC card from the machine and transformer ENABLE D/A menus. These output signals are suitable for monitoring, however, for higher quality of output of D/A signals the optically isolated FDAC or DDAC cards should be used.

6.2.14 THE D/A CHANNEL ASSIGNMENTS MENUS

These menus enable each of the enabled D/A output signals to be directed to a specified output channel number (1 to 8) on the front of the 3PC card with specified scaling. ERROR messages will be given if an attempt is made to send more than one signal to the same D/A output channel.

D/A scaling for a given RTDS internal signal is determined by the value of the internal signal that corresponds to 5 volts D/A output. This value should be entered into the D/A CHANNEL ASSIGNMENTS menu in order to scale the signal.

If D/A output of a signal is enabled, then the signal must be named using the SIGNAL NAMES FOR RUNTIME AND D/A menus. Naming the signal is required because two Sliders and a Switch are available in RunTime for each D/A output signal according to the name given to the D/A output.

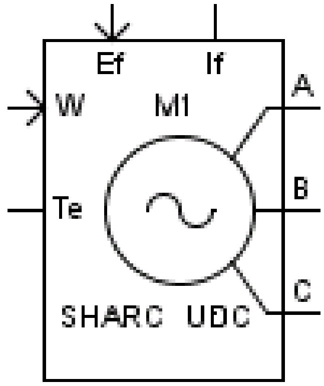
For example, each D/A output signal has a D/A unity scaler for optionally applying a multiplying factor to the D/A output signal. The default slider value is 1.0 (hence the name “unity scaler”). There is also an Offset slider for adding a certain voltage to the D/A output signal. These sliders are dynamically adjustable during a simulation.

The unity scaler slider can be created by following the RunTime pull−down menu: CREATE −> SLIDER −> Subsystem # −> 3PC D/A −> Scale:Name. The offset slider can be created by following the pull−down menu: CREATE −> SLIDER −> Subsystem # −> 3PC D/A −> Offset:Name.

There is also a SWITCH available in RunTime for each D/A output signal (CREATE −> SWITCH −> Subsystem # −> 3PC D/A −> LED:Name) for lighting an LED above the D/A output connection point on the front of the 3PC card. The User can temporary switch on this LED in order to confirm the proper connection point for the D/A output signal.

6.3 SYNCHRONOUS MACHINE MODEL (RTDS_SHARC_MACM2)

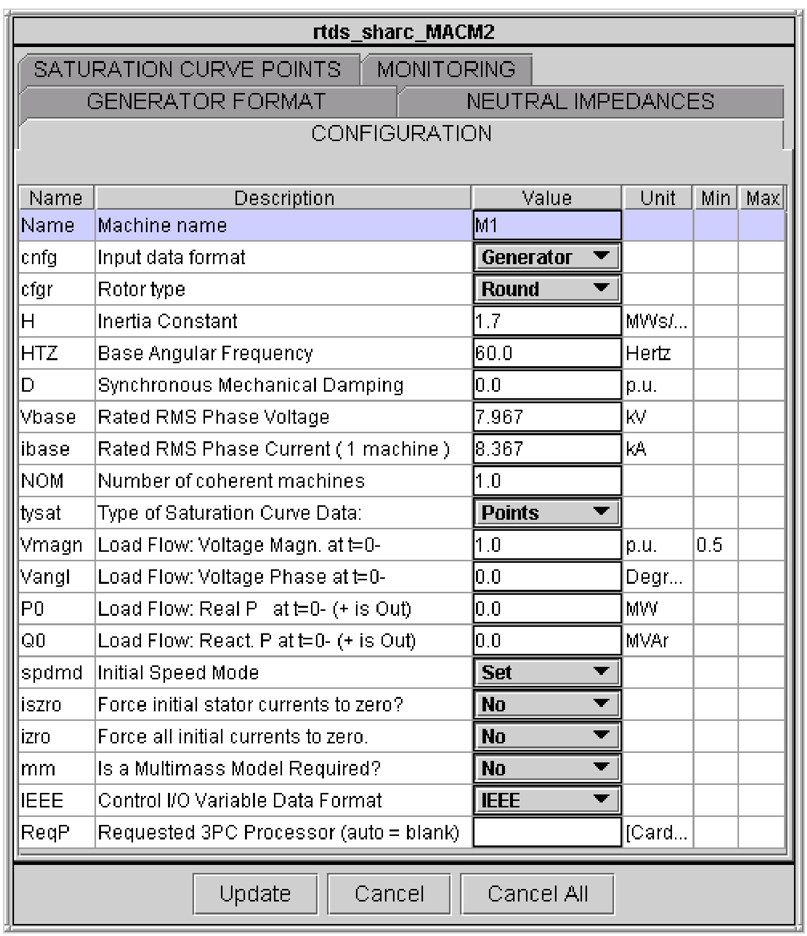
A synchronous machine model based on generalized machine theory may be connected to the user defined power system network in RSCAD / Draft. Exciter (AVR), stabilizer, speed governor, turbine and multi−mass models may be interfaced to the synchronous machine model. The machine model may be configured as either a salient pole or round rotor machine. This model also incorporates several new features; voltage projection, extra points in the field flux saturation curve and field voltage saturation factors.



Ef: Field Voltage (p.u.)
W: Machine speed (rad/sec)
Te: Electrical Torque (p.u.)
A/B/C: Bus Connection Terminals

The CONFIGURATION menu permits the choice between entering the machine data in generator format or in motor format. In the latter case, the GENERATOR FORMAT menu tab is replaced with a MOTOR FORMAT menu tab.

The CONFIGURATION Menu appears as follows:


rtds_sharc_MACM2

SATURATION CURVE POINTS | MONITORING | GENERATOR FORMAT | NEUTRAL IMPEDANCES | CONFIGURATION

Name	Description	Value	Unit	Min	Max
Name	Machine name	M1			
cnfg	Input data format	Generator			
cfgr	Rotor type	Round			
H	Inertia Constant	1.7	MWs/...		
HTZ	Base Angular Frequency	60.0	Hertz		
D	Synchronous Mechanical Damping	0.0	p.u.		
Vbase	Rated RMS Phase Voltage	7.967	kV		
ibase	Rated RMS Phase Current (1 machine)	8.367	kA		
NOM	Number of coherent machines	1.0			
tysat	Type of Saturation Curve Data:	Points			
Vmagn	Load Flow: Voltage Magn. at t=0-	1.0	p.u.	0.5	
Vangl	Load Flow: Voltage Phase at t=0-	0.0	Degr...		
P0	Load Flow: Real P at t=0- (+ is Out)	0.0	MW		
Q0	Load Flow: React. P at t=0- (+ is Out)	0.0	MVAr		
spdmd	Initial Speed Mode	Set			
iszro	Force initial stator currents to zero?	No			
izro	Force all initial currents to zero.	No			
mm	Is a Multimass Model Required?	No			
IEEE	Control I/O Variable Data Format	IEEE			
ReqP	Requested 3PC Processor (auto = blank)		[Card...		

Update | Cancel | Cancel All

The “Cfgr” menu item allows the choice between modelling one damper winding

(Salient) or two damper windings (Round) on the Q−axis of the rotor. If “Salient” is selected then unnecessary data entries will become “greyed out” in the GENERATOR FORMAT and MOTOR FORMAT menus.

The “H” item prompts for the inertia of the machine. H (MW−Sec / MVA) is the rotational energy (MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating. The MVA rating of the machine is (3)(Vbase)(NOM)(ibase) as entered in the CONFIGURATION menu.

The “HTZ” item prompts for the rated machine frequency in Hertz.

The “D” item prompts for a synchronous damping torque factor. The resulting damping torque tends to resist over−speed or under−speed operation. The damping torque factor “D” is in units of per−unit torque over per−unit speed deviation. The response to the “D” item is not used if the multi−mass model is used with the machine. In that case, the multi−mass model determines all mechanical dynamics.

The “Vbase” item prompts for the rated root−mean−squared(RMS) line−to−neutral (L−N) voltage of the machine.

The base current of the model is the product of (NOM)(ibase) as entered in the CONFIGURATION menu.

The remaining items in the CONFIGURATION menu relate to the initialization of the machine model. The initialization feature allows the machine to be initialized at synchronous speed (“HTZ” Hertz) according to:

terminal voltage magnitude	“Vmagn”	p.u.;
terminal voltage phase	“Vangl”	degrees;
real power out of the model	“P0”	MW; and
reactive power out of the model	“Q0”	MVAR.

The angle “Vangl” defines the angle of the “A” phase voltage sine wave at time = 0. The effects of loading and saturation are included in the calculations. The initialization feature presets the initial stator and field currents and also the initial angular position of the rotor. The initialization also pre−calculates the mechanical torque and field voltage which would be required to provide the desired real and reactive power out of the machine for the specified machine terminal voltage. The calculated field voltage and torque are useful in initializing the exciter and governor models prior to the start of a simulation.

The “Initial Speed Mode” of the machine must be selected as “Free” or “Set”. If “Set”, then the machine will initially run at the rated speed (such as 50 or 60 Hz) as specified by the “HTZ” item. If “Free” then the machine speed will vary from the start of the simulation based on the difference between mechanical torque and air−gap electrical torque. A simulation which is begun with a machine in “Set” speed mode must be switched to “Free” mode to enable the proper modelling of mechanical dynamics. This can be accomplished during a simulation by creating a “mode” Switch (Lock / Free) for the machine in Run−time.

A machine which is started in “Set” speed mode and a voltage source model can both be specified as having the same rated frequency in Draft. In that case, the machine and the voltage source model will operate for an extended period without change in their relative phase. However, the relative angular position of the rotor can be shifted with respect to the voltage source during the initial “Set” speed operation. This can be accomplished using an “A_shift” Slider which is available for the machine in RunTime. The initialization feature discussed above presets the “A_shift” Slider with the sum of the angle specified for the machine terminal voltage “Vangl” plus the initial generator load angle. Therefore, adjustment of the “A_shift” Slider is often unnecessary. However, the “A_shift” Slider can be fine−tuned during “Set” speed operations in order to more exactly match the desired real power flow. In that regard, it is generally true that increasing the “A_shift” Slider angle during “Set” speed operation causes more real power to flow out of the machine.

The “A_shift” Slider should be removed and re−created in RunTime after new load flow information is compiled for a machine in Draft. Draft cannot override the setting of a Slider which already exists in RunTime.

It was noted above that the initialization feature calculates the field voltage “Efd” and the mechanical torque “Tm” required for the specified load flow conditions. If no exciter model is used then the field voltage is directly controlled by a “Efd” Slider which is available in RunTime and which is preset to the calculated field voltage. Likewise, if no governor model is used then the applied mechanical torque is controlled by a Slider “Tm” which is available in RunTime and which is preset to the calculated mechanical torque. During “Set” speed operation either the “Efd” Slider or the exciter set point can be adjusted to control the reactive power flowing out of the machine. Efd is a normalized quantity so that Efd = 1.0 corresponds to the field voltage required to produce 1.0 p.u. stator voltage on a synchronous machine when it is running at rated speed with no saturation and no load.

The machine model allows real and reactive power to be monitored out of the machine in RunTime. This feature is useful in establishing the desired load flow. There is no filtering on the output of these measurements and consequently some noise can be expected in the measured values. This optional output can be requested in the MONITORING menu.

The magnitude and relative phase of each voltage source are also controllable in RunTime. This adjustability can be used for initializing the system with machines in “Set” speed mode when a recommended load flow solution is unavailable. In that case, the procedure is to specify the source voltages and machine terminal voltages initially to be equal in magnitude and phase having regard to transformer connections. The machine “A_shift” sliders and voltage source angles to control the real power flow may then iteratively adjusted while adjusting field voltage and voltage source magnitudes to control the reactive power flow.

The air−gap electrical torque “Te” may be monitored in RunTime during a simulation. Prior to switching from “Set” speed mode to “Free” mode there should be a reasonable agreement between the mechanical torque “Tm” which is applied to the machine and the air−gap electrical torque “Te” which can be monitored in RunTime. If no governor is used then the match can be achieved by directly adjusting the mechanical torque Slider “Tm” in RunTime. Alternatively, if a governor is used then the match between “Tm” and “Te” may be achieved by adjusting the governor set−point in RunTime.

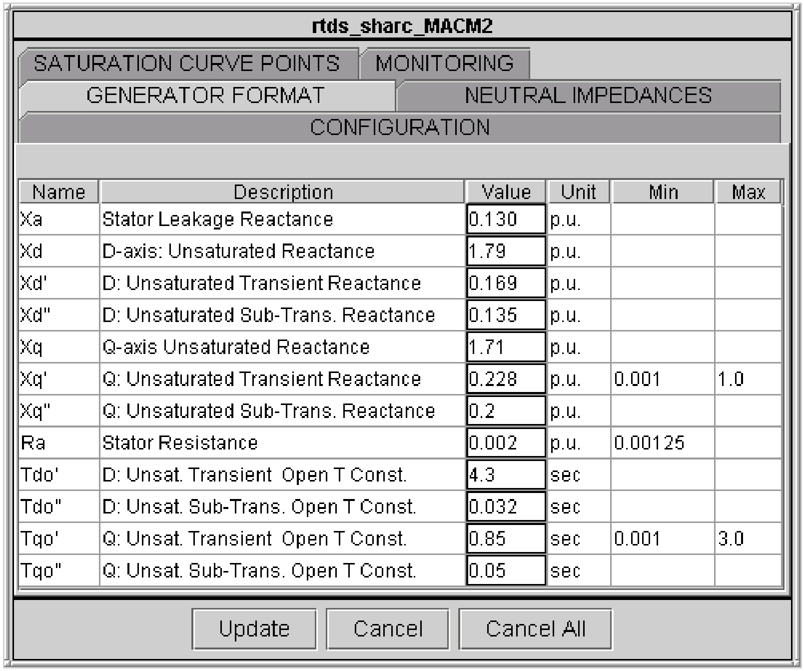
There is a rarely−used feature which allows control of the speed of the machine from RunTime during “Set” speed operations. This can be accomplished by creating an “f_set” Slider in RunTime for the machine and then using it to specify a speed other than the default setting of rated speed. Changing the speed of the machine from the rated speed during the “Set” speed operation will corrupt the ability to adjust the machine relative angle using the “A_shift” Slider.

The prompt “iszro” in the CONFIGURATION menu also presents a rarely used option. This option allows all Stator currents to be forced to be equal to zero while maintaining the correct initial D−axis and Q−axis main mutual fluxes. This is accomplished by initially setting the D−axis and Q−axis stator currents to zero and by adjusting the D−axis and Q−axis damper−winding currents to compensate.

The “izro” menu item in the CONFIGURATION menu allows all initial machine currents to be forced to be equal to zero. In that case the machine rotor angle remains initialized according to the “Load Flow” information: “Vmagn,Vangl, P0, and Q0”. This feature can be used in conducting open circuit tests on the machine. The response to the “izro” item over−rides any response to the “iszro” item.

6.3.1 THE GENERATOR FORMAT MENU

The machine model GENERATOR FORMAT menu appears as follows:



rtds_sharc_MACM2

SATURATION CURVE POINTS | MONITORING

GENERATOR FORMAT | NEUTRAL IMPEDANCES

CONFIGURATION

Name	Description	Value	Unit	Min	Max
Xa	Stator Leakage Reactance	0.130	p.u.		
Xd	D-axis: Unsaturated Reactance	1.79	p.u.		
Xd'	D: Unsaturated Transient Reactance	0.169	p.u.		
Xd"	D: Unsaturated Sub-Trans. Reactance	0.135	p.u.		
Xq	Q-axis Unsaturated Reactance	1.71	p.u.		
Xq'	Q: Unsaturated Transient Reactance	0.228	p.u.	0.001	1.0
Xq"	Q: Unsaturated Sub-Trans. Reactance	0.2	p.u.		
Ra	Stator Resistance	0.002	p.u.	0.00125	
Tdo'	D: Unsat. Transient Open T Const.	4.3	sec		
Tdo"	D: Unsat. Sub-Trans. Open T Const.	0.032	sec		
Tqo'	Q: Unsat. Transient Open T Const.	0.85	sec	0.001	3.0
Tqo"	Q: Unsat. Sub-Trans. Open T Const.	0.05	sec		

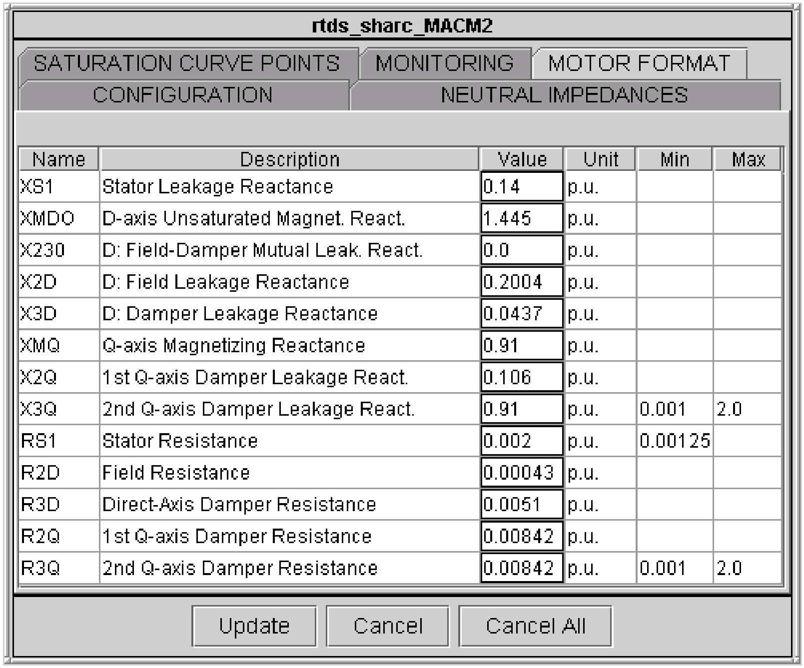
Update | Cancel | Cancel All

The reactances in the GENERATOR FORMAT menu are unsaturated reactances in per unit. The time constants contained in this menu are open−circuited, unsaturated time constants in seconds.

The Xq’ and Tqo’ menu items will appear “greyed out” in this menu if the Rotor Type is specified as “Salient” in the CONFIGURATION menu. The “Salient” selection indicates the modelling of only one Q−axis damper winding.

6.3.2 THE MOTOR FORMAT MENU

The machine model MOTOR FORMAT menu appears as follows:



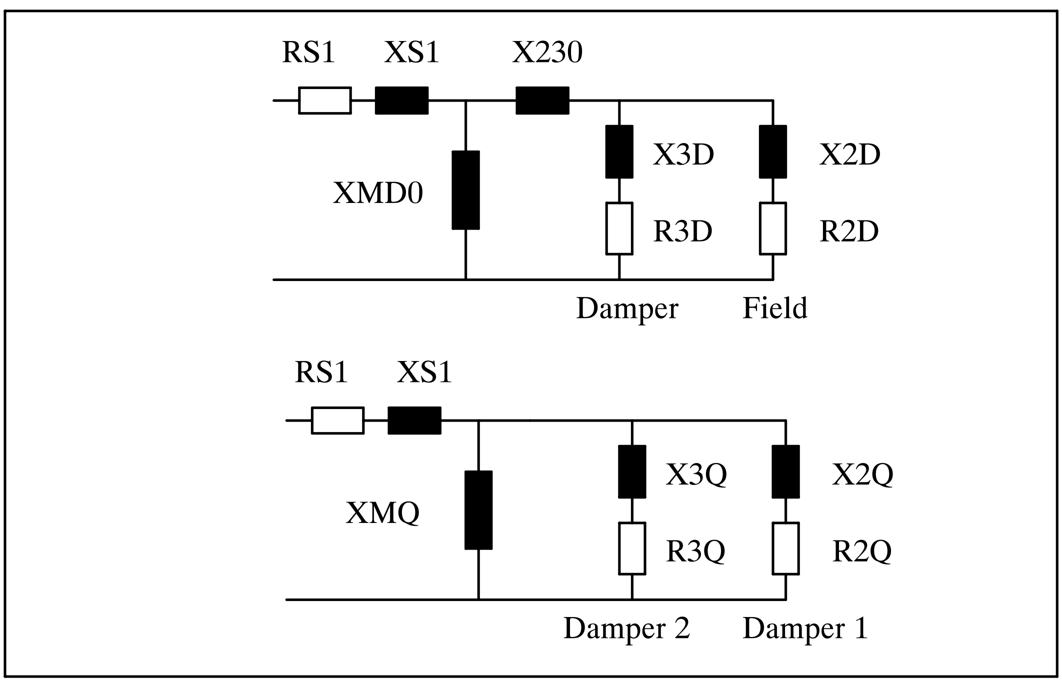
rtds_sharc_MACM2

SATURATION CURVE POINTS | MONITORING | MOTOR FORMAT | CONFIGURATION | NEUTRAL IMPEDANCES

Name	Description	Value	Unit	Min	Max
XS1	Stator Leakage Reactance	0.14	p.u.		
XMDO	D-axis Unsaturated Magnet. React.	1.445	p.u.		
X230	D: Field-Damper Mutual Leak. React.	0.0	p.u.		
X2D	D: Field Leakage Reactance	0.2004	p.u.		
X3D	D: Damper Leakage Reactance	0.0437	p.u.		
XMQ	Q-axis Magnetizing Reactance	0.91	p.u.		
X2Q	1st Q-axis Damper Leakage React.	0.106	p.u.		
X3Q	2nd Q-axis Damper Leakage React.	0.91	p.u.	0.001	2.0
RS1	Stator Resistance	0.002	p.u.	0.00125	
R2D	Field Resistance	0.00043	p.u.		
R3D	Direct-Axis Damper Resistance	0.0051	p.u.		
R2Q	1st Q-axis Damper Resistance	0.00842	p.u.		
R3Q	2nd Q-axis Damper Resistance	0.00842	p.u.	0.001	2.0

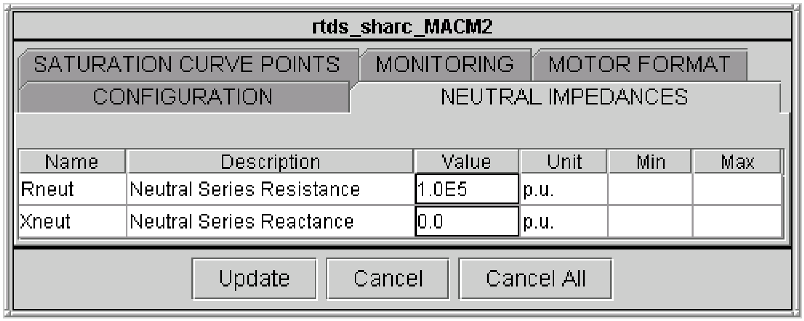
Update | Cancel | Cancel All

The R3Q and X3Q menu items will appear "greyed out" in this menu if the Rotor Type is specified as "Salient" in the CONFIGURATION menu. The "Salient" selection forces the model to include only one Q−axis damper winding. The D−axis and Q−axis quantities in the MOTOR FORMAT menu correspond to p.u. resistances and reactances in the following figure:



6.3.3 THE NEUTRAL IMPEDANCE MENU

The machine model NEUTRAL IMPEDANCES menu appears as follows:



A conduction path between the machine neutral and ground is allowed through an impedance which is specified in per unit on the stator base impedance. The base impedance is (Vbase) / (NOM x ibase) as entered in the CONFIGURATION menu.

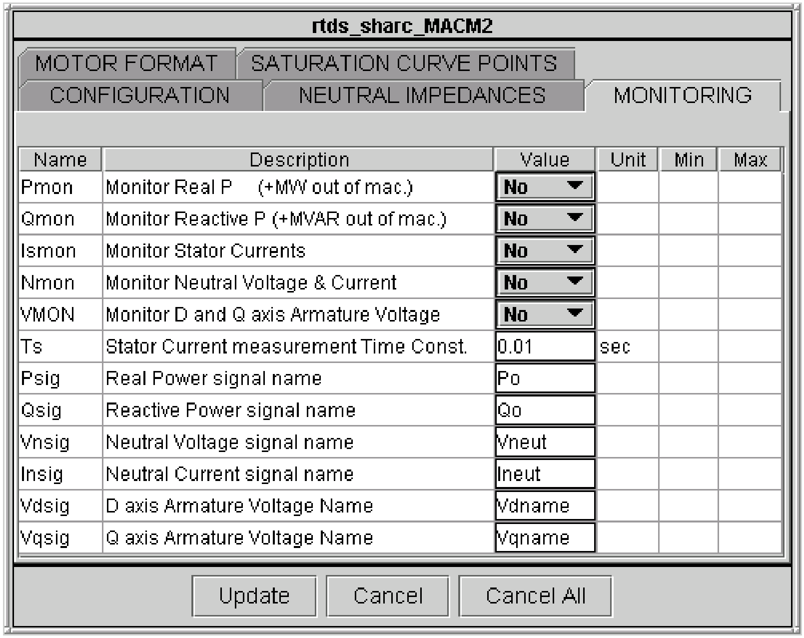
6.3.4 THE SATURATION CURVE MENUS

The CONFIGURATION menu contains the item “tysat” which is identical to the “satur” item found in the GENERAL MODEL CONFIGURATION menu of the rtds_sharc_MACM3 component. Refer to section 6.2.7 above for more information.

6.3.5 THE MONITORING MENU

The machine speed “w”, and the air−gap electrical torque “Te” listed in the RunTime output menus for the machine, may always be monitored . Machine speed “w” is in radians/second corresponding to a 2 pole machine. However, machines of any pole count may be modelled. Machine electrical torque “Te” is in p.u. on a base torque of (3)(Vbase)(NOM)(ibase) / (2 π HTZ) as entered in the CONFIGURATION menu.

The MONITORING menu, shown below, allows the optional selection of additional quantities for monitoring in RunTime. The quantities which are made available as a result of these selections may be displayed on plots or meters.


rtds_sharc_MACM2

MOTOR FORMAT | SATURATION CURVE POINTS | CONFIGURATION | NEUTRAL IMPEDANCES | MONITORING

Name	Description	Value	Unit	Min	Max
Pmon	Monitor Real P (+MW out of mac.)	No			
Qmon	Monitor Reactive P (+MVAR out of mac.)	No			
Ismon	Monitor Stator Currents	No			
Nmon	Monitor Neutral Voltage & Current	No			
VMON	Monitor D and Q axis Armature Voltage	No			
Ts	Stator Current measurement Time Const.	0.01	sec		
Psig	Real Power signal name	Po			
Qsig	Reactive Power signal name	Qo			
Vnsig	Neutral Voltage signal name	Vneut			
Insig	Neutral Current signal name	Ineut			
Vdsig	D axis Armature Voltage Name	Vdname			
Vqsig	Q axis Armature Voltage Name	Vqname			

Update | Cancel | Cancel All

The first outputs available for monitoring are the real and reactive power out of the model in MW and MVAR. These outputs are respectively referred to as “Po” and “Qo” in the RunTime output menus.

The load angle for the generator is given by:

$$\delta = \tan^{-1}\left[\frac{e_d}{-e_q}\right]$$

The negative sign in the above equation occurs because the Q−axis of the rotor lags the D−axis of the rotor by 90 degrees in the model. Therefore, e_q is equal to $-\sqrt{2}$ during open−circuit operation at rated frequency and rated stator voltage. As the generator is loaded e_d changes from a zero value to a positive value.

RMS stator current in kA may be monitored. This output is referred to as “Istator” in the RunTime output menu for the machine. A measurement time constant “Ts” is available in the above menu for smoothing the stator current output value.

Selecting ‘YES’ to the Nmon parameter permits the machine’s neutral voltage and current to be monitored using RSCAD/RunTime, as well as from analogue output channel #3 for Vneut. and analogue output channel #4 for Ineut.

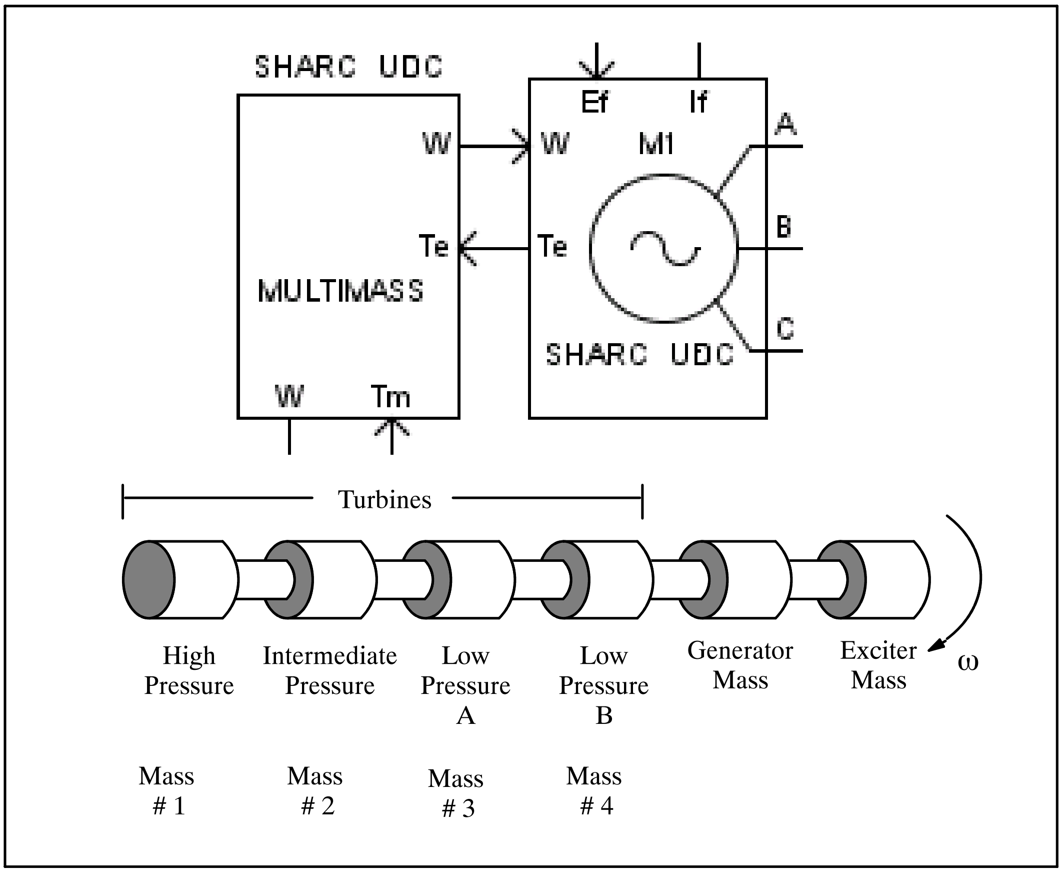
6.4 EXTERNAL FIELD VOLTAGE & MECHANICAL TORQUE SIGNALS

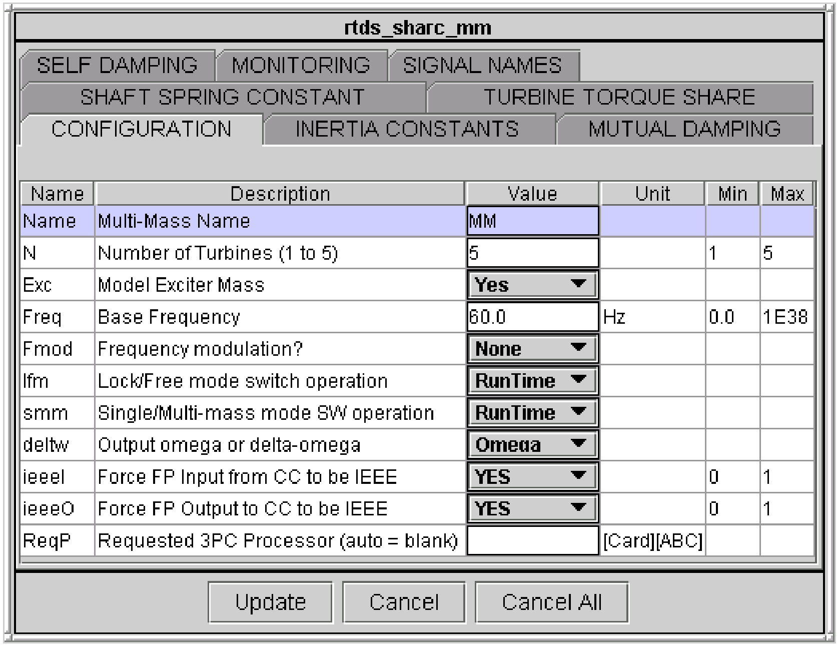
It is possible to supply field voltage and mechanical torque signals to the synchronous machine model from hardware external to the RTDS. Analogue signals representing field voltage and mechanical torque can be interfaced to the RTDS via analogue input channels using the controls compiler. Please refer to the RTDS CONTROL SYSTEMS Manual for assistance.

6.5 MULTI−MASS MODEL (RTDS_SHARC_MM)

Equations representing a single rotating mass are solved within the synchronous machine model. However, in some cases it is necessary to study the interactions between various masses which are connected to a common shaft. Steam turbine−generators, for example, may have numerous masses corresponding to turbine units, generator mass and rotating exciter mass connected to a common shaft. Subsynchronous resonance studies often include multi−mass models in order to simulate the torsional stresses that can occur on the shafts connecting the masses.

The basis for the multi−mass model is derived from an IEEE technical paper [2] entitled “First Benchmark Model for Computer Simulation of Subsynchronous Resonance”. The paper was prepared by the IEEE Subsynchronous Resonance Task Force of the Dynamic System Performance Working Group.



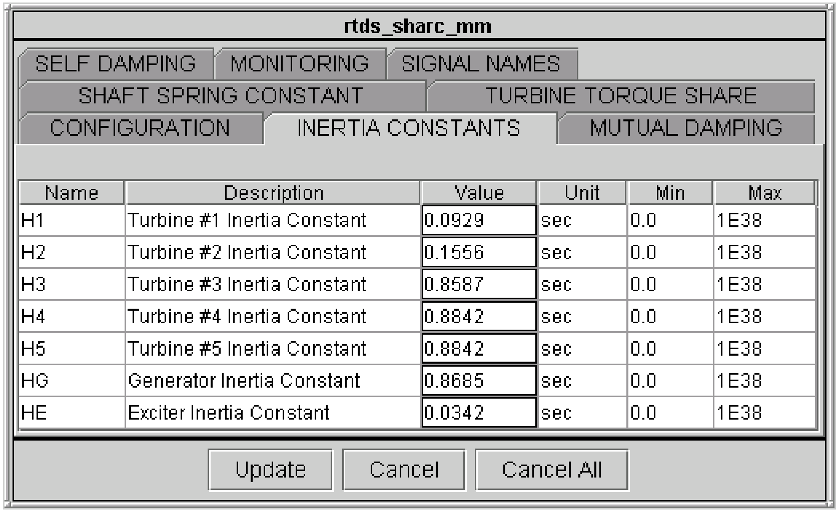


The CONFIGURATION menu is shown above. By connecting the multi−mass icon to the synchronous machine model, the effects of up to five turbine masses, the generator mass and an optional exciter mass can be simulated. Angles of each mass with respect to the generator mass, as well as the various shaft torques may be monitored.

The generator mass angle is chosen as the reference for all the masses connected to the common shaft. Thus, the generator angle is always considered to be at zero degrees and is not made available for display in RSCAD/RunTime. However, angles for the turbine and exciter masses may be monitored in RunTime in units of degrees ahead of the generator mass. Shaft torques in per unit may also be monitored in RunTime. A positive torque on the shaft between mass 1 and 2 corresponds with the angle of mass 1 leading the angle of mass 2. Therefore, positive shaft torques normally correspond with a situation where power is being generated into the ac system.

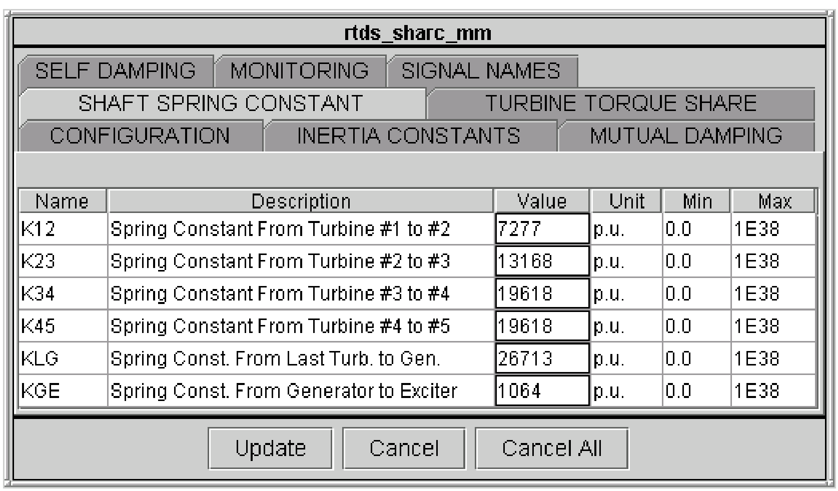
Connecting a multi−mass icon to the synchronous machine model disables the representation of the generator mass within the machine model. Machine speed is then computed within the multi−mass model. In the multi−mass model, data is entered for each turbine mass, the generator mass, the exciter mass and also for the shafts between the masses.

Data for the inertias of the masses, H are entered in the INERTIA CONSTANTS menu, as seen below. The inertia constant, H for a mass indicates the energy stored in the rotating mass at rated speed in units of
[stored MW−Seconds] / [generator MVA rating].



Name	Description	Value	Unit	Min	Max
H1	Turbine #1 Inertia Constant	0.0929	sec	0.0	1E38
H2	Turbine #2 Inertia Constant	0.1556	sec	0.0	1E38
H3	Turbine #3 Inertia Constant	0.8587	sec	0.0	1E38
H4	Turbine #4 Inertia Constant	0.8842	sec	0.0	1E38
H5	Turbine #5 Inertia Constant	0.8842	sec	0.0	1E38
HG	Generator Inertia Constant	0.8685	sec	0.0	1E38
HE	Exciter Inertia Constant	0.0342	sec	0.0	1E38

Data for the shaft spring constants, K is entered in the SHAFT SPRING CONSTANT menu (in units of p.u. torque over p.u. shaft angle deflection) as seen below. The base value for p.u. torque with a 2 pole generator, T_{base} in Newton−meters is equal to [generator VA rating] / [rated electrical frequency in radians per second]. The associated base value for p.u. angle, θ_{base} in radians is equal to [rated electrical frequency in radians per second] x [1 Second]. Accordingly, the base value for K, K_{base} is equal to T_{base} / θ_{base}.



Name	Description	Value	Unit	Min	Max
K12	Spring Constant From Turbine #1 to #2	7277	p.u.	0.0	1E38
K23	Spring Constant From Turbine #2 to #3	13168	p.u.	0.0	1E38
K34	Spring Constant From Turbine #3 to #4	19618	p.u.	0.0	1E38
K45	Spring Constant From Turbine #4 to #5	19618	p.u.	0.0	1E38
KLG	Spring Const. From Last Turb. to Gen.	26713	p.u.	0.0	1E38
KGE	Spring Const. From Generator to Exciter	1064	p.u.	0.0	1E38

Data for Self−Damping and Mutual−Damping are entered in the SELF DAMPING and MUTUAL DAMPING menus (in units of p.u. torque over p.u. speed difference) as seen below. The base value for p.u. speed for a 2 pole generator, ω_{base} is rated electrical frequency in radians per second. For Self−Damping terms, the speed difference is the difference between the angular velocity of the mass in p.u. and 1 (rated). For Mutual−Damping terms, the difference in speed is the difference in p.u. angular speeds of adjacent masses.

rtds_sharc_mm

SELF DAMPING | MONITORING | SIGNAL NAMES
SHAFT SPRING CONSTANT | TURBINE TORQUE SHARE
CONFIGURATION | INERTIA CONSTANTS | MUTUAL DAMPING

Name	Description	Value	Unit	Min	Max
SD1	Turbine #1 Self Damping	0.0	p.u.	0.0	1E38
SD2	Turbine #2 Self Damping	0.0	p.u.	0.0	1E38
SD3	Turbine #3 Self Damping	0.0	p.u.	0.0	1E38
SD4	Turbine #4 Self Damping	0.0	p.u.	0.0	1E38
SD5	Turbine #5 Self Damping	0.0	p.u.	0.0	1E38
SDG	Generator Self Damping	0.0	p.u.	0.0	1E38
SDE	Exciter Self Damping	0.0	p.u.	0.0	1E38

Update | Cancel | Cancel All

rtds_sharc_mm

SELF DAMPING | MONITORING | SIGNAL NAMES
SHAFT SPRING CONSTANT | TURBINE TORQUE SHARE
CONFIGURATION | INERTIA CONSTANTS | MUTUAL DAMPING

Name	Description	Value	Unit	Min	Max
MD12	Damping Between Turbine #1 & #2	0.0	p.u.	0.0	1E38
MD23	Damping Between Turbine #2 & #3	0.0	p.u.	0.0	1E38
MD34	Damping Between Turbine #3 & #4	0.0	p.u.	0.0	1E38
MD45	Damping Between Turbine #4 & #5	0.0	p.u.	0.0	1E38
MDLG	Damping Between Last Turbine & Gen.	0.0	p.u.	0.0	1E38
MDGE	Damping Between Generator & Exciter	0.0	p.u.	0.0	1E38

Update | Cancel | Cancel All

One common form of expressing mechanical damping is the logarithmic decrement factor, LOGDEC. It is defined as:

$$\text{LOGDEC} = \frac{\text{Ln}\,(A_0 / A_n)}{n} = \frac{\text{Ln}\,(A_0 / A_n)}{f\,\Delta T}$$

where A_0 is the amplitude of the first measured oscillation cycle and A_n is the amplitude of the oscillation n cycles later. The number of cycles of decay, n is f times ΔT where f is the frequency of the oscillation and ΔT is the decay time for n cycles. The decay time constant, T_d is defined as the time that it takes for an oscillatory wave to decay in magnitude to [1 / e] of the initial wave magnitude. Based on these definitions the following equation may be written:

$$f \quad \text{LOGDEC} = \frac{\text{Ln}\,(1 / [1 / e])}{T_d} = \frac{1}{T_d}$$

Therefore, the decay time constant T_d in seconds is equal to 1 / [f LOGDEC]. The decrement factor, σ is defined as 1 / T_d = f LOGDEC.

It can be shown that all modes of oscillation (and therefore all physical oscillations) will decay according to a single desired T_d if the Self−Damping input data, SD for each mass is set equal to { 4 [H for the mass in sec.] / [T_d in sec.] } and the Mutual−Damping data inputs are all set equal to 0.

Frequency Modulation

It is possible to add a modulation signal to the machine speed computed within the multi−mass model before it is sent to the synchronous machine model. The modulation signal source can either be from an external analogue signal, or from the controls compiler.

If the modulation signal is generated with the controls compiler then the signal name should be labelled with the name entered for the FNAM parameter in the multi−mass RSCAD/Draft component.

The modulation signal is in hertz. With a scale factor of 2.5 set in the analogue input component, an analogue input signal equal to 2.5 volts would result in 1.0 Hz being added to the frequency computed by the multi−mass model.

6.6 INITIALIZATION & STARTUP

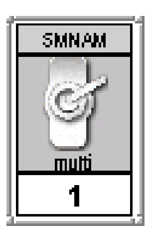
A number of RSCAD/RunTime features have been added in order to facilitate the orderly startup of power system cases which include numerous generators each of which may also include a multi−mass representation.

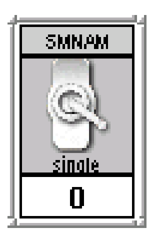
For such large power system models, it may be necessary to run a load−flow solution in order to determine the system power flows which are desired. The load flow information can be entered into generator and source models. However, the node voltages and branch currents always start at 0.0 when a new RTDS case is started. Therefore, even if all machines have initial conditions set, there will still be an electrical startup disturbance due to the time required for the electrical system to reach steady−state.

On startup, the machine (or multi−mass) model may be set into lock speed mode whereby the machine speed is forced to synchronous speed , such as 376.9911 rad/sec (which corresponds to 60 Hz). This will prevent the speed of the machine from being affected by the initial startup disturbance. After the startup disturbance, the machine rotor can be released by setting the RSCAD/RunTime switch to the ‘free’ position. The lock/free and Multi/Single operation may be operated from RunTime using RunTime switch components, or the user may select to operate these parameters using the controls compiler. This selection is available to the user in the CONFIGURATION menu of the multi−mass component icon. The switches shown below will be available in RunTime if the user is NOT using the CC operation. Selecting the CC option will add a controls input wire on the multi−mass icon.

Lock mode forces the machine to operate at synchronous speed.

Free mode has the multi−mass model compute the machine’s speed.





Multi−mass mode simulates all masses defined by the user for the synchronous machine.

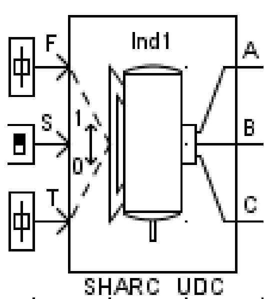
Single mass mode simulates all masses as one equivalent lumped mass.

In addition, when a multi−mass model is included in the system, a RSCAD/RunTime switch is available to select whether the multi–mass model should operate with all masses lumped together as one equivalent mass, or with each of the masses represented individually as specified. By using this switch, the multi–mass model is invoked once the power system model has reached steady–state conditions. While the multi–mass model operates in ‘single mass mode’, the angles of each mass are set equal to that of the generator mass. Whenever the mode is switched from single–mass modelling mode to multi–mass mass modelling mode the angles of the masses are automatically initialized according to the applied torques. A typical startup sequence may be as follows –

1) Start the simulation with the machines in lock mode and single mass.
2) Set machines to free mode after the electrical system has stabilized.
3) Switch from Single–mass mode to Multi–mass mode once the machines have stabilized at synchronous speed.
4) Apply system disturbance.

6.7 INDUCTION MACHINE MODEL (RTDS_SHARC_INDM)

An Induction Machine model which is based on generalized machine theory may be connected to the power system network in RSCAD / Draft. The model is a detailed electromagnetic transients DQ0 representation with optionally either 1 or 2 rotor cages. The main mutual flux linkage path saturates on both the D and Q axis according to an airgap voltage versus magnetizing current curve supplied by the User.

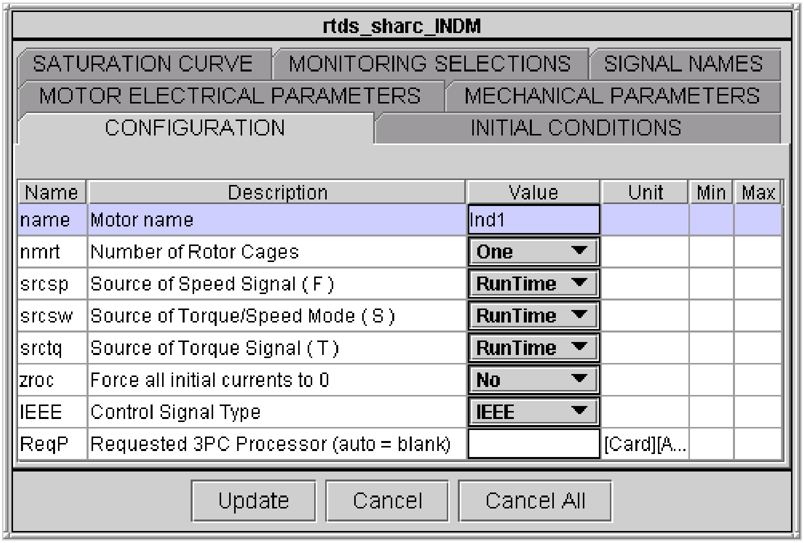


F: Machine speed input (Hertz)
S: Switch input, 1 use W, 0 use T
T: Mechanical Torque input (p.u.)
A/B/C: Bus Connection Terminals

Power System Interface

6.7.1 THE CONFIGURATION MENU

The CONFIGURATION menu appears as follows:



The "nmrt" option allows a choice between modelling one or two rotor cages. This corresponds to modelling one or two windings on both the D and Q axes in the model.

The mechanical speed of the motor can be made either to respond directly to a speed order or the speed can be made to vary according to the applied mechanical torque. As indicated on the motor icon, when the Lock / Free switch input (S) is set to 1 (Lock), the motor will respond to a speed order (in Hertz) applied to the speed input (F). On the other hand, when the Lock/Free switch input (S) is set to 0 (Free), the motor will respond to applied torque (in p.u.) applied to the torque input (T). The reference direction for applied torque is in the direction of positive rotation. Therefore, a positive applied torque will cause the induction machine to generate electrical power into the power system as an induction generator.

CC (Controls Compiler) or RunTime maybe chosen in the CONFIGURATION menu as the source for the Speed signal (F), the Torque/Speed Switch signal (S), and the Torque signal (T). When RunTime is chosen, the image of the icon contains sliders (for F and T) and a switch (for S). In RunTime, it will be possible to create a slider for the Speed Input which is named in the RunTime menu as SP_speed (Set Point speed). Likewise, it will be possible to create a slider for the Torque Input which is named in the RunTime menu as SP_torque (Set Point torque). The Torque/Speed Switch is named Mode in the RunTime menu. When these sliders and/or switch are created in RunTime, they will be pre−set according to the initial conditions specified in the INITIAL CONDITIONS menu discussed below.

The INITIAL CONDITIONS menu will not cause external controls to be directly pre−set because the nature of those controls is not known to the induction motor model. However, based on initial conditions specified in the INITIAL CONDITIONS menu, the model will pre−calculate and write to the MAP file the following information:

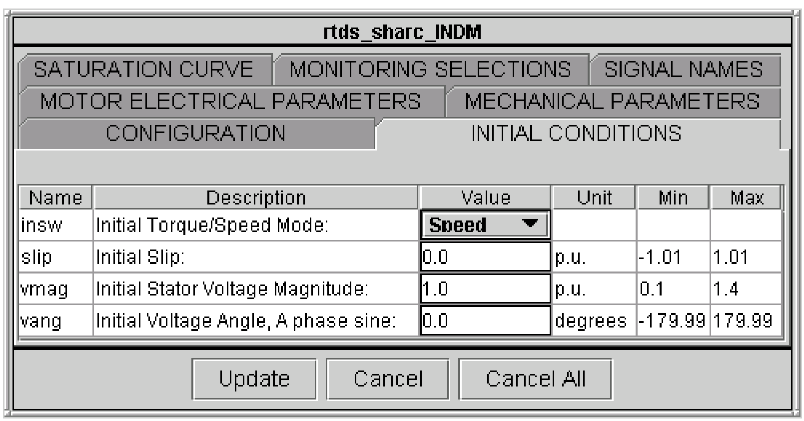
1. Initial Required Driving Torque in per−unit
2. Initial Electrical Powers (inward) in MW and MVAR
3. Initial Magnetizing Reactance in per−unit
4. Initial Speed in per−unit
5. Initial selection for Torque/Speed Mode Switch position

This information may be generally used to initialize control systems modelled using the Controls Compiler.

The CONFIGURATION menu also allows all initial currents to be forced to zero. This is useful for cases where it is wished to start the machine by closing a breaker to apply voltage to the motor.

6.7.2 THE INITIAL CONDITIONS MENU

The induction motor model INITIAL CONDITIONS menu appears as follows:



The “insw” item in the INITIAL CONDITION menu prompts for the specification of whether the machine speed mode will initially be set so that applied torque (T) will influence machine speed, or whether initially, the machine speed order will be received directly through the input (F). This selection has two effects:

1. The map file will indicate whether the machine will start in Lock (speed) or Free (torque) mechanical mode.

2. If the “srcsw” item (Source of Torque/Speed Mode) was set to “Switch” in the CONFIGURATION menu, then the machine will start according to “insw” even without the creation of a switch in RunTime. Also if a switch is created in RunTime then it will be pre−set according to “insw”.

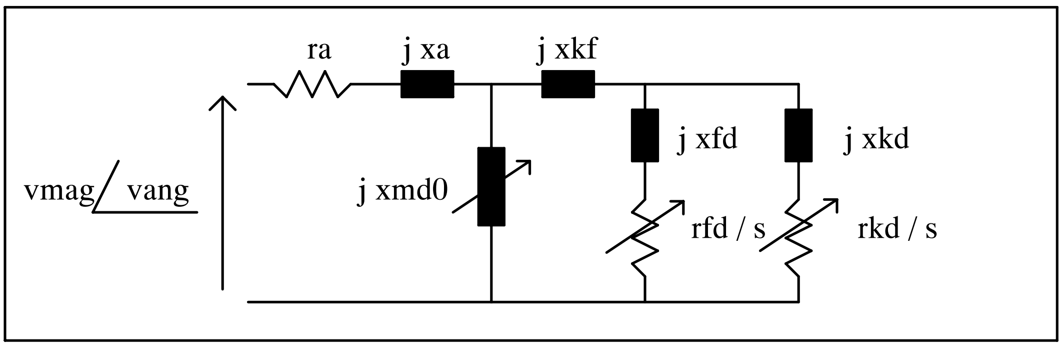
   If the “srcsw” item (Source of Torque/Speed Mode) was set to

"Controls" in the CONFIGURATION menu, then the machine will respond immediately at start−up to the Mode specified at the S input.

The "slip" item in the INITIAL CONDITION menu prompts for the specification of the initial slip of the motor. For example an initial slip of 0.01 p.u. means that the machine will begin operation at 0.99 p.u. speed.

The "vmag" and "vang" items in the INITIAL CONDITION menu prompts for the initial stator terminal voltage magnitude (in p.u.) and angle (in Degrees). The base value for "vmag" per unit is specified by the User in the MOTOR ELECTRICAL PARAMETERS menu discussed below. The response to the "vang" item must be the angle of the A−phase voltage expressed as a sine wave.

In steady−state operation, the motor can be represented by phasors according to a very simple equivalent circuit as illustrated in the following diagram where "s" represents slip in per unit:



The electrical parameters illustrated in the above diagram are specified in the MOTOR ELECTRICAL PARAMETERS menu. Slip and terminal voltage (vmag and vang) are specified in the INITIAL CONDITIONS menu. The voltage versus current magnetizing characteristic of xmd0 at rated frequency is specified in the SATURATION CURVE menu.

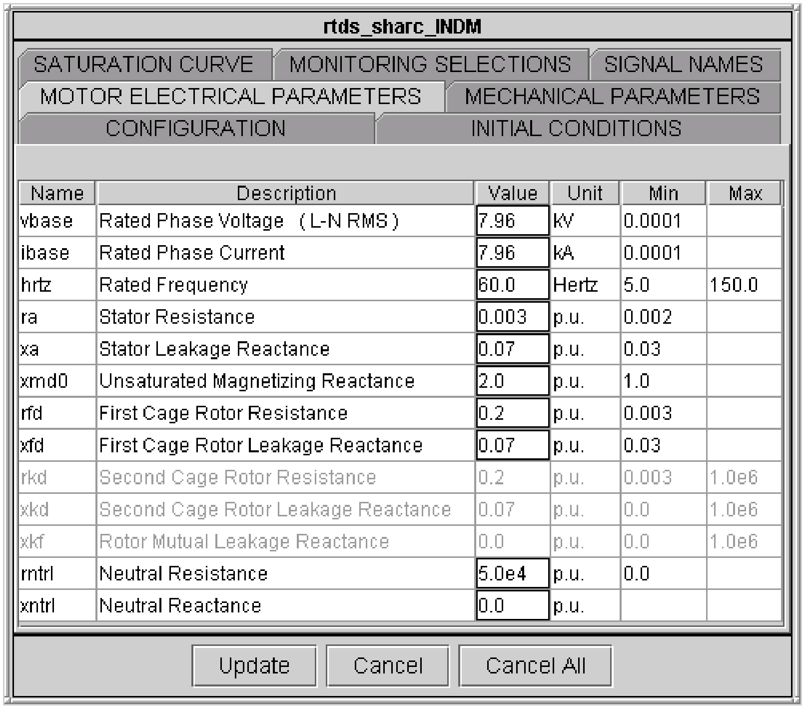
Given that all circuit parameters in the above diagram are known, the RTDS compiler is able to pre−calculate the currents in the above circuit as phasors. This in turn allows the calculation of instantaneous values of currents in all windings on both the D and Q axes. These values of currents are used to initialize the fluxes in the motor model. In addition, these values of current allow the RTDS compiler to pre−calculate the following information and store it in the Map file:

1. Initial Required Driving Torque in per−unit
2. Initial Electrical Powers (inward) in MW and MVAR
3. Initial Magnetizing Reactance in per−unit.

All initial currents can optionally be forced to zero by responding with a "Yes" to the "zroc" item in the CONFIGURATION menu.

6.7.3 THE MOTOR ELECTRICAL PARAMETERS MENU

The induction motor model MOTOR ELECTRICAL PARAMETERS menu appears as follows:



The “vbase” item in the above menu allows the specification of a base line−to−neutral RMS voltage for the model. This is the line−to−line RMS voltage divided by the square root of 3.

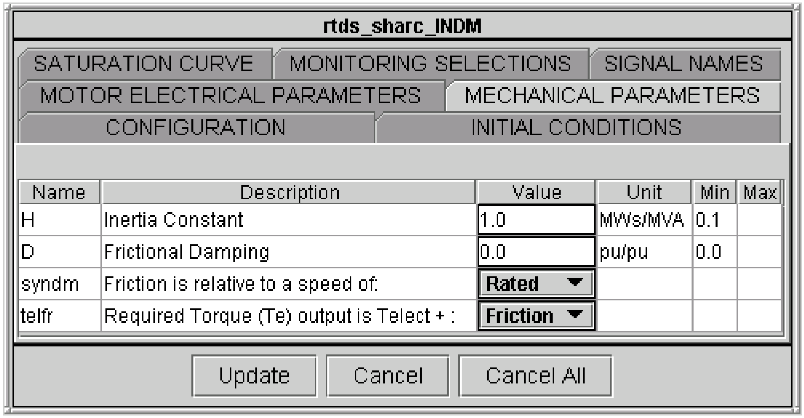
The diagram in the previous section illustrates the D−axis quantities used in a simple equivalent circuit.

The MOTOR ELECTRICAL PARAMETERS menu contains only D−axis quantities. The values used for the corresponding Q−axis quantities are identical to the specified D−axis values.

The base impedance for the neutral resistance and reactance is vbase / ibase.

6.7.4 THE MECHANICAL PARAMETERS MENU

The induction motor model MECHANICAL PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
H	Inertia Constant	1.0	MWs/MVA	0.1	
D	Frictional Damping	0.0	pu/pu	0.0	
syndm	Friction is relative to a speed of:	Rated			
telfr	Required Torque (Te) output is Telect + :	Friction			

The rotational inertia (H) of the induction motor is expressed in MegaWatt−seconds of stored energy at rated speed per MVA of motor rating.

The Frictional Damping of the rotor of the machine is expressed in units of damping torque (per unit) over speed difference (per unit). The frictional damping may be made absolute by selecting “Zero” in response to the item “syndm”. In this case the speed difference will be calculated with respect to zero speed so that the speed difference will be equal to the actual speed. On the other hand, the frictional damping may be made relative to synchronous speed by selecting “Rated”. In this case, the speed difference will be equal to actual speed minus synchronous speed.

A signal of required torque (Te) is always available for monitoring. The value of the signal (Te) will include the electrical torque in per unit plus optionally the frictional damping torque in per unit. The “telfr” menu item is available for making this optional selection.

The electrical torque is positive for operation as a generator. The damping torque will be positive for positive values of the speed difference discussed above.

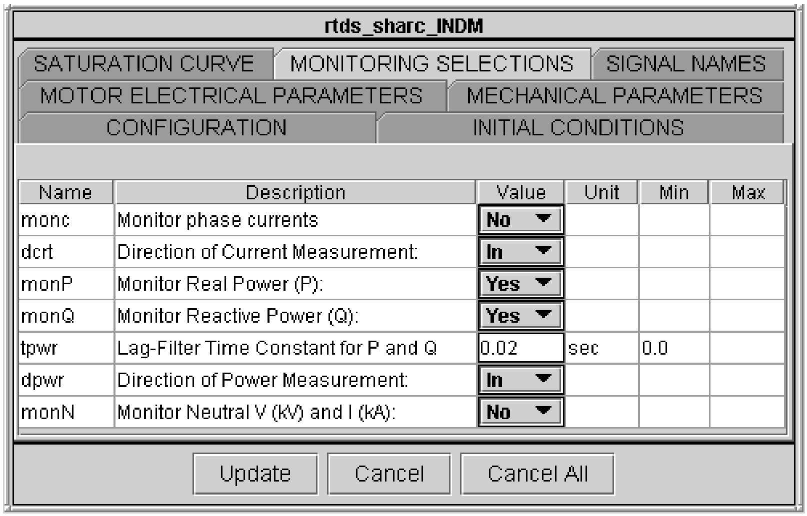
The required torque signal (Te) must be given a distinctive name in the SIGNAL NAMES menu described below. The required torque signal will be available in RunTime by the name which is specified. The required torque signal will also be available as a signal to the modelled control system according to a specified name.

6.7.5 THE SATURATION CURVE MENU

The saturation curve for the main mutual flux linkage path of the induction motor model is specifiable in the SATURATION CURVE menu. The saturation curve which is entered should be the air−gap voltage versus magnetizing current curve for the magnetizing branch “xmd0” at rated frequency. (Reference the figure in section 6.7.2 concerning “xmd0”).

6.7.6 THE MONITORING SELECTIONS MENU

The induction motor model MONITORING SELECTIONS menu appears as follows:



The reference direction for the measured currents is “In” or “Out” of the motor according to the item “dcrt” in the MONITORING SELECTIONS menu. This selection affects currents available for monitoring on analog output channels and also currents available for monitoring in RunTime.

The currents are optionally available for monitoring in RunTime and for use within the RTDS Controls compiler by the menu item “monc” in the MONITORING SELECTIONS menu. If the phase currents are to monitored in RunTime or used in the Controls compiler, then the signals must be given names in the SIGNAL NAMES menu. The currents for display in RunTime will be in units of kA.

Real (P) and reactive (Q) power of the machine may also be selected for monitoring in RunTime using the “monP” and “monQ” menu items in the MONITORING SELECTIONS menu. The units of measured power are MW and MVARS. The P and Q signals are filtered using a first order lag filter with time constant specified in the “tpwr” menu item. If “tpwr” is set to 0.0 then there will be no filtering. The reference direction for power measurement may be specified in the “dpwr” menu item (“In” means into the motor / “Out” means out of the motor).

If P or Q is to be made available for monitoring in RunTime or for use in the Controls compiler then the signals must be given distinctive names in the SIGNAL NAMES menu.

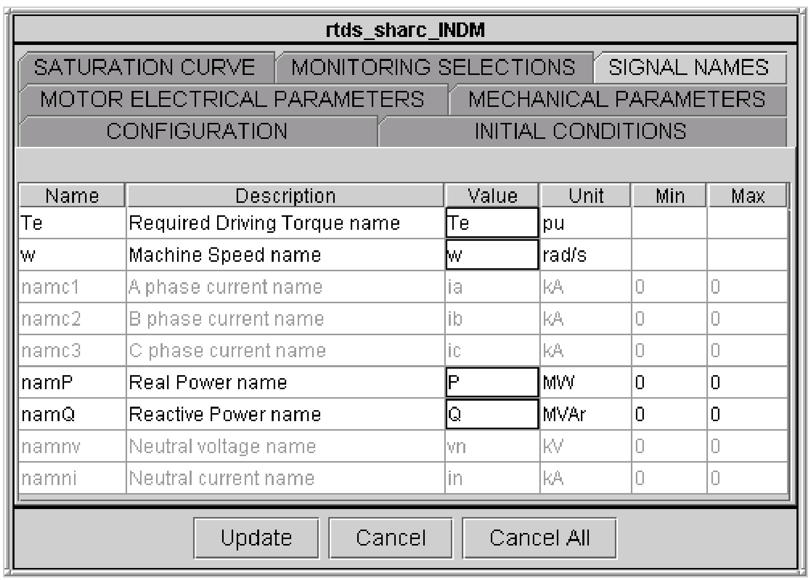
The “monN” menu item may be used to specify if the neutral voltage and current should be available for monitoring in RunTime and for use by the Controls compiler.

The neutral voltage and current will be in units of kV and kA respectively. To be available, the signals must also be given distinctive names in the SIGNAL NAMES menu.

The motor speed in radians per second (w) and the required driving torque in p.u. (Te, which was discussed in Section 6.7.4) are always available for monitoring in RunTime and for use in the Controls compiler. However, these signals (and all others) must be given distinctive names in the SIGNAL NAMES menu. These names will appear in the RunTime selection menus.

6.7.7 THE SIGNAL NAMES MENU

The induction motor model SIGNAL NAMES menu appears as follows:



The SIGNAL NAMES menu lists all of the quantities which have been selected for availability for monitoring in RunTime and for the Controls compiler (quantities which have not been selected appear “greyed out”). Required Driving Torque (Te) and Machine speed (w) are always available. Distinctive names must be specified by which the signals will be available in RunTime menus and to the Controls compiler.

6.8 PERMANENT MAGNET SYNCHRONOUS MACHINE MODEL (_rtds_PMSM)

6.8.1 INTRODUCTION

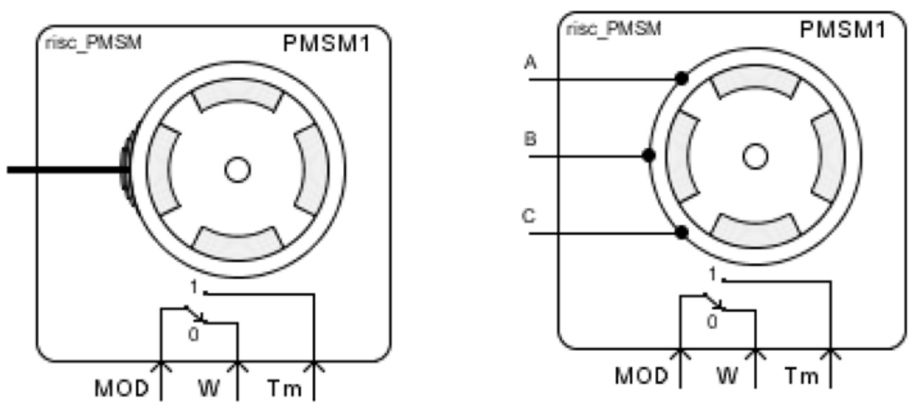
The basic icon for the permanent magnet synchronous machine (_rtds_PMSM) component appears as shown in Figure 6.8.1.

The view of the model can be toggled between 3phase and single−line view. In addition to three stator terminals, there are three control inputs to this model:

MOD: The digital input “MOD“ specifies the operation mode of the ma chine: if (MOD = 0), then the machine operates in “lock” mode and the speed of the machine is controlled by the input control signal “W”. If (MOD = 1), then the machine operates in “free” mode and the mechanical torque is controlled by the input control signal “Tm”. This torque is then used to calculate the rotor speed based on the mechanical swing equations.

W: The digital input “W“ specifies the speed of the machine if the input signal “MOD” is 0.

Tm: The digital input “Tm“ specifies the mechanical torque of the machine if the input signal “MOD” is 1.



Single Line Diagram View 3 Phase View

Figure 6.8.1: _rtds_PMSM Component Icon

The time−domain modeling of this PMSM model is based upon the dq0 theory [3]. The following equations show the differential equations of the PMSM in the dq0 frame.

Equations for the stator windings:

$$\begin{cases} v_d = r_s \cdot i_d + \dfrac{d}{dt}\Psi_d + \omega_r \cdot \Psi_q \\ v_q = r_s \cdot i_q + \dfrac{d}{dt}\Psi_q - \omega_r \cdot \Psi_d \end{cases} \qquad \begin{cases} \Psi_d = L_d \cdot i_d + L_{md} \cdot i_D + \Psi_m \\ \Psi_q = L_q \cdot i_q + L_{mq} \cdot i_Q \end{cases}$$

Equations for the shorted damper windings:

$$\begin{cases} 0 = r_D \cdot i_D + \dfrac{d}{dt}\Psi_D \\ 0 = r_Q \cdot i_Q + \dfrac{d}{dt}\Psi_Q \end{cases} \qquad \begin{cases} \Psi_D = L_{md} \cdot i_d + L_D \cdot i_D + \Psi_m \\ \Psi_Q = L_{mq} \cdot i_q + L_Q \cdot i_Q \end{cases}$$

These equations are very similar to the differential equations of the synchronous machine model described in section 6.2 of this manual. In the above equation, Ψ_m is known as ***magnetic strength***, and it represents the flux linkage induced by the rotor magnets on the stator windings. A magnetic strength of $\Psi_m = 1$ corresponds to 1 pu terminal voltage when the machine is open circuited and running at rated speed.

The dq equivalent circuit of the PMSM is shown below in Figure 6.8.2. The current source in the d−axis equivalent circuit represents the effects of permanent magnets. The relation between magnetic strength and this current source is $\Psi_m = L_{md} \cdot i_m$.

Please note that this PMSM model has some limitations / simplifications. It does not model the effects of iron saturation. Additionally, harmonics of back−EMF voltage which are due to the arbitrary shape of permanent magnets are not modeled.

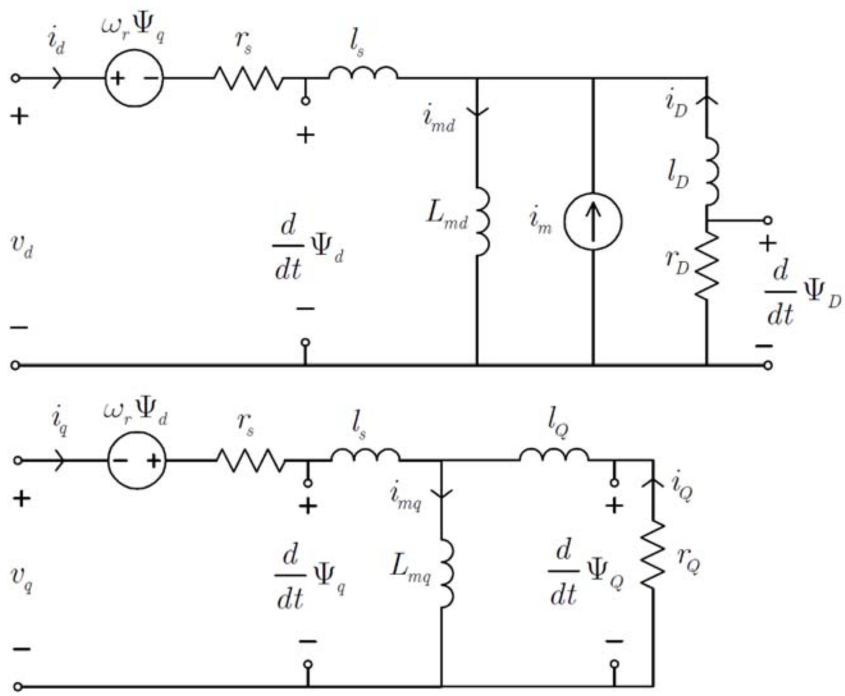


Figure 6.8.2 Dq Equivalent Circuit of the PMSM

6.8.2 MAIN MENU FOR THE _rtds_PMSM COMPONENT

The main menu for the _rtds_PMSM component is shown below.

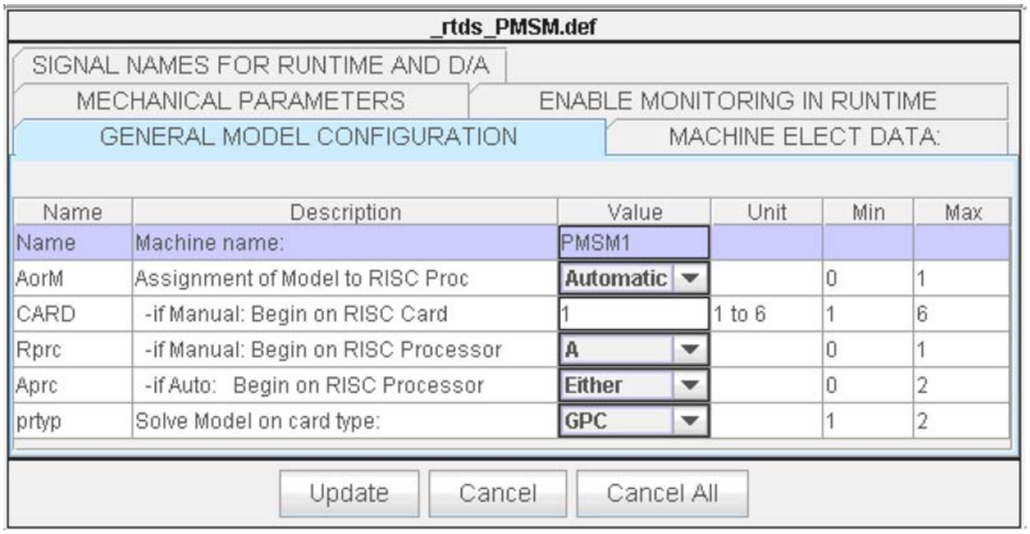


Figure 6.8.3 Main Menu of _rtds_PMSM Component

Name: A unique name must be given for each instance of the component.

AorM: Specify if the model be automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The processor of the above entered CARD is entered here.

Aprc: Parameter is only used if AorM parameter is set to Auto. The user can select the model be assigned to A or B processor or Either A or B.

prtyp: The prtyp parameter allows the user to select on which type of processor the model is to be run. This model is currently available for RISC processor types.

6.8.3 THE MACHINE ELECTRICAL PARAMETERS MENU

The_rtds_PMSM MACHINE ELEC DATA MENU appears as shown in Figure 6.8.4. These parameters describe the electrical transient behaviour of the machine. The parameters in this menu have the following descriptions:

vllrms: Rated Stator Voltage of the Machine (Line–to–Line RMS)

Srated: Rated MVA of the Machine

fb: Rated Operating Frequency of the Machine

Xlspu: Stator Winding Leakage Reactance in Per−Unit

Xmdpu: D−axis Unsaturated Magnetizing Reactance in Per−Unit

XlDpu: Leakage Reactance of the D−axis Damper Winding in Per−Unit

Xmqpu: Q−axis Unsaturated Magnetizing Reactance in Per−Unit

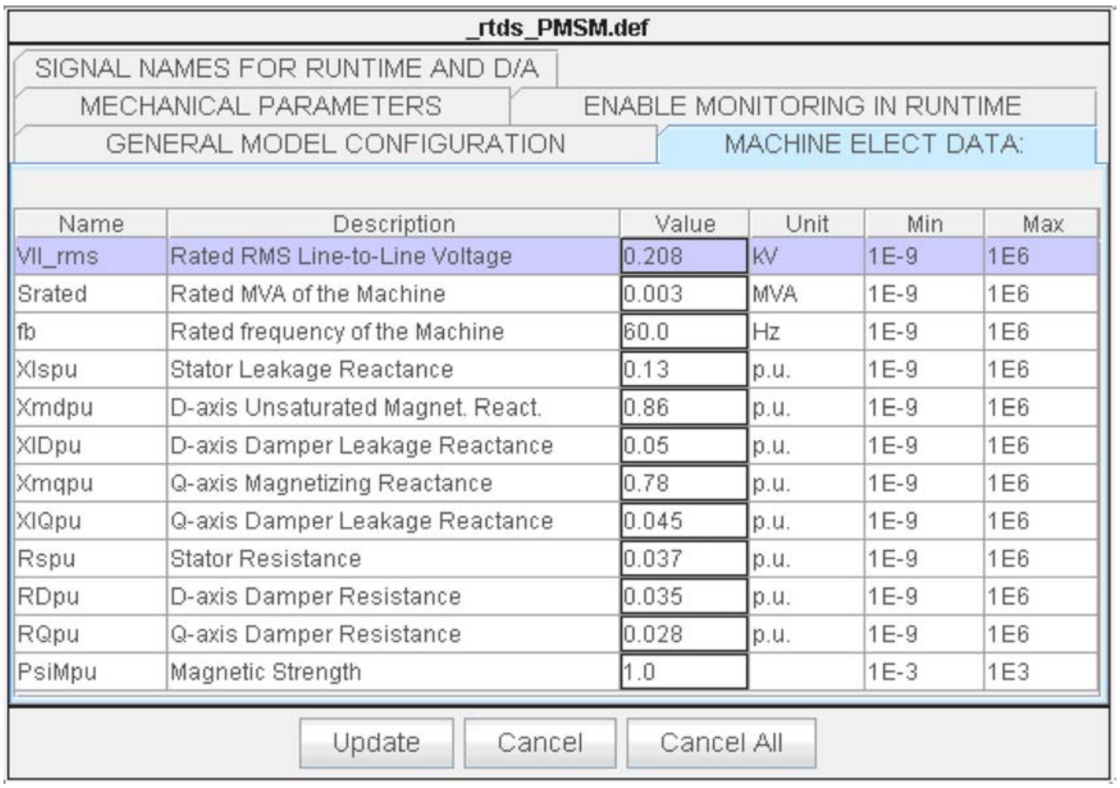
XlQpu: Leakage Reactance of the Q−axis Damper Winding in Per−Unit

Rspu: Stator Winding Resistance in Per−Unit

RDpu: Resistance of the D−axis Damper Winding in Per−Unit

RQpu: Resistance of the Q−axis Damper Winding in Per−Unit

PsiMpu: Magnetic Strength in Per−Unit. Note that PsiMpu = 1.0 corresponds to 1.0 pu terminal voltage in open circuit at rated speed.



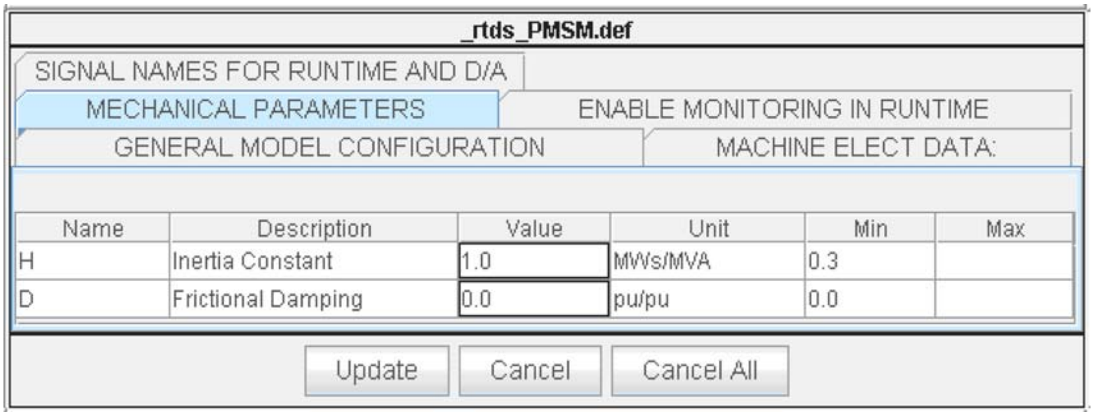
Name	Description	Value	Unit	Min	Max
Vll_rms	Rated RMS Line-to-Line Voltage	0.208	kV	1E-9	1E6
Srated	Rated MVA of the Machine	0.003	MVA	1E-9	1E6
fb	Rated frequency of the Machine	60.0	Hz	1E-9	1E6
Xlspu	Stator Leakage Reactance	0.13	p.u.	1E-9	1E6
Xmdpu	D-axis Unsaturated Magnet. React.	0.86	p.u.	1E-9	1E6
XlDpu	D-axis Damper Leakage Reactance	0.05	p.u.	1E-9	1E6
Xmqpu	Q-axis Magnetizing Reactance	0.78	p.u.	1E-9	1E6
XlQpu	Q-axis Damper Leakage Reactance	0.045	p.u.	1E-9	1E6
Rspu	Stator Resistance	0.037	p.u.	1E-9	1E6
RDpu	D-axis Damper Resistance	0.035	p.u.	1E-9	1E6
RQpu	Q-axis Damper Resistance	0.028	p.u.	1E-9	1E6
PsiMpu	Magnetic Strength	1.0		1E-3	1E3

Figure 6.8.4 Machine Electrical Parameters Menu

6.8.4 THE MECHANICAL PARAMETERS MENU

The _rtds_PMSM MECHANICAL PARAMETERS MENU appears as shown in Figure 6.8.5. These parameters describe the mechanical dynamics of the machine.

H: The rotational inertia (H) of the PMSM is expressed in MegaWatt−seconds of stored energy at rated speed per MVA of motor rating.

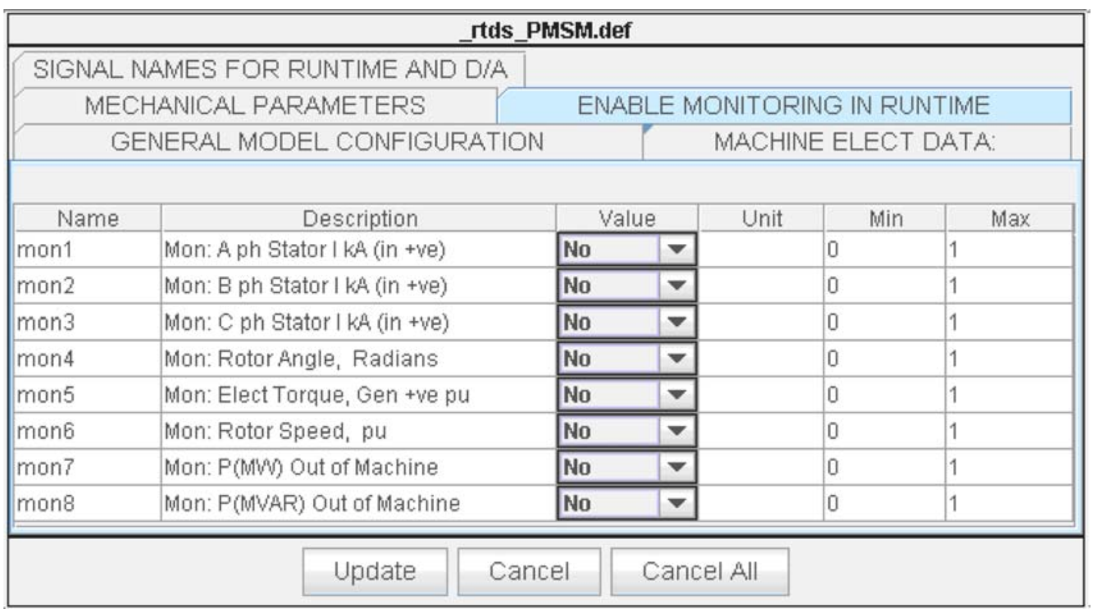


Name	Description	Value	Unit	Min	Max
H	Inertia Constant	1.0	MWs/MVA	0.3	
D	Frictional Damping	0.0	pu/pu	0.0	

Figure 6.8.5 Mechanical Parameters Menu

6.8.5 THE ENABLE MONITORING IN RUNTIME MENU

The _rtds_PMSM ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.8.6. The user has the option of monitoring stator currents, rotor angle and speed, electric torque, active and reactive powers of the machine. The component monitors the currents going into the stator of the machine and the active and reactive power generated by the machine. Similar to other machine models a positive electric torque corresponds to the generator operation of the machine.



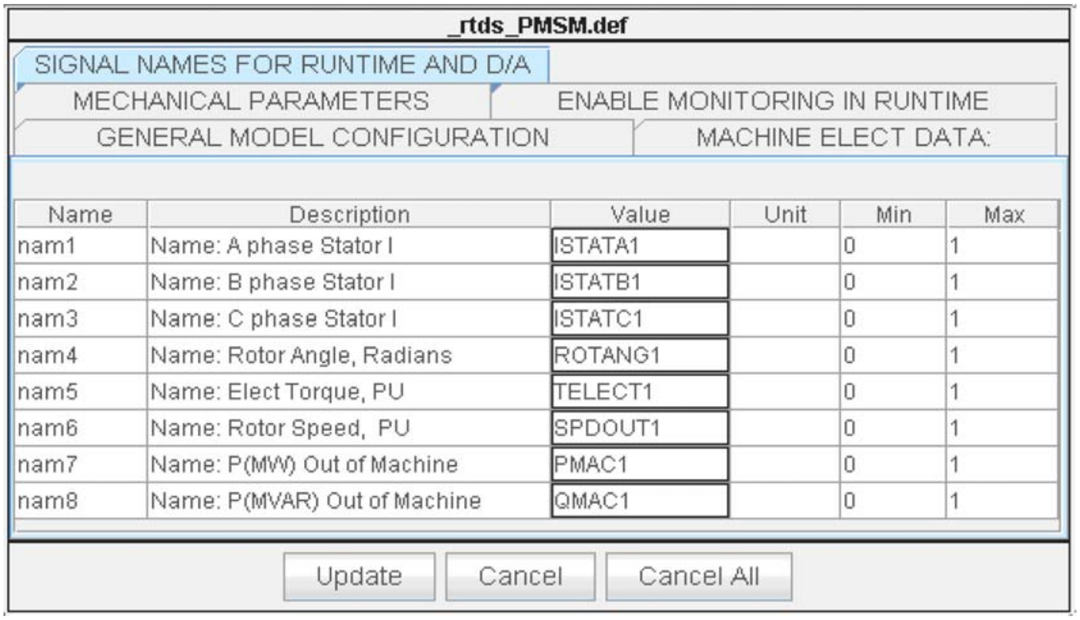
Name	Description	Value	Unit	Min	Max
mon1	Mon: A ph Stator I kA (in +ve)	No		0	1
mon2	Mon: B ph Stator I kA (in +ve)	No		0	1
mon3	Mon: C ph Stator I kA (in +ve)	No		0	1
mon4	Mon: Rotor Angle, Radians	No		0	1
mon5	Mon: Elect Torque, Gen +ve pu	No		0	1
mon6	Mon: Rotor Speed, pu	No		0	1
mon7	Mon: P(MW) Out of Machine	No		0	1
mon8	Mon: P(MVAR) Out of Machine	No		0	1

Figure 6.8.6 Enable Monitoring Menu

6.8.6 THE SIGNAL NAMES FOR RUNTIME AND D/A MENU

The _rtds_PMSM SIGNAL NAMES FOR RUNTIME AND D/A MENU appears as shown in Figure 6.8.7. This menu enables users to provide names for the monitored signals. If the user has chosen to monitor signals in the ENABLE

MONITORING IN RUNTIME MENU, it is possible to specify the names of those monitored quantities in this menu.



Name	Description	Value	Unit	Min	Max
nam1	Name: A phase Stator I	ISTATA1		0	1
nam2	Name: B phase Stator I	ISTATB1		0	1
nam3	Name: C phase Stator I	ISTATC1		0	1
nam4	Name: Rotor Angle, Radians	ROTANG1		0	1
nam5	Name: Elect Torque, PU	TELECT1		0	1
nam6	Name: Rotor Speed, PU	SPDOUT1		0	1
nam7	Name: P(MW) Out of Machine	PMAC1		0	1
nam8	Name: P(MVAR) Out of Machine	QMAC1		0	1

Figure 6.8.7 Signal Names for RunTime and D/A Menu

6.8.7 SUMMARY

The _rtds_PMSM permanent magnet synchronous machine component for large time−step simulation provides a model that is flexible in configuration so as to meet the various needs of different users. This model is a dq−based transient model, and its equivalent circuit is very similar to the synchronous machine model.

Please note that similar to other machine models in RTDS, this machine model is an equivalent two pole model, i.e. it is assumed that different pole−pairs of the machine observe the same flux levels.

Currently, this model has the following limitations:

– Zero−sequence is not included (i.e. the zero−sequence equations are not solved)

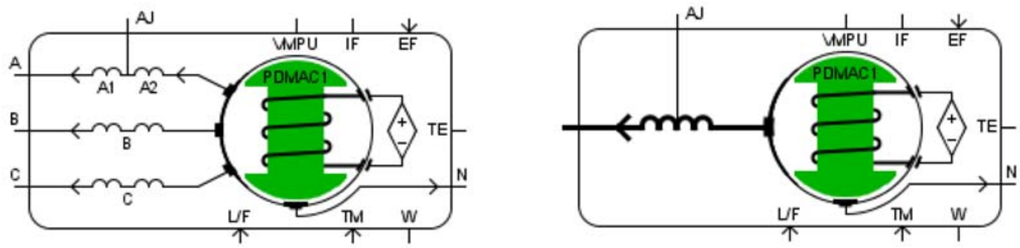
– The effects of iron saturation are ignored.

– Harmonics of the back−emf voltages due to arbitrary shaped permanent magnets are not represented.

6.9 PHASE–DOMAIN SYNCHRONOUS MACHINE (PDSM) FOR INTERNAL FAULTS

6.9.1 INTRODUCTION

This chapter describes the phase domain synchronous machine (PDSM) model available for simulating stator–ground faults. The basic icon for the _rtds_PDSM_FLT_v1 component appears as shown in Figure 6.9.1. In addition to the stator terminals (A,B, and C), the neutral of the machine (N) and a point of fault in phase A (AJ) are available for connection to other power system components.



3 Phase View Single Line View

Figure 6.9.1 _rtds_PDSM_FLT_v1 component Icon

The **embedded phase domain approach** [4] is used to implement this model in the environment of the real–time digital simulator (RTDS). The term **phase domain** means that the values of machine inductances change with the change in rotor position and level of saturation. The term **embedded** means that the network solution is incorporated in solving the differential equations of the machine. This approach shows superior numerical performance compared to the conventional interfaced approach [5].

The phase domain feature of this model makes it capable of simulating synchronous machines internal faults. To be able to simulate synchronous machine internal faults, the self and mutual inductances of machine windings including faulted windings must be computed as functions of rotor position and saturation. The phase domain synchronous machine model "_rtds_PDSM_FLT_v1" can use two methods to compute the inductance matrix of the machine:
DQ–Based Method: In this approach [6,7], it is assumed that not only the healthy windings create a perfect sinusoidally distributed magneto–motive force (MMF), but also, the MMF due to the faulted windings will be sinusoidal. The advantage of this method is that the users do not need to know the information about the distribution of the windings and rotor geometry, and the dq data required for operating the component "lf_sharc_sld_MACV31" is adequate for operating this component. This method however does not show the phase–belt harmonics (3rd, 5th, and 7th harmonics due to the non–sinusoidal distribution of the windings and permeance). Furthermore, as the point of fault becomes closer to the end of a

winding, the MMF of the sub−winding becomes less sinusoidal; therefore this approximation becomes less accurate.

MWFA−Based Method: this method is based on the Modified Winding Function Approach (MWFA) [8] in which the actual distributions of the windings are considered in computing the inductances of the windings. By incorporating the improvements introduced in [4,9], this method can also incorporate the actual shape of the rotor pole−arc and effects of operating point−dependent saturation. The minimum data required to use this model is the number of poles, number of stator slot, actual distribution of the windings, and the geometry of rotor poles. In contrast to the dq−based approach, this method correctly represents the phase−belt harmonics, and inductances of small portions of a winding can be represented more accurately. Due to unavailability of required data to most users, MWFA option is not available for the users.

In the phase−domain synchronous machine model ”_rtds_PDSM_FLT_v1”, the rotor damper grid is modeled as amortisseur windings along d−axis and q−axis, which is the conventional method of modeling damper grids in system studies [10]. It is shown that this representation may cause significant error in modeling turn−turn faults for multiple pole synchronous machines [9]. Alternatively, one d−axis damper winding and one q−axis damper winding must be considered for each pole of a synchronous machine for accurate simulation of solid turn−turn faults [9]. With the present technology, the computational capacity of the RTDS hardware does not allow implementation of such a complex machine model. When stator−to−ground faults are the subject of study, the phase−domain synchronous machine model ”_rtds_PDSM_FLT_v1” is applicable, as the synchronous machine neutral is grounded with an impedance much larger than the leakage impedance of the stator and the dampers [9, 11, 12]. Therefore, the primary application of the phase−domain synchronous machine model ”_rtds_PDSM_FLT_v1” is closed−loop testing of stator−ground fault protection devices.

If the dq−based method is used for computing synchronous machine inductances, the model can operate differential and neutral overvoltage protection schemes. Third harmonic voltage of the neutral and terminals can be generated separately and added to the fundamental voltage. Using this method, even a dq−based model can be used for ”100% stator−ground fault protection scheme.

6.9.2 MAIN MENU FOR THE _rtds_PDSM_FLT_v1 COMPONENT

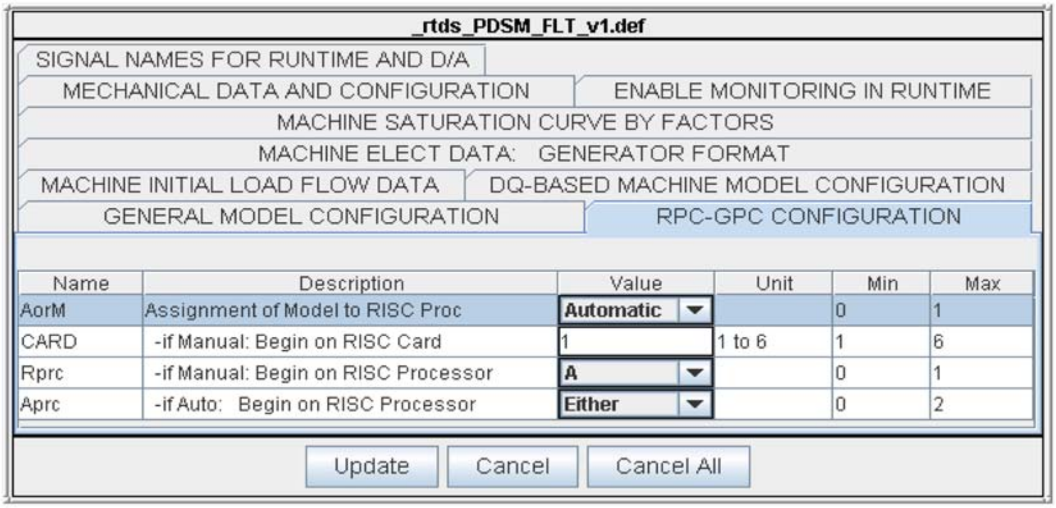
Most menu options in ”_rtds_PDSM_FLT_v1” are similar to the ”lf_sharc_sld_MACV31” machine model. A brief explanation is provided for the common menus. Please refer to documentation for ”lf_sharc_sld_MACV31” for more details. The _rtds_PDSM_FLT_v1 RPC_GPC CONFIGURATION MENU appears as shown in Figure 6.9.2.

AorM: Specify if the model be automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The processor of the above entered CARD is entered here.

Aprc: Parameter is only used if AorM parameter is set to Auto. The user can select the model be assigned to A or B processor or Either A or B.

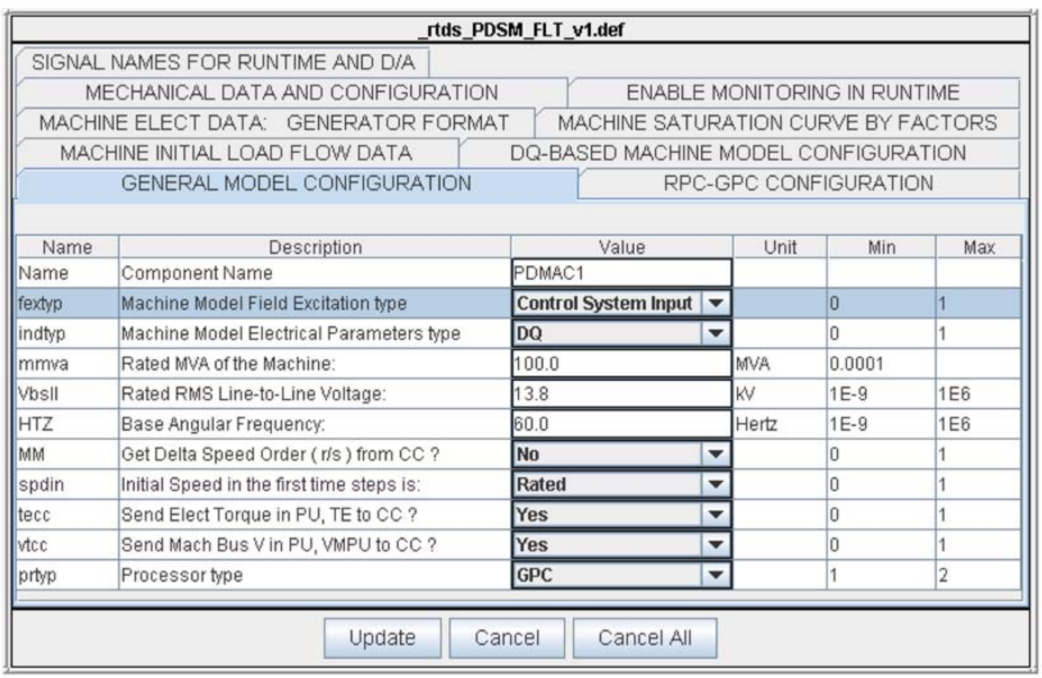


Name	Description	Value	Unit	Min	Max
AorM	Assignment of Model to RISC Proc	Automatic		0	1
CARD	-if Manual: Begin on RISC Card	1	1 to 6	1	6
Rprc	-if Manual: Begin on RISC Processor	A		0	1
Aprc	-if Auto: Begin on RISC Processor	Either		0	2

Figure 6.9.2 Main Menu of _rtds_PDSM_FLT_v1 component

6.9.3 GENERAL MODEL CONFIGURATION MENU FOR THE _rtds_PDSM_FLT_v1 COMPONENT

The _rtds_PDSM_FLT_v1 GENERAL MODEL CONFIGURATION MENU appears as shown in Figure 6.9.3.



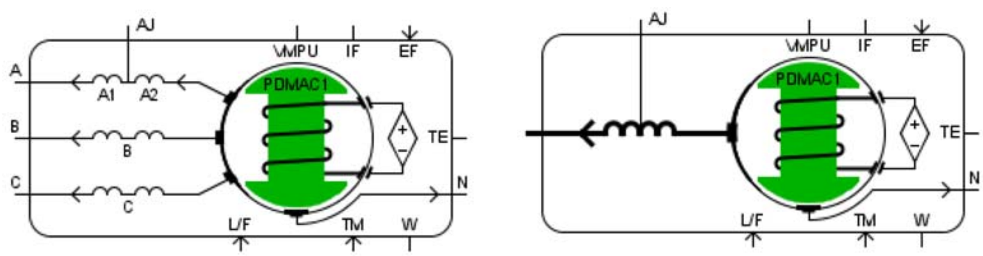
Name	Description	Value	Unit	Min	Max
Name	Component Name	PDMAC1			
fextyp	Machine Model Field Excitation type	Control System Input		0	1
indtyp	Machine Model Electrical Parameters type	DQ		0	1
mmva	Rated MVA of the Machine:	100.0	MVA	0.0001	
Vbsll	Rated RMS Line-to-Line Voltage:	13.8	kV	1E-9	1E6
HTZ	Base Angular Frequency:	60.0	Hertz	1E-9	1E6
MM	Get Delta Speed Order (r/s) from CC ?	No		0	1
spdin	Initial Speed in the first time steps is:	Rated		0	1
tecc	Send Elect Torque in PU, TE to CC ?	Yes		0	1
vtcc	Send Mach Bus V in PU, VMPU to CC ?	Yes		0	1
prtyp	Processor type	GPC		1	2

Figure 6.9.3 General Model Configuration Menu

Name: A unique name must be given for each instance of the component.

fextyp:

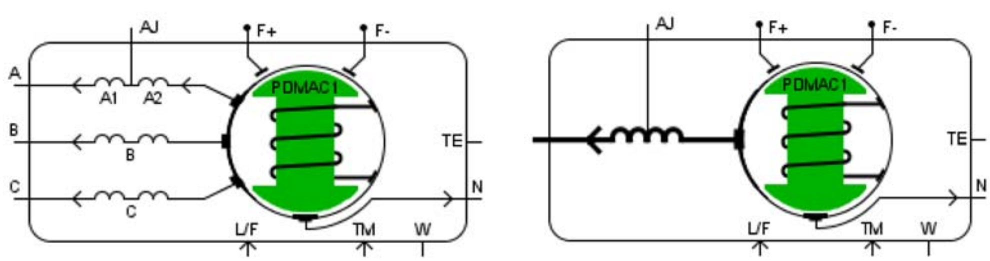
This option determines the type of field excitation which the user intends to use. If “Control System Input” is chosen, then the component will have the following view in the draft canvas, which is similar to lf_sharc_sld_MACV31 machine model. In this case the value of field voltage is determined by the the input control signal EF. With EF=1, the machine generates 1 pu terminal voltage in open circuit in linear steady−state conditions. User has the option of sending PU terminal voltage out and connecting the machine to the exciter models from the RSCAD library. If the “Power System Node” is selected‘, then the component will have the following view in the draft canvas. In this case, two power system nodes will appear (F+ and F−) which can be used to energize the field winding using actual power system components (e.g. DC source model or power electronics). If this option selected, the user has to provide the field current (kA) required for 1 pu unsaturated open−circuit terminal voltage at rated speed. This value is entered in the DQ−BASED MACHINE CONFIGURATION MENU. After compiling the circuit, the required field voltage for 1 pu unsaturated open−circuit terminal voltage at rated speed, and the required field voltage for initialization of the machine will be written in the MAP file.



3 Phase View

Single Line View

Figure 6.9.4 Component Icon for fextyp = Control System Input



3 Phase View

Single Line View

Figure 6.9.5 Component Icon for fextyp = Power System Node

indtyp:

This option determines the method of computing machine inductances discussed in the introductory section of this document. If the option “DQ” is selected, then the model assumes sinusoidal distribution for the faulted and unfaulted windings. If the node AJ is floating or connected to a large impedance, then the component will behave identical to lf_sharc_sld_MACV31 machine model. Connecting node AJ to ground through fault impedance can facilitate simulating synchronous machine stator−ground faults, and consequently testing stator−ground faults protection schemes. With the option of (indtyp =DQ), the machine does not generate phase belt harmonics, thus cannot be used for testing stator−ground faults protection schemes based on the existence of third harmonic voltage. These harmonics, however, can be generated separately and added to node voltages sent to the relay under test. The DQ−based model can operate neutral overvoltage and differential protection schemes depending on the type of neutral grounding [8,9]. . With this option (indtyp =DQ), similar to lf_sharc_sld_MACV31 machine model, the synchronous machine electric data can be entered in the form of impedances and time constants (generator) or impedances and resistances (R and X). Also, saturation characteristic of the machine can be specified as linear, saturation curve by points or saturation curve by factors.

If the option “MWFA” is selected, then the model considers the actual distributions of the windings and permeance as discussed in the introductory chapter of this document. The inductances of the synchronous machine under study must be computed based on the distributions of the windings and geometry of the rotor. This requires an offline module which receives the geometrical details of the machine, computes inductances as functions of rotor position and saturation and stores them in an inductance file [4,9] which will be entered in the MWFA−BASED MACHINE CONFIGURATION MENU. **The option of (indtyp =MWFA) is not presently available for the users.**

mmva: Rated MVA of the Machine (see MACV31 for more details).

Vbsl: Rated Stator Voltage of the Machine (Line−to−Line RMS) (see MACV31 for more details).

HTZ: Rated Operating Frequency of the Machine in Hz (see MACV31 for more details).

MM:

The “MM” menu item prompts for an indication of whether the machine speed calculation is internal to the model or, alternatively, whether the speed is to be calculated externally and provided to the machine model through an optional CC input (DW). ΔW is speed deviation in units of radians / second with respect to rated speed. For example, when the machine is operating at rated speed, as specified by the HTZ item, then $\Delta W = 0.0$ radians / second.

Choosing “Yes” in the “MM” menu item causes the MECHANICAL DATA AND CONFIGURATION menu tab to disappear. This corresponds with the fact that the machine speed is calculated external to the model when a “Yes” response is given for the “MM” item. Conversely, the CC input of mechanical torque TM per unit, and the CC output of machine speed W radians / second are also removed from the icon when a “Yes” response is given for the “MM” item.

In the case of a “No” response to the “MM” item, the reference direction for the mechanical torque CC input (TM) is positive torque when the machine is generating positive power into the electrical system. Also, in the case of a “No” response to the “MM” item, the CC output for machine speed (W) is in units of radians / second.

spdin:

The “spdin” menu item prompts for information concerning the speed of the model in the first time−steps. The two choices are: “Zero” and “Rated”. When initializing the machine according to a load flow it is important that the User select “Rated”. When the response of “Zero” is given, then the MACHINE INITIAL LOAD FLOW DATA menu tab will disappear. In that case, all currents in the stator and the rotor of the machine will be initially set to 0.0 in addition to setting initial speed to 0.0.

tecc:

The “tecc” item prompts for a request that Machine Electrical Torque in p.u. should be provided through an optional CC output point on the icon (TE), as shown on the above icon. This is required when the speed of the machine is calculated external to the model, such as when speed is calculated in an external multi−mass model (see item MM above). The TE output is in P.U. torque as determined by the machine MVA (item “mmva”) and rated speed in radians / second (item “HTZ” in Hertz). The reference direction for TE is positive torque when the machine is generating positive power into the electrical system.

vtcc:

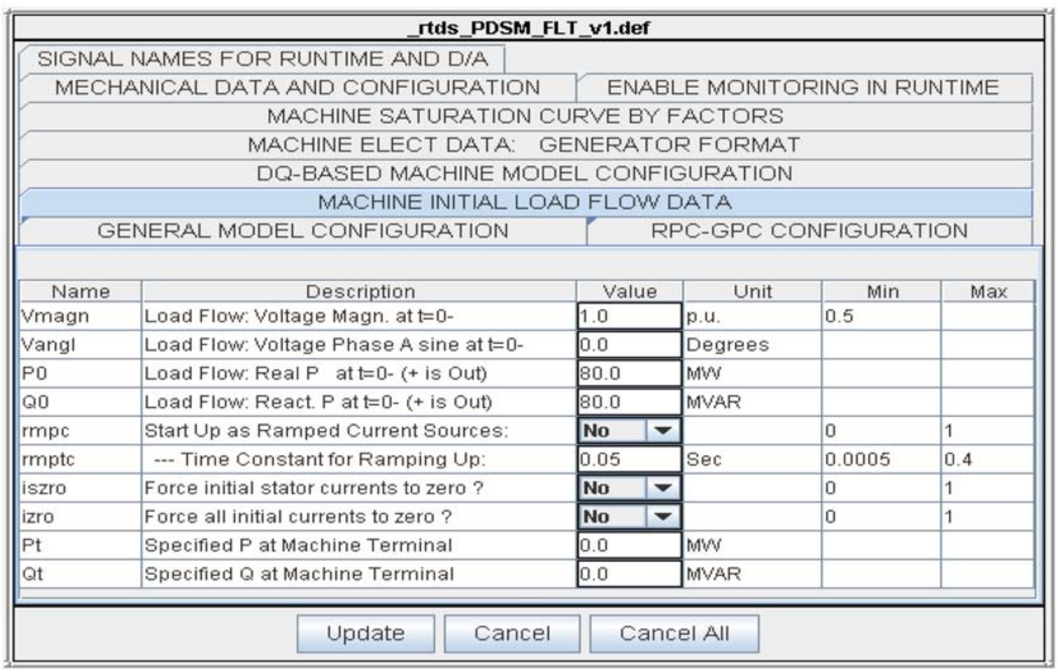
The “vtcc” item prompts for a request that the machine p.u. terminal voltage should be provided through an optional CC output point on the icon (VMPU). The VMPU output is calculated by taking the square root of the sum of the line−to−line voltages squared and then scaling to per unit. The per unit base comes from the item “Vbsll” noted above.

prtyp: The prtyp parameter allows the user to select on which type of processor the model is to be run. This model is currently available for RISC processor types.

The "cfgr" option in lf_sharc_sld_MACV31 machine model allows the choice between modelling one damper winding or two damper windings on the Q–axis of the rotor. In _rtds_PDSM_FLT_v1 faulted phase domain synchronous machine model, only one damper winding in each d– and q–axis is modeled.

6.9.4 MACHINE INITIAL LOAD FLOW DATA MENU FOR THE _rtds_PDSM_FLT_v1 COMPONENT

It is only possible to accurately initialize the machine model according to a load flow when the machine is to begin running at synchronous speed ("HTZ" in the GENERAL MODEL CONFIGURATION menu). Therefore, the MACHINE INITIAL LOAD FLOW menu tab will only appear when the initial speed (the "spdin" menu item in the GENERAL MODEL CONFIGURATION menu) is set to be "Rated". When the response is a "Zero" to the "spdin" menu item, then the machine will begin at zero speed and all currents in the machine will also be initialized as zero. The _rtds_PDSM_FLT_v1 MACHINE INITIAL LOAD FLOW DATA MENU appears as shown in Figure 6.9.6.



Name	Description	Value	Unit	Min	Max
Vmagn	Load Flow: Voltage Magn. at t=0-	1.0	p.u.	0.5	
Vangl	Load Flow: Voltage Phase A sine at t=0-	0.0	Degrees		
P0	Load Flow: Real P at t=0- (+ is Out)	80.0	MW		
Q0	Load Flow: React. P at t=0- (+ is Out)	80.0	MVAR		
rmpc	Start Up as Ramped Current Sources:	No		0	1
rmptc	--- Time Constant for Ramping Up:	0.05	Sec	0.0005	0.4
iszro	Force initial stator currents to zero ?	No		0	1
izro	Force all initial currents to zero ?	No		0	1
Pt	Specified P at Machine Terminal	0.0	MW		
Qt	Specified Q at Machine Terminal	0.0	MVAR		

Figure 6.9.6 Machine Initial Load Flow Data Menu

The four menu items at the top of the above menu allow initial terminal conditions of the machine to be specified which are sufficient for initializing the machine. These initial terminal conditions are available from the output of the load flow program. The effects of loading and saturation are included in the initialization calculations.

Vmagn: The magnitude "Vmagn" defines the magnitude of the terminal voltage.

Vangl: The angle "Vangl" defines the angle of the "A" phase terminal voltage sine wave in Degrees at time = 0.

P0: Initial output active power at time = 0.

Q0: Initial output reactive power at time = 0.

The effects of loading and saturation are included in the initialization calculations. The initialization feature calculates and initializes the initial stator and field currents and also the initial angular position of the rotor. The initialization also pre−calculates the mechanical torque and normalized field voltage which would be required to provide the desired real and reactive power (P0 and Q0) out of the machine for the specified machine terminal voltage (Vmagn). The calculated field voltage and torque are useful in initializing the exciter and governor models prior to the start of a simulation.

rmpc, rmptc:

The "rmpc" menu item in the above menu prompts whether the machine should begin with zero output currents and then ramp to the pre−calculated initial output currents according to an exponential time constant. The "rmptc" is the time−constant for this ramping−up procedure. **Presently, this option is not available in the phase−domain faulted synchronous machine model _rtds_PDSM_FLT_v1.**

iszro:

Generally, select "No" when the "iszro" item prompts for whether or not the compiler should "force initial stator currents to zero". This feature is carried over from very early versions of the machine model. The "iszro" menu item allows all initial stator currents to be forced to zero.

izro:

The "izro" menu item can be used to start the machine with rotor or stator currents set to zero regardless of the load flow data

6.9.5 DQ−BASED MACHINE MODEL CONFIGURATION

The _rtds_PDSM_FLT_v1 DQ−BASED MACHINE MODEL CONFIGURATION MENU appears as shown in Figure 6.9.7.

cnfg: The "cnfg" entry in the DQ−BASED MACHINE MODEL CONFIGURATION menu permits the the choice between entering the machine data in "Generator" format or alternatively in "R and X" format. "R and X" format is sometimes referred to as Motor format. In the "R and X" format case, the R AND X FORMAT menu tab replaces the GENERATOR FORMAT menu tab.

Ifnorm: The "Ifnorm" menu is activated if "fextyp" is selected as "Power System Node" in the GENERAL MODEL CONFIGURATION MENU. If this option selected, the user has to provide the field current (kA) required for 1 pu unsaturated open−circuit terminal voltage at rated speed. After compiling the circuit, the required field voltage for 1 pu unsaturated open−circuit terminal voltage at rated speed, and the required field voltage for Initialization of the machine will be written in the MAP file.

satur: The “satur” menu item prompts for an indication of whether D−axis saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2).

FLTprc: In this menu the user identifies the point on the phase A winding in which this stator winding is divided into two sub−windings A1 and A2. This is shown by the percentage of the fault from the neutral side. The location of fault can be as close as 5% to one end of the winding.

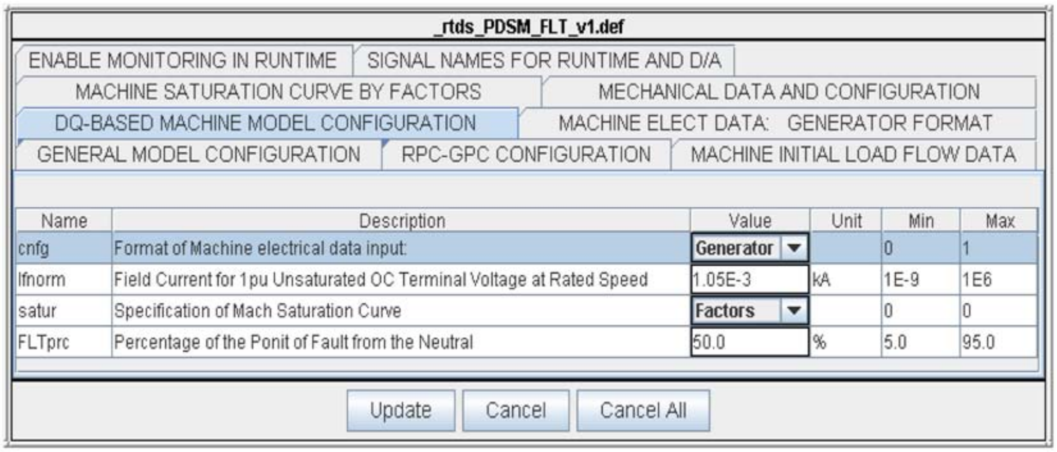


Figure 6.9.7 DQ−Based Machine Model Configuration Menu

6.9.6 THE MACHINE ELECT DATA MENUS

The machine electrical data parameters are used for determining the per unit resistances and reactances on the D and Q axes of the machine model. The resistances and reactances are as shown in Figure 6.9.8. These resistances and reactances can be entered directly or converted from “Generator” type data. As mentioned earlier, In _rtds_PDSM_FLT_v1 faulted phase domain synchronous machine model, only one damper winding in each d− and q−axis is modeled. Also, the D−axis transfer admittance X230 is not considered.

There are two alternative menus for specifying the main machine electrical data parameters. If the default “Generator” is selected as the “Format of Machine electrical data” in the GENERAL MODEL CONFIGURATION menu, then the menu MACHINE ELECT DATA: GENERATOR FORMAT menu becomes available. Alternatively, the MACHINE ELECT DATA: R AND X FORMAT menu becomes available.

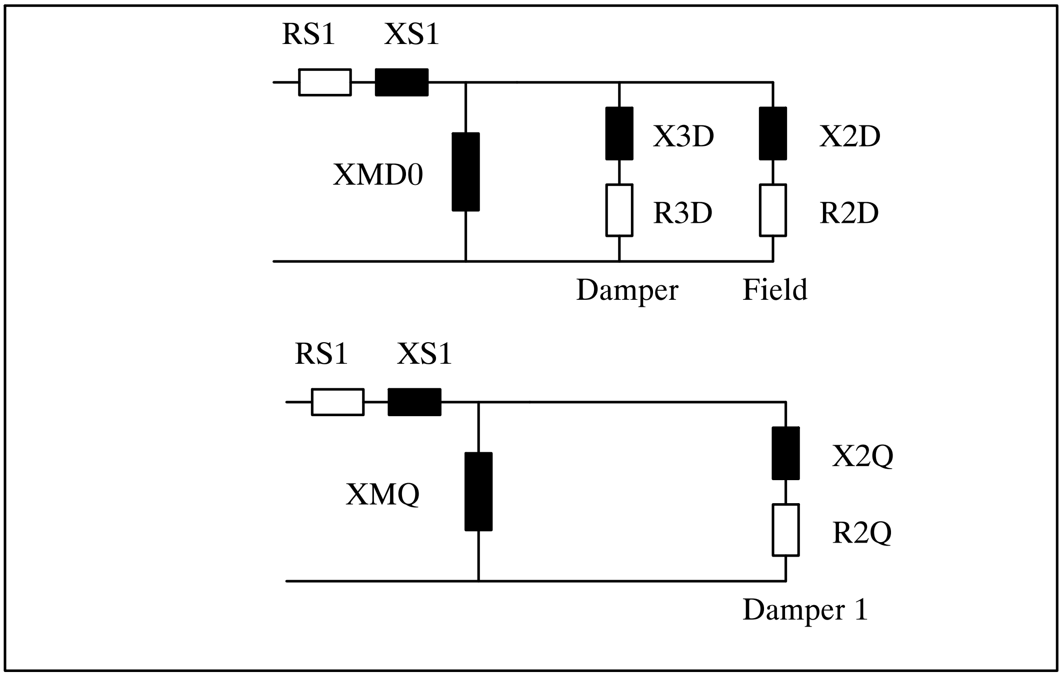


Figure 6.9.8 DQ−Based Machine Model Configuration Menu

6.9.7 MACHINE ELECT DATA: R AND X FORMAT MENU

The _rtds_PDSM_FLT_v1 MACHINE ELECTRIC DATA: R AND X FORMAT MENU appears as shown in Figure 6.9.9:

XS1: Stator leakage reactance in p.u.

XMD0: D−axis unsaturated magnetizing reactance in p.u.

X2D: Field leakage reactance in p.u.

X3D: D−axis damper leakage reactance in p.u.

XMQ: D−axis unsaturated magnetizing reactance in p.u.

X2Q: Q−axis damper leakage reactance in p.u.

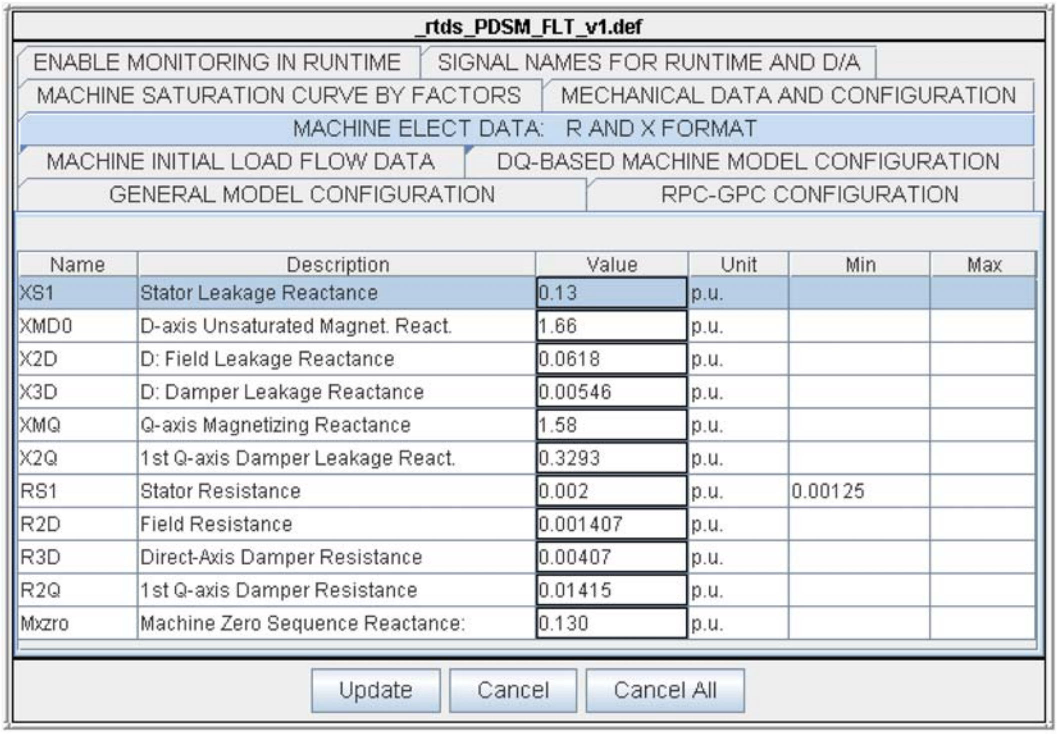
RS1: Stator resistance in p.u.

R2D: Stator resistance in p.u.

R3D: Field resistance in p.u.

R2Q: Q−axis damper resistance in p.u.

Mxzro: Machine zero sequence reactance in p.u.Note that, the machine zero sequence resistance is assumed to be equal to the stator resistance.



Name	Description	Value	Unit	Min	Max
XS1	Stator Leakage Reactance	0.13	p.u.		
XMD0	D-axis Unsaturated Magnet. React.	1.66	p.u.		
X2D	D: Field Leakage Reactance	0.0618	p.u.		
X3D	D: Damper Leakage Reactance	0.00546	p.u.		
XMQ	Q-axis Magnetizing Reactance	1.58	p.u.		
X2Q	1st Q-axis Damper Leakage React.	0.3293	p.u.		
RS1	Stator Resistance	0.002	p.u.	0.00125	
R2D	Field Resistance	0.001407	p.u.		
R3D	Direct-Axis Damper Resistance	0.00407	p.u.		
R2Q	1st Q-axis Damper Resistance	0.01415	p.u.		
Mxzro	Machine Zero Sequence Reactance:	0.130	p.u.		

Figure 6.9.9 Machine Electrical Data: R and X Format Menu

6.9.8 MACHINE ELECT DATA: GENERATOR FORMAT MENU

The _rtds_PDSM_FLT_v1 MACHINE ELECTRIC DATA: GENERATOR FORMAT MENU appears as shown in Figure 6.9.10. The reactances in the GENERATOR FORMAT menu are unsaturated reactances in per unit. The time constants contained in the menu are open−circuited unsaturated time constants in seconds.

Xa: Stator leakage reactance in p.u.

Xd: D−axis unsaturated reactance in p.u.

Xd’: D−axis unsaturated transient reactance in p.u.

Xd”: D−axis unsaturated sub−transient reactance in p.u.

Xq: Q−axis reactance in p.u.

Xq’: Q−axis transient reactance in p.u.

Xq”: Q−axis sub−transient reactance in p.u.

Ra: Stator resistance in p.u.

Tdo’: D−axis unsaturated transient open−circuit time constant in (s).

Tdo”: D−axis unsaturated sub−transient open−circuit time constant in (s).

Tqo”: Q−axis unsaturated sub−transient open−circuit time constant in (s).

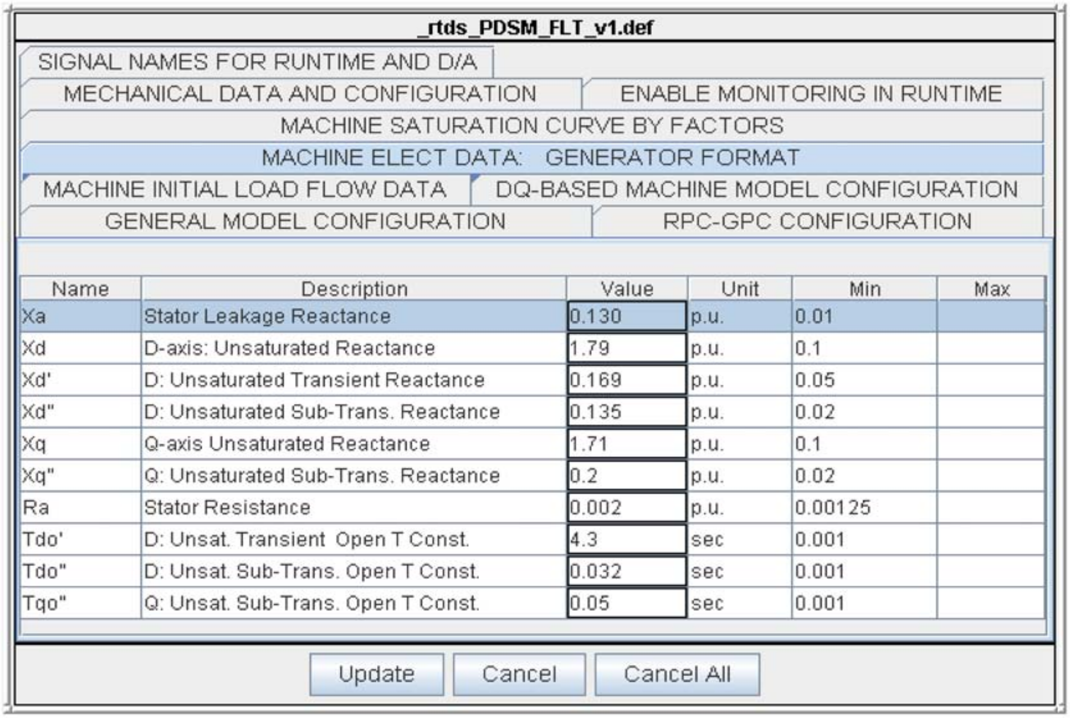


Figure 6.9.10 Machine Electrical Data: Generator Format Menu

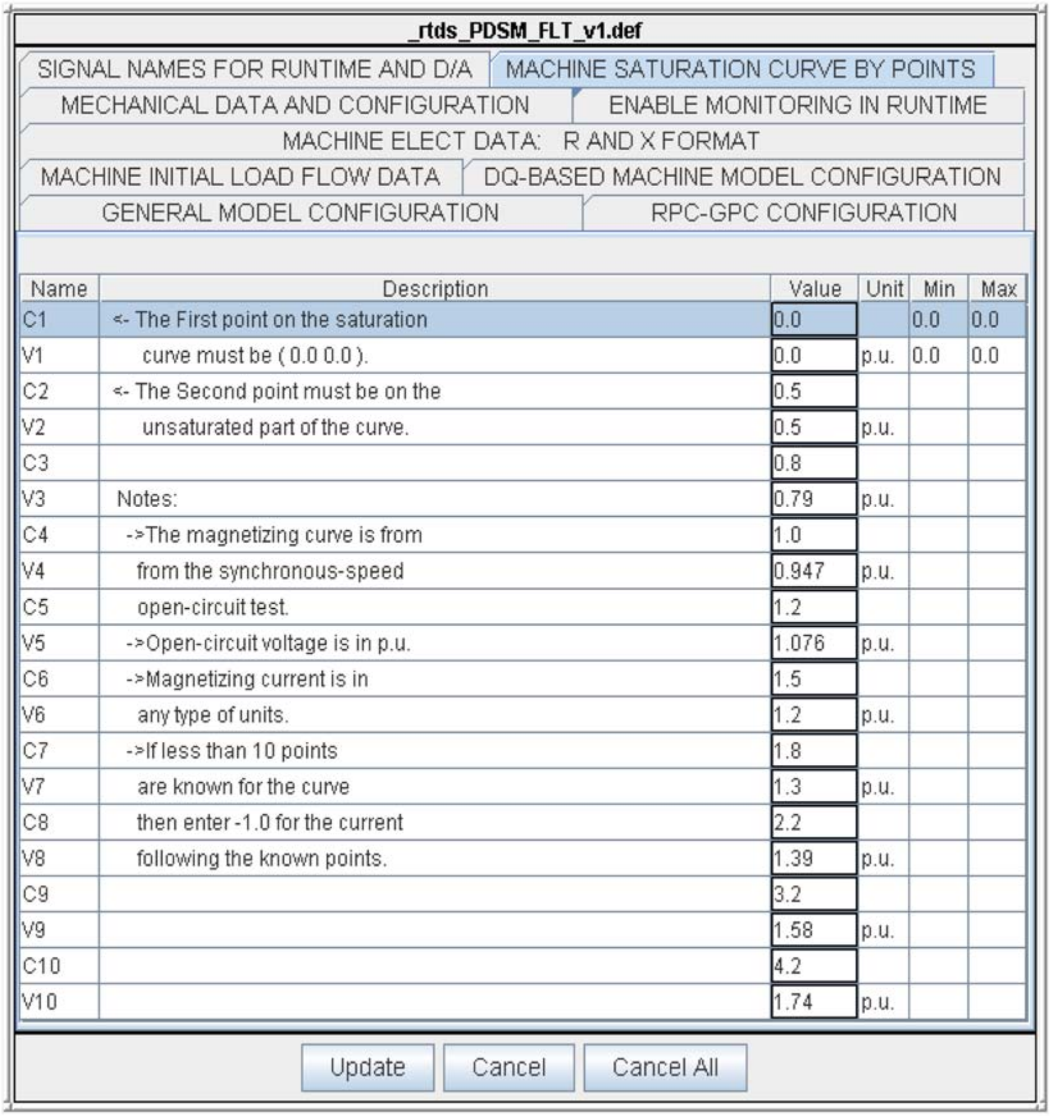
6.9.9 THE MACHINE SATURATION CURVE MENUS

The DQ−BASED MACHINE MODEL CONFIGURATION menu contains an item labelled “satur” which allows the method of specifying machine D−axis saturation to be chosen. The choices are “Linear”, “Points”, and “Factors. If “Linear” is chosen, then the D−axis will not saturate. The other two choices are explained below.

6.9.10 The MACHINE SATURATION CURVE BY POINTS MENU

The MACHINE SATURATION CURVE BY POINTS menu appears as follows: This method requires a saturation curve for the D−axis of the machine to be entered using points on the curve. The required curve can be obtained during synchronous−speed open−circuit operation by varying the field current and monitoring the stator voltage. The curve is a plot of stator voltage in per−unit versus magnetizing current specified in units of the User’s choice. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point allows it to provide scaling information for magnetizing currents entered in the menu. If fewer than 10 points are known for the curve, then enter −1.0 for the currents following the known points. An unsaturated machine can be represented by entering a straight line in the menu.

In the lf_sharc_sld_MACV31 machine model, linear interpolation is used to generate and store the saturation curve of the machine whereas, in the _rtds_PDSM_FLT_v1 machine model, cubic spline method is used for generating the saturation curve from limited number of points provided by the user. This may cause small differences between the results of initialization and simulation.

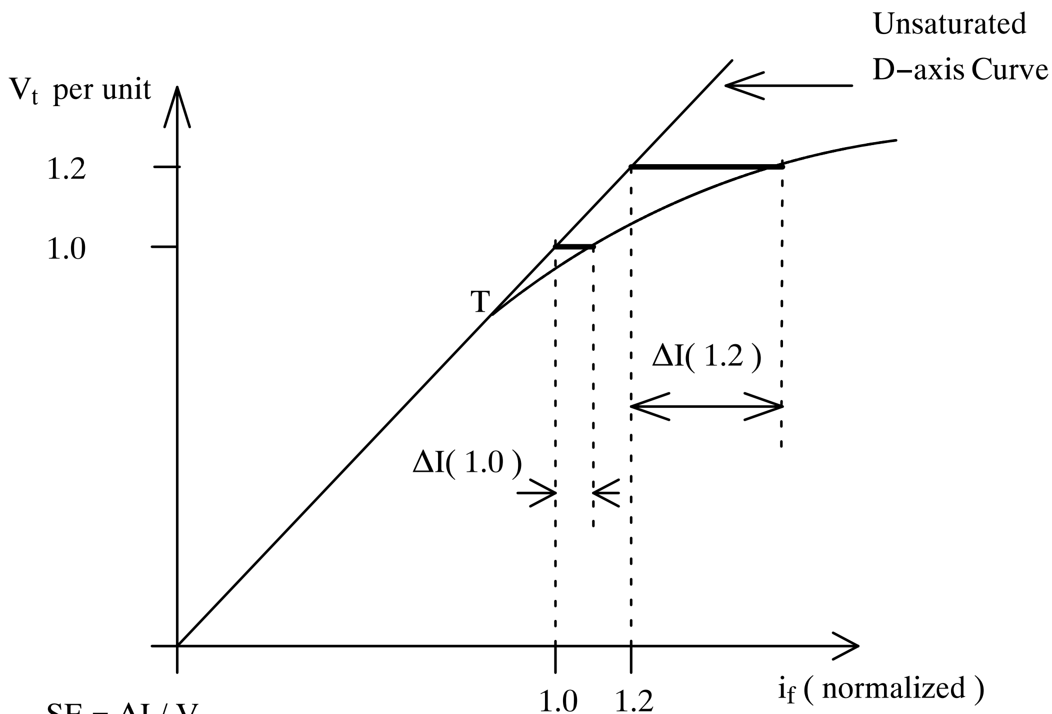


Name	Description	Value	Unit	Min	Max
C1	<- The First point on the saturation	0.0		0.0	0.0
V1	curve must be (0.0 0.0).	0.0	p.u.	0.0	0.0
C2	<- The Second point must be on the	0.5			
V2	unsaturated part of the curve.	0.5	p.u.		
C3		0.8			
V3	Notes:	0.79	p.u.		
C4	->The magnetizing curve is from	1.0			
V4	from the synchronous-speed	0.947	p.u.		
C5	open-circuit test.	1.2			
V5	->Open-circuit voltage is in p.u.	1.076	p.u.		
C6	->Magnetizing current is in	1.5			
V6	any type of units.	1.2	p.u.		
C7	->If less than 10 points	1.8			
V7	are known for the curve	1.3	p.u.		
C8	then enter -1.0 for the current	2.2			
V8	following the known points.	1.39	p.u.		
C9		3.2			
V9		1.58	p.u.		
C10		4.2			
V10		1.74	p.u.		

Figure 6.9.11 Machine Saturation Curve By Points Menu

6.9.11 MACHINE SATURATION CURVE BY FACTORS MENU

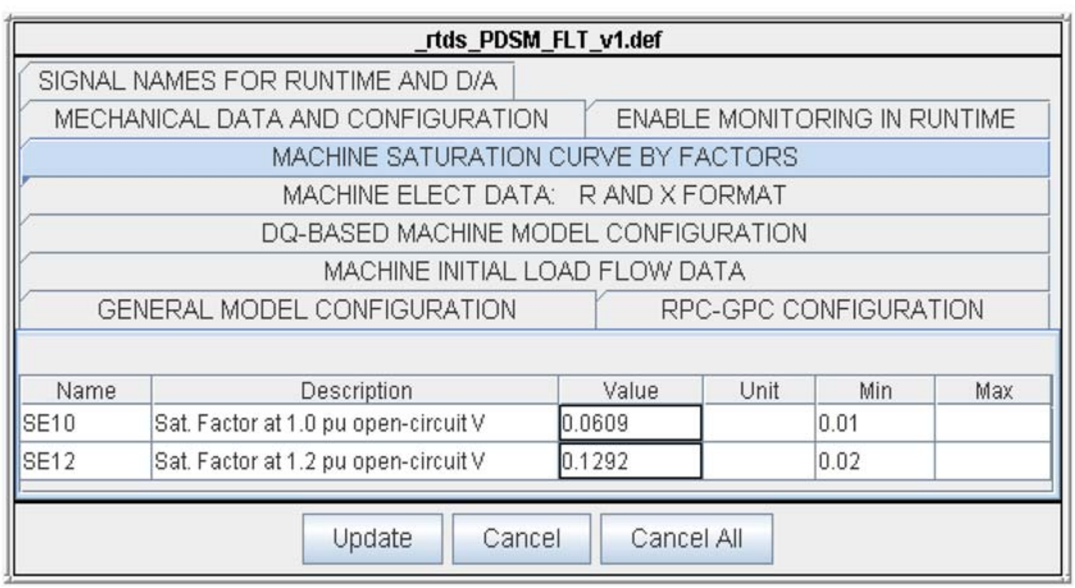
The required saturation curve is the curve which can be obtained during synchronous−speed open−circuit operation by varying the field current and monitoring the stator voltage.The two factors to be specified in the above menu are defined in Figure 6.9.12. The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.



$SE = \Delta I / V_t$
$SE(1.0) = \Delta I(1.0) / 1.0$
$SE(1.2) = \Delta I(1.2) / 1.2$

Figure 6.9.12 Machine Saturation Curve By Factors SE10 and SE12

The MACHINE SATURATION CURVE BY FACTORS menu appears as shown in Figure 6.9.13.



_rtds_PDSM_FLT_v1.def

SIGNAL NAMES FOR RUNTIME AND D/A
MECHANICAL DATA AND CONFIGURATION | ENABLE MONITORING IN RUNTIME
MACHINE SATURATION CURVE BY FACTORS
MACHINE ELECT DATA: R AND X FORMAT
DQ-BASED MACHINE MODEL CONFIGURATION
MACHINE INITIAL LOAD FLOW DATA
GENERAL MODEL CONFIGURATION | RPC-GPC CONFIGURATION

Name	Description	Value	Unit	Min	Max
SE10	Sat. Factor at 1.0 pu open-circuit V	0.0609		0.01	
SE12	Sat. Factor at 1.2 pu open-circuit V	0.1292		0.02	

Update Cancel Cancel All

Figure 6.9.13 Machine Saturation Curve By Factors Menu

6.9.12 THE MECHANICAL DATA AND CONFIGURATION MENU

This menu is needed when the model is configured to internally calculate the speed of the machine. This menu is only available if the "MM" item in the GENERAL MODEL CONFIGURATION menu has been set to "No". Responding with a "Yes" to the "MM" item configures the model to receive a speed order from the CC. Therefore, when the "MM" item is specified as "No" in the GENERAL MODEL CONFIGURATION menu, then the MECHANICAL DATA AND CONFIGURATION menu is made available for specifying the required mechanical data. The MECHANICAL DATA AND CONFIGURATION menu appears as shown in Figure 6.9.14.

H:

The "H" menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating. The MVA rating of the machine is as entered in the GENERAL MODEL CONFIGURATION menu in response to the "mmva" item.

D:

The "D" menu item prompts for a synchronous damping torque factor. The resulting damping torque tends to resist over−speed or under−speed operation. The damping torque factor "D" is in units of per−unit torque over per−unit speed deviation.When the machine model is responsible for calculating the machine speed (MM = "No" in the GENERAL MODEL CONFIGURATION menu), then the machine can be run in locked speed mode or in free speed mode. In locked speed mode, the speed of the machine is determined by a machine slider (CONSPD) in RunTime which has a default value of synchronous speed. It is usually not necessary to change the default value of the CONSPD slider. Therefore, it is usually not necessary to create or use the CONSPD slider.In the free speed mode, the machine speed is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (TM), electrical torque (TE), and the damping torque.

MSW:

If the "Location of the Lock/Free Mode Switch" is specified as RunTime using the "MSW" item in the above menu, then a switch labelled "LockFree" will appear in the CREATE−>SWITCH menu in RunTime for the machine. If the "Location of the Lock/Free Mode Switch" is specified as CC (Controls Compiler) using the "MSW" item in this menu, then a CC integer input labelled "L/F" will appear on the lower edge of the icon. If an integer 0 is supplied to the L/F input, then the machine will run in locked speed mode. If an integer 1 is supplied to the L/F input, then the machine will run in free speed mode.

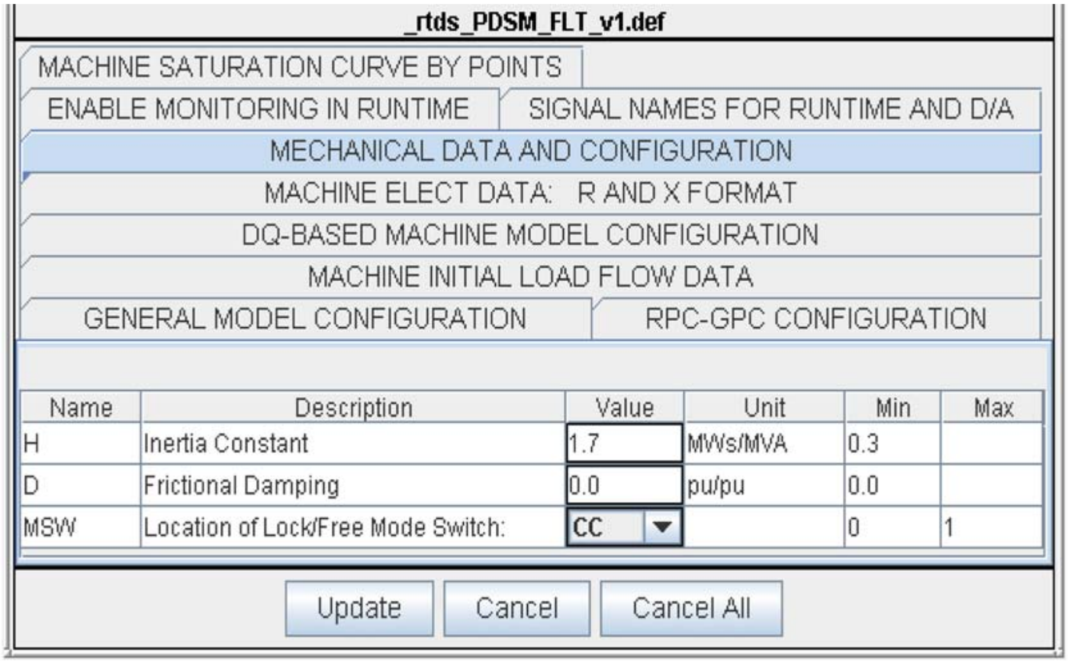


Figure 6.9.14 Mechanical Data And Configuration Menu

6.9.13 THE ENABLE MONITORING IN RUNTIME MENU

The _rtds_PDSM_FLT_v1 ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.9.15.

Active and Reactive Power Out of the Machine:

The active and reactive power of the machine can be monitored. Similar to other machine models the positive direction of monitoring is out of the machine.

Stator Currents:

The user has the option of monitoring the currents of stator windings: A1, A2, B, C, and the neutral current.

dcrt:

This parameter allows the user to determine the direction of monitored current (into the winding or out of winding). The direction of monitored currents will be shown by arrows on the _rtds_PDSM_FLT_v1 icon in the draft canvas.

Stator Voltages:

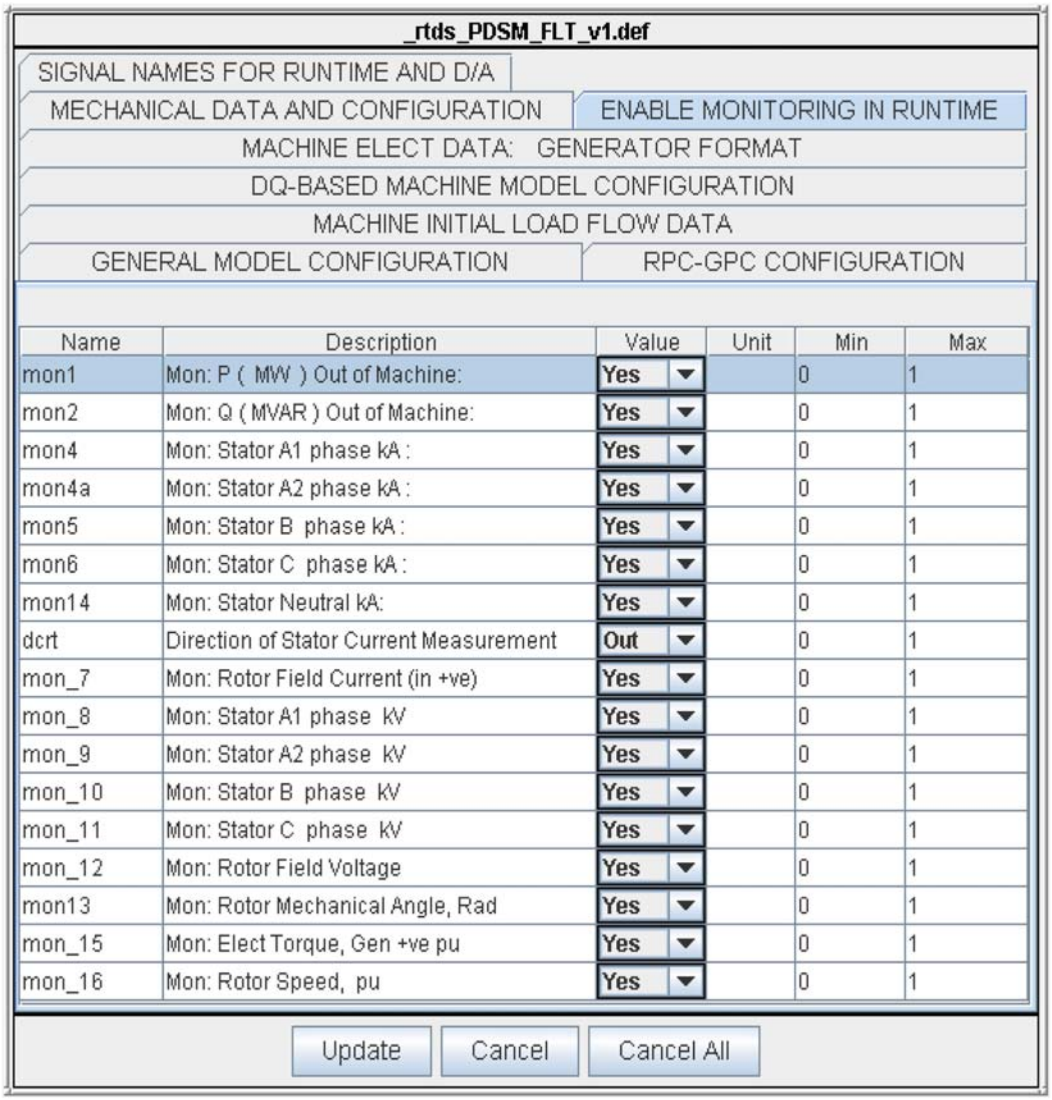
The voltage drop across the stator windings: A1, A2, B, and C can also be monitored.

Rotor Field Current and Voltage:

The field winding current and voltage can be monitored in runtime. The direction of monitored field current is into the field winding. The unit for the field current and voltage is kA and kV if “fextyp” is selected as Power System Node in the GENERAL MODEL CONFIGURATION MENU. Otherwise these quantities will be monitored in “Norm” values.

Rotor Angle, Electric Torque, and Rotor Speed:

Mechanical quantities such as rotor angle, electric torque and rotor speed can also be monitored in Radians, pu , and pu respectively. For generator mode of the machine, the electric torque is positive (similar to other machine models in RTDS).

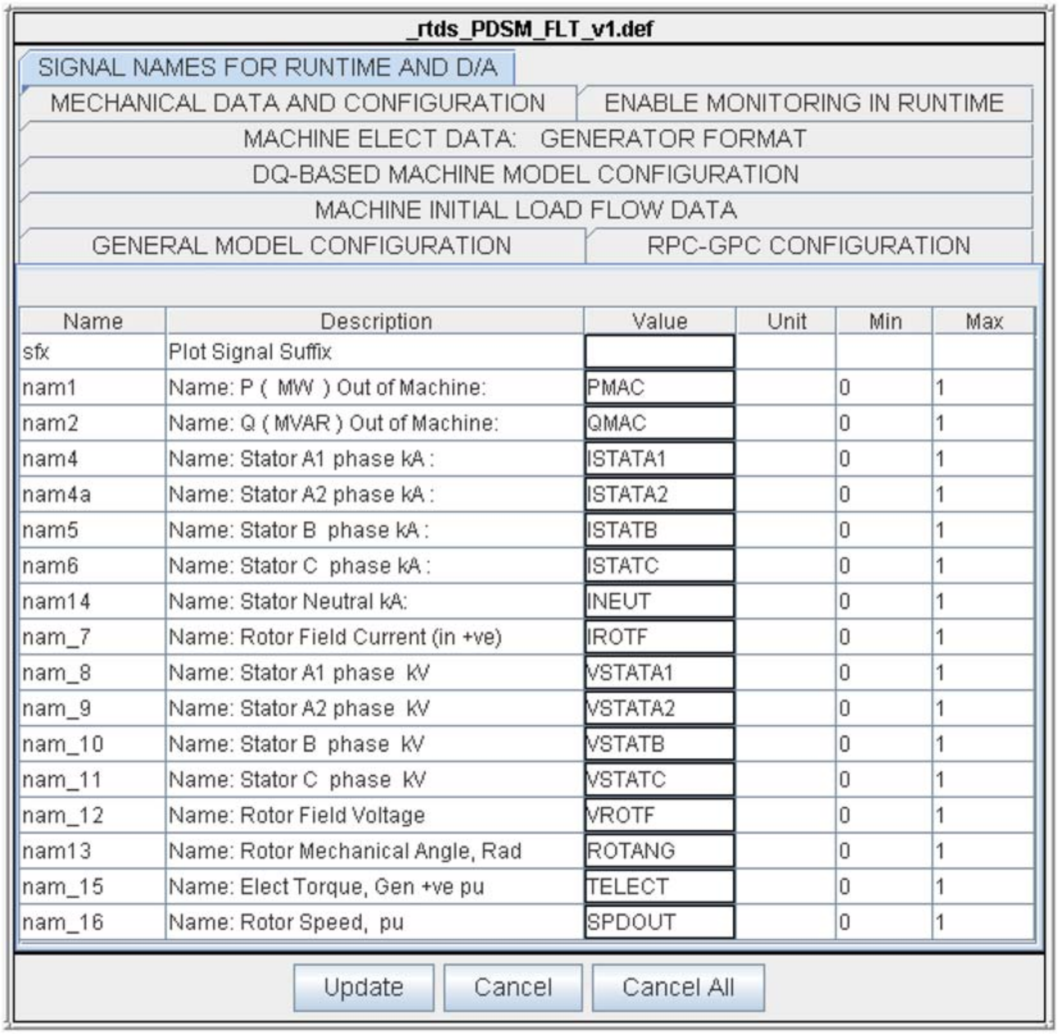


Name	Description	Value	Unit	Min	Max
mon1	Mon: P (MW) Out of Machine:	Yes		0	1
mon2	Mon: Q (MVAR) Out of Machine:	Yes		0	1
mon4	Mon: Stator A1 phase kA :	Yes		0	1
mon4a	Mon: Stator A2 phase kA :	Yes		0	1
mon5	Mon: Stator B phase kA :	Yes		0	1
mon6	Mon: Stator C phase kA :	Yes		0	1
mon14	Mon: Stator Neutral kA:	Yes		0	1
dcrt	Direction of Stator Current Measurement	Out		0	1
mon_7	Mon: Rotor Field Current (in +ve)	Yes		0	1
mon_8	Mon: Stator A1 phase kV	Yes		0	1
mon_9	Mon: Stator A2 phase kV	Yes		0	1
mon_10	Mon: Stator B phase kV	Yes		0	1
mon_11	Mon: Stator C phase kV	Yes		0	1
mon_12	Mon: Rotor Field Voltage	Yes		0	1
mon13	Mon: Rotor Mechanical Angle, Rad	Yes		0	1
mon_15	Mon: Elect Torque, Gen +ve pu	Yes		0	1
mon_16	Mon: Rotor Speed, pu	Yes		0	1

Figure 6.9.15 Enabling Monitoring in Runtime Menu

6.9.14 THE SIGNAL NAMES FOR RUNTIME MENU

The _rtds_PDSM_FLT_v1 SIGNAL NAMES IN RUNTIME MENU appears as shown in Figure 6.9.16. The user must dedicate a unique name for the monitored signals. A suffix can also be added to the signal names.



Name	Description	Value	Unit	Min	Max
sfx	Plot Signal Suffix				
nam1	Name: P (MW) Out of Machine:	PMAC		0	1
nam2	Name: Q (MVAR) Out of Machine:	QMAC		0	1
nam4	Name: Stator A1 phase kA :	ISTATA1		0	1
nam4a	Name: Stator A2 phase kA :	ISTATA2		0	1
nam5	Name: Stator B phase kA :	ISTATB		0	1
nam6	Name: Stator C phase kA :	ISTATC		0	1
nam14	Name: Stator Neutral kA:	INEUT		0	1
nam_7	Name: Rotor Field Current (in +ve)	IROTF		0	1
nam_8	Name: Stator A1 phase kV	VSTATA1		0	1
nam_9	Name: Stator A2 phase kV	VSTATA2		0	1
nam_10	Name: Stator B phase kV	VSTATB		0	1
nam_11	Name: Stator C phase kV	VSTATC		0	1
nam_12	Name: Rotor Field Voltage	VROTF		0	1
nam13	Name: Rotor Mechanical Angle, Rad	ROTANG		0	1
nam_15	Name: Elect Torque, Gen +ve pu	TELECT		0	1
nam_16	Name: Rotor Speed, pu	SPDOUT		0	1

Figure 6.9.16 Signal Names for Monitoring in RunTime Menu

6.9.15 MACHINE INFORMATION WRITTEN IN THE MAP FILE

After compiling a draft case containing an _rtds_PDSM_FLT_v1 machine model, the MAP file will contain information about this phase–domain machine model. Figure 6.9.17 shows an example of the MAP file. It contains the name of the machine model, the type of field excitation, type of inductance calculation, and the electric parameters of the machine in the dq equivalent circuit. It mentions the location of fault on phase A. It also identifies the required field voltage and mechanical torque for the initial conditions.

```
==========================================================================================
 RISC-based CModel component model of type "PDSM (Phase Domain Synchronous Machine)"
   named: PDMAC1
   in subsystem: 1
   is a DQ-based machine model.
   It uses control components for field excitation.

   It has the following electric parameters:
   ====================================
   Rated MVA of the Machine:                      100.000000    MVA
   Rated RMS Line-to-Line Voltage:                13.800000    kV
   Base Angular Frequency:                        60.000000    Hz
   Stator Leakage Inductance:                     0.130000    p.u.
   Field Leakage Inductance:                      0.061789    p.u.
   D-axis Damper Leakage Inductance:              0.005458    p.u.
   Q-axis Damper Leakage Inductance:              0.073245    p.u.
   D-axis Unsaturated Magnetizing Inductance:     1.660000    p.u.
   Q-axis Unsaturated Magnetizing Inductance:     1.580000    p.u.
   D-axis Self Inductance:                        1.790000    p.u.
   Q-axis Self  Inductance:                       1.710000    p.u.
   Zero Sequence  Inductance:                     0.130000    p.u.
   Stator Resistance:                             0.002000    p.u.
   Field Resistance:                              0.001407    p.u.
   D-axis Damper Resistance:                      0.004070    p.u.
   Q-axis Damper Resistance:                      0.087707    p.u.
       ============================================

   The phase A winding is divided into two sub-windings A1 & A2:
       ============================================
       sub-winding A1 has     50.00 % of the total number of turns in phase A.
       sub-winding A2 has     50.00 % of the total number of turns in phase A.
       ============================================

   For the specified initial conditions at rated speed:
       =============================================
       Voltage Magn. at t=0-:                 1.000000    p.u.
       Voltage Phase A sine at t=0-:          0.000000    Degrees
       Real P   at t=0- (+ is Out):           80.000000    MW
       React. P at t=0- (+ is Out):           80.000000    MVAR

     It requires:
       The Initial Rotor Angle to be at:     -2.618529    Rad
       The Initial Mechanical Torque of:      0.802560    p.u.
       The Initial Field Voltage to be at:    2.886229    Norm
==========================================================================================

RISC-based CModel Component: CBPDSM30 named "PDMAC1" --> RPC-GPC Card #2 Processor B
```

Figure 6.9.17 Machine Information Written in the MAP File

6.9.16 SUMMARY

The Cbuilder _rtds_PDSM_FLT_v1, phase domain synchronous machine (PDSM) model, available for simulating stator−ground faults for large time−step simulation provides a model that is flexible in configuration so as to meet the various needs of different users particularly those interested in closed−loop testing of synchronous machines protection relays. The performance of this model in closed−loop testing of some of these schemes (such as differential protection, 100% stator−ground fault protection, and loss of field excitation) is validated [13]. This model is an embedded phase − domain model [4]. The user has the option of using control components for exciting the field windings or connecting the field winding directly to power system components. The user can operate the model in dq−based or MWFA−based modes [9]. In the dq−based mode, the model does not generate phase−belt harmonics. The detailed information about the distribution of the windings and permeance are required for operating the model in the MWFA−based mode.

Although, in the _rtds_PDSM_FLT_v1 phase domain synchronous machine model, only phase A can be subject to internal faults. However, the performance of relay models and physical relays in detecting faults in phases B and C can be tested by switching the name of monitored phase currents and voltages. For example sending phase A current of the machine to phase B of the relay, phase

B of the machine to phase C of the relay and phase C of the machine to phase A of the relay.

At the moment, this model has the following limitations:

1. The offline program ,which uses the Modified Winding Function Approach (MWFA) to compute the inductances of the machine based on the distribution of windings and permeance, is not integrated into the RSCAD software. Therefore, the MWFA option in the “General Model Configuration Menu” can not be used presently.

2. The dq−based option in the _rtds_PDSM_FLT_v1, phase domain synchronous machine (PDSM) model, calculates the inductances of faulted windings based on the research performed in [6,7]. This method was originally developed for two−pole synchronous machines. Although, the authors claim that the method can be generalized for multipole machines, however, this matter is not proved. In any case, the model is capable of operating differential relay and neutral over voltage relays. If the 3rd harmonic voltages of the neutral and terminals are simulated separately, then “100% ground−fault protection” can also be tested.

3. Six computational load units of RTDS are required for real−time simulation of a _rtds_PDSM_FLT_v1, phase domain synchronous machine (PDSM) model. Therefore this component cannot be stacked on a GPC card processor.

6.10 SINGLE PHASE INDUCTION MACHINE MODEL (SPIM)

6.10.1 INTRODUCTION

Most small power (generally below 2 kW) induction machines have to operate with single−phase a.c. power supplies that are readily available in homes, and remote rural areas [14].

When power electronics converters are used, three phase a.c. output is produced and thus three phase induction motors may still be used. However, for most applications, the induction motors are fed directly from the available single−phase a.c. power grids. In this sense, we call them single phase induction motors [14].

These machine are used to drive fans, pumps, air compressors, refrigeration compressors, air conditioning fans and blowers, saws, grinders and office machines [15].

To be self−starting, the induction machine needs a rotating field at zero speed. This in turn implies the presence of two windings in the stator, while the rotor has a standard squirrel cage [14]. The first winding is called the main winding while the second winding (for start, especially) is called the auxiliary winding [14].

Single phase IMs may run only on the main winding only once they started on two windings. A typical case of single phase single−winding IM occurs when a three IMs ends up with an open phase. The power factor and efficiency degrade while the peak torque also decreases significantly [14]. Thus, except for low powers (less than 1/4 kW in general), the auxiliary winding is active also during running conditions to improve performance.

The followings are the main types of single−phase induction motors in use today:

− Split−Phase Induction Motors

− Capacitor Induction Motors

− Shaded−Pole Induction Motors

The split−phase motor sometimes called resistance split−phase, achieves its starting torque by having a higher resistance and possibly lower reactance in the auxiliary circuit, which is usually wound 90 electrical degrees from the main winding. At a speed in the region of maximum torque, the auxiliary winding is switched off. The switch may be activated by speed (centrifugal), voltage, current, or temperature [15]. The starting torque of these motors is moderate, but the starting current is relatively high. Efficiency and power factor are moderate, with efficiency ranging from about 40% at 0.1 hp to about 70% at 0.75 hp [14].

Capacitor induction motors are in the forms of “Capacitor−Start Motors”, “Permanent−Split Capacitor Motors” and “Two Value Capacitor Motors”.

In the “capacitor−start” motor the starting torque is obtained by use of a capacitor in series with the auxiliary winding while starting, then switching the auxiliary winding out as the motor reaches running speed. The capacitor causes the auxiliary winding current to lead the main current. These machines are used for hard to start applications such as pumps, compressors, etc. up to the rating of 5 hp [15].

A "permanent−split capacitor motor" is designed for applications where starting torque requirements are low, but improved running performance is required. In this case, the motor is designed to have a capacitor in series with the auxiliary winding all the time [15].

In a "two−value capacitor motor", a start capacitor is placed in parallel with the run capacitor. This allows the motor to be designed for optimum running efficiency without sacrificing efficiency to get starting torque. Two−value capacitor motors have been available for years in the range of 1−10 hp [15].

In "shaded−pole machines", the auxiliary winding is usually a simple shorted turn of conductor around one side of each stator pole, called a shading coil. Shaded−pole motors are simple in construction and are therefore relatively low cost and reliable. Starting current is relatively high, starting torque is relatively low, running current is relatively high, and efficiency and power factor are low [15]. They are widely used to drive small fans (1/5 hp and below), because they are low in cost and reliable.

6.10.2 THEORY AND ANALYSIS

This chapter briefly describes the analysis and method of modeling single phase induction machines. For further information please see the references [14] and [16]−[18].

As mentioned above, a single phase induction machine consists of two stator windings known as main and auxiliary with the angular space of normally 90°. The stator windings are usually asymmetric, i.e. main and auxiliary windings do not have similar parameters. The rotor has the standard squirrel cage, which in rotating field theory can be represented by two d− and q−axis windings. Figure 6.10.1 shows the diagram of an idealized two phase induction machine. Windings *as* and *bs* represent stator windings and windings *ar* and *br* represent rotor windings. The rotor angle is shown by θ_r and rotor speed is shown by ω_r. In this analysis, stator phase a is the main winding of the machine and stator phase b is the auxiliary winding. As previously mentioned they are not symmetric and they do not have similar parameters. The rotor windings are symmetric and have similar parameters. The ratio of effective turns between the auxiliary and main windings $\left(\frac{N_{bs}}{N_{as}}\right)$ is usually shown by symbol a.

The following assumptions are made in this analysis:

− Similar to other machine models in RTDS, multi−pole single phase IMs are modeled as an equivalent two pole machine. Torque and speed are monitored in p.u..

− It is assumed that the machine windings produce a sinusoidal MMF, thus space harmonics are ignored.

− As the rotor is a cylindrical round rotor, saturation is modeled similar to the three phase induction machine by adjusting the magnetizing inductance as a function of the total magnetizing current peak value. Saturation in the leakage paths is ignored..

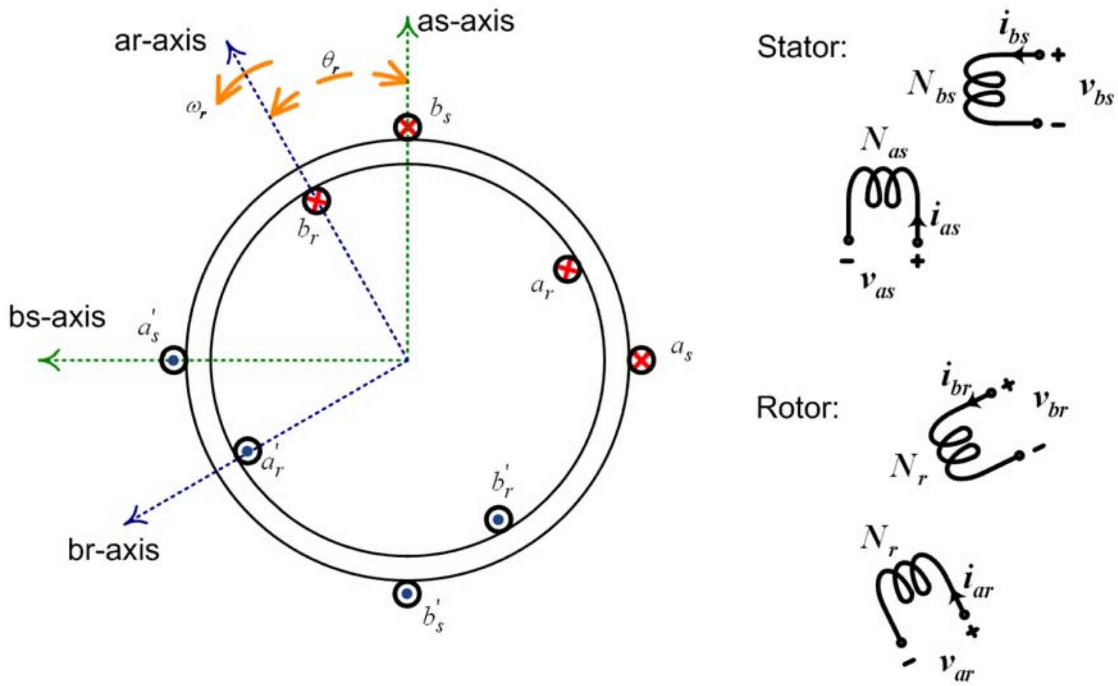


Figure 6.10.1 Diagram of an idealized two phase induction machine

EQUIVALENT CIRCUITS:

Voltage equations for the two phase induction machine are presented in the following equation. As can be seen, stator phase a and b have different resistances.

$$\begin{matrix} \overbrace{\begin{bmatrix} v_{as} \\ v_{bs} \end{bmatrix}}^{\underline{v}_{abs}} \\ \underbrace{\begin{bmatrix} v_{ar} \\ v_{br} \end{bmatrix}}_{\underline{v}_{abr}} \end{matrix} = \begin{bmatrix} \overbrace{\begin{bmatrix} r_{as} & 0 \\ 0 & r_{bs} \end{bmatrix}}^{[r_s]} & \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \\ \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} & \underbrace{\begin{bmatrix} r_r & 0 \\ 0 & r_r \end{bmatrix}}_{[r_r]} \end{bmatrix} + \begin{bmatrix} \overbrace{\begin{bmatrix} i_{as} \\ i_{bs} \end{bmatrix}}^{\underline{i}_{abs}} \\ \underbrace{\begin{bmatrix} i_{ar} \\ i_{br} \end{bmatrix}}_{\underline{i}_{abr}} \end{bmatrix} + \frac{d}{dt} \cdot \begin{bmatrix} \overbrace{\begin{bmatrix} \psi_{as} \\ \psi_{bs} \end{bmatrix}}^{\underline{\psi}_{abs}} \\ \underbrace{\begin{bmatrix} \psi_{ar} \\ \psi_{br} \end{bmatrix}}_{\underline{\psi}_{abr}} \end{bmatrix}$$

Also, the relation between flux linkages and currents is shown in the flux linkage equations. Ψ_{as} and Ψ_{bs} are flux linkages for stator windings a and b, and Ψ_{ar} and Ψ_{br} are flux linkages for rotor windings. $[L_{ss}]$ and $[L_{rr}]$ are the inductance matrices for stator and rotor windings, and $[L_{sr}]$ is the inductance matrix for the mutual windings between the stator and rotor windings.

$$\begin{matrix}\overbrace{\begin{bmatrix}\psi_{as}\\ \psi_{bs}\end{bmatrix}}^{\underline{\psi}_{abs}}\\ \underbrace{\begin{bmatrix}\psi_{ar}\\ \psi_{br}\end{bmatrix}}_{\underline{\psi}_{abr}}\end{matrix} = \begin{bmatrix} \overbrace{\begin{bmatrix}L_{asas} & L_{asbs}\\ L_{bsas} & L_{bsbs}\end{bmatrix}}^{[L_{ss}]} & \overbrace{\begin{bmatrix}L_{asar} & L_{asbr}\\ L_{bsar} & L_{bsbr}\end{bmatrix}}^{[L_{sr}]} \\ \underbrace{\begin{bmatrix}L_{aras} & L_{arbs}\\ L_{bras} & L_{brbs}\end{bmatrix}}_{[L_{sr}]^T} & \underbrace{\begin{bmatrix}L_{arar} & L_{arbr}\\ L_{brar} & L_{brbr}\end{bmatrix}}_{[L_{rr}]}\end{bmatrix} \cdot \begin{matrix}\overbrace{\begin{bmatrix}i_{as}\\ i_{bs}\end{bmatrix}}^{\underline{i}_{abs}}\\ \underbrace{\begin{bmatrix}i_{ar}\\ i_{br}\end{bmatrix}}_{\underline{i}_{abr}}\end{matrix}$$

The values of these inductances are functions of rotor position and saturation. The above voltage and flux linkage equations can be transferred to stator frame of reference so that the inductances do not depend on the rotor position hence d− and q−axis equivalent circuits can be achieved. Note that, because of asymmetry in stator windings, transforming the above equations to rotor frame of reference does not result in a position−independent inductance matrix.

In one approach [17], q− and d−axis equivalent circuits are extracted with reference to main and auxiliary windings individually, thus the magnetizing inductances in q− and d−axis are not equal. Figure 6.10.2 shows the equivalent circuit of the machine using this approach. Many machines have their data available in this form.

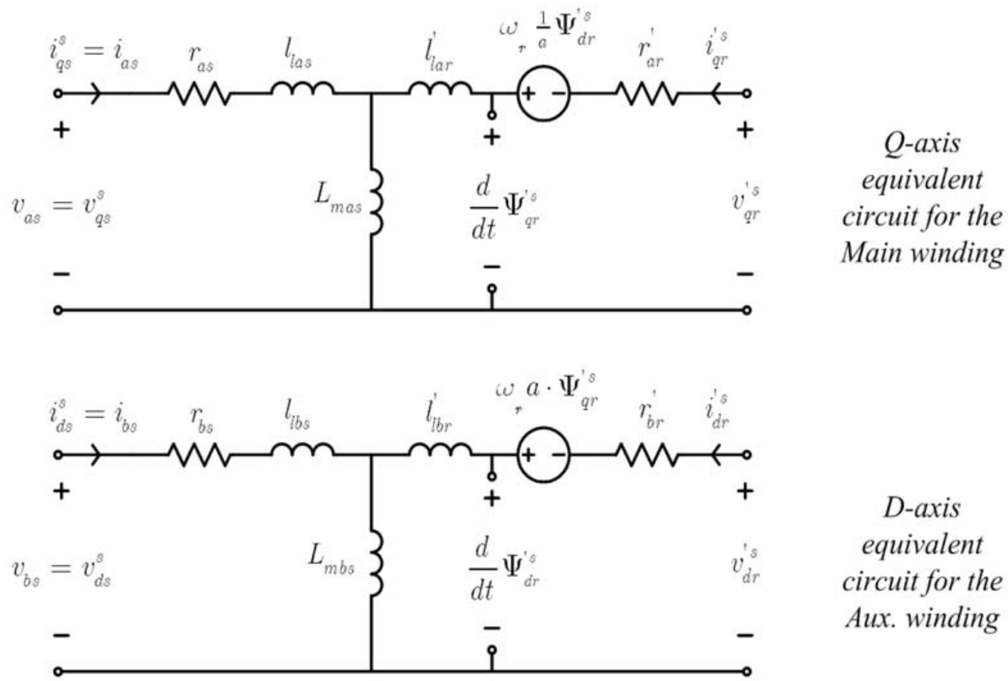


Figure 6.10.2 Equivalent circuit of an idealized two phase induction machine (rotor windings reflected to main and aux. windings).

Another approach, which is used in the model presented here, reflects all the windings to the main stator winding. Figure 6.10.3 shows the equivalent circuit of the machine using this approach.

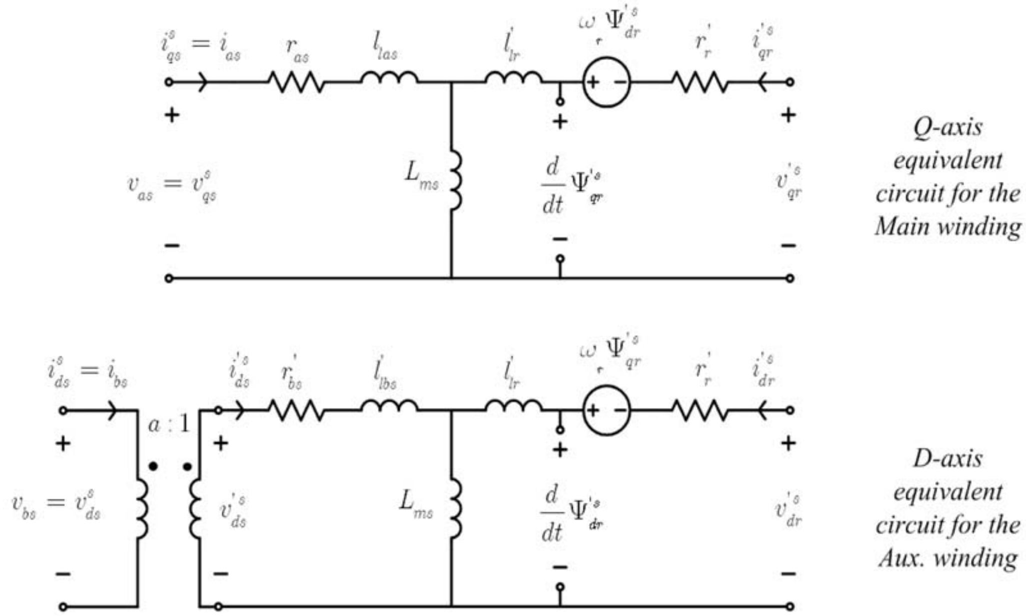


Figure 6.10.3 Equivalent circuit of an idealized two phase induction machine (all windings reflected to the main windings).

Usually, data for single phase induction machines is available in both formats. These parameters can be transferred from one circuit to another using the value of Aux./ Main turns ratio (a). These parameters can be measured using standard no−load and lock rotor test and standstill frequency response test [19]. In the model developed for RTDS, the input data for the rotor is in the form of parameters in the equivalent circuit shown in Figure 6.10.3. Therefore, only one value for rotor resistance and leakage inductance is required. In case the available data is in the form of equivalent circuit shown in Figure 6.10.2., then q−axis rotor resistance and leakage inductance is adequate for the model. D−axis rotor parameters are equal to q−axis parameters multiplied by (a^2). The required resistance and leakage inductance of the main and auxiliary windings are the directly measured values from the terminals of the main and auxiliary windings. The magnetizing inductance is the value calculated from the side of the main winding, therefore if the data is available is in the form of parameters in Figure 6.10.2 , then only q−axis magnetizing inductance $L_{mas} = L_{mq}$ is required. D−axis magnetizing inductance $L_{mbs} = L_{md}$ is equal to q−axis magnetizing inductance multiplied by (a^2). This will be clarified further in this document.

Machine impedances and resistances are usually available in Ohm, however the model allows the user to input data in both Ohm and p.u..

TORQUE EQUATION:

The following equation is used for calculating electromagnetic torque (T_e) in the equivalent two−pole single phase indcution machine model presented here. In this equation i_{as}, i_{bs} are stator currents shown in Figure 6.10.1 and i'_{ar}, i'_{br} are rotor currents reflected to the stator main winding.

$$T_e = L_{ms} \cdot \begin{bmatrix} i_{as} & i_{bs} \end{bmatrix} \begin{bmatrix} -\sin(\theta_r) & -\cos(\theta_r) \\ a \cdot \cos(\theta_r) & -a \cdot \sin(\theta_r) \end{bmatrix} \begin{bmatrix} i'_{ar} \\ i'_{br} \end{bmatrix}$$

6.10.3 MODEL SPECIFICATIONS AND CAPABILITIES

This chapter describes the Single Phase Induction Machcine (SPIM) model. The basic icon for the _rtds_SPIM component appears as shown in Figure 6.10.4.

The terminals for stator main and auxiliary windings and the neutral point are respectively shown by M , A and N. Each of the main and auxiliary windings have embedded series breakers that can be controlled independently using control signals.

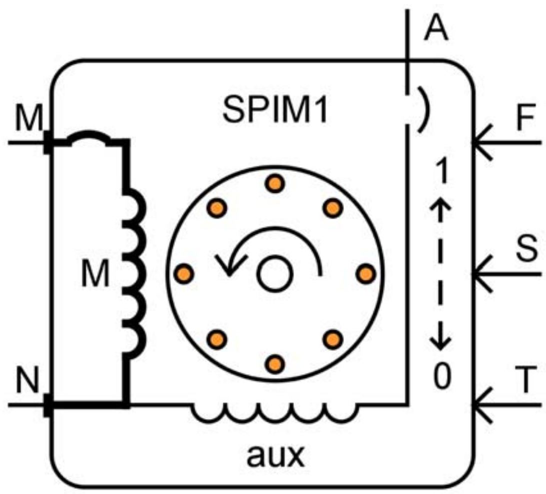


Figure 6.10.4 _rtds_SPIM component icon.

Single−phase induction motors are usually in the forms of Split−Phase Induction Motors, Capacitor Induction Motors, and Shaded−Pole Induction Motors.

A split−phase induction motor can be achieved by connecting the terminal A of the machine to the main terminal M. Parameters of the auxiliary windings can be modified so that the high ratio of resistance to reactance is achieved.

Capacitor, resistance, or a combination of R and C elements can be inserted between nodes A and M, resulting in a capacitor−start, capacitor−run, two−value capacitor motor or other arrangements.

Shorting the auxiliary winding (i.e. connecting node A to N) approximately represents a shaded−pole machine.

The control input S determines whether the machine operates in lock or free mode. If S is set to 1, then the pu speed of the machine is determined by the control input F, otherwise if S is set to 0, then the speed of the machine is determined by mechanical swing equations. In this case, the mechanical torque comes from the control input T in pu.

The **embedded phase domain approach** [4] is used to implement this model in the environment of the real−time digital simulator (RTDS). The term **phase domain** means that the values of machine inductances change with the change in rotor position and level of saturation. The term **embedded** means that the network solution is incorporated in solving the differential equations of the machine. This approach shows superior numerical performance compared to the conventional interfaced approach [5].

As the rotor is a cylindrical round rotor, saturation is modeled similar to the one for three phase induction machines by adjusting the magnetizing inductance as a function of the total magnetizing current peak value [14]. This is shown in the following equation:

$$i_m = \sqrt{i_{md}^2 + i_{mq}^2} \qquad\qquad L_{ms\_sat} = f(i_m)$$

As mentioned above, machine impedances and resistances are usually available in Ohm, however the model allows the user to input data either in pu values or original ohmic values.

One computational load unit of RTDS is required for real−time simulation of a _rtds_SPIM, single phase induction machine (SPIM) model. Ten machines can be stacked on a processor of a GPC card.

The single phase induction machine menus are explained below:

6.10.4 MAIN MENU FOR THE _rtds_SPIM

Many of the menus in the model _rtds_SPIM are similar to the menus for other induction machine models in RTDS (lf_rtds_sharc_sld_INDM and lf_rtds_risc_sld_INDM). These menus are discussed here. RPC_GPC CONFIGURATION MENU appears as shown in Figure 6.10.5.

AorM: Specify if the model be automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: Parameter is only used if AorM parameter is set to Manual. The user can select the model be assigned to A or B processor.

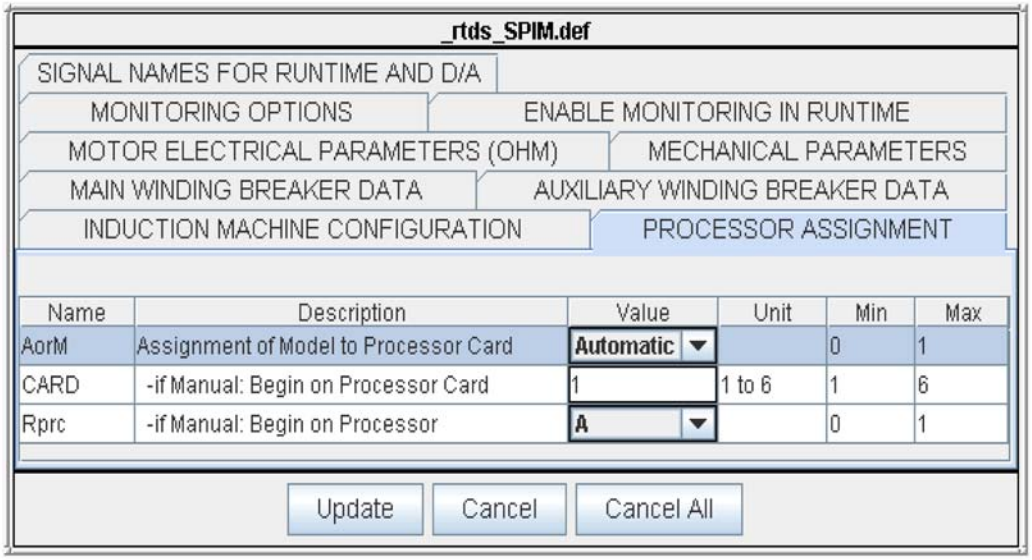


Figure 6.10.5 Processor assignment menu for _rtds_SPIM

6.10.5 THE MENU FOR INDUCTION MACHINE CONFIGURATION

The menu for induction machine configuration appears as shown in Figure 6.10.6. The following is the explanation of parameters in this menu:

Name: A unique name must be given for each instance of the component.

Vbsln: Rated Stator Voltage of the Machine (Line−to−Neutral RMS)

pbase: Rated MVA of the Machine. Although the rating of single phase induction machines is limited to few kVAs, this rating has to be entered in MVA.

hrtz: Rated Operating Frequency of the Machine in Hz

trataM: Effective Ratio of Turns between the Auxiliary to Main Winding $a = \left(\frac{N_{bs}}{N_{as}}\right)$.

cnfg: Using this parameter the user has the option of entering machine resistances and impedances in “Ohm” or “pu”.

tysat: The “tysat” menu item prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2).

spdin: The “spdin” menu item prompts for information concerning the speed of the model in the first time−steps. The two choices are: “Zero” and “Rated”. Note that all winding currents are set to 0.0 in the first time−step.

Mbkr: This option allows the inclusion of an embedded breaker in the Main winding of the machine.

Abkr: This option allows the inclusion of an embedded breaker in the Auxiliary winding of the machine.

prtyp: The prtyp parameter allows the user to select on which type of processor the model is to be run. This model is currently available for RISC processor types.

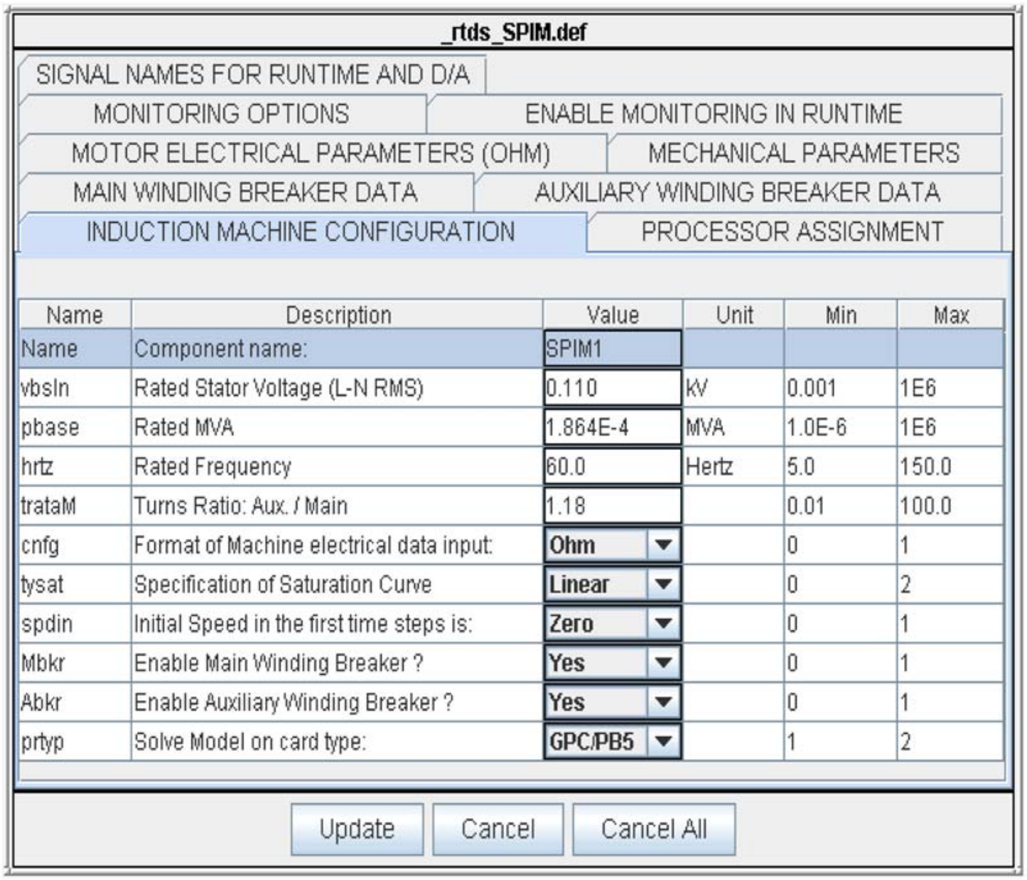


Figure 6.10.6 The Menu for Induction Machine Configuration

6.10.6 MOTOR ELECTRICAL PARAMETERS (OHM)

As mentioned, the user has the option of entering machine resistances and impedances in “Ohm” or “pu”. If the parameter “cnfg” is set to “Ohm” in the “menu for the induction machine configuration”, then the menu MOTOR ELECTRICAL PARAMETERS appears as shown in Figure 6.10.7. In this menu:

rMs: Resistance of the main winding in Ohm. This parameter corresponds to (r_{as}) in Figure 6.10.3.

xlMs: Leakage Reactance of the main winding in Ohm. This parameter corresponds to $(\omega \cdot l_{las})$ in Figure 6.10.3.

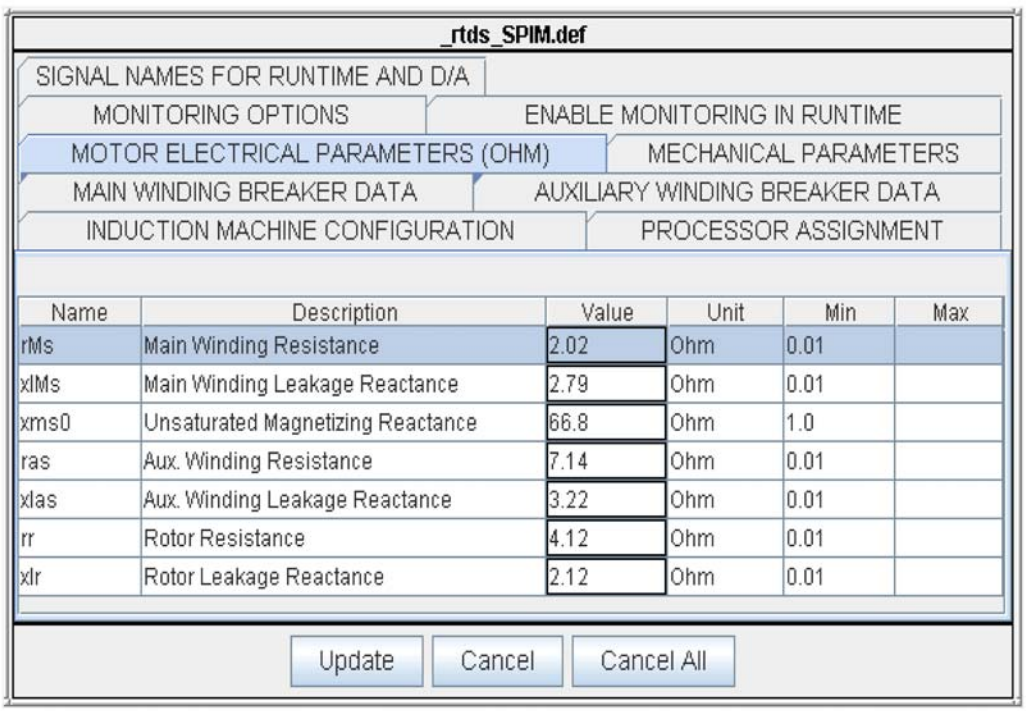
xms0: Unsaturated Magnetizing Reactance in Ohm. This parameter corresponds to $(\omega \cdot L_{ms})$ in Figure 6.10.3.

ras: Resistance of the Auxiliary winding in Ohm. This parameter is directly measured from the terminals of auxiliary winding and corresponds to $\left(r_{bs} = a^2 \cdot r'_{bs}\right)$ in Figure 6.10.3.

xlas: Leakage Reactance of the Auxiliary winding in Ohm. This parameter is directly measured from the auxiliary winding and corresponds to $\left(\omega \cdot l_{lbs} = a^2 \cdot \omega \cdot l'_{lbs}\right)$ in Figure 6.10.3.

rr: Resistance of the rotor winding in Ohm. This parameter corresponds to (r'_r) in Figure 6.10.3. If rotor resistances for both main and auxiliary axes are given, use the one corresponding to the main axis (q−axis).

xlr: Leakage Reactance of the rotor winding in Ohm. This parameter corresponds to $(\omega \cdot l'_{lr})$ in Figure 6.10.3. If rotor leakage reactances are given for both main and auxiliary axes, use the one corresponding to the main axis (q−axis).



Name	Description	Value	Unit	Min	Max
rMs	Main Winding Resistance	2.02	Ohm	0.01	
xlMs	Main Winding Leakage Reactance	2.79	Ohm	0.01	
xms0	Unsaturated Magnetizing Reactance	66.8	Ohm	1.0	
ras	Aux. Winding Resistance	7.14	Ohm	0.01	
xlas	Aux. Winding Leakage Reactance	3.22	Ohm	0.01	
rr	Rotor Resistance	4.12	Ohm	0.01	
xlr	Rotor Leakage Reactance	2.12	Ohm	0.01	

Figure 6.10.7 Motor Electrical Parameters (OHM) Menu of _rtds_SPIM component.

6.10.7 MOTOR ELECTRICAL PARAMETERS (PU)

If the parameter "cnfg" is set to "PU" in the menu for "INDUCTION MACHINE CONFIGURATION", then the menu MOTOR ELECTRICAL PARAMETERS appears as shown in Figure 6.10.8. In this menu:

rMspu: Resistance of the main winding in pu. This parameter corresponds to (r_{as}) in Figure 6.10.3.

xlMspu: Leakage Reactance of the main winding in pu. This parameter corresponds to $(\omega \cdot l_{las})$ in Figure 6.10.3.

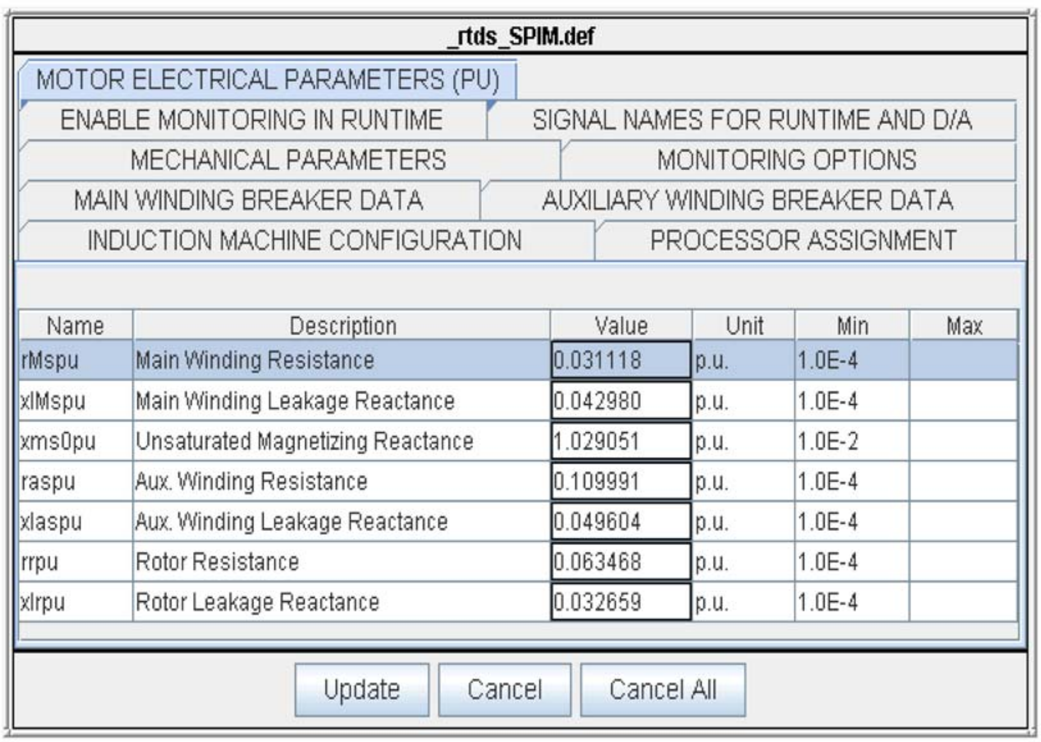
xms0pu: Unsaturated Magnetizing Reactance in pu. This parameter corresponds to $(\omega \cdot L_{ms})$ in Figure 6.10.3.

raspu: Resistance of the Auxiliary winding in pu. This parameter is directly measured from the auxiliary winding terminals and corresponds to $\left(r_{bs} = a^2 \cdot r'_{bs}\right)$ in Figure 6.10.3.

xlaspu: Leakage Reactance of the Auxiliary winding in pu. This parameter is directly measured from the auxiliary winding and corresponds to $\left(\omega \cdot l_{lbs} = a^2 \cdot \omega \cdot l'_{lbs}\right)$ in Figure 6.10.3.

rrpu: Resistance of the rotor winding in pu. This parameter corresponds to (r'_r) in Figure 6.10.3. If rotor resistances for both main and auxiliary axes are given, use the one corresponding to the main axis (q−axis).

xlrpu: Leakage Reactance of the rotor winding in pu. This parameter corresponds to $(\omega \cdot l'_{lr})$ in Figure 6.10.3. If rotor leakage reactances are given for both main and auxiliary axes, use the one corresponding to the main axis (q−axis).



Name	Description	Value	Unit	Min	Max
rMspu	Main Winding Resistance	0.031118	p.u.	1.0E-4	
xlMspu	Main Winding Leakage Reactance	0.042980	p.u.	1.0E-4	
xms0pu	Unsaturated Magnetizing Reactance	1.029051	p.u.	1.0E-2	
raspu	Aux. Winding Resistance	0.109991	p.u.	1.0E-4	
xlaspu	Aux. Winding Leakage Reactance	0.049604	p.u.	1.0E-4	
rrpu	Rotor Resistance	0.063468	p.u.	1.0E-4	
xlrpu	Rotor Leakage Reactance	0.032659	p.u.	1.0E-4	

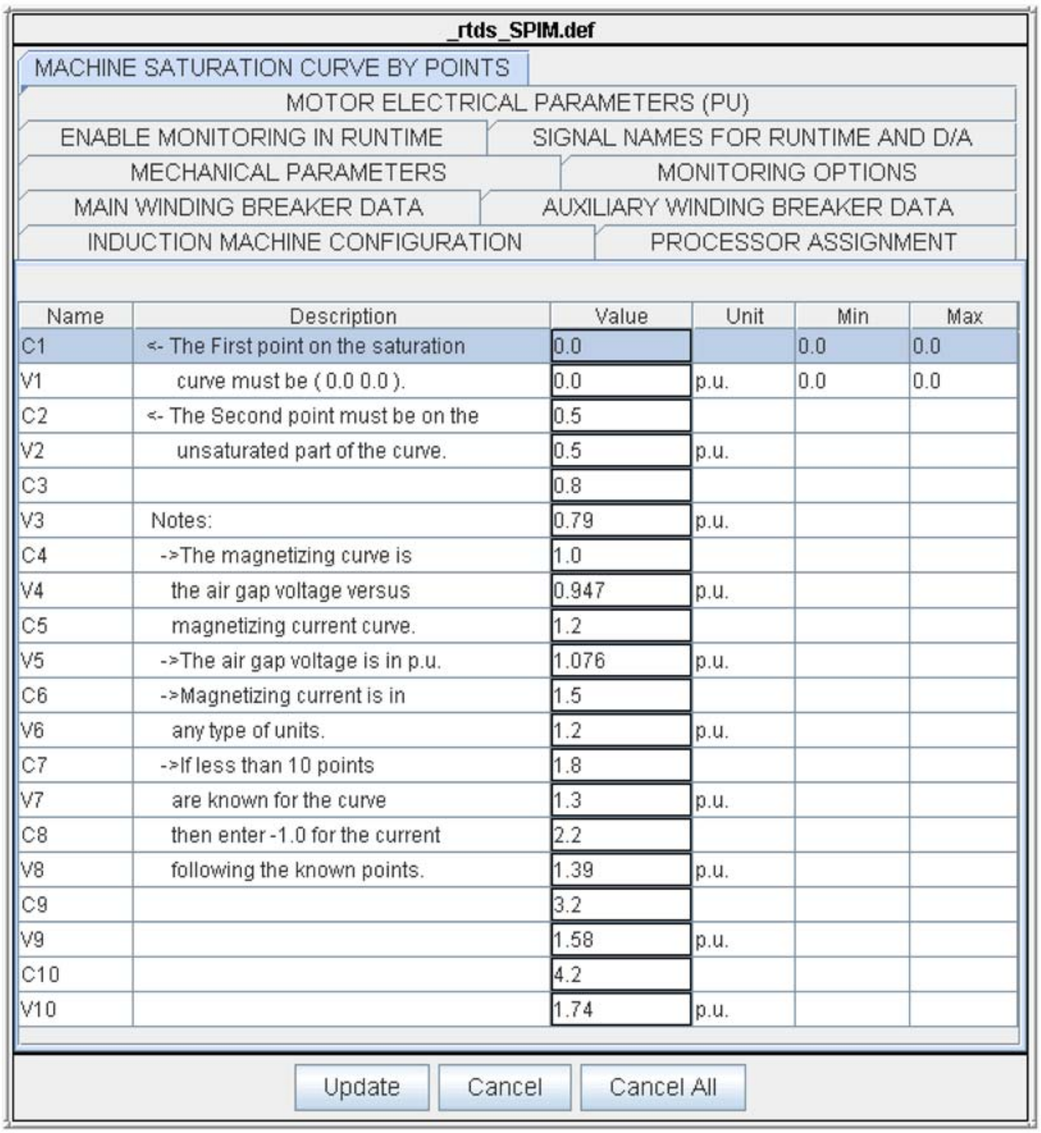
Figure 6.10.8 Motor Electrical Parameters (PU) Menu of _rtds_SPIM component.

6.10.8 THE MACHINE SATURATION CURVE MENUS

The “tysat” menu item in the “INDUCTION MACHINE CONFIGURATION” menu prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2). The choices are “Linear”, “Points”, and “Factors. If “Linear” is chosen, then machine will not saturate. The other two choices are explained below. The saturation curve for the main magnetizing flux linkage path of the induction machine model is specifiable in the SATURATION CURVE menu. The saturation curve which is entered should be the air−gap voltage versus magnetizing current curve for the magnetizing branch “xms0” at rated frequency.

6.10.9 THE MACHINE SATURATION CURVE BY POINTS MENU

The MACHINE SATURATION CURVE BY POINTS menu appears as follows:



_rtds_SPIM.def

MACHINE SATURATION CURVE BY POINTS | MOTOR ELECTRICAL PARAMETERS (PU) | ENABLE MONITORING IN RUNTIME | SIGNAL NAMES FOR RUNTIME AND D/A | MECHANICAL PARAMETERS | MONITORING OPTIONS | MAIN WINDING BREAKER DATA | AUXILIARY WINDING BREAKER DATA | INDUCTION MACHINE CONFIGURATION | PROCESSOR ASSIGNMENT

Name	Description	Value	Unit	Min	Max
C1	<- The First point on the saturation	0.0		0.0	0.0
V1	curve must be (0.0 0.0).	0.0	p.u.	0.0	0.0
C2	<- The Second point must be on the	0.5			
V2	unsaturated part of the curve.	0.5	p.u.		
C3		0.8			
V3	Notes:	0.79	p.u.		
C4	->The magnetizing curve is	1.0			
V4	the air gap voltage versus	0.947	p.u.		
C5	magnetizing current curve.	1.2			
V5	->The air gap voltage is in p.u.	1.076	p.u.		
C6	->Magnetizing current is in	1.5			
V6	any type of units.	1.2	p.u.		
C7	->If less than 10 points	1.8			
V7	are known for the curve	1.3	p.u.		
C8	then enter -1.0 for the current	2.2			
V8	following the known points.	1.39	p.u.		
C9		3.2			
V9		1.58	p.u.		
C10		4.2			
V10		1.74	p.u.		

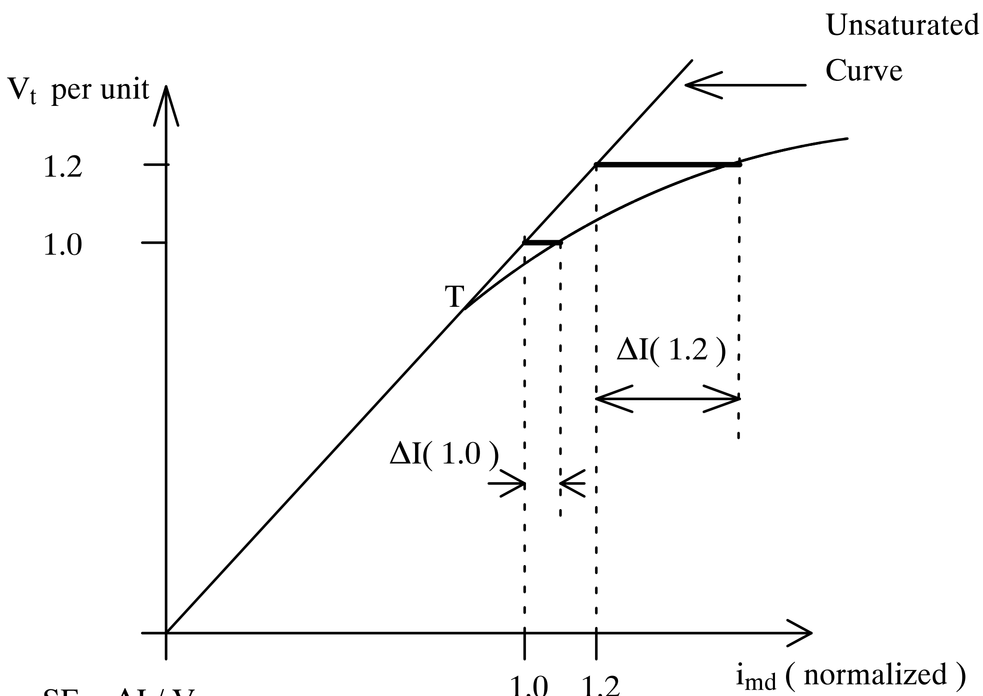
Update | Cancel | Cancel All

Figure 6.10.9 Machine Saturation Curve By Points Menu

This method requires a saturation curve for the machine to be entered using points on the curve. The curve is a plot of air−gap voltage in per−unit versus magnetizing current specified in units of the user’s choice. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point allows to provide scaling information for magnetizing currents entered in the menu. If fewer than 10 points are entered for the curve, then enter −1.0 for the currents following the last known point.

6.10.10 MACHINE SATURATION CURVE BY FACTORS MENU

The two factors to be specified in the above menu are defined in Figure 6.10.10. The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.



$SE = \Delta I / V_t$
$SE(1.0) = \Delta I(1.0) / 1.0$
$SE(1.2) = \Delta I(1.2) / 1.2$

Figure 6.10.10 Machine Saturation Curve By Factors SE10 and SE12

The MACHINE SATURATION CURVE BY FACTORS menu appears as shown in Figure 6.10.11.

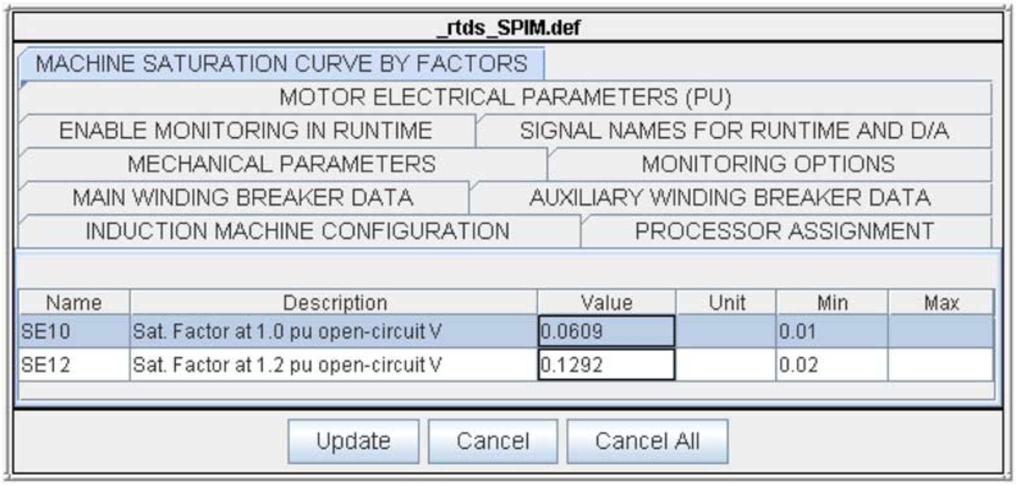


Figure 6.10.11 Machine Saturation Curve By Factors Menu

6.10.11 MAIN WINDING BREAKER DATA

As mentioned, the user has the option of including an embedded breaker in series with the main winding. The menu MAIN WINDING BREAKER DATA appears as shown in Figure 6.10.12. In this menu:

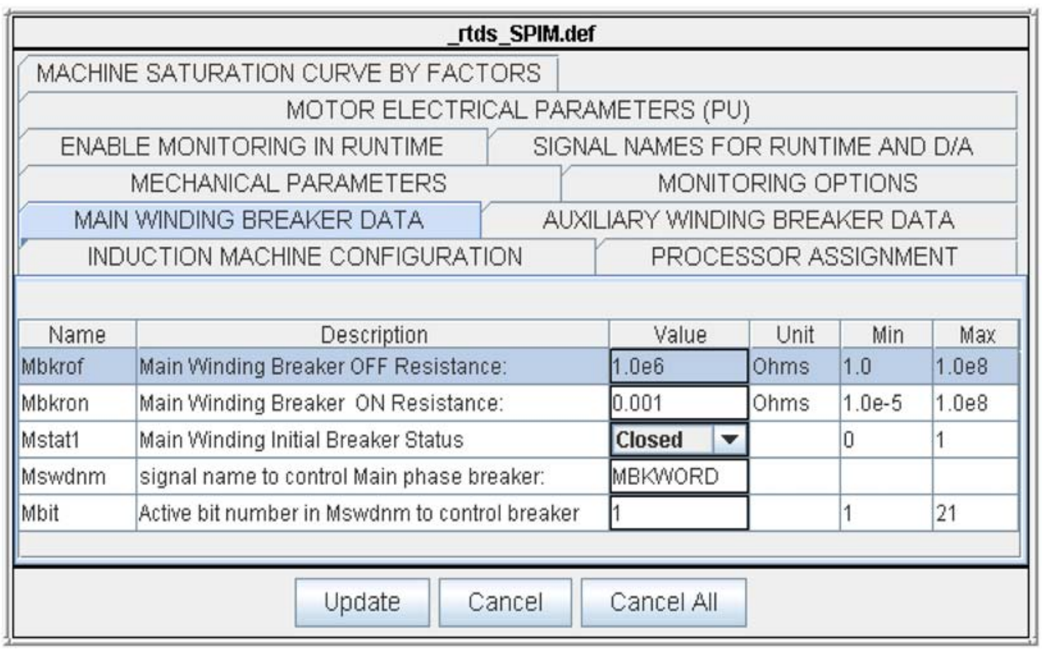


Figure 6.10.12 Menu for the Main Winding Breake Menu

Mbkrof: Resistance of the breaker when it is open.

Mbkron: Resistance of the breaker when it is closed.

Mstat1: Initial status of the breaker.

Mswdnm: Integer signal that controls the status of the breaker.

Mbit: Active bit number in “MSwdnm” that controls the status of the breaker.

6.10.12 AUXILIARY WINDING BREAKER DATA

As mentioned, the user has the option of including an embedded breaker in series with the auxiliary winding as well. The menu AUXILIARY WINDING BREAKER DATA appears as shown in Figure 6.10.13. In this menu:

Abkrof: Resistance of the breaker when it is open.

Abkron: Resistance of the breaker when it is closed.

Astat1: Initial status of the breaker.

Aswdnm: Integer signal that controls the status of the breaker.

Abit: Active bit number in “ASwdnm” that controls the status of the breaker.

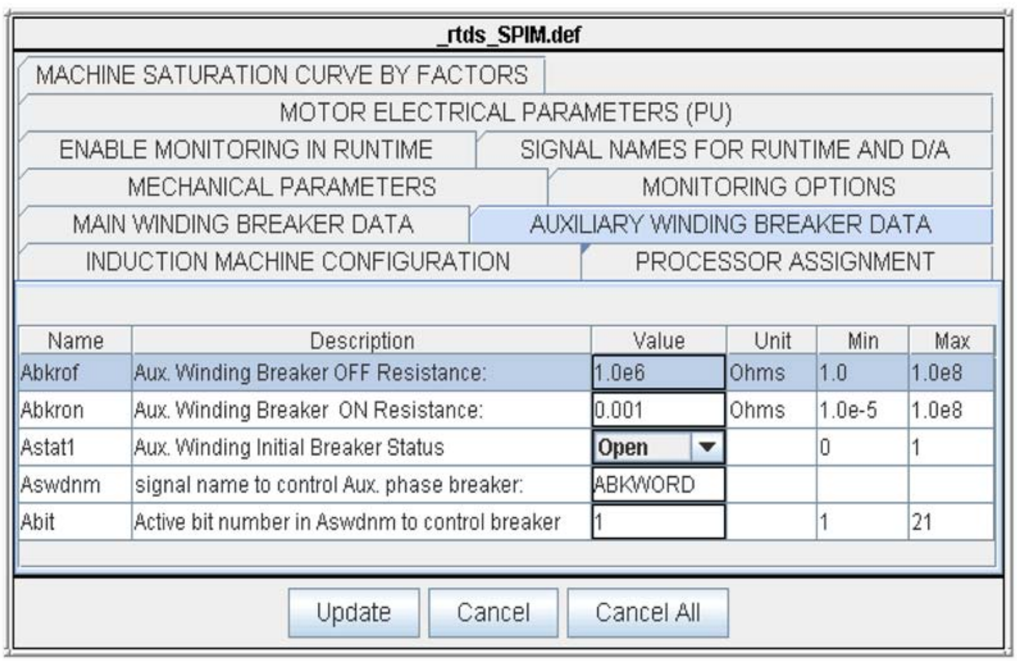


Figure 6.10.13 Menu for the Auxiliary Winding Breaker Data

6.10.13 THE MECHANICAL PARAMETERS MENU

In this model the mechanical swing equations of the rotor are solved inside the model. This menu specifies the inertia constant (H) and frictional damping (D) of the mass. The MECHANICAL PARAMETERS menu appears as shown in Figure 6.10.14.

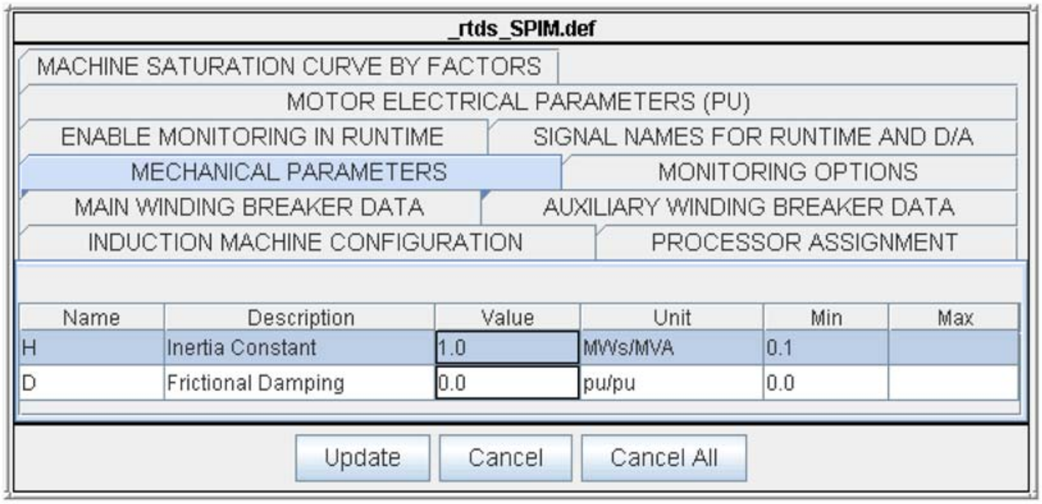


Figure 6.10.14 Mechanical Parameters Menu of _rtds_SPIM component

H: The “H” menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating. The MVA rating of the machine is as entered in the GENERAL MODEL CONFIGURATION menu in response to the “pbase” item.

D: The “D” menu item prompts for the frictional damping factor. The resulting damping torque tends to resist the speed. The damping torque factor “D” is in units of per−unit torque over per−unit speed deviation from zero speed.

In locked speed mode, the pu speed of the machine is determined by a control input F in the icon. In the free speed mode, the machine speed ω is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (T_m), electrical torque (T_e), and the damping torque. The following equation shows this relation:

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

Similar to other machine models in RTDS, **when the speed is positive, positive electric torque corresponds to generating operation of the machine and negative electric torque corresponds to motoring operation of the machine**. **When the speed is negative, positive torque corresponds to motoring operation of the machine, and negative torque corresponds to generating operation of the machine.** This is shown in the following table:

Speed	Positive Torque	Negative Torque
+	Generator	Motor
−	Motor	Generator

Note that, positive speed according to our convention means anti–clockwise rotation of the rotor. For a two phase machine, if the current in the auxiliary winding leads the current of the main winding, then the rotation of the total MMF will be clockwise and steady state speed will be negative. This phenomenon takes place in capacitor single phase induction machines.

6.10.14 MONITORING OPTION MENU

The user has the option of using a low–pass filter $\left(\frac{1}{1 + S \cdot T}\right)$ when the active power is monitored. The menu MONITORING OPTIONS appears as shown in Figure 6.10.15. In this menu:

tpwr: Specifies the time constant (T) that the first order low pass filter will use on the signal for real power monitored from the machine.

Dpwr: Specifies the direction of active power monitored from the machine.

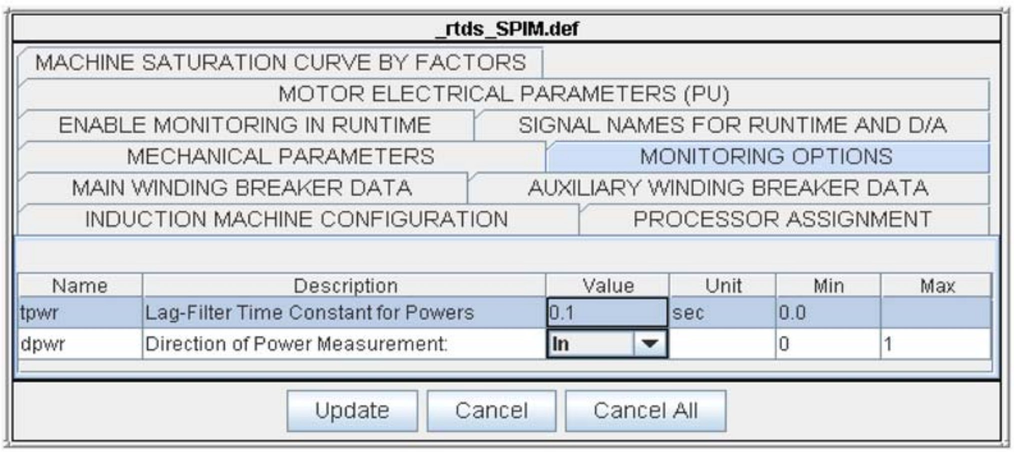


Figure 6.10.15 Menu for _rtds_SPIM Monitoring Options

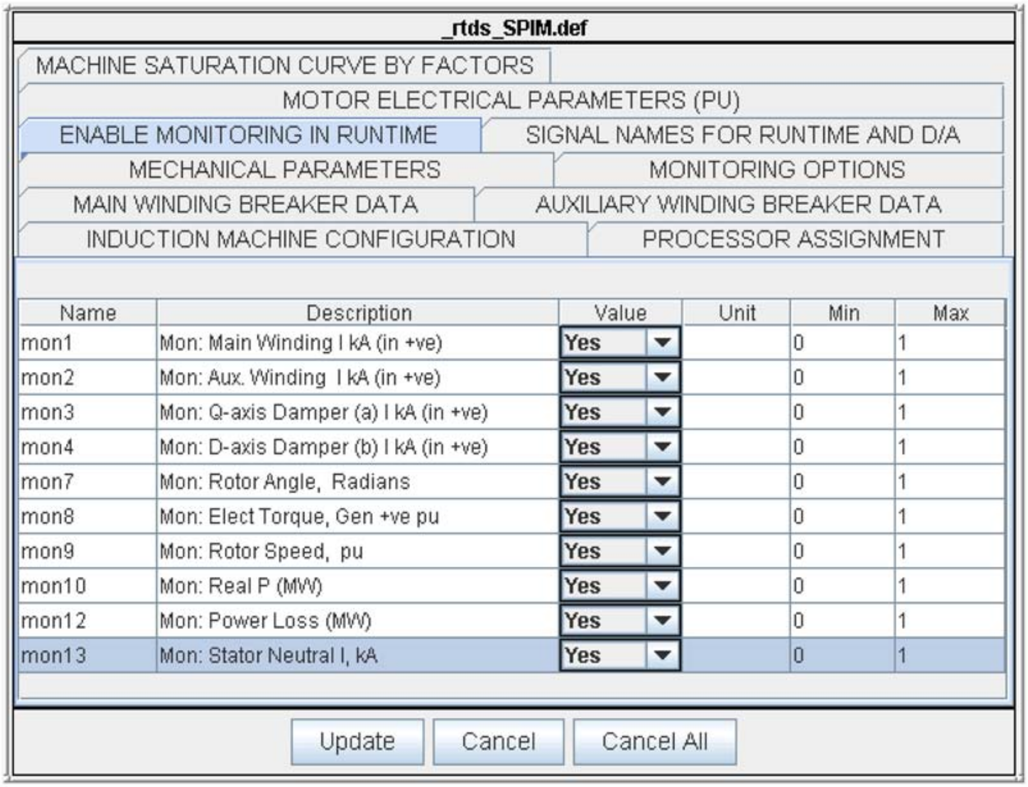
6.10.15 THE ENABLE MONITORING IN RUNTIME MENU

The _rtds_SPIM ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.10.16.

Stator and Rotor Currents: The user has the option of monitoring the stator main and auxiliary currents, neutral current, and the rotor winding currents in kA.

Rotor Angle, Electric Torque, and Rotor Speed: Mechanical quantities such as rotor angle, electric torque and rotor speed can also be monitored in Radians, pu , and pu respectively.

Active Power and Power Loss of the Machine:The active power and resistive losses of the machine can be monitored. The direction of monitored power can be selected in the "Monitoring Options" menu.



Name	Description	Value	Unit	Min	Max
mon1	Mon: Main Winding I kA (in +ve)	Yes		0	1
mon2	Mon: Aux. Winding I kA (in +ve)	Yes		0	1
mon3	Mon: Q-axis Damper (a) I kA (in +ve)	Yes		0	1
mon4	Mon: D-axis Damper (b) I kA (in +ve)	Yes		0	1
mon7	Mon: Rotor Angle, Radians	Yes		0	1
mon8	Mon: Elect Torque, Gen +ve pu	Yes		0	1
mon9	Mon: Rotor Speed, pu	Yes		0	1
mon10	Mon: Real P (MW)	Yes		0	1
mon12	Mon: Power Loss (MW)	Yes		0	1
mon13	Mon: Stator Neutral I, kA	Yes		0	1

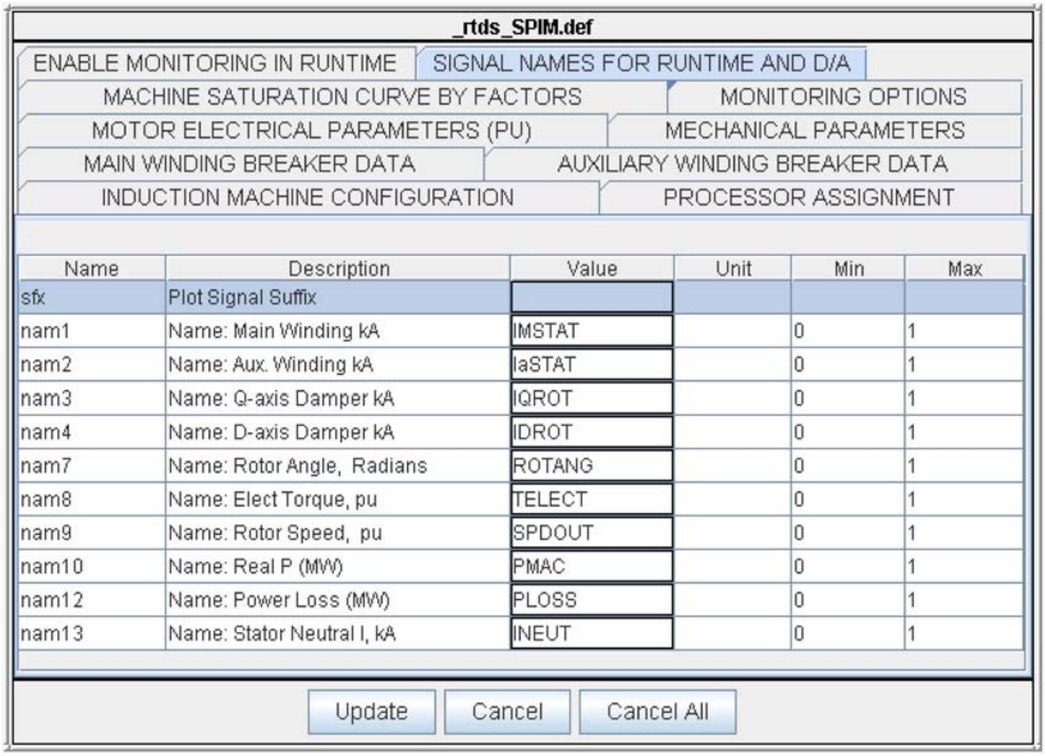
Figure 6.10.16 Menu for _rtds_SPIM Enable Monitoring in RUNTIME

6.10.16 THE SIGNAL NAMES FOR RUNTIME MENU

The _rtds_SPIM SIGNAL NAMES FOR MONITORING IN RUNTIME MENU appears as shown in Figure 6.10.17. The user must dedicate a unique name for the monitored signals. A suffix can also be added to the signal names.

6.10.17 MACHINE INFORMATION WRITTEN IN THE MAP FILE

After compiling a draft case containing an _rtds_SPIM machine model, the MAP file will contain information about this single phase induction machine model. Figure 6.9.18 shows an example of the MAP file. It contains the name of the machine model, the electric parameters of the machine in the dq equivalent circuit, and the Aux./ Main winding turn ratio.



_rtds_SPIM.def

ENABLE MONITORING IN RUNTIME | SIGNAL NAMES FOR RUNTIME AND D/A | MACHINE SATURATION CURVE BY FACTORS | MONITORING OPTIONS | MOTOR ELECTRICAL PARAMETERS (PU) | MECHANICAL PARAMETERS | MAIN WINDING BREAKER DATA | AUXILIARY WINDING BREAKER DATA | INDUCTION MACHINE CONFIGURATION | PROCESSOR ASSIGNMENT

Name	Description	Value	Unit	Min	Max
sfx	Plot Signal Suffix				
nam1	Name: Main Winding kA	IMSTAT		0	1
nam2	Name: Aux. Winding kA	IaSTAT		0	1
nam3	Name: Q-axis Damper kA	IQROT		0	1
nam4	Name: D-axis Damper kA	IDROT		0	1
nam7	Name: Rotor Angle, Radians	ROTANG		0	1
nam8	Name: Elect Torque, pu	TELECT		0	1
nam9	Name: Rotor Speed, pu	SPDOUT		0	1
nam10	Name: Real P (MW)	PMAC		0	1
nam12	Name: Power Loss (MW)	PLOSS		0	1
nam13	Name: Stator Neutral I, kA	INEUT		0	1

Update | Cancel | Cancel All

Figure 6.10.17 Menu for _rtds_SPIM Signal Names for Monitoring

```
RISC-based CModel component model of type "SPIM (Single Phase Induction Machine)"
  named: SPIM1
  in subsystem: 1

has the following electric parameters:
  ======================================
  Rated MVA of the Machine:           0.000186  MVA
  Rated RMS Line-to-Neutral Voltage:  0.110000  kV
  Base Angular Frequency:             60.000000  Hz
  Main Winding Resistance:            0.031118  p.u.
  Main Winding Leakage Reactance      0.042980  p.u.
  Unsaturated Magnetizing Reactance:  1.029051  p.u.
  Aux. Winding Resistance:            0.109991  p.u.
  Aux. Winding Leakage Reactance:     0.049604  p.u.
  Rotor Resistance:                   0.063468  p.u.
  Rotor Leakage Reactance:            0.032659  p.u.
  Aux. / Main Winding Turn/ Ratio is: 1.180000

RISC-based CModel Component: SPIM6 named "SPIM1" --> RPC-GPC Card #2 Processor A
```

Figure 6.10.18 Machine Information Written in the MAP File

6.10.18 EXAMPLE CASES

Few example cases are added to the "Samples" directory. These examples help in understanding the analysis and operation of the single phase induction machine. These examples include Capacitor−Start Induction Motors, Capacitor−Run Induction Motors, Split−Phase Induction Motors, and an induction machine in which the main and auxiliary windings are supplied by different sources.

6.10.19 SUMMARY

The Cbuilder _rtds_SPIM, phase domain single phase induction machine (SPIM) model, provides a model that is flexible in configuration. This model is an embedded phase − domain model [4]. This model has the following assumptions and specifications:

1. It is assumed that the machine windings produce a sinusoidal MMF, thus space harmonics are ignored.
2. Similar to other machine models in RTDS, multi−pole single phase IMs are modeled as an equivalent two pole machine.
3. As the rotor is a cylindrical round rotor, saturation is modeled similar to the three phase induction machine by adjusting the magnetizing inductance as a function of the total magnetizing current peak value. Saturation in the leakage paths is ignored.
4. One computational load unit of RTDS is required for real−time simulation of an _rtds_SPIM, single phase induction machine (SPIM) model. Therefore 10 _rtds_SPIM components can be stacked on a RISC processor.
5. As explained, main types of single−phase induction motors are in the forms of Split−Phase Induction Motors, Capacitor Induction Motors, and Shaded−Pole Induction Motors. Because of the flexibility of the machine model, the above machine types can be implemented by connecting main and auxiliary windings to passive elements. Although a shaded−pole machine, can be simulated by shorting the auxiliary winding, the resulted machine will not be self starting. In the model _rtds_SPIM, the main and auxiliary windings have an angular shift of 90°. This arrangement does not induce any current in the shorted auxiliary winding when the rotor speed is zero.

6.11 DC MACHINE MODEL (DCMAC)

6.11.1 INTRODUCTION

DC machines are the oldest electric machines in existence, designed based on Faraday principle. The first rotating machines incorporating Ampere's *commutator* appeared in 1833 [20].

Although a DC machine can operate as either a generator or a motor, at present its use as a generator is limited because of the widespread use of the AC power [21]. Almost all electric power supply networks are AC systems of generation, transformation, transmission and distribution; and as DC supplies are readily derived by rectification, there is little need for large DC generators. Additionally, the use of AC motors in industry is widely acceptable wherever they are inherently suitable or can be given appropriate characteristic by means of power electronic devices. However, there are important fields of application in which DC motors offer technical advantages. DC machines can be designed for wide ranges of voltage / current or speed / torque characteristic [20].

Larger DC motors are used in machine tools, industrial pumps, cranes, paper mills, rolling mills, and etc.

DC motors are used in electric trains and battery−fed vehicles. Due to their highly desirable torque−speed characteristic, DC series motors drive intercity and rapid transit trains.

Smaller series DC motors supplied by single phase AC serve portable drills, sewing machines and hand tools. Miniature DC motors working from dry cells operate razors, cameras, tape recorders and similar small tools. DC series motors are also known as "universal motors".

Many devices associated with closed−loop control systems are operated using Small DC machines (in fractional horse power rating).

6.11.2 THEORY AND ANALYSIS

This chapter briefly describes the analysis and method of modeling direct−current machines. For further information please see the references [15], [18], [20−24]. Conventional DC motors consist of one or more field windings positioned on the stator, an armature winding located on a magnetic rotor or armature, and a magnetic structure forming a stator (referred to as a yoke). The essential features of a two−pole DC machine are shown in Figure 6.11.1. The stator has salient poles that are excited by one or more field windings. The field windings produce an air−gap flux distribution that is symmetrical around the *pole axis* (also known as *field axis* or *d−axis*).

The armature winding is located on the rotor. The voltage induced in the turns of the armature winding is alternating. A commutator−brush combination is used as a mechanical rectifier to make the armature terminal voltage unidirectional and also to make the MMF wave due to the armature current fixed in space [21]. As a consequence, the MMF due to the armature current is along the axis midway the two adjacent poles, called the *quadrature axis*. The armature MMF axis can be changed by changing the position of the brush assembly [20,21].

Also, in larger DC machines, additional windings exist that produce flux but are not involved directly in the electromechanical energy conversion. These windings assist in the *commutation* process.

The effects of armature reaction and utilization of *Compensating* windings will be discussed later.

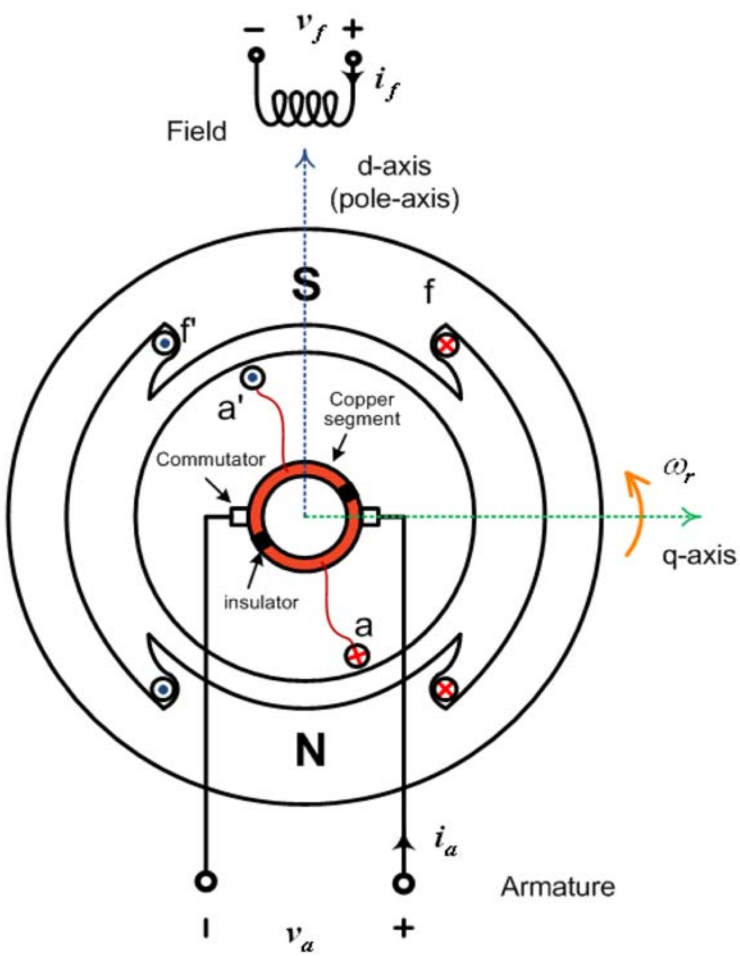


Figure 6.11.1 Diagram of an idealized two−pole DC Machine

The following assumptions are made in the analysis of DC machines in this document:

– Similar to other machine models in RTDS, a multi−pole DC machine is modeled as an equivalent two pole machine. Torque and speed are monitored in p.u..

– Space harmonics are ignored.

– It is assumed that armature and field self inductances are not affected by saturation. However, effects of saturation on the armature back EMF is considered.

EQUIVALENT CIRCUIT:

Voltage equations for a two pole DC machine are presented in the following equation. This DC machine has one field winding f and one armature winding a. Here, v_f and i_f are the field winding voltage and current, and v_a and i_a are the armature winding voltage and current. Field and armature self inductances are shown by L_{ff} and L_{aa}, and field and armature resistances are shown by r_f and r_a.

$$\underbrace{\begin{bmatrix} v_f \\ v_a \end{bmatrix}}_{\underline{v}} = \underbrace{\begin{bmatrix} L_{ff} & 0 \\ 0 & L_{aa} \end{bmatrix}}_{[L]} \cdot \frac{d}{dt} \underbrace{\begin{bmatrix} i_f \\ i_a \end{bmatrix}}_{\underline{i}} + \underbrace{\begin{bmatrix} r_f & 0 \\ 0 & r_a \end{bmatrix}}_{[r]} \cdot \begin{bmatrix} i_f \\ i_a \end{bmatrix} + \underbrace{\begin{bmatrix} 0 \\ E_{fe} \end{bmatrix}}_{\underline{E_{fe}}}$$

Figure 6.11.2. represents the equivalent circuit of the DC machine with one field winding. This circuit corresponds to the above equation.

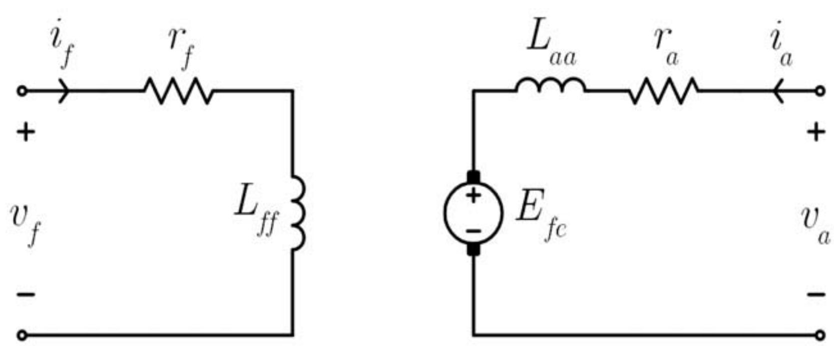


Figure 6.11.2 Equivalent circuit of an idealized DC machine with one field winding

As mentioned previously, due to the effects of commutators, the MMF caused by armature current is stationary. Hence, there is no induced voltage from armature on the field winding (armature reaction phenomenon [20, 21, 23, 24] will be discussed later). The term E_{fe} is the effective induced voltage on the armature winding. It has two components; the induced back EMF voltage due to the field winding (E_{f0}) and the reduction in the back–EMF voltage caused by *armature reaction* (AR). This can be expressed as:

$$E_{fe} = E_{f0} - AR$$

The back EMF voltage due to the field winding (E_{f0}) is a function of total flux under each pole (φ) and the speed of machine (ω_m). In this equation k is a constant.

$$E_{f0} = k \cdot \varphi \cdot \omega_m$$

Flux (φ) is due to the current (i_f) flowing into the field winding. This relationship is not usually linear, and is affected by saturation. Armature reaction (AR) is mostly affected by the current (i_a) flowing into the armature winding. Method of modeling the effects of saturation and armature reaction will be discussed later.

If the machine contains two field windings, the following equivalent circuit is used to represent the machine dynamics:

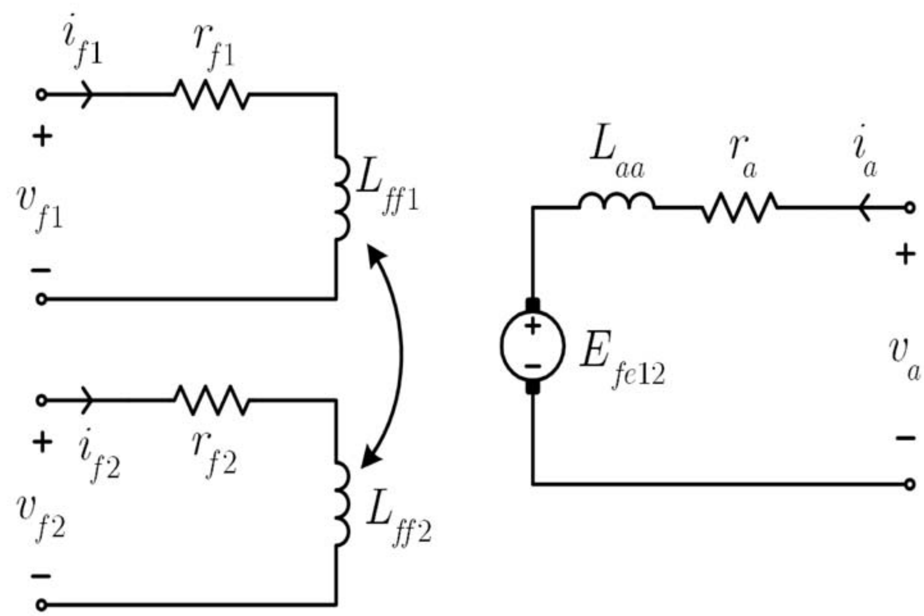


Figure 6.11.3 Equivalent circuit of an idealized DC machine with two field windings

Here, the back−EMF is a function of total effective field current ($i_{fe12} = i_{f1} + \frac{N_{fe2}}{N_{fe1}} \cdot i_{f2}$). N_{fe1} and N_{fe2} are the effective turns of the first and second field windings.

DC machine data is usually available in the form of (Ohm) for machine resistances and (H) for machine inductances. These parameters can be measured using standstill step response test and standstill frequency response test [19]. The open−circuit characteristic of the machine is also required for transient modeling of DC machines.

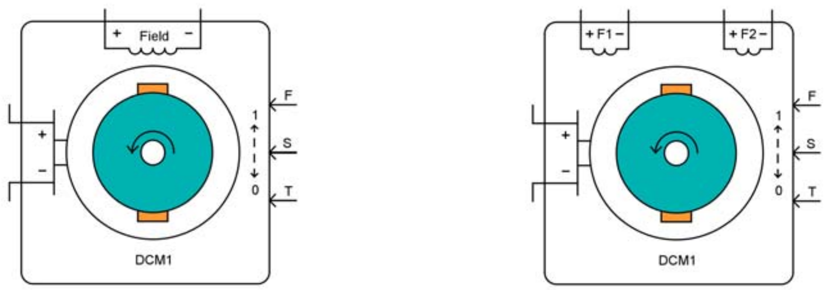
TORQUE EQUATION:

The following equation is used for calculating electromagnetic torque (T_e) in the equivalent two−pole DC machine model presented here. In this equation i_a is the armature current.

$$T_e = k \cdot \varphi \cdot i_a$$

6.11.3 MODEL SPECIFICATIONS AND CAPABILITIES

This chapter describes the DC Machine (DCMAC) model. The basic icon for the _rtds_DCMAC component appears as shown in Figure 6.11.4. Armature and field winding terminals are distinct. As the machine is a *direct−current* device, (+) and (−) signs are used to differentiate terminals. This does not mean that AC signals cannot be applied on this machine. This arrangement allows the user to easily configure a DC machine as a *separately excited*, *shunt* or *series connected* type. The model is capable of including an extra field winding as shown in Figure 6.11.4−b, facilitating the simulation of *compound* DC machines. *Commutator* windings do not contribute to electromechanical energy conversion, therefore these windings are not modeled in this component.



a) One Field Winding   b) Two Field Windings

Figure 6.11.4 _rtds_DCMAC DC Machine Icon

The control input S determines whether the machine operates in lock or free mode. If S is set to 1, then the pu speed of the machine is determined by the control input F, otherwise if S is set to 0, then the speed of the machine is determined by mechanical swing equations. In this case, the mechanical torque comes from the control input T in pu.

As mentioned earlier, pole flux (φ) varies with the current (i_f) flowing into the field winding. This relationship is affected by saturation. To extract this relationship the user needs to input DC machine open−circuit characteristic. The user has the option of considering a linear characteristic or considering a saturated characteristic.

Three options are available to enter saturated open−circuit characteristic:

− Entering p.u. open−circuit voltages and corresponding p.u. field currents by points on the open−circuit curve.

− Entering *saturation factors* SE(1.0) and SE(1.2) from the normalized open−circuit curve.

− Representing the perunitized saturation curve using an *exponential* function. This option is added to make this DC machine model compatible with the DC machine model in PSCAD.

As mentioned earlier, the open−circuit voltage (or back−EMF) has the following relationship with the pole flux (φ). using this relationship and the entered saturation curve, the relationship between pole flux (φ) and field current (i_f) can be identified.

$$E_{f0} = k \cdot \varphi \cdot \omega_m$$

To the best of author's knowledge, there is no standard formula to calculate armature reaction (AR). Armature reaction is mostly affected by the armature current (i_a) and not by the field current (i_f). Experimental results show a quadratic relation between the armature reaction and the armature current. The following equation is used to calculate (AR) in the DC machine model _rtds_DCMAC. Constants $arfc1$ and $arfc2$ are proportional and quadratic constants entered by the user. i_a is the armature current.

$$AR = arfc1 \cdot |ia| + arfc2 \cdot |ia|^2$$

One computational load unit of RTDS is required for real−time simulation of a _rtds_DCMAC, direct−current machine model (DCMAC) . Menus of the DC machine model are explained below:

6.11.4 PROCESSOR ASSIGNMENT MENU FOR _rtds_DCMAC

Processor assignment menu is used to specify the processor which the model will be assigned to. PROCESSOR ASSIGNMENT MENU appears as shown in Figure 6.11.5.

AorM: Specify if the model is automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: This parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: This parameter is only used if AorM parameter is set to Manual. The user can select the model be assigned to A or B processor.

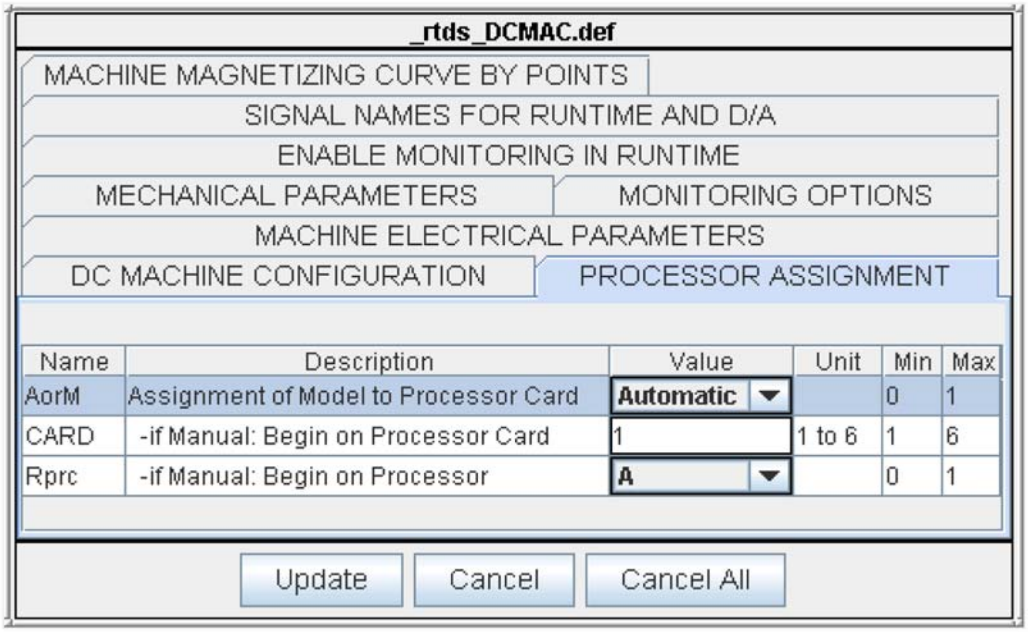


Figure 6.11.5 Processor assignment menu for _rtds_DCMAC

6.11.5 CONFIGURATION MENU FOR _rtds_DCMAC

Configuration menu for the component _rtds_DCMAC appears as shown in Figure 6.11.6. The following is the explanation of parameters in this menu:

Name: A unique name must be given for each instance of the component.

Vbsar: Rated Armature Voltage of the Machine (DC kV)

ibsar: Rated Armature Current of the Machine (DC kA)

ibsfld: Rated Current of the Field Winding (DC kA)

WbsRPM: Rated Speed of the Machine (RPM)

fldno: Number of Field Windings in the Machine. The user may specify one or two field windings. If “fldno” is set to two, “ibsfld” corresponds to the rated current of the first field winding.

ocspd: Speed in which magnetizing data (open−circuit characteristic and armature reaction) is measured.

tysat: The “tysat” menu item prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve, using saturation factors SE(1.0) and SE(1.2), or estimated by an exponential curve. Select “linear” if no saturation data is available.

tyar: The “tyar” menu item prompts for an indication of whether the effects of armature reaction will be included in the model.

prtyp: The “prtyp” parameter allows the user to select the type of processor on which the model is to be run.

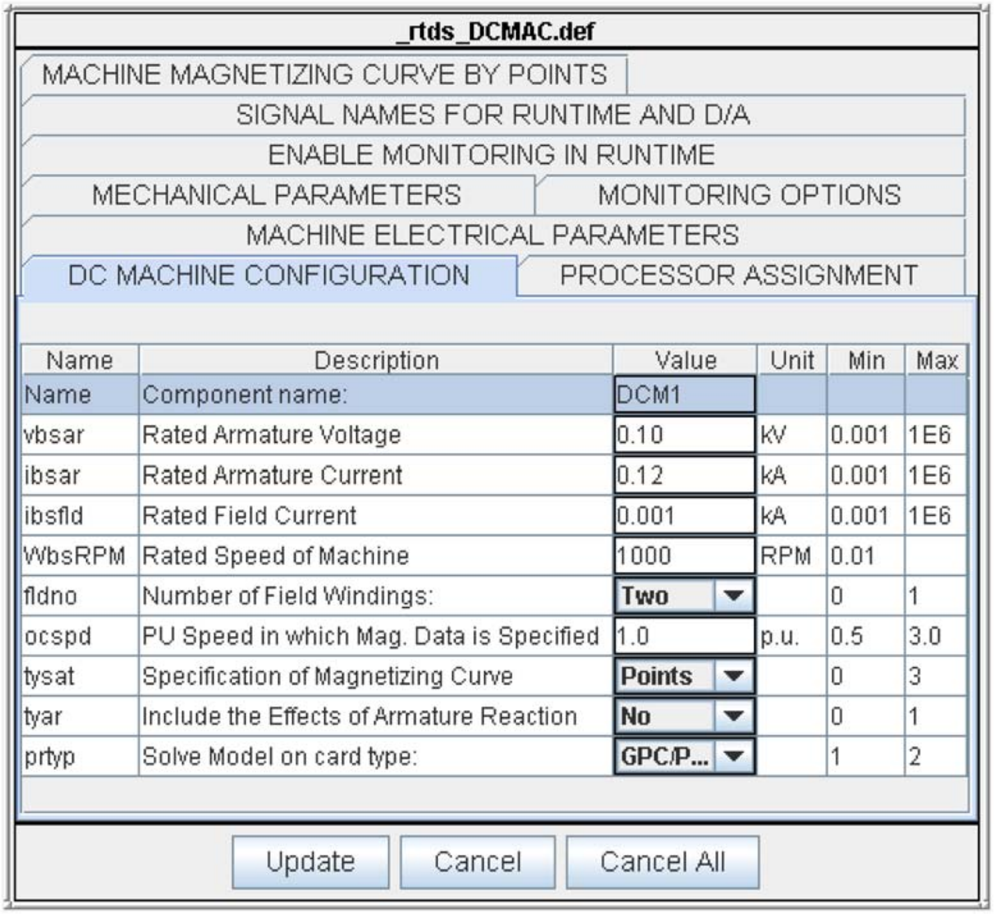


Figure 6.11.6 Configuration menu for _rtds_DCMAC

6.11.6 MACHINE ELECTRICAL PARAMETERS MENU FOR _rtds_DCMAC

DC machine inductances and resistances are specified in the “DC Machine Electrical Parameters Menu” as shown in Figure 6.11.7. The following is the explanation of parameters in this menu:

ra: Resistance of the Armature Winding in (Ohm). This parameter corresponds to (r_a) in Figure 6.11.2.

Laa: Self Inductance of the Armature Winding in (H). This parameter corresponds to (L_{aa}) in Figure 6.11.2.

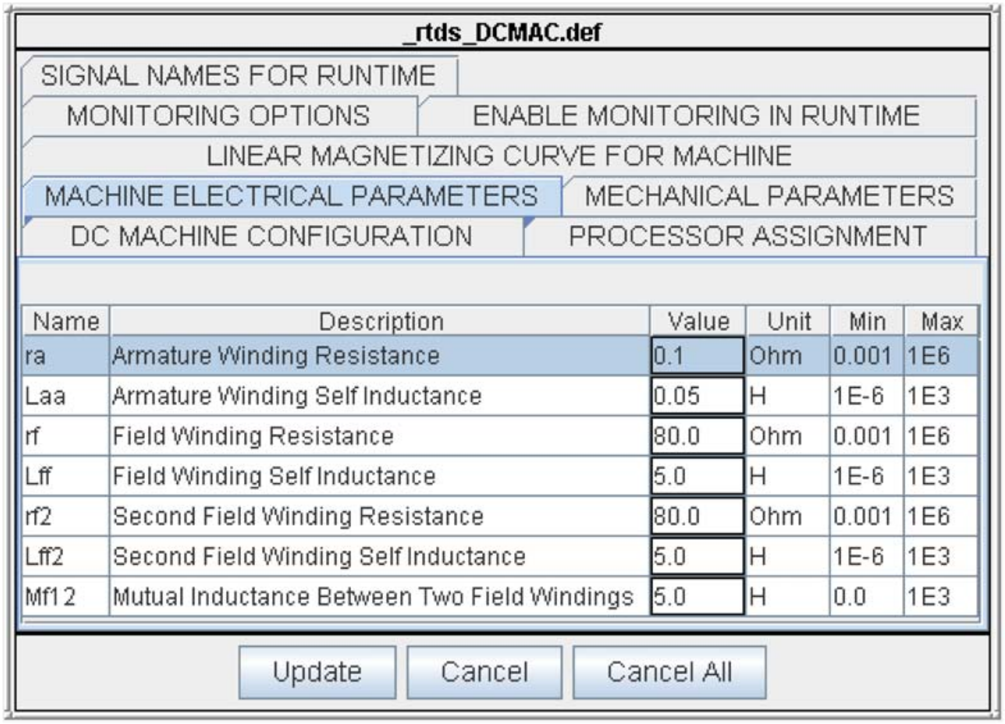
rf: Resistance of the Field Winding in (Ohm). This parameter corresponds to (r_f) in Figure 6.11.2.

Lff: Self Inductance of the Field Winding in (H). This parameter corresponds to (L_{ff}) in Figure 6.11.2.

rf2: Resistance of the Optional Second Field Winding in (Ohm). This parameter corresponds to (r_{f2}) in Figure 6.11.3.

Lff2: Self Inductance of the Optional Second Field Winding in (H). This parameter corresponds to (L_{ff2}) in Figure 6.11.3.

Mf12: Mutual Inductance Between the First Field Winding and Optional Second Field Winding in (H).



Name	Description	Value	Unit	Min	Max
ra	Armature Winding Resistance	0.1	Ohm	0.001	1E6
Laa	Armature Winding Self Inductance	0.05	H	1E-6	1E3
rf	Field Winding Resistance	80.0	Ohm	0.001	1E6
Lff	Field Winding Self Inductance	5.0	H	1E-6	1E3
rf2	Second Field Winding Resistance	80.0	Ohm	0.001	1E6
Lff2	Second Field Winding Self Inductance	5.0	H	1E-6	1E3
Mf12	Mutual Inductance Between Two Field Windings	5.0	H	0.0	1E3

Figure 6.11.7 Machine Electrical Parameters Menu for _rtds_DCMAC

6.11.7 THE MECHANICAL PARAMETERS MENU

In this DC machine model the mechanical swing equations of the rotor are solved inside the model. This menu specifies the inertia constant (H) and frictional damping (D) of the mechanical mass connected to the shaft. The MECHANICAL PARAMETERS menu appears as shown in Figure 6.11.8.

H: The "H" menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating.

D: The "D" menu item prompts for the frictional damping factor. The resulting damping torque tends to resist the speed. The damping torque factor "D" is in units of per−unit torque over per−unit speed deviation from zero speed. In locked speed mode, the pu speed of the machine is determined by a control input F in the icon. In the free or speed mode, the machine speed ω is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (T_m), electrical torque (T_e), and the damping torque. The following equation shows this relationship.

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

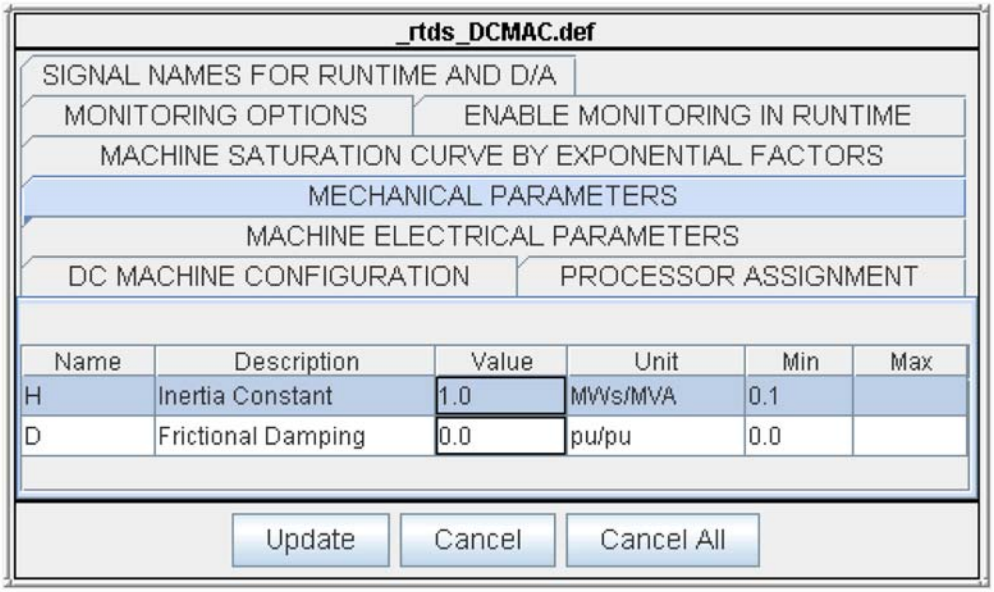


Figure 6.11.8 Machine Mechanical Parameters Menu for _rtds_DCMAC

Similar to other machine models in RTDS, **when the speed is positive, positive electric torque corresponds to generating operation of the machine and negative electric torque corresponds to motoring operation of the machine**. **When the speed is negative, positive torque corresponds to motoring operation of the machine, and negative torque corresponds to generating operation of the machine.** This is shown in the following table. Note that, positive speed according to EMTDC and RTDS conventions means anti–clockwise rotation of the rotor.

Speed	Positive Torque	Negative Torque
+	Generator	Motor
–	Motor	Generator

6.11.8 THE MACHINE SATURATION CURVE MENUS

The “tysat” menu item in the “DC MACHINE CONFIGURATION” menu prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve, using saturation factors SE(1.0) and SE(1.2), or using an exponential function. The choices are “Linear”, “Points”, “Factors” and “Exponential Factors”. The menus are explained below:

6.11.9 LINEAR MAGNETIZING CURVE MENU

If “tysat” is chosen as “ Linear”, then machine will not saturate and a linear relationship is assumed between the back EMF and the field winding current. The LINEAR MAGNETIZING CURVE FOR MACHINE menu appears as shown in Figure 6.11.9.

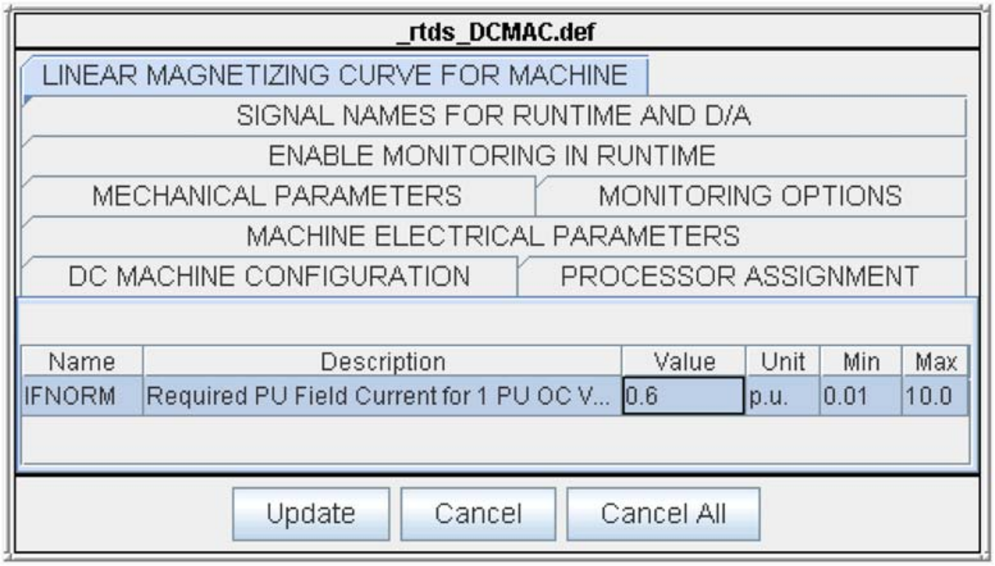


Figure 6.11.9 Linear O.C. Magnetizing Curve for _rtds_DCMAC

IFNORM: Assuming a linear relationship, the required p.u. field current to generate 1.0 p.u open−circuit voltage is needed to generate the linear open−circuit characteristic.

6.11.10 THE MACHINE SATURATION CURVE BY POINTS MENU

The MACHINE SATURATION CURVE BY POINTS menu appears as follows:

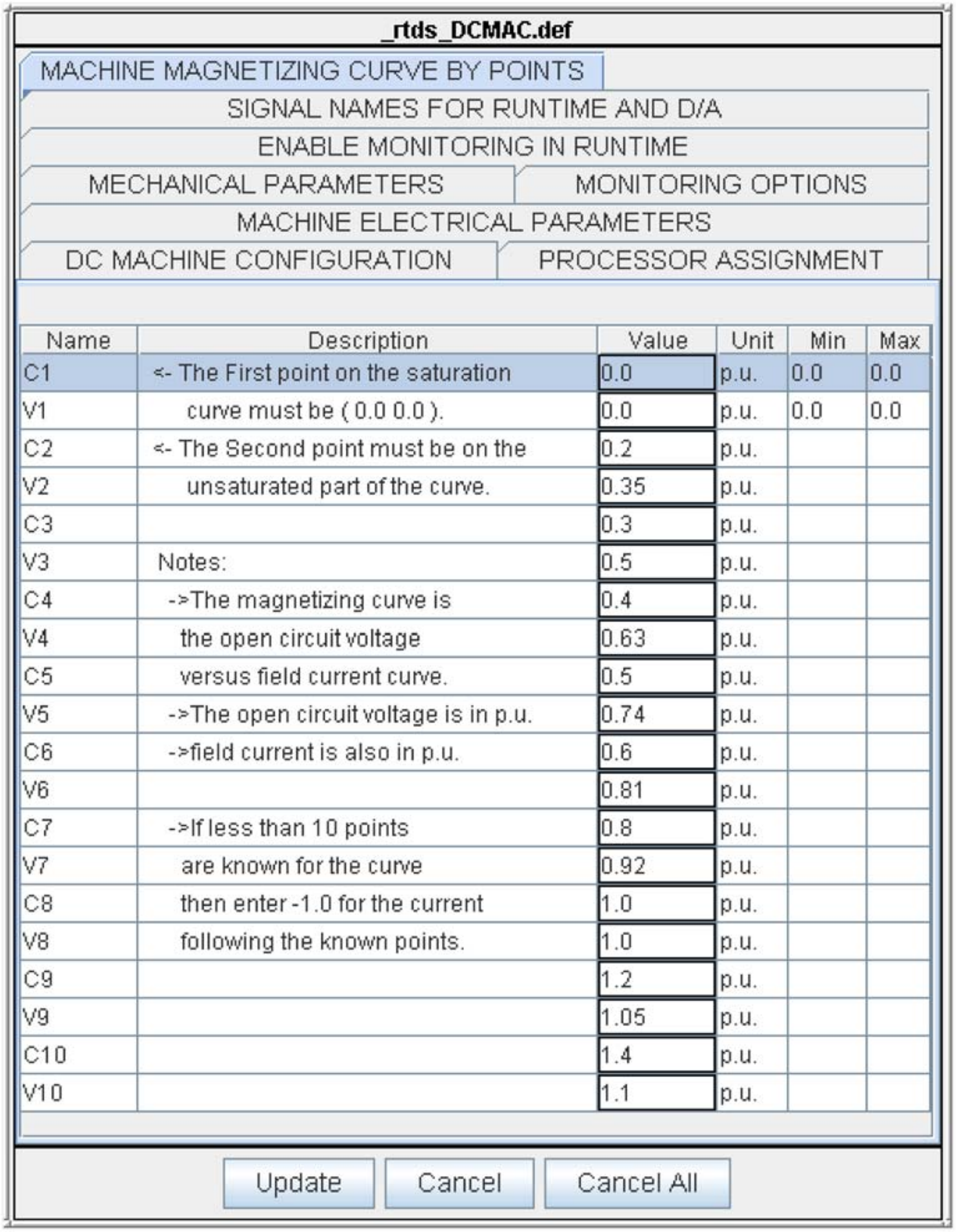
This method requires a saturation curve for the machine to be entered using points on the curve. The curve is a plot of air−gap voltage (back−EMF) in per−unit versus the field current also in per−unit. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point provides scaling information for magnetizing currents entered in the menu. If fewer than 10 points are entered for the curve, then enter −1.0 for the currents following the last known point.

6.11.11 MACHINE SATURATION CURVE BY FACTORS MENU

The two factors to be specified in this menu are defined in Figure 6.11.11. The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.

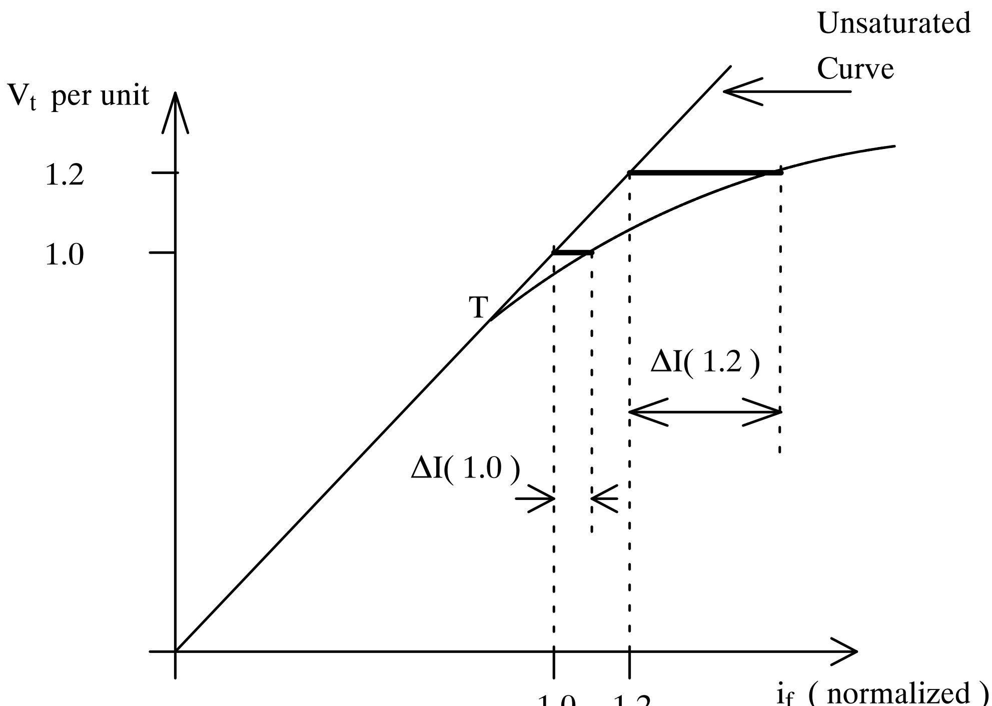
The MACHINE SATURATION CURVE BY FACTORS menu appears as shown in Figure 6.11.12.

IFNORMF: As can be seen in Figure 6.11.11, the field current is expressed in *normal* values not per–unit, therefore to generate the pu back–EMF curve versus pu field current, the required p.u. field current to generate 1.0 p.u open–circuit voltage on the air–gap line is needed.



Name	Description	Value	Unit	Min	Max
C1	<- The First point on the saturation	0.0	p.u.	0.0	0.0
V1	curve must be (0.0 0.0).	0.0	p.u.	0.0	0.0
C2	<- The Second point must be on the	0.2	p.u.		
V2	unsaturated part of the curve.	0.35	p.u.		
C3		0.3	p.u.		
V3	Notes:	0.5	p.u.		
C4	->The magnetizing curve is	0.4	p.u.		
V4	the open circuit voltage	0.63	p.u.		
C5	versus field current curve.	0.5	p.u.		
V5	->The open circuit voltage is in p.u.	0.74	p.u.		
C6	->field current is also in p.u.	0.6	p.u.		
V6		0.81	p.u.		
C7	->If less than 10 points	0.8	p.u.		
V7	are known for the curve	0.92	p.u.		
C8	then enter -1.0 for the current	1.0	p.u.		
V8	following the known points.	1.0	p.u.		
C9		1.2	p.u.		
V9		1.05	p.u.		
C10		1.4	p.u.		
V10		1.1	p.u.		

Figure 6.11.10 O.C. Magnetizing Curve by Points for rtds DCMAC



$SE = \Delta I / V_t$

$SE(1.0) = \Delta I(1.0) / 1.0$

$SE(1.2) = \Delta I(1.2) / 1.2$

Figure 6.11.11 Machine Saturation Curve By Factors SE1.0 and SE1.2

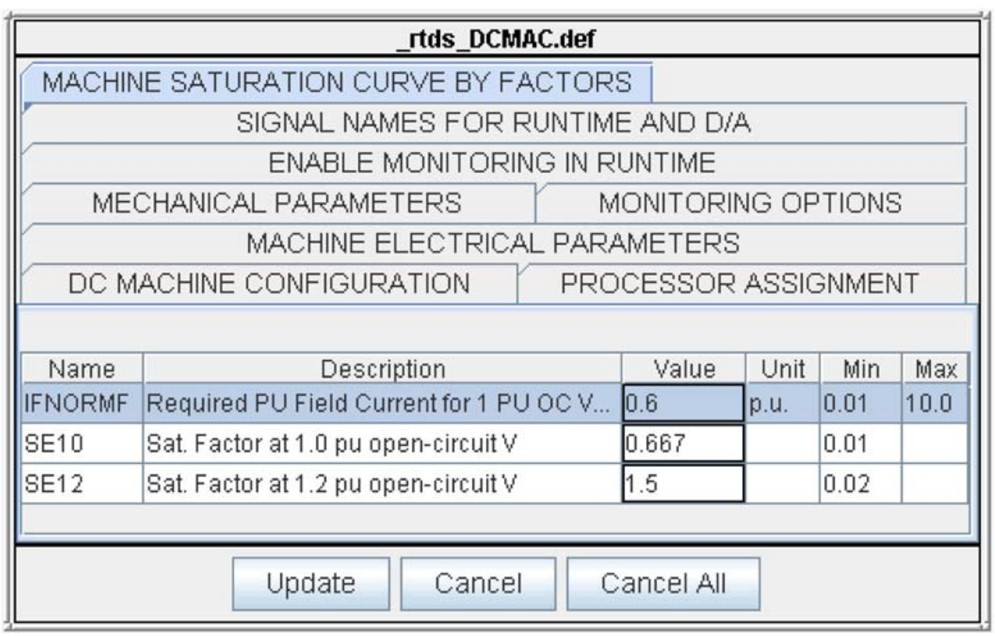


Figure 6.11.12 O.C. Magnetizing Curve by Factors for _rtds_DCMAC

6.11.12 MACHINE SATURATION CURVE BY EXPONENTIAL FACTORS MENU

In this option, the saturation curve is approximated by an exponential function as shown in the following equation. Here, V_{oc_sat} is called the saturated armature open−circuit voltage and represents the maximum open−circuit voltage that can be achieved by increasing the field current as shown in Figure 6.11.13.

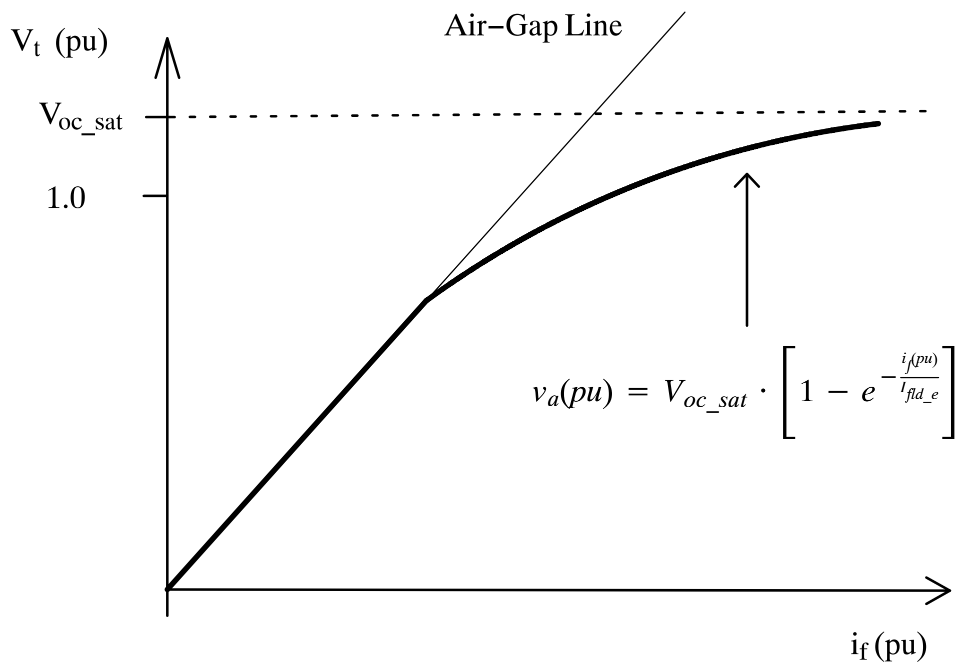


Figure 6.11.13 Machine Saturation Curve By Exponential Factors

In this figure, both back_EMF voltage and field current are presented in per−unit. The saturation curve exponential constant is shown by I_{fld_e}.

$$v_a(pu) = V_{oc\_sat} \cdot \left[1 - e^{-\frac{i_f(pu)}{I_{fld\_e}}}\right]$$

The MACHINE SATURATION CURVE BY EXPONENTIAL FACTORS menu appears as shown in Figure 6.11.14. Here is the description of menus:

VOCSAT: Saturated armature open−circuit voltage representing the maximum open−circuit voltage that can be achieved by increasing the field current. This parameter is shown as (V_{oc_sat}) in the above equation.

IFLDE: Saturation curve exponential constant shown as (I_{fld_e}) in the above equation.

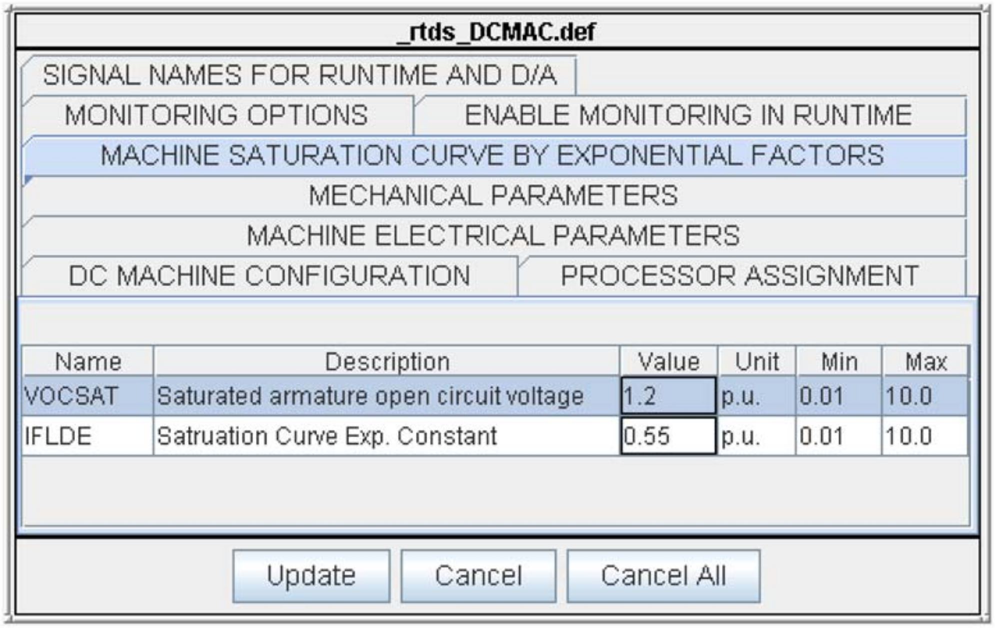


Figure 6.11.14 O.C. Magnetizing Curve by Exponential Factors for _rtds_DCMAC

6.11.13 MACHINE ARMATURE REACTION SPECIFICATION MENU

As mentioned previously, the assumption is that armature reaction is mostly affected by the armature current (i_a) and not by the field current (i_f). Experimental results show a quadratic relation between the armature reaction and the armature current. The following equation is used to calculate (AR) in the DC machine model _rtds_DCMAC:

$$AR = arfc1 \cdot |ia| + arfc2 \cdot |ia|^2$$

The MACHINE ARMATURE REACTION menu appears as shown in Figure 6.11.15. Here is the description of menus:

ARFC1: Armature reaction proportional constant which represents $arfc1$ in the above equation.

ARFC2: Armature reaction quadratic constant which represents $arfc2$ in the above equation.

ARMAX: The user may specify the maximum allowed armature reaction.

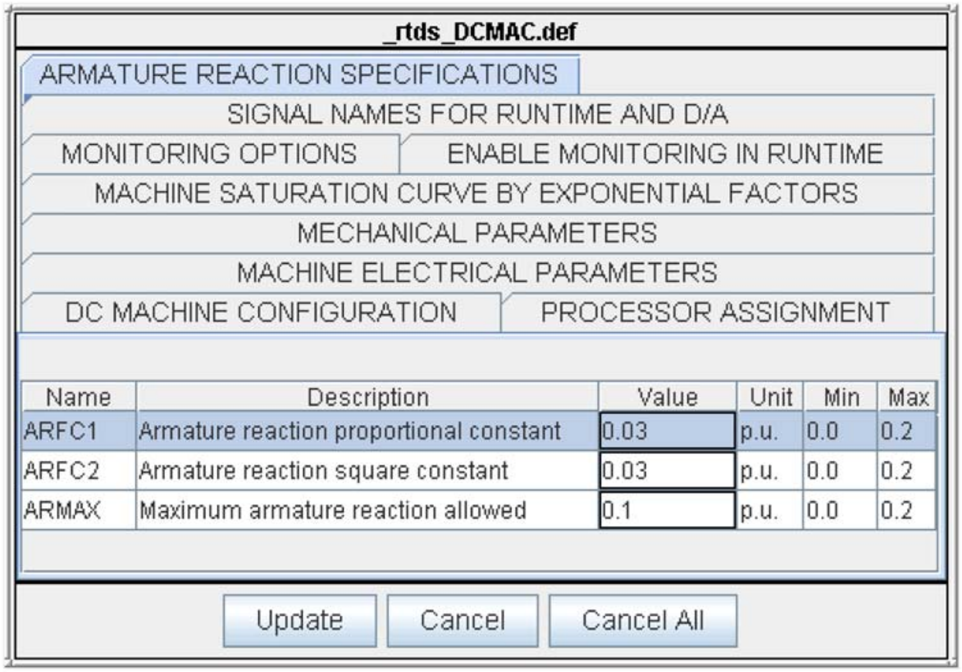


Figure 6.11.15 Armature reaction Menu for _rtds_DCMAC

6.11.14 MONITORING OPTION MENU

The user has the option of using a low−pass filter $\left(\frac{1}{1 + S \cdot T}\right)$ when the power is monitored. The menu MONITORING OPTIONS appears as shown in Figure 6.11.16.

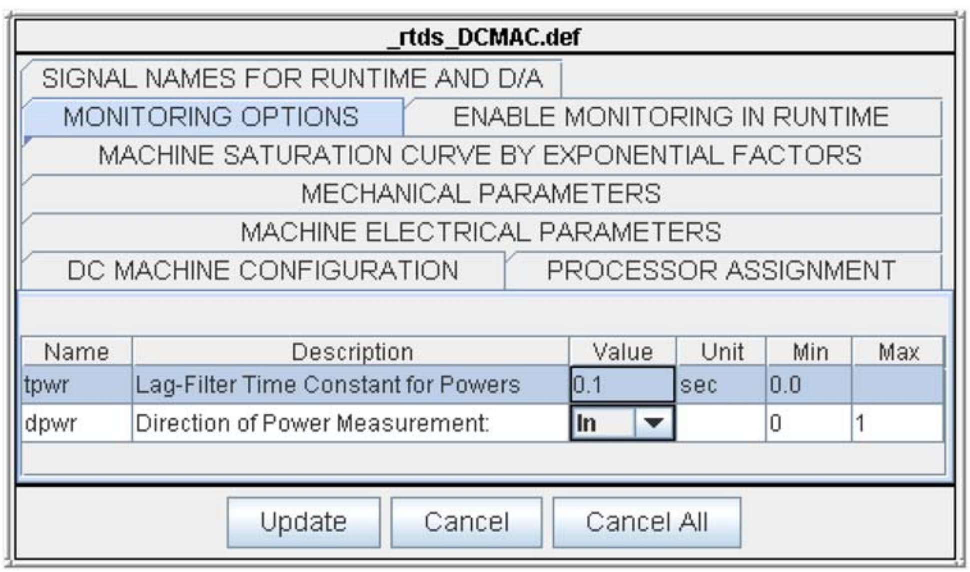


Figure 6.11.16 Monitoring Option Menu for _rtds_DCMAC

In this menu:

tpwr: Specifies the time constant (T) that the first order low pass filter will use on the signal for real power monitored from the machine.

Dpwr: Specifies the direction of active power monitored from the machine.

6.11.15 THE ENABLE MONITORING IN RUNTIME MENU

The _rtds_DCMAC ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.11.17.

Armature and Field Currents: The user has the option of monitoring the armature and field winding currents in kA.

Rotor Angle, Electric Torque, and Rotor Speed: Mechanical quantities such as rotor angle, electric torque and rotor speed can also be monitored in Radians, pu , and pu respectively.

Active Power and Power Loss of the Machine:The active power of armature and field windings also the resistive losses of the machine can be monitored. The direction of monitored power can be selected in the "Monitoring Options" menu.

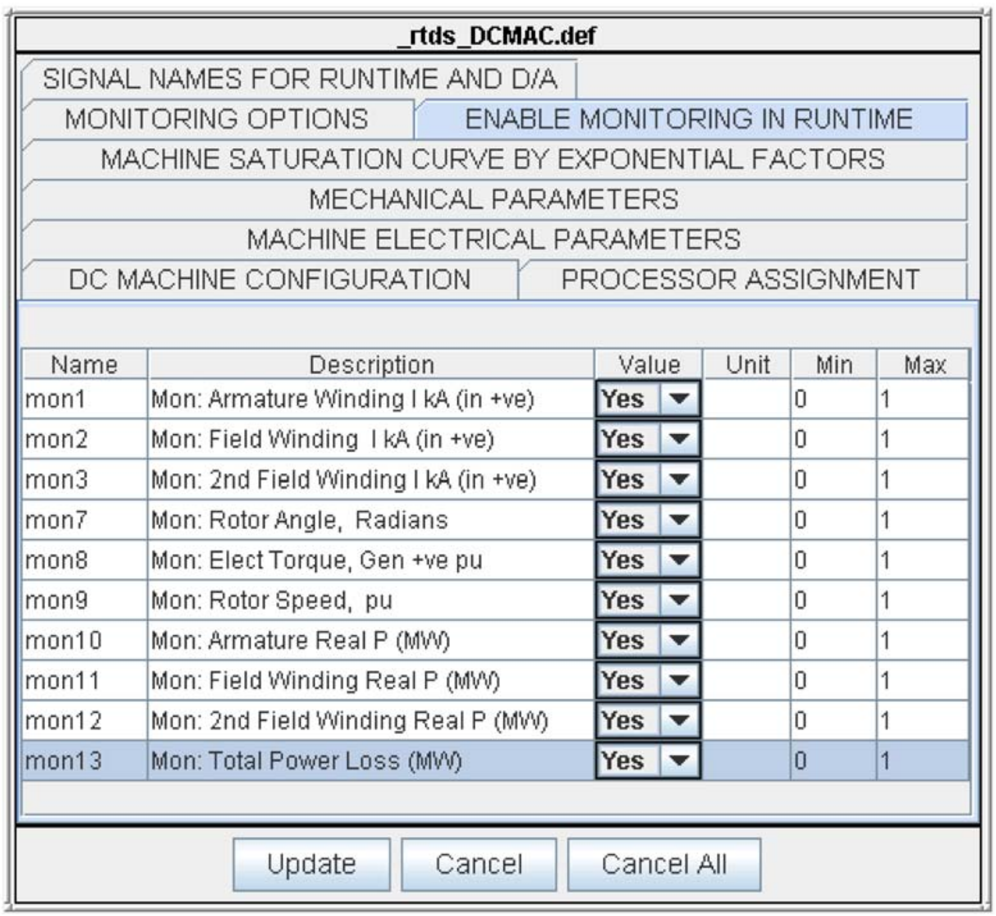


Figure 6.11.17 Enable Monitoring in Runtime Menu for _rtds_DCMAC

6.11.16 THE SIGNAL NAMES FOR RUNTIME MENU

The _rtds_DCMAC SIGNAL NAMES FOR RUNTIME MENU appears as shown in Figure 6.11.18. The user must dedicate a unique name for the monitored signals. A suffix can also be added to the signal names.

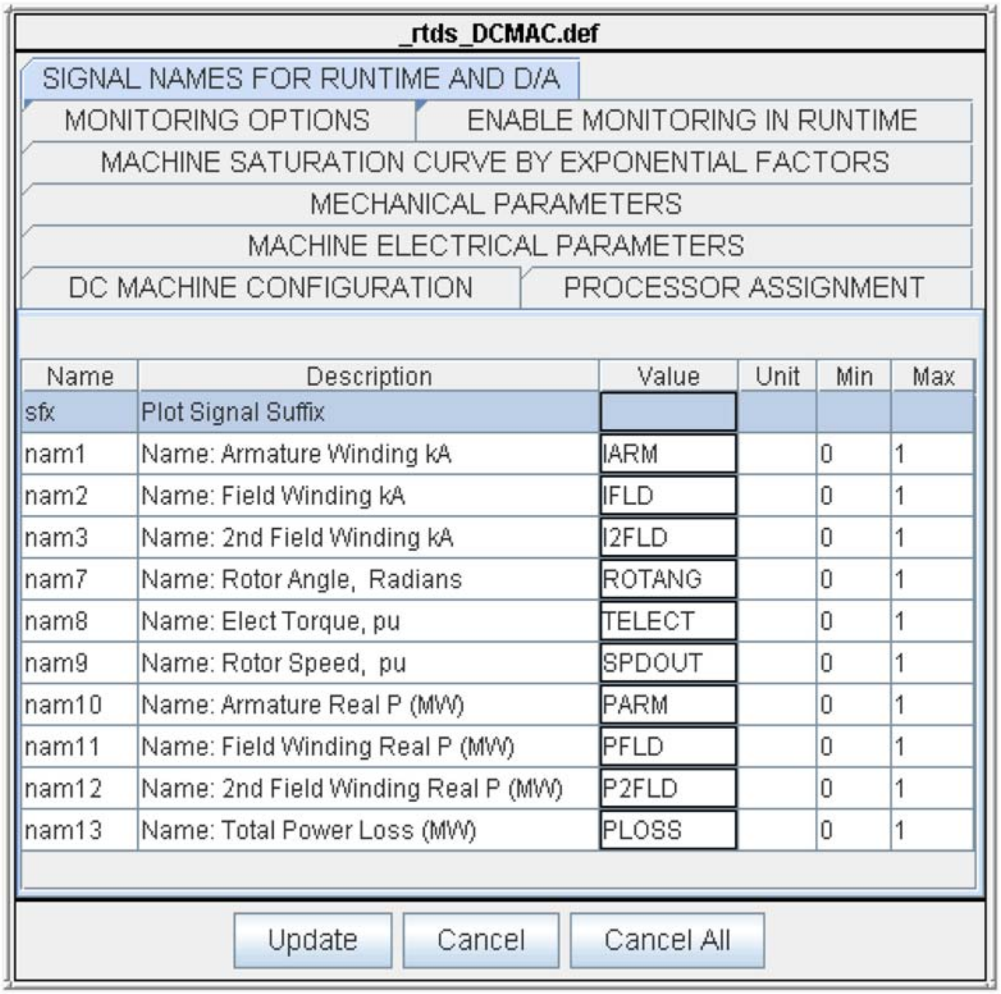


Figure 6.11.18 Signal Names for RunTime Menu for _rtds_DCMAC

6.11.17 MACHINE INFORMATION WRITTEN IN THE MAP FILE

After compiling a draft case containing an _rtds_DCMAC machine model, the MAP file will contain information about this DC machine model. Figure 6.11.19 shows an example of the MAP file. It contains the name of the machine model, rating of the armature and field windings, inductances and resistances of these windings.

```
RISC-based CModel component model of type "DCMAC (Direct Current Machine)"
  named: DCM1
  in subsystem: 1

has the following electric parameters:
  ========================================
  Rated Armature Voltage:   0.100000  kV
  Rated Armature Current:   0.120000  kA
  Rated Field Current:      0.001000  kA
  Armature Winding Resistance:        0.100000  Ohm
  Armature Winding Self Inductance:   0.050000  H
  Field Winding Resistance:           80.000000  Ohm
  Field Winding Self Inductance:      5.000000  H

RISC-based CModel Component: DCMAC2 named "DCM1" --> RPC-GPC Card #2 Processor A
```

Figure 6.11.19 DC Machine Information Written in the MAP File

6.11.18 EXAMPLE CASES

Example cases are added to the tutorial "samples" directory. These examples help in understanding the analysis and operation of the direct−current machine model. These examples include a separately excited DC machine, series motors and simple electric traction circuits.

SEPARATELY EXCITED DC MACHINE:

The following exercise on a separately excited machine helps with the procedure of data preparation for _rtds_DCMAC model. The data is taken from example 4.2 of [21]. A simulation case containing this DC machine model is added to the samples directory.

Parameter	Symbol	Value
Rated Armature Voltage	vbsar	0.1 (kV)
Rated Armature Current	ibsar	0.12 (kA)
Rated Field Current	ibsfld	0.001 (kA)
Rated Speed of Machine	WbsRPM	1000 RPM
Armature Winding Resistance	ra	0.1 (Ohm)
Armature Winding Inductance	Laa	0.05 (H)
Field Winding Resistance	rf	80.0 (Ohm)
Field Winding Inductance	Lff	5.0 (H)

The open circuit characteristic of this machine is given in the following table. The field current is expressed in (A) and armature open−circuit voltage is expressed in (V). As can be seen, due to remanence, even with no field current there exist a small

6.38 (V) on the terminals of the machine. It must be noted that, in RTDS machine models, saturation curve must cross (0,0) and effects of hysteresis and remanence are not included. Therefore this data must be modified so that the armature voltage is zero when there is no current in the field winding.

Field Current (A)	Armature O.C. Voltage (V)
0	6.38
0.064	10.25
0.15	25.14
0.20	34.62
0.3	50.48
0.38	63.06
0.50	74.08
0.60	81.04
0.79	91.88
1	100
1.20	105.42
1.40	110.44
1.52	111.99

This open−circuit data can be per−unitized using the rated values of the field current and armature voltage. The perunitized data can be used in the menu for MACHINE SATURATION CURVE BY POINTS.

Figure 6.11.20 shows the per−unitized saturation curve. As can be seen, the required field current to achieve 1.0 p.u. open circuit voltage on the air−gap line is $I_{f\_norm} = 0.6(p.u.) = 0.6(A)$. This parameter is used in the LINEAR MAGNETIZING CURVE and SATURATION CURVE BY FACTORS menus.

Saturation factors (SE1.0 and SE1.2) are needed in the menu for SATURATION CURVE BY FACTORS. Figure 6.11.21 shows the normalized saturation curve for the above DC machine. According to the instructions listed in Section 6.11.11, factors SE1.0 and SE1.2 are computed as follows:

$$SE(1.0) = \frac{0.67}{1.0} = 0.67$$

$$SE(1.2) = \frac{1.8}{1.2} = 1.5$$

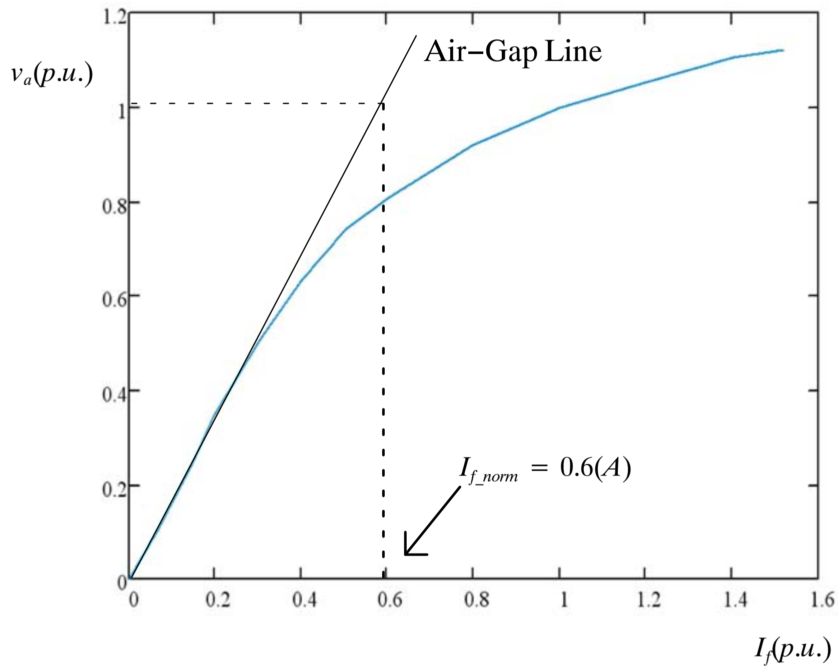


Figure 6.11.20 Per−unitized open circuit magnetizing curve

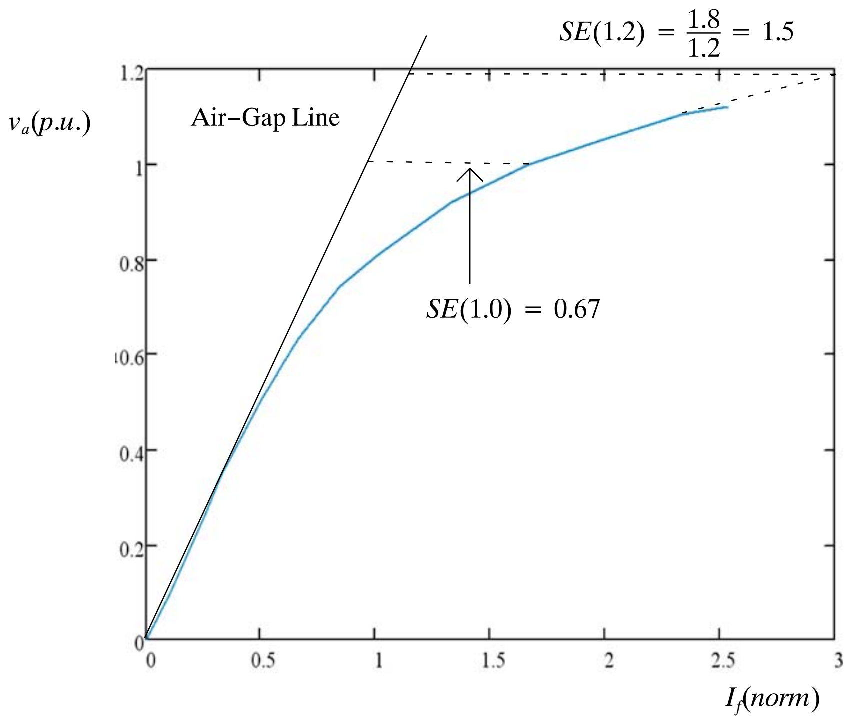


Figure 6.11.21 Normalized open circuit magnetizing curve

SERIES CONNECTED DC MOTOR:

In this motor the field winding is connected in series with the armature winding. In a series motor, a high torque is obtained in low speeds and a low torque is obtained in high speed. Series motors are therefore used where large starting torques are required as in traction cars, cranes, automobile starters, blenders and various hand tools [15], [21]. Another property of these motors is their ability to operate with AC excitation. If a series connected DC machine is excited with AC voltage, the resulting torque is pulsating but uni−directional [15], [21], therefore an average torque can be achieved and the motor can be utilized. Series connected DC motors are often called *universal motors* as they can operate with both AC and DC. Examples including series connected DC motors operating with both AC and DC are added to the "samples" directory.

6.11.19 SUMMARY

The _rtds_DCMAC, direct−current machine model (DCMAC), provides a model that is flexible in configuration. This model is an embedded phase – domain model [4]. This model has the following assumptions and specifications:

1. Space harmonics and slot harmonics are ignored.
2. Similar to other machine models in RTDS, a multi−pole DC machine is modeled as an equivalent two pole machine. Torque and speed are monitored in p.u.
3. It is assumed that armature and field self inductances are not affected by saturation. However, effects of *saturation* on the armature back EMF is considered. Effects of *armature reaction* are considered.
4. One computational load unit of RTDS is required for real−time simulation of an _rtds_DCMAC, direct−current machine model (DCMAC).
5. Both ends of each winding in this model are available for connecting to other power system components. This arrangement allows the user to easily configure the DC machine as a *separately excited*, *shunt* and *series connected* type. The model is capable of including an extra field winding as shown in Figure 6.11.3−b, facilitating the simulation of *compound* DC machines.
6. *Commutator* and *compensating* windings are not modeled in this component.

6.12 INDUCTION MACHINE MODELS (INDM)

This chapter describes the analysis, method of modeling, and specifications of induction machine models (lf_rtds_risc_sld_INDM & _rtds_INDM).

6.12.1 INTRODUCTION

Electrical energy represents more than 30% of all used energy and it is on the rise [14]. Part of electrical energy is used directly to produce heat or light, and the larger part of that is converted into mechanical energy in electric motors. The most common family of motors used in home, business and industry is the induction motor [15]. This type of machine is the most rugged and most widely used electric machine in the industry [23].

Small power induction motors, in most home applications, are in the form of single−phase induction machines described in Section 6.10.

For higher power applications (tens or hundreds of horsepower), three phase induction machines are used. These applications include pumps, fans, compressors, paper mills, textile mills, electric ships, electric trains, and so forth [14,15].

Induction machines can be used in the form of self−excited induction generators to generate electricity. Doubly−fed induction generators are widely used in wind turbines to produce electricity.

The induction machine (IM) gets its name from its method of transferring power from the primary windings on the stationary part (stator) to the rotating part (rotor). The winding arrangement on the part of the machine connected to the grid (the stator in general) produces a traveling field in the machine airgap. This traveling field will induce voltages in conductors on the part of the machine not connected to the grid (the rotor, or the mover in general), – the secondary. If the windings on the secondary (rotor) are closed, A.C. currents occur in the rotor. The interaction between the primary field and secondary currents produces torque from zero rotor speed onward. The rotor speed at which the rotor currents are zero is called the ideal no−load (or synchronous) speed [14].

The rotor winding may be multiphase (wound rotors) or made of bars short−circuited by end rings (cage rotors). All primary and secondary windings are placed in uniform slots stamped into thin silicon steel sheets called laminations. The induction machine has a rather uniform airgap of 0.2 to 3 mm. The largest values correspond to large power, 1 MW or more [14,15].

The secondary windings may be short−circuited or connected to an external impedance or to a power source of variable voltage and frequency. In the latter case however the induction machine works as a synchronous machine as it is doubly fed and both stator and rotor frequencies are imposed.

The above principle of operation is based on the rotating magnetic field concept. The original work was done Galileo Ferraris in Italy and Nicola Tesla in the United States. Both machines were based on a two−phase a.c. system, however Tesla recognized that more than two phases can be used [15]. In Ferrari's patent the rotor was made of a copper cylinder, while in the Tesla's patent the rotor was made of a ferromagnetic cylinder provided with a short−circuited winding. Economic advantages of three−phase system over two−phase led to the world−wide adaptation of three phase induction machines.

The induction motor with the wound rotor was invented by Dolivo−Dobrovolsky in 1889. Subsequently the cage rotor and double−cage rotor with a very similar topology were also invented by him.

Thus, around 1900 the induction motor was ready for wide industrial use. In early 1900, in Europe, locomotives provided with induction motor propulsion, were capable of delivering 200 km/h. However, it wasn't until 1985, when IGBT PWM inverters with sufficient switching frequency promoted the return of induction motors in electric tractions for high speed trains [14].

6.12.2 THEORY AND ANALYSIS

This chapter briefly describes the analysis and method of modeling induction machines. For further information please see the references [14], [16], [23] and [26].

Here the analysis starts with a wound rotor induction machine, and later expands to induction machines with cage rotors. As mentioned above, a three phase induction machine consists of three stator windings known as phases as, bs and cs with the angular space of normally 120° electrical. The stator windings are usually symmetric. The rotor also has three windings ar , br and cr located in an angular displacement of 120° electrical.

Figure 6.12.1 shows the diagram of an idealized two−pole three−phase induction machine. Windings as, bs and cs represent stator windings and windings ar , br and cr represent rotor windings. Stator axis is shown by $as - axis$ representing the angle of MMF produced by phase A on the stator. Rotor axis is shown by $ar - axis$ representing the angle of MMF produced by phase A on the rotor. Rotor angle is the angle between $as - axis$ and $ar - axis$, shown by θ_r and rotor speed is shown by ω_r. The ratio of stator effective turns over rotor effective turns (N_s/N_r) is shown by symbol a.

The following assumptions are made in this analysis:

– Similar to other machine models in RTDS, multi−pole IMs are modeled as an equivalent two pole machine. Torque and speed are monitored in p.u..

– It is assumed that the machine windings produce a sinusoidal MMF, thus space harmonics are ignored.

– As the rotor is a cylindrical round rotor, saturation is modeled by adjusting the magnetizing inductance as a function of the total magnetizing current peak value.

– Saturation in the leakage paths is ignored.

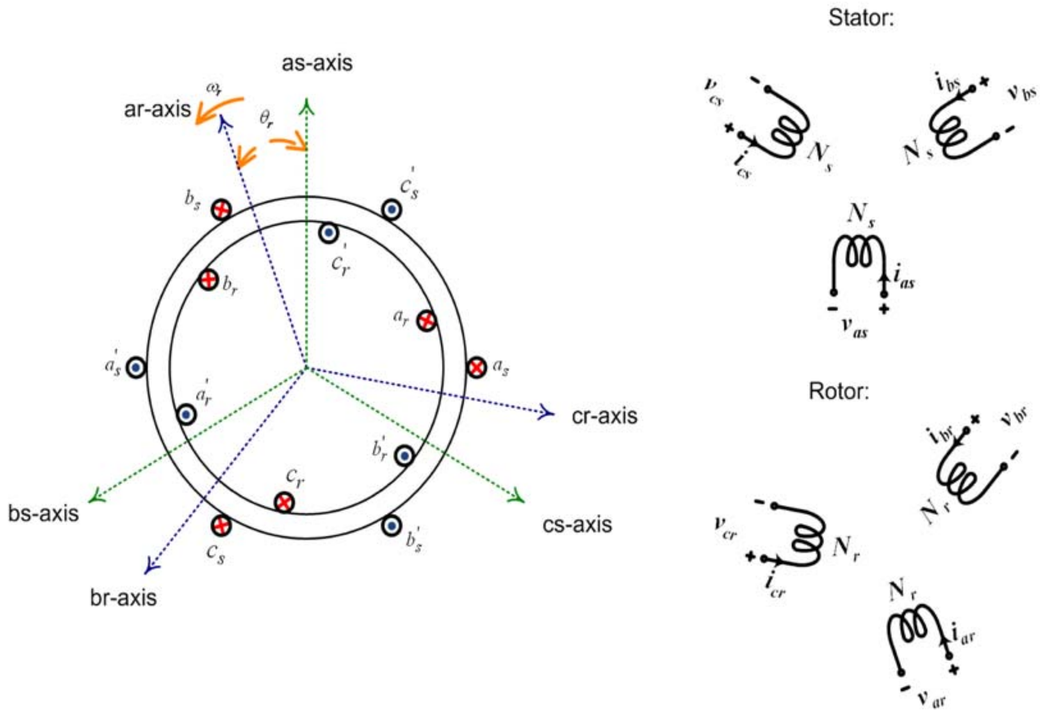


Figure 6.12.1 Diagram of an idealized three phase induction machine.

Voltage equations for a three phase induction machine are presented in the following equation. Here, $\underline{v}_{abcs}$ and $\underline{v}_{abcr}$ are vectors of stator and rotor voltages. Stator and rotor currents and flux−linkages are shown by $\underline{i}_{abcs}$, $\underline{i}_{abcr}$, $\underline{\psi}_{abcs}$, and $\underline{\psi}_{abcr}$ respectively. Resistance matrices of stator and rotor are shown by $[r_s]$ and $[r_r]$.

$$\overbrace{\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{bs} \end{bmatrix}}^{\underline{v}_{abcs}} \atop \underbrace{\begin{bmatrix} v_{ar} \\ v_{br} \\ v_{br} \end{bmatrix}}_{\underline{v}_{abcr}} = \begin{bmatrix} \overbrace{\begin{bmatrix} r_s & 0 & 0 \\ 0 & r_s & 0 \\ 0 & 0 & r_s \end{bmatrix}}^{[r_s]} & \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \\ \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} & \underbrace{\begin{bmatrix} r_r & 0 & 0 \\ 0 & r_r & 0 \\ 0 & 0 & r_r \end{bmatrix}}_{[r_r]} \end{bmatrix} + \begin{bmatrix} \overbrace{\begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix}}^{\underline{i}_{abcs}} \\ \underbrace{\begin{bmatrix} i_{ar} \\ i_{br} \\ i_{cr} \end{bmatrix}}_{\underline{i}_{abcr}} \end{bmatrix} + \frac{d}{dt} \cdot \begin{bmatrix} \overbrace{\begin{bmatrix} \psi_{as} \\ \psi_{bs} \\ \psi_{cs} \end{bmatrix}}^{\underline{\psi}_{abcs}} \\ \underbrace{\begin{bmatrix} \psi_{ar} \\ \psi_{br} \\ \psi_{cr} \end{bmatrix}}_{\underline{\psi}_{abcr}} \end{bmatrix}$$

Also, the relation between flux linkages and currents is shown in the flux linkage equations. Ψ_{as}, Ψ_{bs} and Ψ_{cs} are flux linkages for stator windings a, b and c, and Ψ_{ar}, Ψ_{ar} and Ψ_{cr} are flux linkages for rotor windings. $[L_{ss}]$ and $[L_{rr}]$ are the inductance matrices for stator and rotor windings, and $[L_{sr}]$ is the inductance matrix for the mutual inductances between the stator and rotor windings.

$$\overbrace{\begin{bmatrix}\psi_{as}\\\psi_{bs}\\\psi_{cs}\end{bmatrix}}^{\underline{\psi}_{abcs}} \atop \underbrace{\begin{bmatrix}\psi_{ar}\\\psi_{br}\\\psi_{cr}\end{bmatrix}}_{\underline{\psi}_{abcr}} = \begin{bmatrix} \overbrace{\begin{bmatrix}L_{asas} & L_{asbs} & L_{ascs}\\ L_{bsas} & L_{bsbs} & L_{bscs}\\ L_{csas} & L_{csbs} & L_{cscs}\end{bmatrix}}^{[L_{ss}]} & \overbrace{\begin{bmatrix}L_{asar} & L_{asbr} & L_{ascr}\\ L_{bsar} & L_{bsbr} & L_{bscr}\\ L_{csar} & L_{csbr} & L_{cscr}\end{bmatrix}}^{[L_{sr}]} \\ \underbrace{\begin{bmatrix}L_{aras} & L_{arbs} & L_{arcs}\\ L_{bras} & L_{brbs} & L_{brcs}\\ L_{cras} & L_{crbs} & L_{crcs}\end{bmatrix}}_{[L_{sr}]^T} & \underbrace{\begin{bmatrix}L_{arar} & L_{arbr} & L_{arcr}\\ L_{brar} & L_{brbr} & L_{brcr}\\ L_{crar} & L_{crbr} & L_{crcr}\end{bmatrix}}_{[L_{rr}]} \end{bmatrix} \cdot \overbrace{\begin{bmatrix}i_{as}\\i_{bs}\\i_{cs}\end{bmatrix}}^{\underline{i}_{abcs}} \atop \underbrace{\begin{bmatrix}i_{ar}\\i_{br}\\i_{cr}\end{bmatrix}}_{\underline{i}_{abcr}}$$

The values of these inductances are functions of rotor position. In a machine with sinusoidally distributed windings, these inductances vary with rotor position in a sinusoidal manner. They also vary with saturation.

6.12.2.1 EQUIVALENT CIRCUIT

The above voltage and flux linkage equations can be transferred to a frame of reference so that the inductances do not depend on the rotor position. For transient simulation, rotor frame of reference is the most suitable frame [16]. This change of variables to the rotor frame of reference is done using Park's transformation, hence d− q− and 0−axis equivalent circuits can be achieved. This procedure can be found in electric machine textbooks [9], [14] and [23], therefore it's not explained further here. RTDS induction machine models lf_rtds_risc_sld_INDM and _rtds_vsc_INDM model use the d− and q−axis equivalent circuits for transient simulation of induction machines [25], [27]. The induction machine model _rtds_INDM solves the machine differential equations directly in the phase−domain [4], [5]. Simulation results for all these models are identical, the difference is in the features provided for these models which will be discussed later.

Figure 6.12.2 shows the d− and q−axis transient equivalent circuits of the wound rotor induction machine. Here r_s and r_r are stator and rotor resistances respectively. Stator and rotor leakage inductances are shown by L_{ls} and L'_{lr}, and L_m is the magnetizing inductance. Note that rotor parameters are referred to stator side. Machine impedances and resistances are usually available in p.u. which is required by the induction machine models developed for RTDS. These parameters can be measured using standard no−load and lock rotor test and standstill frequency response test [19], [23].

Steady−state equivalent circuit for a symmetric three−phase induction machine can be extracted by analyzing the machine in the stator frame of reference and utilizing phasors. Details of this procedure are not mentioned here. For a wound−rotor induction machine the steady−state equivalent circuit is shown in Figure 6.12.3. Here, $\overline{V}_s$, $\overline{V}_r$, $\overline{I}_s$ and $\overline{I}_r$ are phasors of stator and rotor voltages and currents. Operating frequency on the stator side is the synchronous frequency ω_s and for the rotor side is $s \cdot \omega_s = \omega_s - \omega_r$. Slip is shown by s and rotor speed by ω_r. This steady−state equivalent circuit and the ones discussed later in this document are used for initialization of the induction machine models in RTDS.

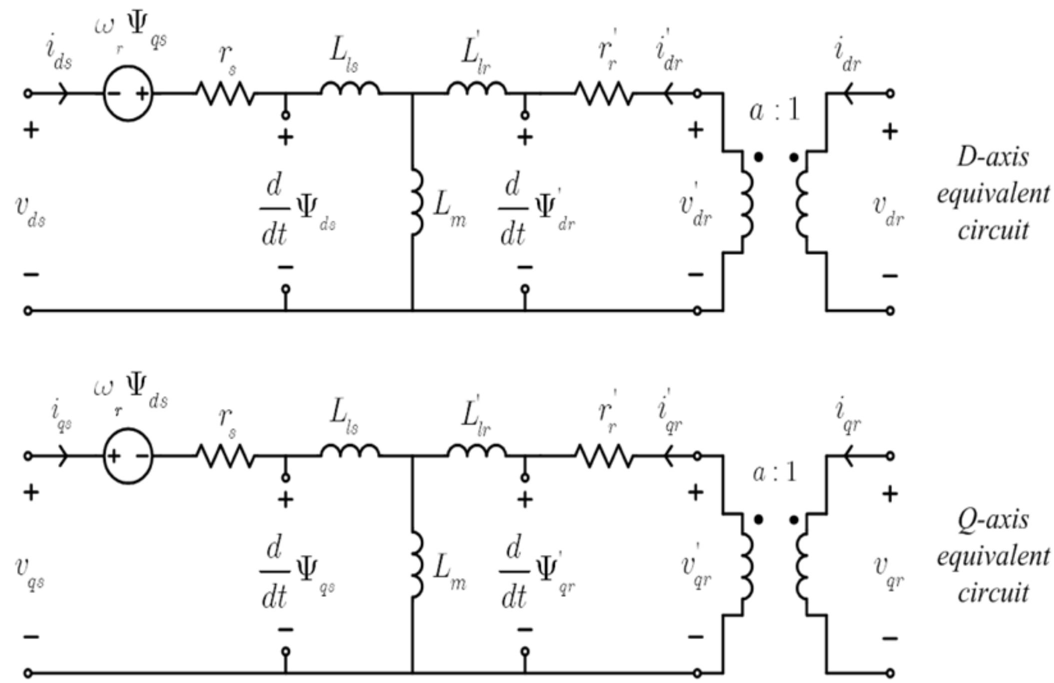


Figure 6.12.2 DQ0 equivalent circuit of an idealized three phase induction machine (one winding in the rotor)

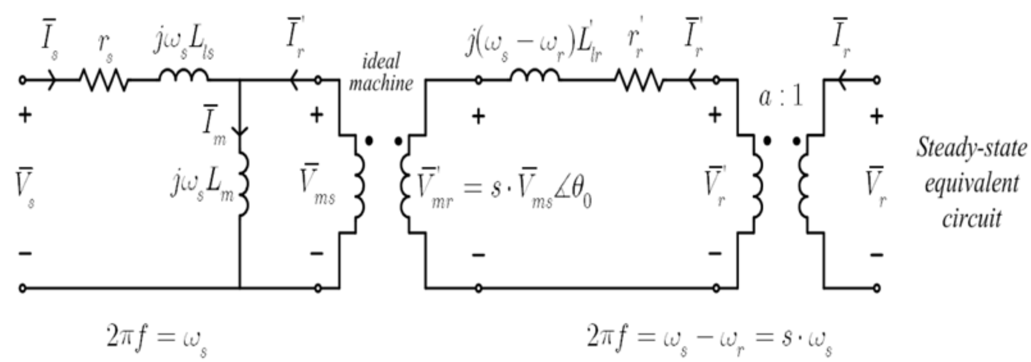


Figure 6.12.3 Steady−state equivalent circuit of an idealized three phase induction machine (one winding in the rotor)

External Windings on the Rotor:

Assuming external set of windings exists on the rotor, a similar approach as above can be used to extract the transient dq0 and steady−state equivalent circuit of a symmetric three phase induction machine. Figure 6.12.4 shows the d− and q−axis equivalent circuits of the induction machine with two sets of three−phase rotor windings. Here, L'_{lr1} and L'_{lr2} are the leakage inductances of rotor winding 1 and 2 and

L'_{lr12} is the representation of the leakage flux which links rotor windings 1 and 2 but not the stator. Resistances of rotor winding 1 and 2 are shown by r'_{r1} and r'_{r2} . Note that rotor parameters are referred to stator side.

For this machine, the steady−state equivalent circuit is shown in Figure 6.12.5. Similarly, this equivalent circuit can be used for initialization of the induction machine with extra rotor windings.

Having two separate set of rotor windings is a rare arrangement for an induction machine, however deep bar and double squirrel−cage rotor bars can be analyzed in a manner similar to that of an induction machine with two sets of rotor windings. This is explained further in the following paragraphs:

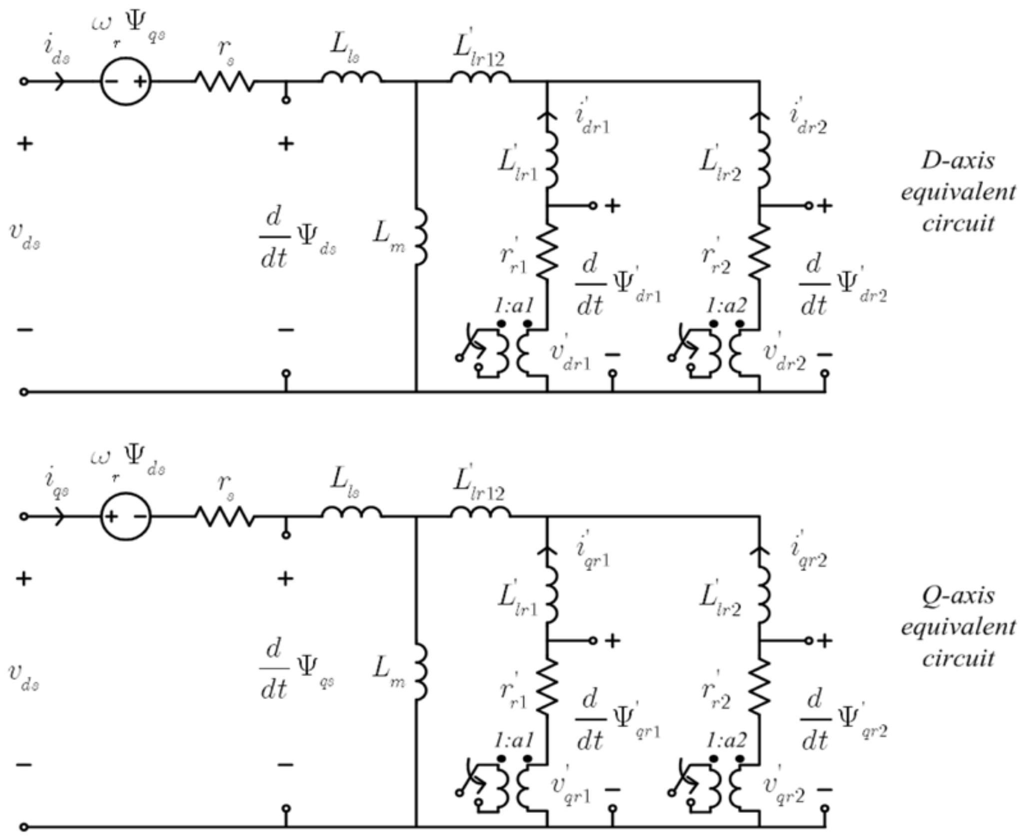


Figure 6.12.4 DQ equivalent circuit of an idealized three phase induction machine (two windings in the rotor)

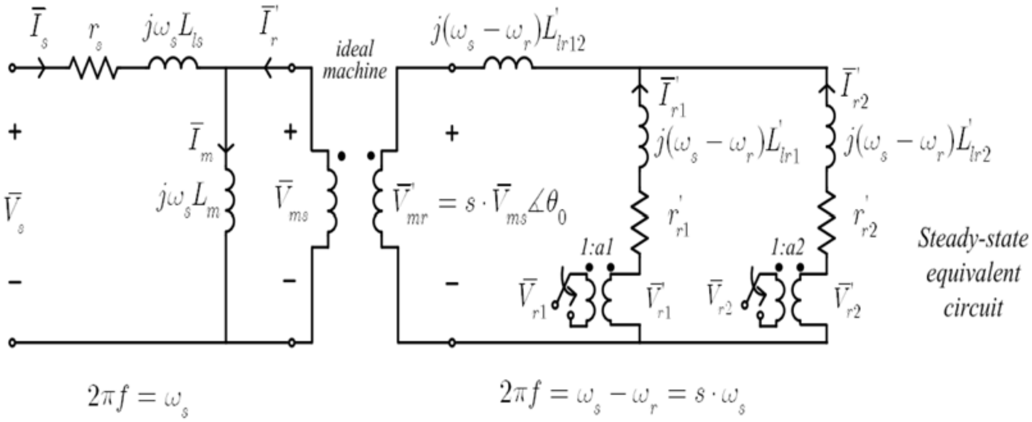


Figure 6.12.5 Steady−state equivalent circuit of an idealized three phase induction machine (two windings in the rotor)

Cage Rotor:

A more common form of rotor winding in induction motors is the squirrel−cage rotor. Squirrel−cage rotors consist of copper, aluminium, or alloy bars inserted or cast into rotor slots [23]. A desired rotor resistance can be obtained by appropriate choice of the size and the material of the rotor bars. For lower rated slips and consequently higher efficiency, lower rotor resistance is required. Higher starting torque can be achieved by higher rotor resistances [23].

To achieve a high starting torque as well as high efficiency, a double−cage rotor can be utilized:

Double Squirrel Cage Rotor [23]:

Arrangement of rotor bars in a double cage rotor is shown in Figure 6.12.6. Both sets of bars are connected to shorting end rings in a squirrel−cage form. The upper bars have small cross−sections and can be made of higher resistivity material, therefore they have high resistance. Lower bars are larger in cross−section and have lower resistance. Upper bars are located close to the rotor surface and rotor slots are widened so that a high reluctance path is provided for leakage flux of these bars resulting in a low leakage inductance. Narrow and (relatively) long slots between upper and lower bars provide a low−reluctance path for the leakage flux of the lower bars, therefore a high leakage inductance. In Figure 6.12.6, ϕ_1 and ϕ_2 are flux leakages of upper and lower bars and ϕ_{12} is the leakage flux which links both bars but not the stator. With the above description, path reluctance of ϕ_1 is much smaller than that of ϕ_{12}, and path reluctance of ϕ_{12} is much smaller than path reluctance of ϕ_2. This means ($\Re_1$ << $\Re_{12}$ << $\Re_2$) . The equivalent magnetic equivalent circuit of this magnetic system is also shown in Figure 6.12.6 . Magneto−motive force created by upper and lower bars are shown by $\mathcal{F}_1$ and $\mathcal{F}_2$. Electric equivalent circuit for this magnetic circuit can be extracted as shown in Figure 6.12.6. Here, as discussed above, the leakage inductance of lower bars L_{lr2} are larger than mutual leakage inductance L_{lr12} and leakage inductance of the lower bars L_{lr1} ($L_{lr1} << L_{lr12} << L_{lr2}$). Also resistance of upper bars are larger than resistance of lower bars ($r_{r1} > r_{r2}$).

The frequency of rotor currents is $s \cdot \omega_s = \omega_s - \omega_r$, where, ω_s is the stator side synchronous frequency, ω_r is the rotor speed and s is slip. At standstill, $s = 1$, and in the rotor equivalent circuit inductances are dominant over resistances. As $L_{lr12} << L_{lr2}$, most current flows into upper bars, and high resistance of this bar causes a high starting torque. At rated speed $s \cdot \omega_s << 1$ therefore, resistances dominate inductances. As $r_{r1} > r_{r2}$ most current flows into lower bars, and low resistance of these bars causes a high efficiency. By adjusting the relative areas and materials of two sets of bars and dimensions of slots between them, a combination of high starting torque and high rated efficiency can be achieved.

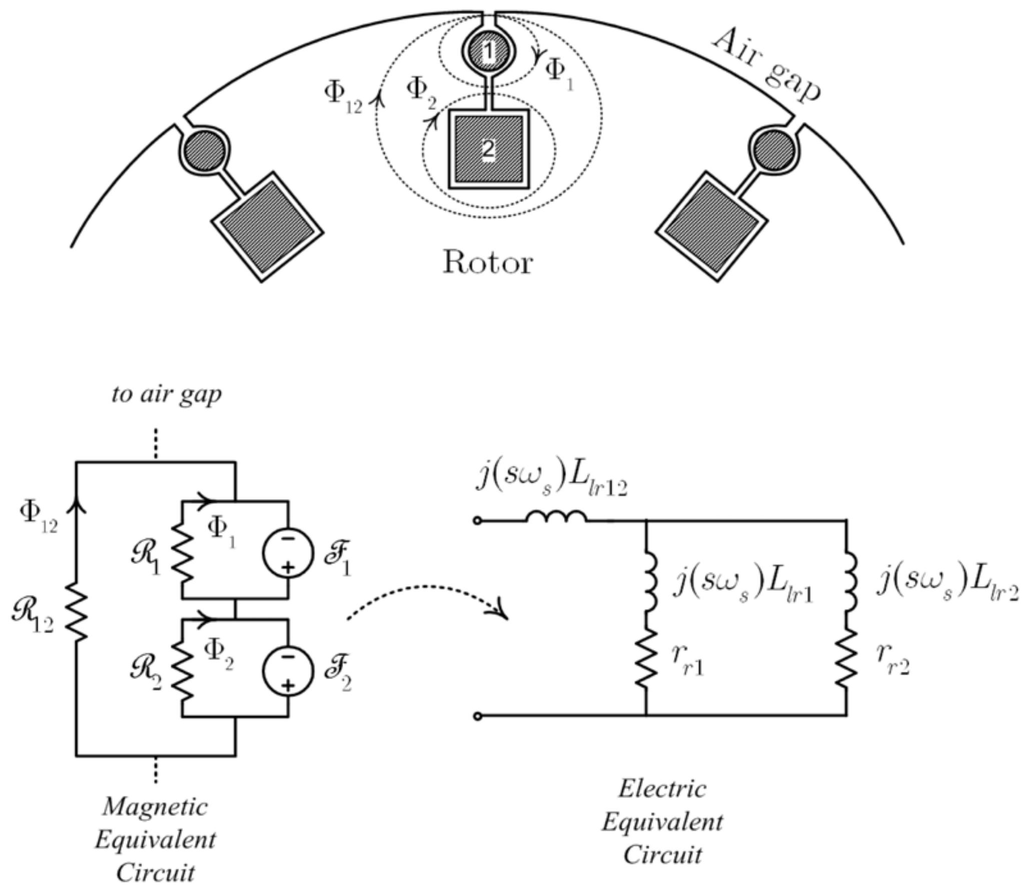


Figure 6.12.6 Arrangement of rotor bars in a double cage rotor iduction machine

The equivalent circuit in Figure 6.12.6 is identical for the rotor equivalent circuit of an induction machine with two rotor windings provided in Figure 6.12.4 and Figure 6.12.5. Due to the fact that path reluctance of ϕ_1 is much smaller than that of ϕ_{12}, the leakage inductance of upper rotor winding is ignored in some literature [10], [23]. This feature is utilized in induction machine models provided by software packages such as PSSE, PSCAD/EMTDC and ATP. In RTDS induction machine models, this leakage inductance is not ignored. However, the user has the option of entering very small values for this leakage inductance, thus making RTDS induction machine model compatible with the above software packages.

Deep Bar Rotor:

A torque−speed relation similar to that of a double−cage rotor may be achieved using deep and narrow rotor bars as shown in Figure 6.12.7. Leakage flux produced by current in the top section encounters a relatively high−reluctance path whereas the leakage flux produced by the lower sections encounter lower reluctances. At high rotor frequencies for which the leakage impedances dominate, the current is concentrated toward the top of the conductor, therefore the effective resistance is high. At low rotor frequencies, the current is approximately uniformly distributed and the effective rotor resistance is low. Ladder form equivalent circuit similar to the ones in Figure 6.12.4 and Figure 6.12.5 can represent the deep bar rotors [23]. For deep bars to be effective, a minimum depth of 1.0 cm is required [23], therefore deep bars are not utilized for small induction motors.

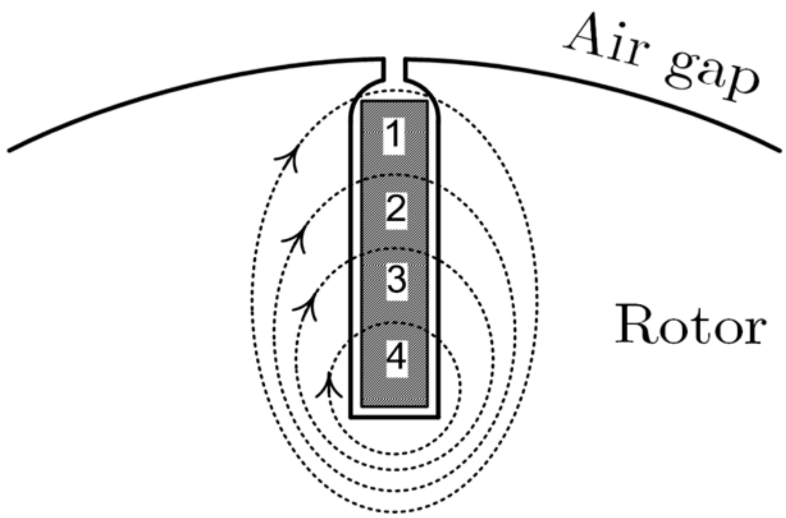


Figure 6.12.7 Deep rotor bar in the induction machine

TORQUE EQUATION:

The following equation is used for calculating electromagnetic torque (T_e) in the equivalent two−pole three phase induction machine model presented here [16], [26]. In this equation i_{ds}, i_{qs} are d− and q−axis components of stator currents shown in Figure 6.12.2 and Figure 6.12.4 and i'_{dr}, i'_{qr} are total d− and q−axis components of rotor currents reflected to the stator winding. L_m is the magnetizing inductance in those figures.

$$T_e = L_m \cdot \left[i_{ds} \cdot i'_{qr} - i_{qs} \cdot i'_{dr} \right]$$

ZERO SEQUENCE:

For full transient modelling of induction machines, zero sequence component and zero sequence equivalent circuit need to be considered for both stator and rotor (unless rotor winding/bars are shorted). **This is especially important for correct modeling of single−phase faults**.

In RTDS, small time−step induction machine model (rtds_vsc_INDM) assumes an open neutral for both stator and rotor, thus zero sequences are ignored.

Induction machine model (lf_rtds_risc_indm) considers stator zero sequence, also accepts values for neutral impedance. Neutral point is not accessible.

Induction machine model (_rtds_INDM) considers zero sequence in both stator and rotor as this model is a phase−domain induction machine model. Both stator and rotor neutral points are available for the user.

SATURATION:

As the rotor is a cylindrical round rotor, total magnetizing MMF and magnetizing flux are aligned, therefore saturation is modeled by adjusting the magnetizing inductance as a function of total magnetizing flux peak in lf_rtds_risc_indm machine model [27] and as a function of total magnetizing current peak in _rtds_INDM phase−domain induction machine model.

PARAMETER MEASURMENT:

As mentioned previously, induction machine models in RTDS require stator and rotor resistances and leakage inductances, also the magnetizing inductance shown in Figure 6.12.3 and Figure 6.12.5. These parameters can be measured using standard no−load and lock rotor test and standstill frequency response test [19], [23].

PER−UNIT BASES:

The following are the per−unit base values used in RTDS 3−phase induction machine models.

Voltage: Rated Stator Voltage of the Machine (Line−to−Neutral RMS) is used as the base value for the voltage.

Power: Rated MVA of the Machine is used as the base value for the power.

Current: Rated Stator Current of the Machine (Line−to−Neutral RMS) is used as the base value for the current.

Impedance: Voltage base value / Current base current is used as the base value for the impedance.

Electric Speed: Rated frequency of the Machine * 2π is used as the base value for the electric speed.

Torque: Base power / base electric speed is used as the base value for the torque.

6.12.3 SPECIFICATIONS OF INDUCTION MACHINE MODEL (IF_RTDS_RISC_INDM)

This chapter describes the menus for Induction Machine Model (lf_rtds_risc_indm).

6.12.3.1 MODEL SPECIFICATIONS AND CAPABILITIES

This chapter describes the three−phase Induction Machine Model (lf_rtds_risc_indm). The basic icon for the lf_rtds_risc_indm component appears as shown in Figure 6.12.8. The terminals for stator windings are respectively shown by A, B and C. Stator windings are star−connected with the neutral grounded through a user−defined impedance. The neutral point is not accessible to the user. The rotor in this model is shorted. The user has the option of having one or two windings in the rotor. Two computational load units of RTDS is required for real−time simulation of a lf_rtds_risc_indm, three−phase Induction Machine Model. The control signal which determines whether the machine operates in lock or free mode is received from the CONTROL COMPILER INPUT MENU. This menu is described below.

The **Interface approach** [25], [27] is used to implement this model in the environment of the real−time digital simulator (RTDS). For the purpose of numerical stability, machine terminals are connected through 300 pu un−compensated resistances.

The menus for this machine explained below:

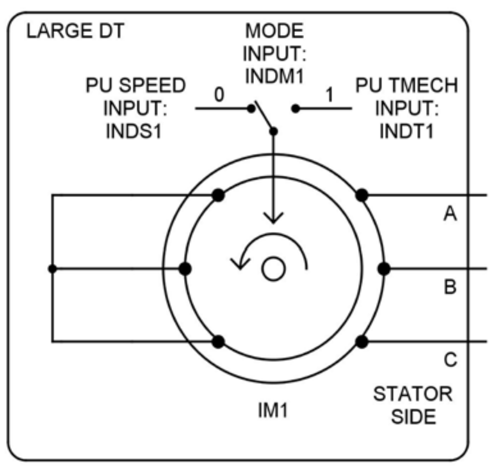


Figure 6.12.8 lf_rtds_risc_INDM component icon.

6.12.3.2 THE MENU FOR INDUCTION MACHINE CONFIGURATION

The menu for induction machine configuration appears as shown in Figure 6.12.9. The following is the explanation of parameters in this menu:

Name: A unique name must be given for each instance of the component.

tysat: The “tysat” menu item prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2).

nmrt: Number of winding sets in the rotor (one or two).

rf2in: This option allows an added internal rotor resistance. The value of this resistance is controlled using a CC input defined in the CONTROL COMPILER INPUT MENU. With (rf2in = yes) icon for the lf_rtds_risc_indm component appears as shown in Figure 6.12.10.

radd1: The initial value of the added resistance if (rf2in = yes).

spcsp: The induction machine can be initialized either using the initial slip or initial power.

zroc: Enabling this option forces all initial currents to zero.

prtyp: The prtyp parameter allows the user to select on which type of processor the model is to be run. This model is currently available for GPC and PB5 processor types.

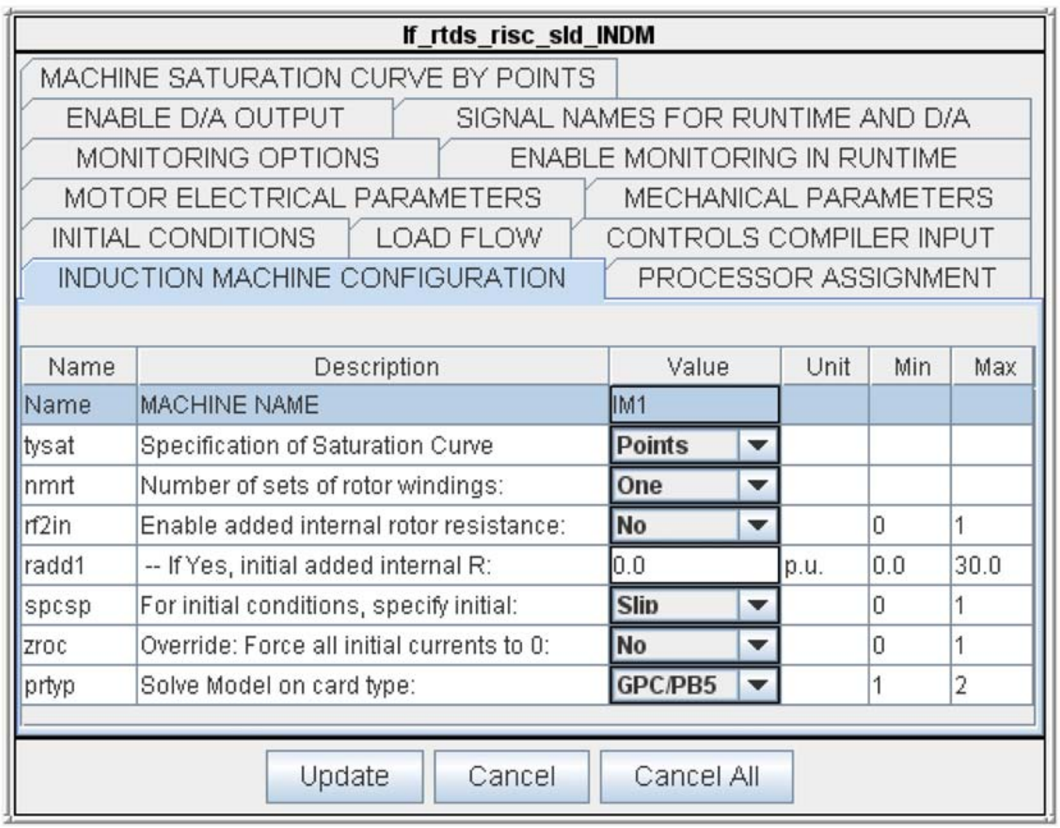


Figure 6.12.9 configuration menu for lf_rtds_risc_sld_INDM

6.12.3.3 THE MENU FOR PROCESSOR ASSIGNMENT

The menu for induction machine processor assignment appears as shown in Figure 6.12.11. The following is the explanation of parameters in this menu:

AorM: Specify if the model be automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: Parameter is only used if AorM parameter is set to Manual. The user can select the model be assigned to A or B processor.

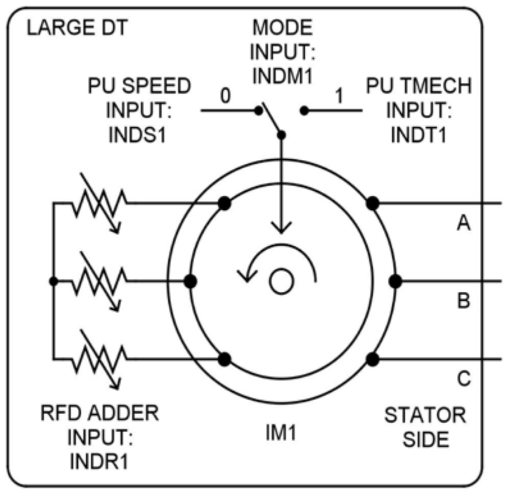


Figure 6.12.10 lf_rtds_risc_INDM component icon (rf2in = yes).

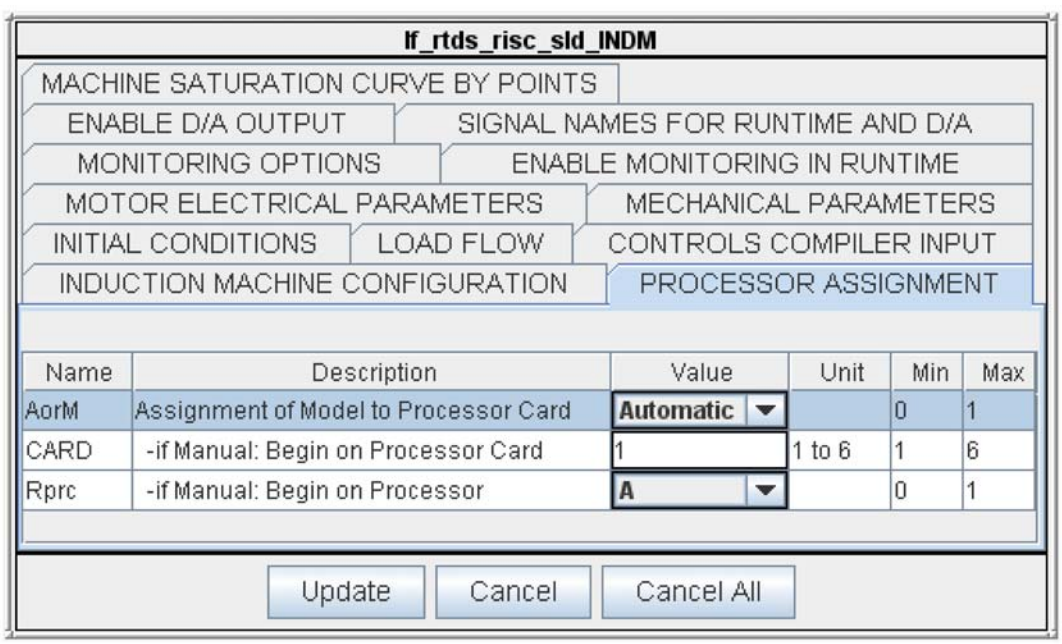


Figure 6.12.11 Processor assignment menu for lf_rtds_risc_sld_INDM

6.12.3.4 THE MENU FOR INDUCTION MACHINE INITIAL CONDITIONS

The menu for induction machine initial conditions appears as shown in Figure 6.12.12. As mentioned earlier, the induction machine with shorted rotor windings can be initialized either using the initial slip or initial power. The effects of loading and saturation are included in the initialization calculations. The following is the explanation of parameters in this menu:

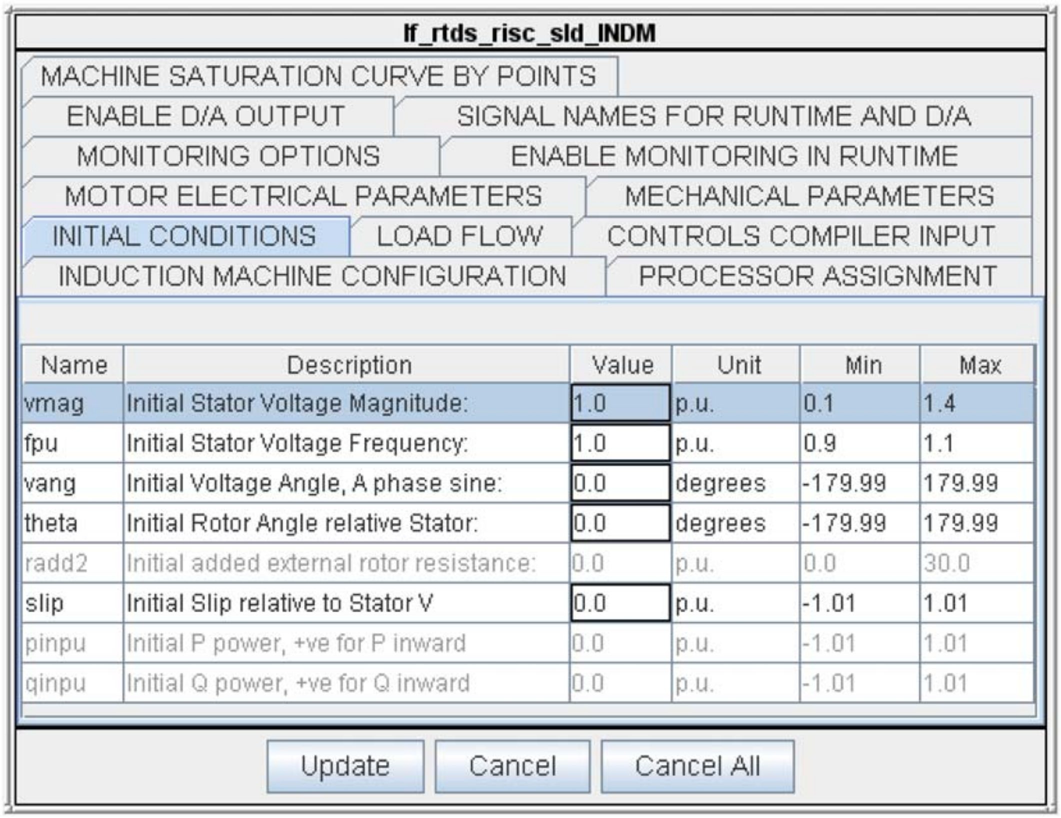


Figure 6.12.12 Initial condition menu for lf_rtds_risc_sld_INDM

vmag: The magnitude "vmag" defines the magnitude of the stator terminal voltage in pu.

fpu: "fpu" defines the initial frequency of the terminal voltage in pu.

vang: The angle "vang" defines the angle of the "A" phase terminal voltage sine wave in Degrees at time = 0.

theta: "theta" defines the initial rotor angle with respect to "A" phase terminal voltage sine wave in Degrees at time = 0.

radd2: The initial added external resistance of the rotor. This parameter is not active in lf_rtds_risc_indm component.

slip: "slip" defines the initial slip relative to stator voltage in pu.

pinpu: Initial input active power at time = 0.

qinpu: Initial input reactive power at time = 0. This parameter is not active in lf_rtds_risc_indm component.

The machine model initializes the winding currents based on the requested initial conditions, also writes various calculated initial conditions in the MAP file.

6.12.3.5 THE MENU FOR INDUCTION MACHINE LOAD FLOW

Unlike the synchronous machine model, the load flow program is not capable of including induction machines at the moment. However, a menu is provided in this machine model for the results of load flow program. The values in this menu are not used in the induction machine model presently.

6.12.3.6 THE CONTROLS COMPILER INPUT MENU

The CONTROLS COMPILER INPUT Menu for the induction machine appears as shown in Figure 6.12.13. Similar to other machine models in RTDS, the induction machine model can operate in a LOCK or FREE mode. In LOCK mode, the speed of the machine is forced to a value which is a control input to the machine. In FREE mode, the speed of the machine is determined by mechanical swing equations. In this case, the mechanical torque comes from the control input T in pu.

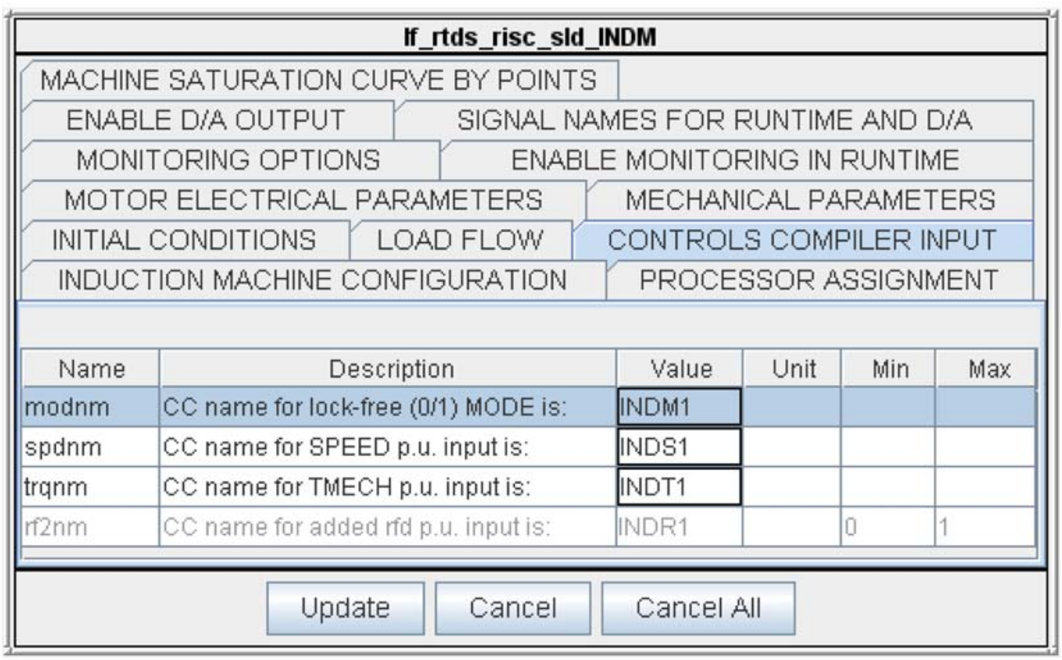


Figure 6.12.13 Control compiler menu for lf_rtds_risc_sld_INDM

modnm: "modnm" is the name of CC input integer signal which defines the induction machine mode of operation: If this signal is 0, then the machine operates in the "LOCK" mode, if this signal is 1, then machine operates in "FREE" mode.

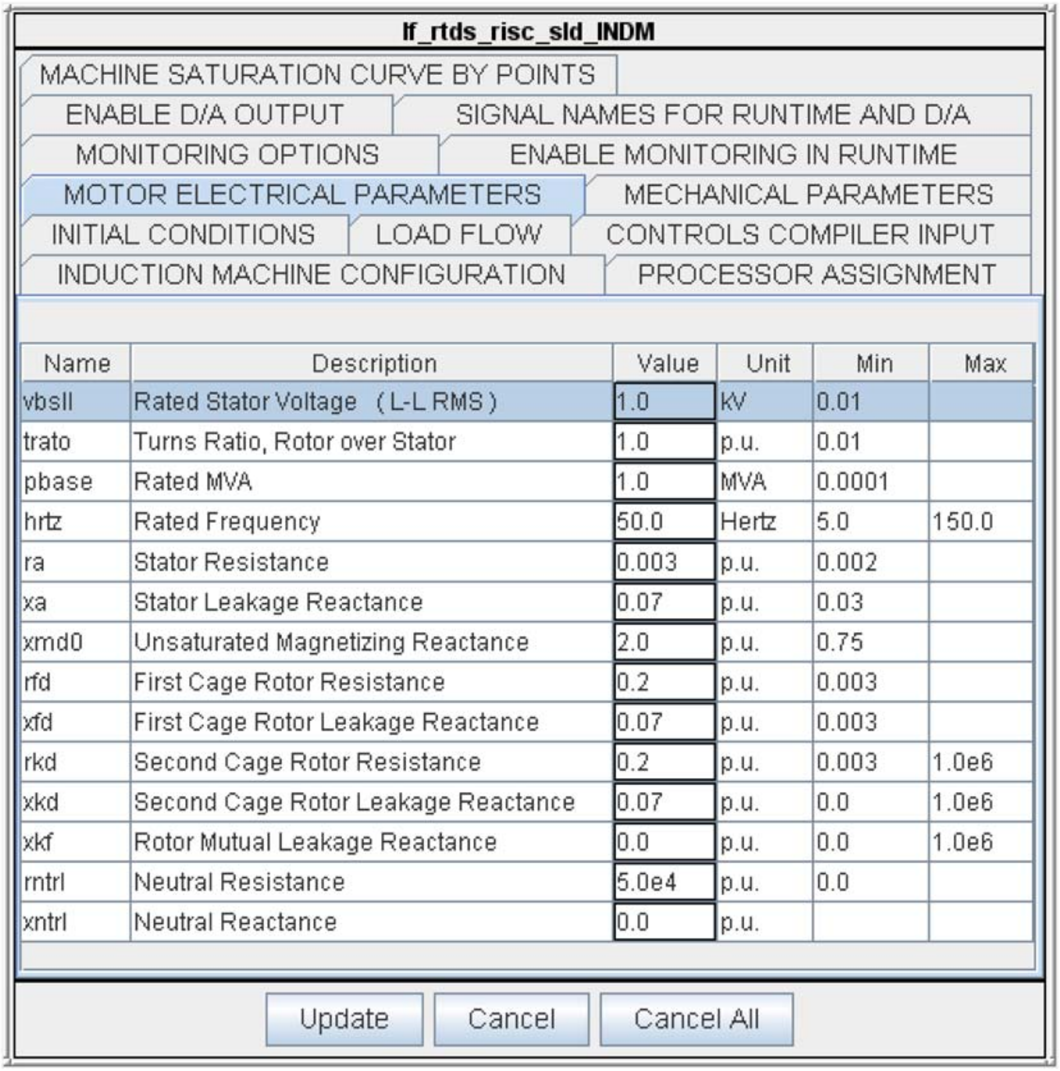
spdnm: "spdnm" is the name of CC input signal which defines the speed of induction machine if the mode of operation is "LOCK".

trqnm: "trqnm" is the name of CC input signal which defines the mechanical torque applied to the shaft of the induction machine if the mode of operation is "FREE".

rf2nm: added "rf2nm" is the name of CC input signal which defines the value of rotor resistance if the option "rf2in = yes" in the CONFIGURATION menu.

6.12.3.7 MOTOR ELECTRICAL PARAMETERS

The menu MOTOR ELECTRICAL PARAMETERS appears as shown in Figure 6.12.14. In this menu:



Name	Description	Value	Unit	Min	Max
vbsll	Rated Stator Voltage (L-L RMS)	1.0	kV	0.01	
trato	Turns Ratio, Rotor over Stator	1.0	p.u.	0.01	
pbase	Rated MVA	1.0	MVA	0.0001	
hrtz	Rated Frequency	50.0	Hertz	5.0	150.0
ra	Stator Resistance	0.003	p.u.	0.002	
xa	Stator Leakage Reactance	0.07	p.u.	0.03	
xmd0	Unsaturated Magnetizing Reactance	2.0	p.u.	0.75	
rfd	First Cage Rotor Resistance	0.2	p.u.	0.003	
xfd	First Cage Rotor Leakage Reactance	0.07	p.u.	0.003	
rkd	Second Cage Rotor Resistance	0.2	p.u.	0.003	1.0e6
xkd	Second Cage Rotor Leakage Reactance	0.07	p.u.	0.0	1.0e6
xkf	Rotor Mutual Leakage Reactance	0.0	p.u.	0.0	1.0e6
rntrl	Neutral Resistance	5.0e4	p.u.	0.0	
xntrl	Neutral Reactance	0.0	p.u.		

Figure 6.12.14 Motor Electrical Parameters menu for lf_rtds_risc_sld_INDM

Vbsll: Rated Stator Voltage of the Machine (Line−to−Line RMS)

trato: Effective Ratio of Turns (Rotor over Stator). This parameter corresponds to $(1/a)$ in Figure 6.12.5

pbase: Rated MVA of the Machine.

hrtz: Rated Operating Frequency of the Machine in Hz. ($\omega_s = 2\pi \cdot hrtz$)

ra: Resistance of the Stator Winding in pu. This parameter corresponds to (r_s) in Figure 6.12.5.

xa: Leakage Reactance of the Stator Winding in pu. This parameter corresponds to ($\omega_s \cdot L_{ls}$) in Figure 6.12.5.

xmd0: Unsaturated Magnetizing Reactance in pu. This parameter corresponds to ($\omega_s \cdot L_m$) in Figure 6.12.5.

rfd: Resistance of First Rotor Cage (or Winding) in pu. This parameter corresponds to (r'_{r1}) in Figure 6.12.5.

xfd: Leakage Reactance of First Rotor Cage (or Winding) in pu. This parameter corresponds to ($\omega_s \cdot L'_{lr1}$) in Figure 6.12.5.

rkd: Resistance of Second Rotor Cage (or Winding) in pu. This parameter corresponds to (r'_{r2}) in Figure 6.12.5.

xkd: Leakage Reactance of Second Rotor Cage (or Winding) in pu. This parameter corresponds to ($\omega_s \cdot L'_{lr2}$) in Figure 6.12.5.

xkf: Rotor Mutual Leakage Reactance in pu. This parameter corresponds to ($\omega_s \cdot L'_{lr12}$) in Figure 6.12.5.

rntrl: Neutral Resistance in pu.

xntrl: Neutral Reactance in pu.

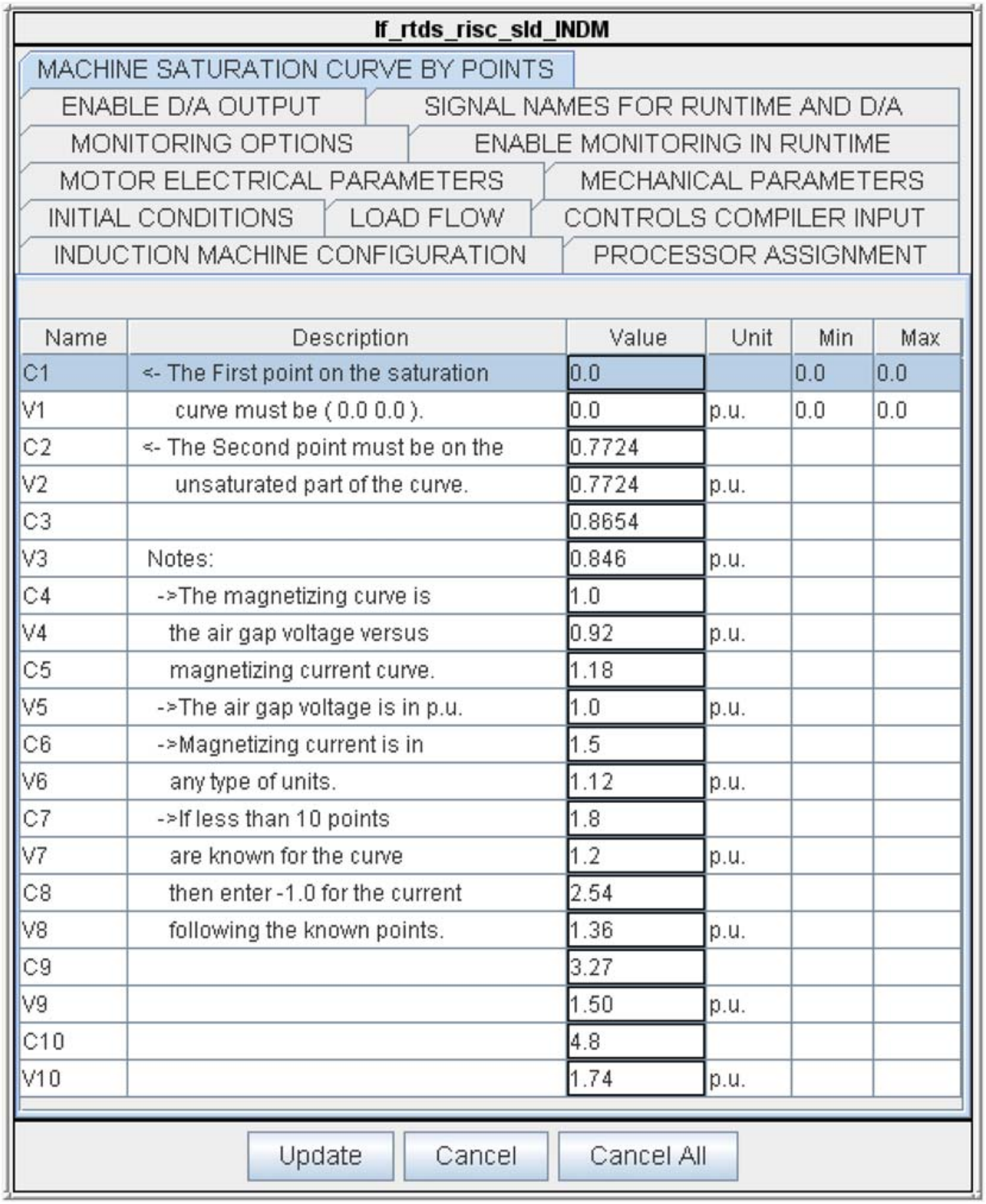
6.12.3.8 THE MACHINE SATURATION CURVE MENUS

The “tysat” menu item in the “INDUCTION MACHINE CONFIGURATION” menu prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2). The choices are “Linear”, “Points”, and “Factors. If “Linear” is chosen, then machine will not saturate. The other two choices are explained below. The saturation curve for the main magnetizing flux linkage path of the induction machine model is specifiable in the SATURATION CURVE menu. The saturation curve which is entered should be the air−gap voltage versus magnetizing current curve for the magnetizing branch at rated frequency.

Induction machine resistances and inductances are in p.u. with the base values described previoiusly in Section PER−UNIT BASES.

6.12.3.9 THE MACHINE SATURATION CURVE BY POINTS MENU

The MACHINE SATURATION CURVE BY POINTS menu appears as follows. This method requires a saturation curve for the machine to be entered using points on the curve. The curve is a plot of air−gap voltage in per−unit versus magnetizing current specified in units of the user’s choice. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point allows to provide scaling information for magnetizing currents entered in the menu. If fewer than 10 points are entered for the curve, then enter –1.0 for the currents following the last known point.


lf_rtds_risc_sld_INDM

MACHINE SATURATION CURVE BY POINTS
ENABLE D/A OUTPUT | SIGNAL NAMES FOR RUNTIME AND D/A
MONITORING OPTIONS | ENABLE MONITORING IN RUNTIME
MOTOR ELECTRICAL PARAMETERS | MECHANICAL PARAMETERS
INITIAL CONDITIONS | LOAD FLOW | CONTROLS COMPILER INPUT
INDUCTION MACHINE CONFIGURATION | PROCESSOR ASSIGNMENT

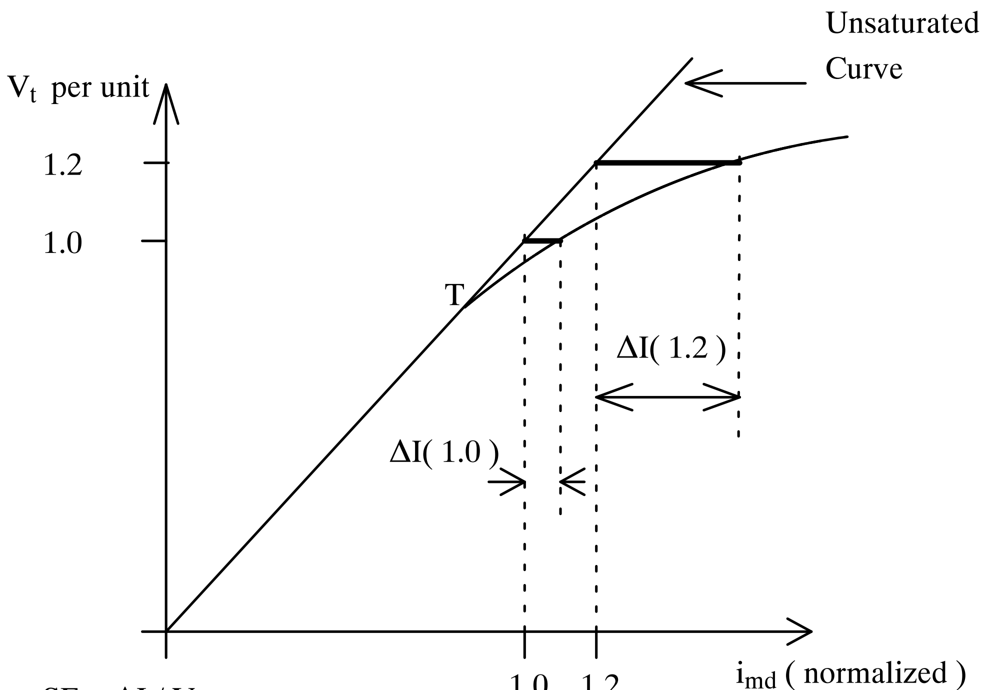
Name	Description	Value	Unit	Min	Max
C1	<- The First point on the saturation	0.0		0.0	0.0
V1	curve must be (0.0 0.0).	0.0	p.u.	0.0	0.0
C2	<- The Second point must be on the	0.7724			
V2	unsaturated part of the curve.	0.7724	p.u.		
C3		0.8654			
V3	Notes:	0.846	p.u.		
C4	->The magnetizing curve is	1.0			
V4	the air gap voltage versus	0.92	p.u.		
C5	magnetizing current curve.	1.18			
V5	->The air gap voltage is in p.u.	1.0	p.u.		
C6	->Magnetizing current is in	1.5			
V6	any type of units.	1.12	p.u.		
C7	->If less than 10 points	1.8			
V7	are known for the curve	1.2	p.u.		
C8	then enter -1.0 for the current	2.54			
V8	following the known points.	1.36	p.u.		
C9		3.27			
V9		1.50	p.u.		
C10		4.8			
V10		1.74	p.u.		

Update | Cancel | Cancel All

Figure 6.12.15 Machine Saturation Curve By Points Menu

6.12.3.10 MACHINE SATURATION CURVE BY FACTORS MENU

The two factors to be specified in the menu are defined in Figure 6.12.16. The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.



$SE = \Delta I / V_t$

$SE(1.0) = \Delta I(1.0) / 1.0$

$SE(1.2) = \Delta I(1.2) / 1.2$

Figure 6.12.16 Machine Saturation Curve By Factors SE10 and SE12

The MACHINE SATURATION CURVE BY FACTORS menu appears as shown in Figure 6.12.17.

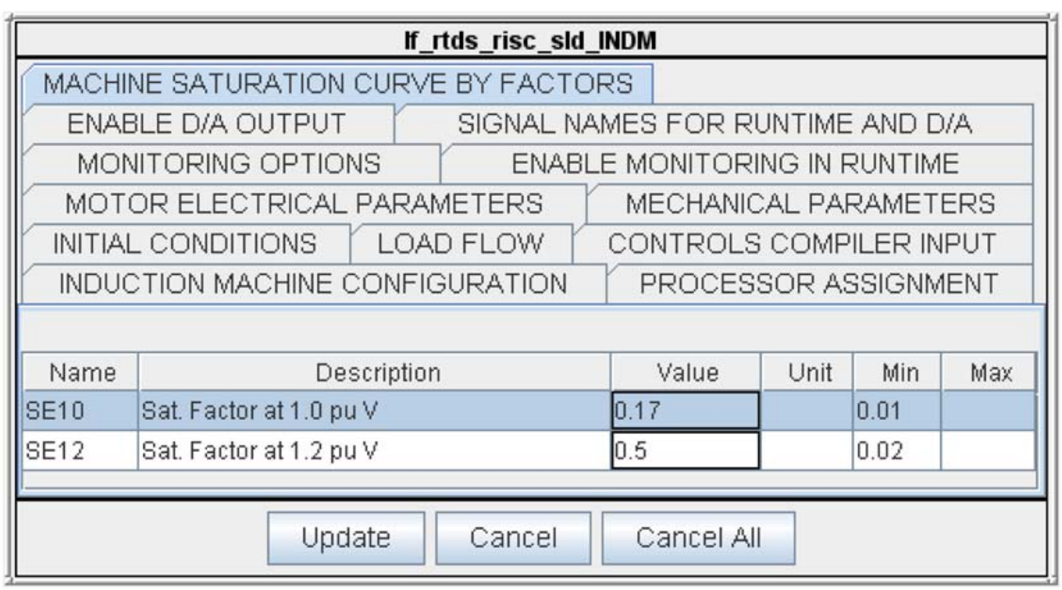


Figure 6.12.17 Machine Saturation Curve By Factors Menu

6.12.3.11 THE MECHANICAL PARAMETERS MENU

In this model, in FREE mode, the mechanical swing equations of the rotor are solved inside the model. This menu specifies the inertia constant (H) and frictional damping (D) of the mass. The MECHANICAL PARAMETERS menu appears as shown in Figure 6.12.18.

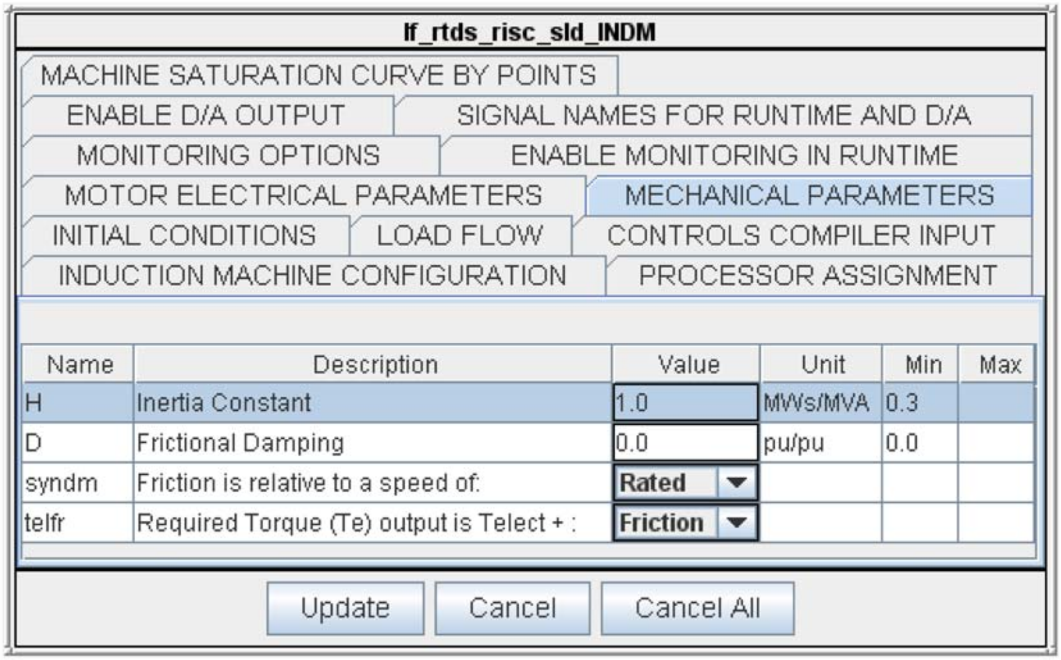


Figure 6.12.18 Mechanical Parameters Menu

H: The “H” menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating. The MVA rating of the machine is as entered in the GENERAL MODEL CONFIGURATION menu in response to the “pbase” item.

D: The “D” menu item prompts for the frictional damping factor. The resulting damping torque tends to resist the speed. The damping torque factor “D” is in units of per−unit torque over per−unit speed deviation from zero (or synchronous) speed.

In locked speed mode, the pu speed of the machine is determined by a control input spdnm in the icon. In free speed mode, the machine speed ω is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (T_m), electrical torque (T_e), and the damping torque. The following equation shows this relation:

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

syndm: The “syndm” menu allows the user to decide whether the frictional torque is relative to speed ($D \cdot \omega(pu)$) by selecting “syndm = Zero” or relative to the deviation of speed from synchronous speed ($D \cdot (\omega(pu) - 1)$) by selecting "syndm = Rated". The default value for this option is "Zero".

telfr: The "telfr" menu allows the user to monitor electric torque as calculated using the equation discussed previously, or add the frictional torque to it as well. The default value for this option is "nil".

Similar to other machine models in RTDS, **when the speed is positive, positive electric torque corresponds to generating operation of the machine and negative electric torque corresponds to motoring operation of the machine**. **When the speed is negative, positive torque corresponds to motoring operation of the machine, and negative torque corresponds to generating operation of the machine.** This is shown in the following table. Note that, positive speed according to RTDS and EMTDC convention means anti−clockwise rotation of the rotor.

Speed	Positive Torque	Negative Torque
+	Generator	Motor
−	Motor	Generator

6.12.3.12 MONITORING OPTION MENU

The user has the option of using a low−pass filter $\left(\frac{1}{1 + S \cdot T}\right)$ when the active power is monitored. The menu MONITORING OPTIONS appears as shown in Figure 6.12.19.

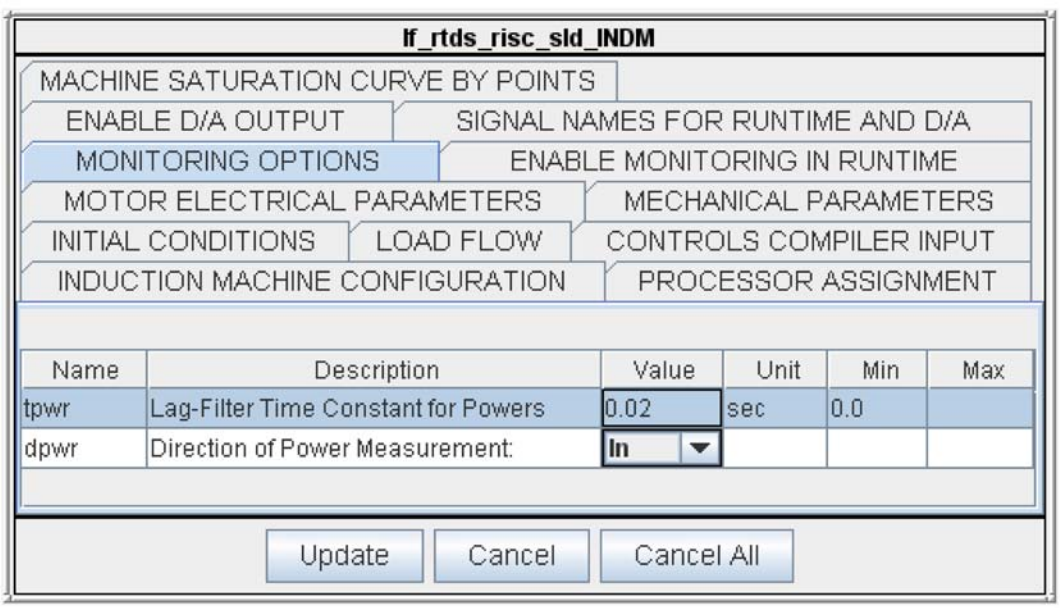


Figure 6.12.19 Monitoring options menu for induction machine

In this menu:

tpwr: Specifies the time constant (T) that the first order low pass filter will use on the signal for real power monitored from the machine.

Dpwr: Specifies the direction of active power monitored from the machine.

6.12.3.13 THE ENABLE MONITORING IN RUNTIME MENU

The lf_rtds_risc_sld_INDM ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.12.20.

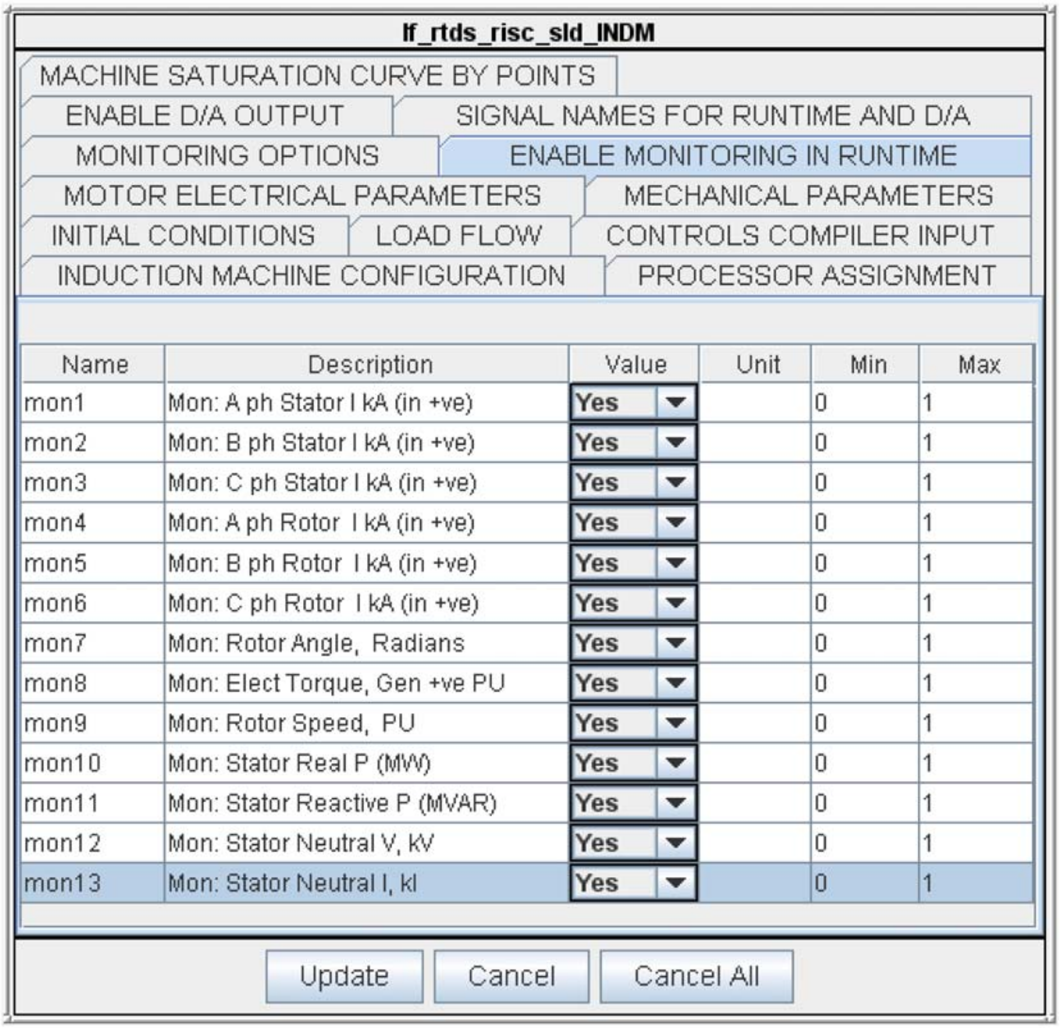


Figure 6.12.20 Enable monitoring in RUNTIME menu

Stator and Rotor Currents: The user has the option of monitoring the stator and rotor currents in kA.

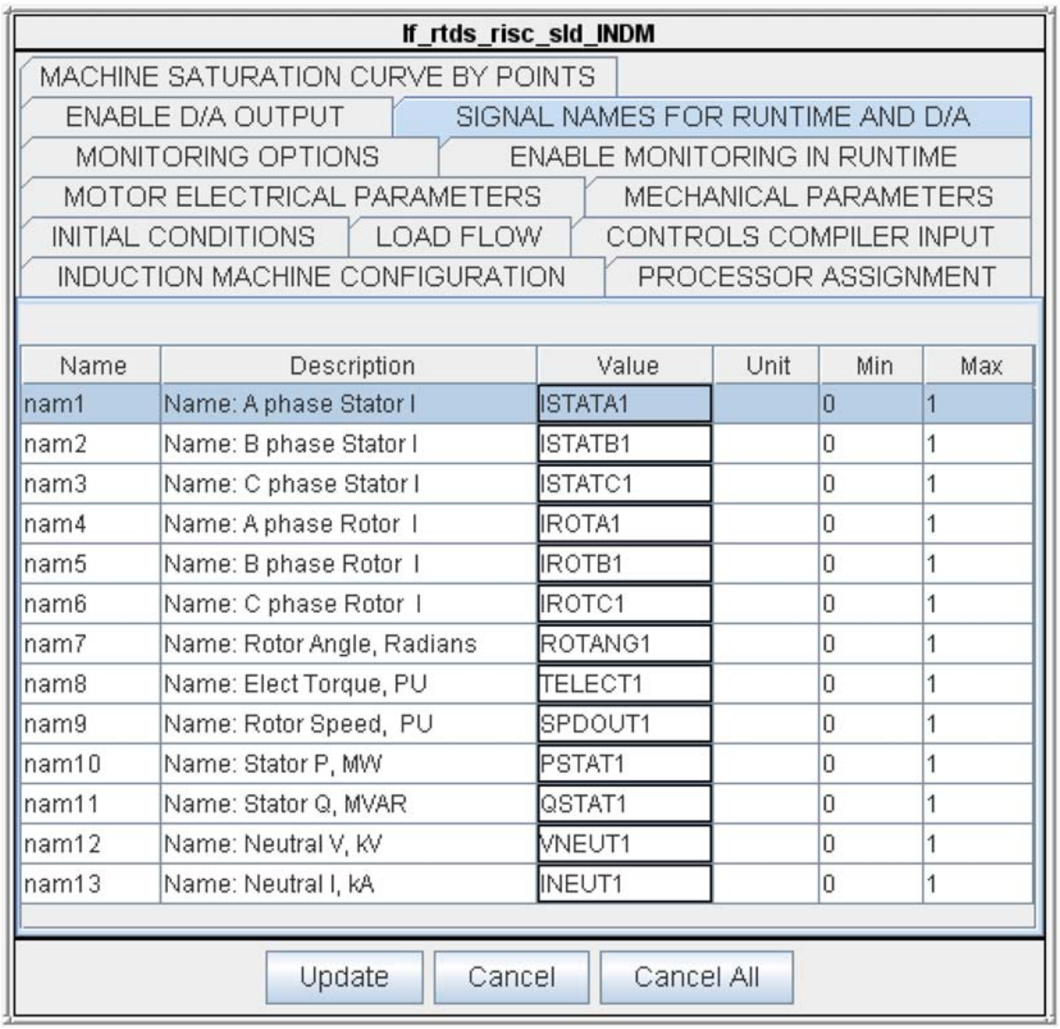
Rotor Angle, Electric Torque, and Rotor Speed: Mechanical quantities such as rotor angle, electric torque and rotor speed can also be monitored in Radians, pu , and pu respectively.

Active and Reactive Power of the Machine: The active and reactive power of the machine can be monitored. The direction of monitored power can be selected in the "Monitoring Options" menu.

Neutral Voltage and Current: Neutral voltage and currents can be monitored.

6.12.3.14 THE SIGNAL NAMES FOR RUNTIME MENU

The SIGNAL NAMES FOR MONITORING IN RUNTIME MENU appears as shown in Figure 6.12.21. The user must dedicate a unique name for the monitored signals.



Name	Description	Value	Unit	Min	Max
nam1	Name: A phase Stator I	ISTATA1		0	1
nam2	Name: B phase Stator I	ISTATB1		0	1
nam3	Name: C phase Stator I	ISTATC1		0	1
nam4	Name: A phase Rotor I	IROTA1		0	1
nam5	Name: B phase Rotor I	IROTB1		0	1
nam6	Name: C phase Rotor I	IROTC1		0	1
nam7	Name: Rotor Angle, Radians	ROTANG1		0	1
nam8	Name: Elect Torque, PU	TELECT1		0	1
nam9	Name: Rotor Speed, PU	SPDOUT1		0	1
nam10	Name: Stator P, MW	PSTAT1		0	1
nam11	Name: Stator Q, MVAR	QSTAT1		0	1
nam12	Name: Neutral V, kV	VNEUT1		0	1
nam13	Name: Neutral I, kA	INEUT1		0	1

Figure 6.12.21 Signal Names for RUNTIME menu

6.12.3.15 MACHINE INFORMATION WRITTEN IN THE MAP FILE

After compiling a draft case containing an lf_rtds_risc_sld_INDM machine model, the MAP file will contain information about this induction machine model. It contains the name of the machine model, initial required P, Q and torque, and initial speed and magnetizing reactance.

```
RISC-based Induction Machine model named: IM2
   in subsystem: #1
   is assigned to RPC-GPC Card #2 Processor B

   Initial required P = 0.000000 PU = 0.000000 MW.
   Initial required Q = 0.000000 PU = 0.000000 MVAR.
     -- +ve values indicate P or Q into machine.

   Initial required torque = 0.000000 PU
     -- +ve for generation of power.
     -- includes any mechanical friction effects.

   Initial machine speed = 0.000000 PU

   Initial magnetizing reactance = 2.000000 PU
```

Figure 6.12.22 Written information in the MAP file

6.12.4 SPECIFICATIONS OF INDUCTION MACHINE MODEL (_RTDS_INDM)

This chapter describes the menus for Induction Machine Model (_rtds_INDM).

6.12.4.1 MODEL SPECIFICATIONS AND CAPABILITIES

This chapter describes the three–phase Induction Machine Model (_rtds_INDM). The basic icon for the _rtds_INDM component appears as shown in Figure 6.12.23. Stator windings are respectively shown by AS, BS and CS. Stator windings are star–connected with the neutral available as a power system node and it is shown by NS. At the moment, the user has the option of having one set of windings in the rotor. Rotor windings are respectively shown by AR, BR and CR. Rotor windings are star–connected with the neutral also available as a power system node and it is shown by NR.

The control signal which determines whether the machine operates in lock or free mode is received from the CONTROL COMPILER INPUT MENU. This menu is described later.

The **embedded phase domain approach** [4] is used to implement this model in the environment of the real–time digital simulator (RTDS). The term **phase domain** means that the values of machine inductances change with the change in rotor position and level of saturation. The term **embedded** means that the network solution is incorporated in solving the differential equations of the machine. This approach shows superior numerical performance compared to the conventional interfaced approach [5]. Stator and rotor zero sequences are automatically included in the solution.

Five computational load units of RTDS are required for real–time simulation of a _rtds_INDM, three phase induction machine model.

The menus for this machine are explained below:

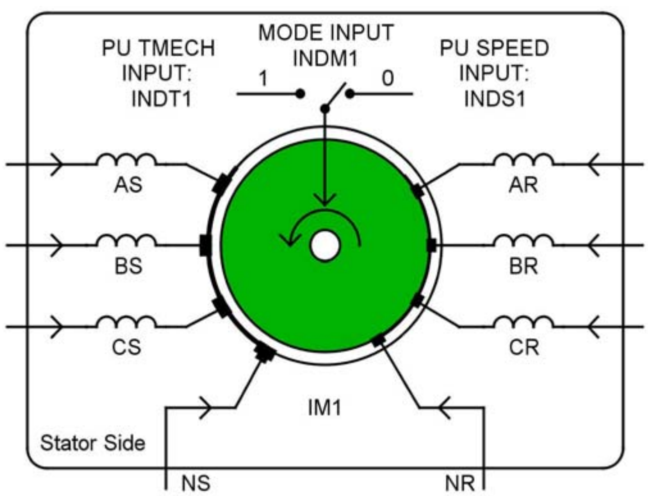


Figure 6.12.23 _rtds_INDM component icon.

6.12.4.2 THE MENU FOR INDUCTION MACHINE CONFIGURATION

The menu for induction machine configuration appears as shown in Figure 6.12.24. The following is the explanation of parameters in this menu:

Name: A unique name must be given for each instance of the component.

tysat: The "tysat" menu item prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2).

sngnd: This option allows the user to ground the stator neutral. With (sngnd = yes) , the _rtds_INDM component appears as shown in Figure 6.12.25.

rngnd: This option allows the user to ground the rotor neutral. With (rngnd = yes), the _rtds_INDM component appears as shown in Figure 6.12.25.

zroc: Enabling this option forces all initial currents to zero.

prtyp: The prtyp parameter allows the user to select which type of processor the model is to be run. This model is currently available for GPC and PB5 processor types.

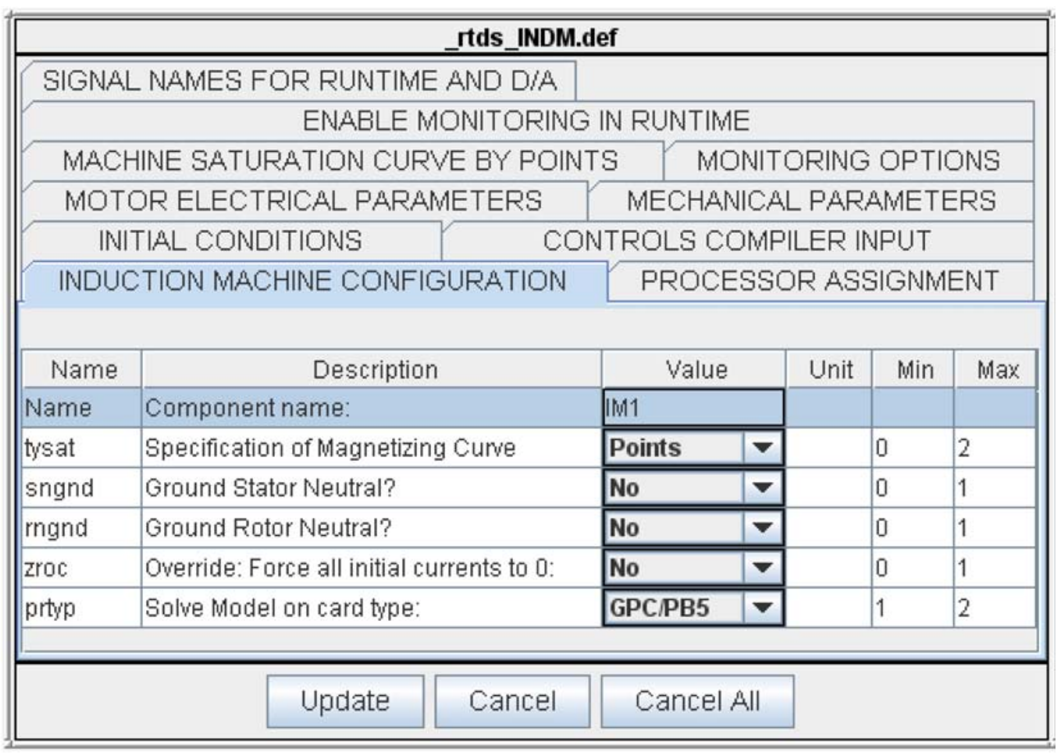


Figure 6.12.24 configuration menu for _rtds_INDM

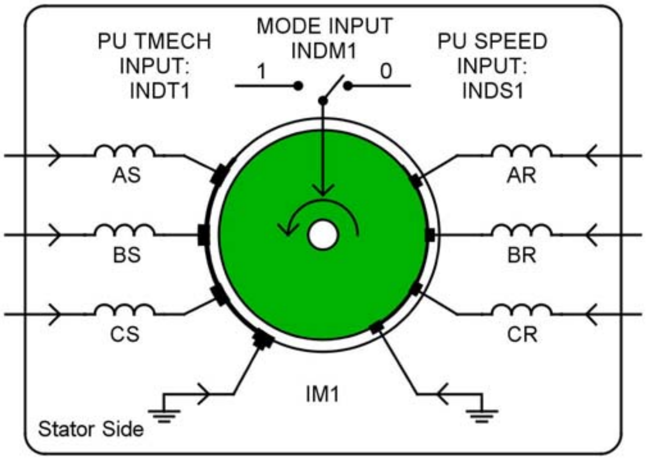


Figure 6.12.25 _rtds_INDM component icon (sngnd = rngnd = yes).

6.12.4.3 THE MENU FOR PROCESSOR ASSIGNMENT

The menu for induction machine processor assignment appears as shown in Figure 6.12.26. The following is the explanation of parameters in this menu:

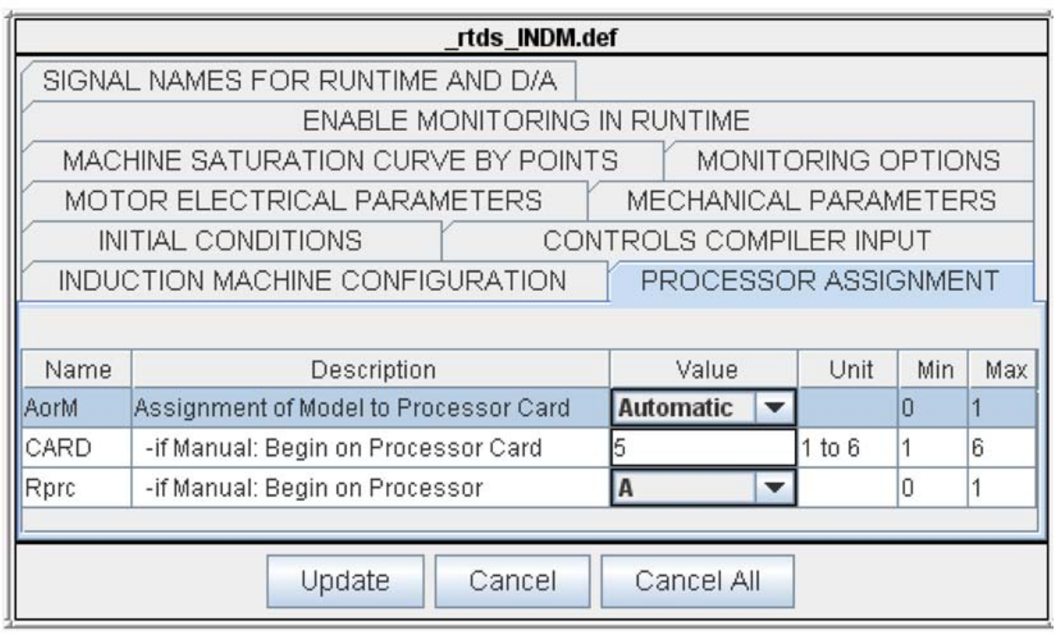


Figure 6.12.26 Processor assignment menu for _rtds_INDM

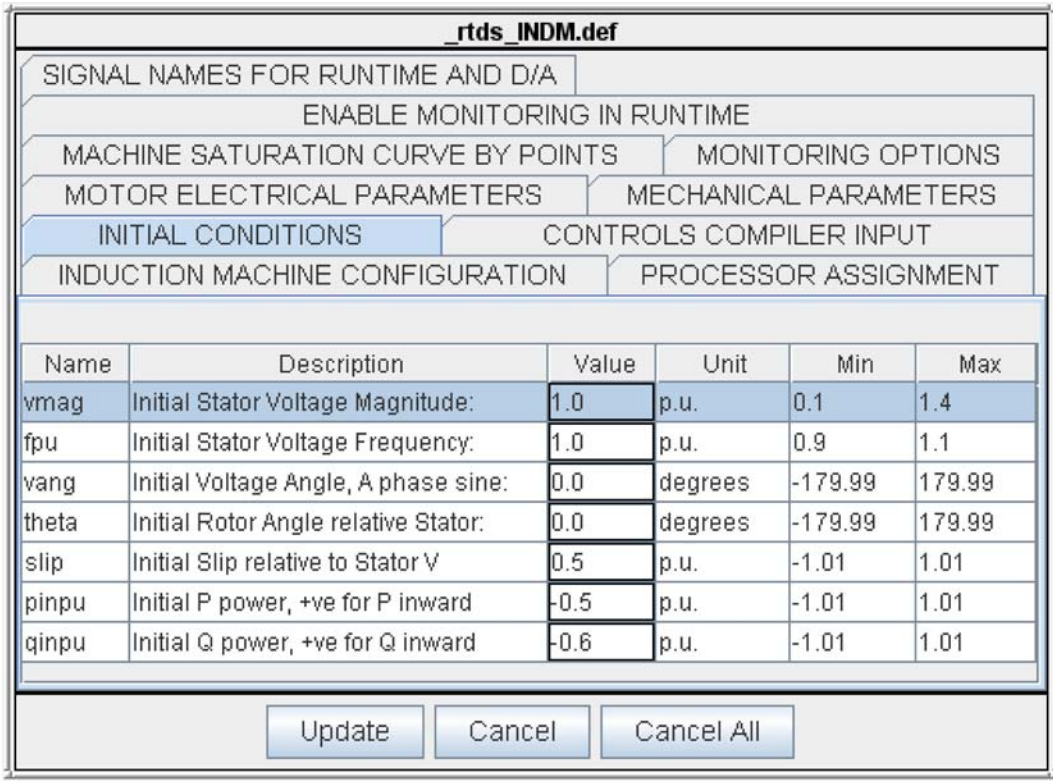
AorM: Specify if the model be automatically assigned to a processor (Automatic) or manually assigned (Manual).

CARD: Parameter is only used if AorM parameter is set to Manual. The model can be manually assigned to an RTDS processor. The card number that the model is to be assigned is entered here.

Rprc: Parameter is only used if AorM parameter is set to Manual. The user can select the model be assigned to A or B processor.

6.12.4.4 THE MENU FOR INDUCTION MACHINE INITIAL CONDITIONS

The menu for induction machine initial conditions appears as shown in Figure 6.12.27.



Name	Description	Value	Unit	Min	Max
vmag	Initial Stator Voltage Magnitude:	1.0	p.u.	0.1	1.4
fpu	Initial Stator Voltage Frequency:	1.0	p.u.	0.9	1.1
vang	Initial Voltage Angle, A phase sine:	0.0	degrees	-179.99	179.99
theta	Initial Rotor Angle relative Stator:	0.0	degrees	-179.99	179.99
slip	Initial Slip relative to Stator V	0.5	p.u.	-1.01	1.01
pinpu	Initial P power, +ve for P inward	-0.5	p.u.	-1.01	1.01
qinpu	Initial Q power, +ve for Q inward	-0.6	p.u.	-1.01	1.01

Figure 6.12.27 Initial condition menu for _rtds_INDM

As mentioned earlier, the _rtds_INDM induction machine with **active rotor windings** can be initialized using both initial slip and power. The results of initialization will be initial winding currents and rotor initial voltage which will be written in the MAP file. The effects of saturation are included in the initialization calculations. The following is the explanation of parameters in this menu:

vmag: The magnitude "vmag" defines the magnitude of the stator terminal voltage in pu.

fpu: "fpu" defines the initial frequency of the terminal voltage in pu.

vang: The angle "vang" defines the angle of the "A" phase terminal voltage sine wave in Degrees at time = 0.

theta: "theta" defines the initial rotor angle with respect to "A" phase terminal voltage sine wave in Degrees at time = 0.

slip: "slip" defines the initial slip relative to stator volatge in pu.

pinpu: Initial input active power at time = 0.

qinpu: Initial input reactive power at time = 0.

The machine model initializes the winding currents based on the requested initial conditions, also writes various calculated initial conditions in the MAP file.

6.12.4.5 THE CONTROLS COMPILER INPUT MENU

The CONTROLS COMPILER INPUT Menu for the induction machine appears as shown in Figure 6.12.28. Similar to other machine models in RTDS, the induction machine model can operate in a LOCK or FREE mode. In LOCK mode, the speed of machine is forced to a value which is a control input to the machine. In FREE mode, the speed of the machine is determined by mechanical swing equations. In this case, the mechanical torque comes from the control input T in pu.

modnm: "modnm" is the name of CC input integer signal which defines the induction machine mode of operation: If this signal is 0, then the machine operates in the "LOCK" mode, if this signal is 1, then machine operates in "FREE" mode.

spdnm: "spdnm" is the name of CC input signal which defines the speed of induction machine if the mode of operation is "LOCK".

trqnm: "trqnm" is the name of CC input signal which defines the mechanical torque applied to the shaft of induction machine if the mode of operation is "FREE".

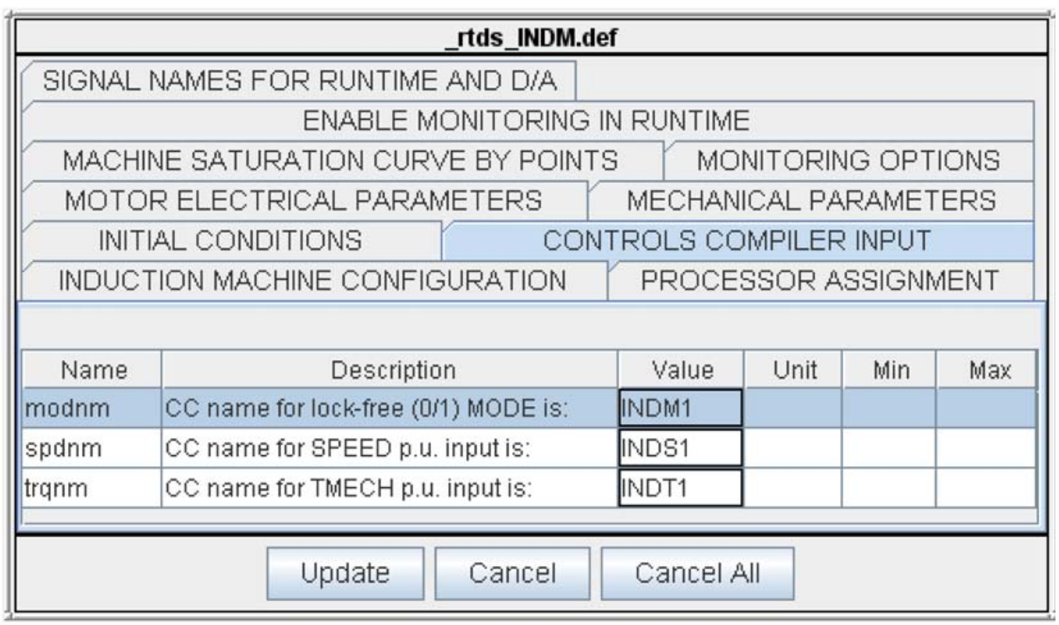


Figure 6.12.28 Control compiler menu for _rtds_INDM

6.12.4.6 MOTOR ELECTRICAL PARAMETERS

The menu MOTOR ELECTRICAL PARAMETERS appears as shown in Figure 6.12.29. In this menu:

Vbsll: Rated Stator Voltage of the Machine (Line−to−Line RMS)

trato: Effective Ratio of Turns (Rotor over Stator). This parameter corresponds to $(1/a)$ in Figure 6.12.5

pbase: Rated MVA of the Machine.

hrtz: Rated Operating Frequency of the Machine in Hz. $(\omega_s = 2\pi \cdot hrtz)$

ra: Resistance of the Stator Winding in pu. This parameter corresponds to (r_s) in Figure 6.12.5.

xa: Leakage Reactance of the Stator Winding in pu. This parameter corresponds to $(\omega_s \cdot L_{ls})$ in Figure 6.12.5.

xmd0: Unsaturated Magnetizing Reactance in pu. This parameter corresponds to $(\omega_s \cdot L_m)$ in Figure 6.12.5.

rfd: Resistance of First Rotor Cage (or Winding) in pu. This parameter corresponds to (r'_{r1}) in Figure 6.12.5.

xfd: Leakage Reactance of First Rotor Cage (or Winding) in pu. This parameter corresponds to $(\omega_s \cdot L'_{lr1})$ in Figure 6.12.5.

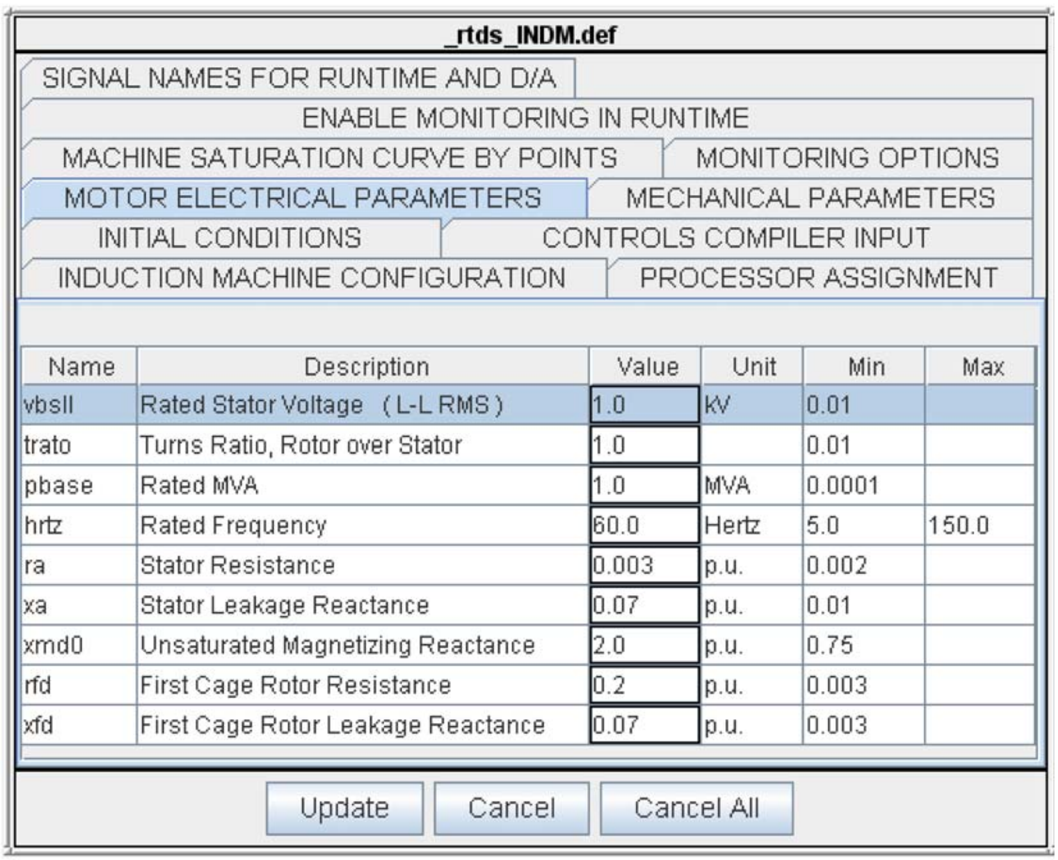


Figure 6.12.29 Motor Electrical Parameters menu for _rtds_INDM

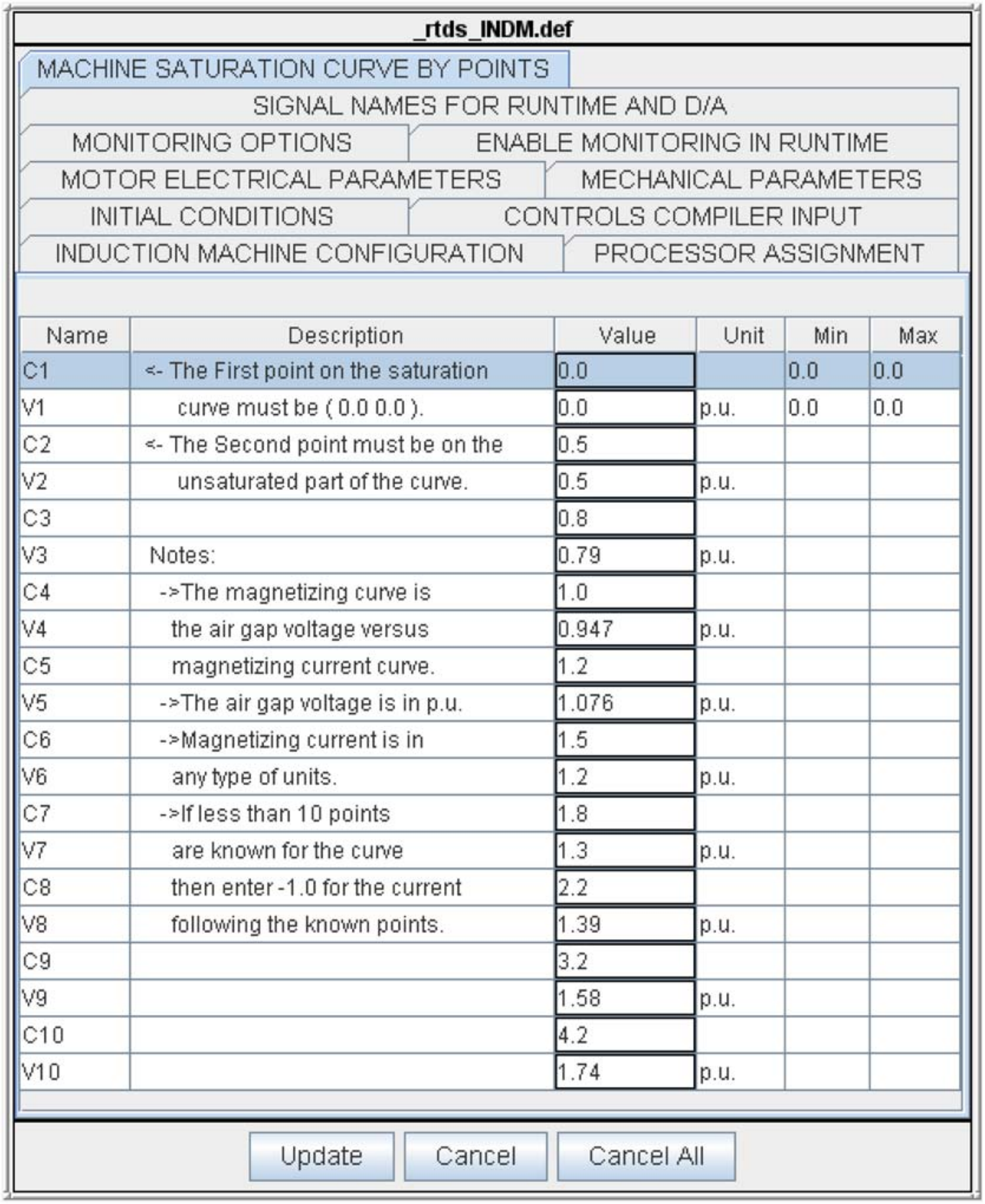
6.124.7 THE MACHINE SATURATION CURVE MENUS

The “tysat” menu item in the “INDUCTION MACHINE CONFIGURATION” menu prompts for an indication of whether saturation will be included in the model and, if so, whether the curve will be specified using points on the curve or using saturation factors SE(1.0) and SE(1.2). The choices are “Linear”, “Points”, and “Factors. If “Linear” is chosen, then the machine will not saturate. The other two choices are explained below. The saturation curve for the main magnetizing flux linkage path of the induction machine model is specifiable in the SATURATION CURVE menu. The saturation curve which is entered should be the air−gap voltage versus magnetizing current curve for the magnetizing branch at rated frequency.

6.12.4.8 THE MACHINE SATURATION CURVE BY POINTS MENU

The MACHINE SATURATION CURVE BY POINTS menu appears as follows.

This method requires a saturation curve for the machine to be entered using points on the curve. The curve is a plot of air−gap voltage in per−unit versus magnetizing current specified in units of the user’s choice. The first point in the curve (C1, V1) must be (0.0, 0.0). The second point in the curve (C2, V2) must be on the unsaturated part of the magnetizing curve. The position of the second point provides scaling information for magnetizing currents entered in the menu. If fewer than 10 points are entered for the curve, then enter −1.0 for the currents following the last known point.



_rtds_INDM.def

MACHINE SATURATION CURVE BY POINTS | SIGNAL NAMES FOR RUNTIME AND D/A | MONITORING OPTIONS | ENABLE MONITORING IN RUNTIME | MOTOR ELECTRICAL PARAMETERS | MECHANICAL PARAMETERS | INITIAL CONDITIONS | CONTROLS COMPILER INPUT | INDUCTION MACHINE CONFIGURATION | PROCESSOR ASSIGNMENT

Name	Description	Value	Unit	Min	Max
C1	<- The First point on the saturation	0.0		0.0	0.0
V1	curve must be (0.0 0.0).	0.0	p.u.	0.0	0.0
C2	<- The Second point must be on the	0.5			
V2	unsaturated part of the curve.	0.5	p.u.		
C3		0.8			
V3	Notes:	0.79	p.u.		
C4	->The magnetizing curve is	1.0			
V4	the air gap voltage versus	0.947	p.u.		
C5	magnetizing current curve.	1.2			
V5	->The air gap voltage is in p.u.	1.076	p.u.		
C6	->Magnetizing current is in	1.5			
V6	any type of units.	1.2	p.u.		
C7	->If less than 10 points	1.8			
V7	are known for the curve	1.3	p.u.		
C8	then enter -1.0 for the current	2.2			
V8	following the known points.	1.39	p.u.		
C9		3.2			
V9		1.58	p.u.		
C10		4.2			
V10		1.74	p.u.		

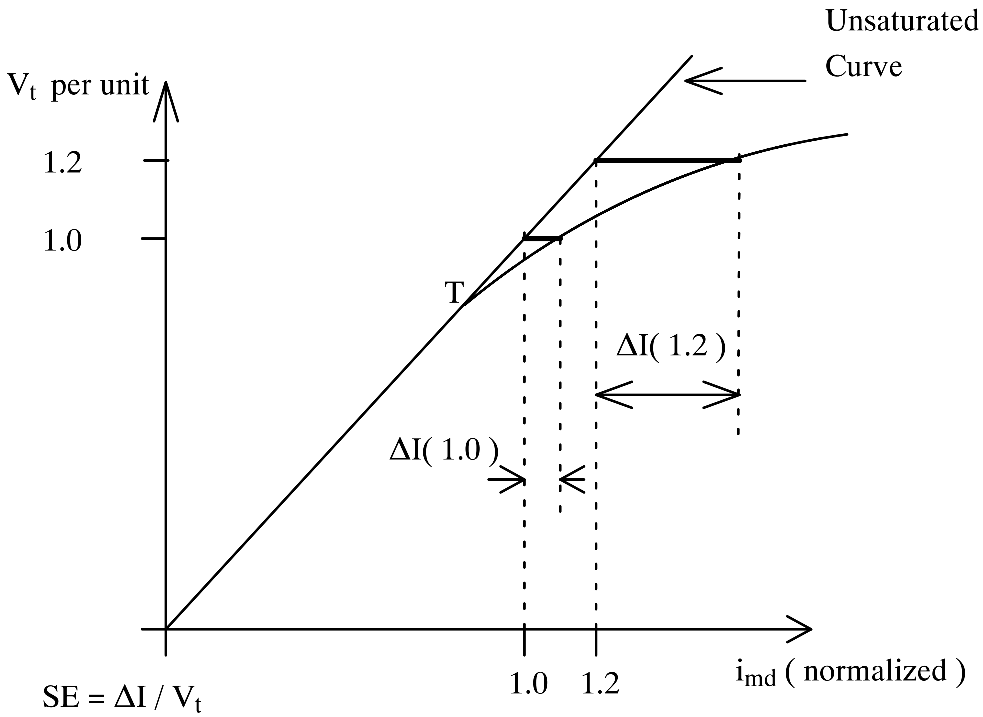
Update | Cancel | Cancel All

Figure 6.12.30 Machine Saturation Curve By Points Menu

6.12.4.9 MACHINE SATURATION CURVE BY FACTORS MENU

The two factors to be specified in the menu are defined in Figure 6.12.31. The saturation curve defined by the SE(1.0) and SE(1.2) factors is displaced to the right of the unsaturated curve by a quadratically increasing amount defined by the two points. The two factors are also sufficient to define the point T where the saturation curve becomes tangent to the unsaturated curve.

The MACHINE SATURATION CURVE BY FACTORS menu appears as shown in Figure 6.12.32.



$SE = \Delta I / V_t$

$SE(1.0) = \Delta I(1.0) / 1.0$

$SE(1.2) = \Delta I(1.2) / 1.2$

Figure 6.12.31 Machine Saturation Curve By Factors SE10 and SE12

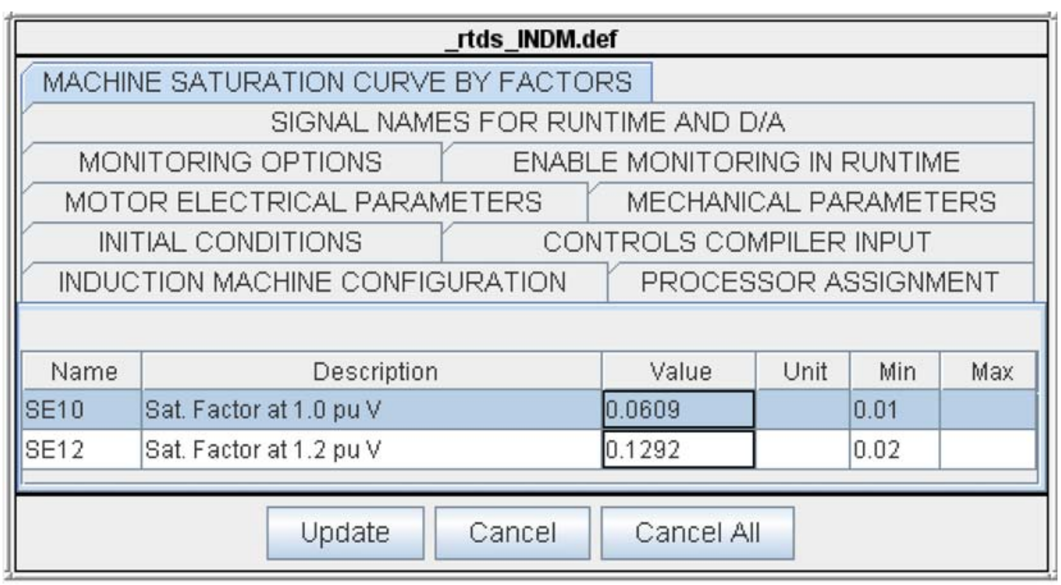


Figure 6.12.32 Machine Saturation Curve By Factors Menu

6.12.4.10 THE MECHANICAL PARAMETERS MENU

In this model, in FREE mode, the mechanical swing equations of the rotor are solved inside the model. This menu specifies the inertia constant (H) and frictional damping (D) of the mass. The MECHANICAL PARAMETERS menu appears as shown in Figure 6.12.33.

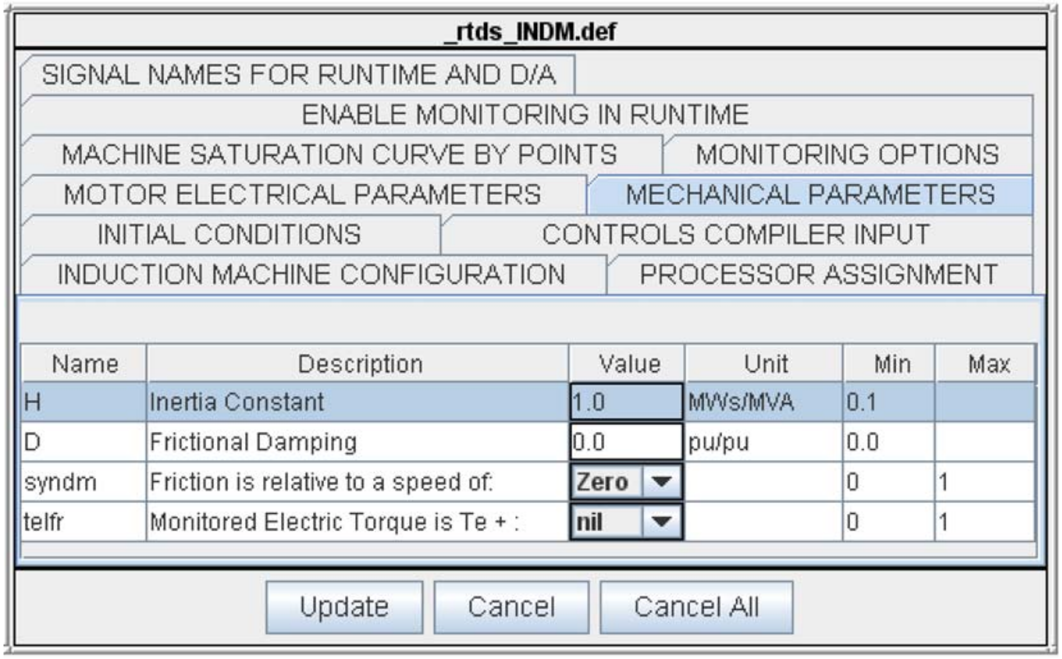


Figure 6.12.33 Mechanical Parameters Menu

H: The “H” menu item prompts for the inertia of the machine. H (in MW−Sec / MVA) is the rotational energy (in MW−Sec.) stored in the machine rotor at rated speed per MVA of machine rating. The MVA rating of the machine is as entered in the GENERAL MODEL CONFIGURATION menu in response to the “pbase” item.

D: The “D” menu item prompts for the frictional damping factor. The resulting damping torque tends to resist the speed. The damping torque factor “D” is in units of per−unit torque over per−unit speed deviation from zero (or synchronous) speed.

In locked speed mode, the pu speed of the machine is determined by a control input spdnm in the icon. In the free speed mode, the machine speed ω is determined by the sum of the torques that act on the total inertia of the machine. These include mechanical torque (T_m), electrical torque (T_e), and the damping torque. The following equation shows this relation:

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

syndm: The “syndm” menu allows the user to decide whether the frictional torque is relative to speed ($D \cdot \omega(pu)$) by selecting “syndm = Zero” or relative to the deviation of speed from synchronous speed ($D \cdot (\omega(pu) - 1)$) by selecting "syndm = Rated". The default value for this option is "Zero".

telfr: The "telfr" menu allows the user to monitor electric torque as calculated using the equation discussed previously, or add the frictional torque to it as well. The default value for this option is "nil".

Similar to other machine models in RTDS, **when the speed is positive, positive electric torque corresponds to generating operation of the machine and negative electric torque corresponds to motoring operation of the machine**. **When the speed is negative, positive torque corresponds to motoring operation of the machine, and negative torque corresponds to generating operation of the machine.** This is shown in the following table. Note that, positive speed according to RTDS and EMTDC convention means anti–clockwise rotation of the rotor.

Speed	Positive Torque	Negative Torque
+	Generator	Motor
–	Motor	Generator

6.12.4.11 MONITORING OPTION MENU

The user has the option of using a low–pass filter $\left(\frac{1}{1 + S \cdot T}\right)$ when the active power is monitored. The menu MONITORING OPTIONS appears as shown in Figure 6.12.34.

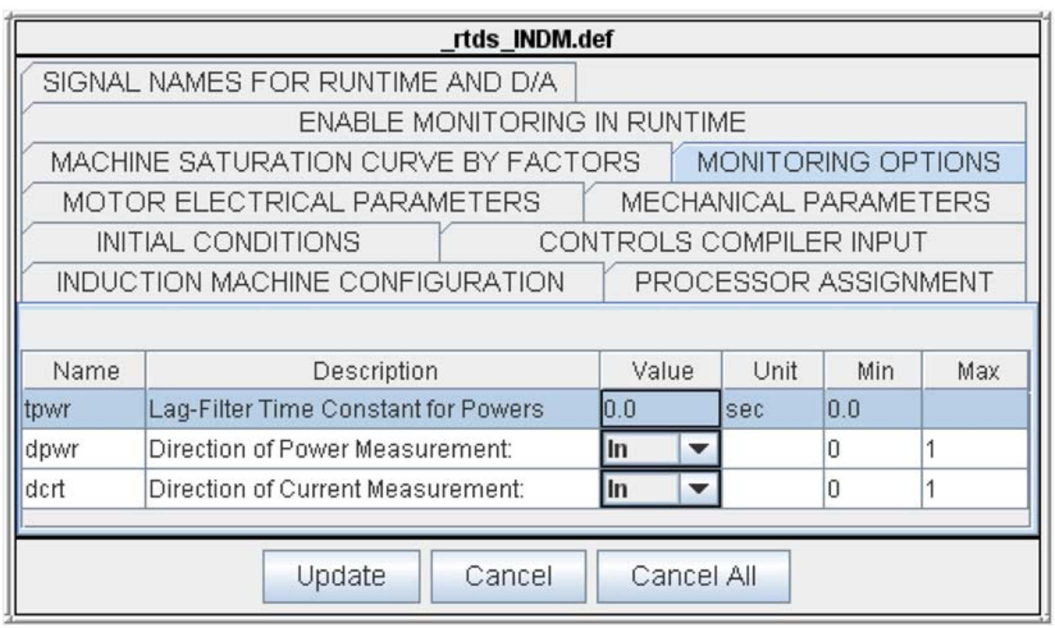


Figure 6.12.34 Monitoring options menu for induction machine

In this menu:

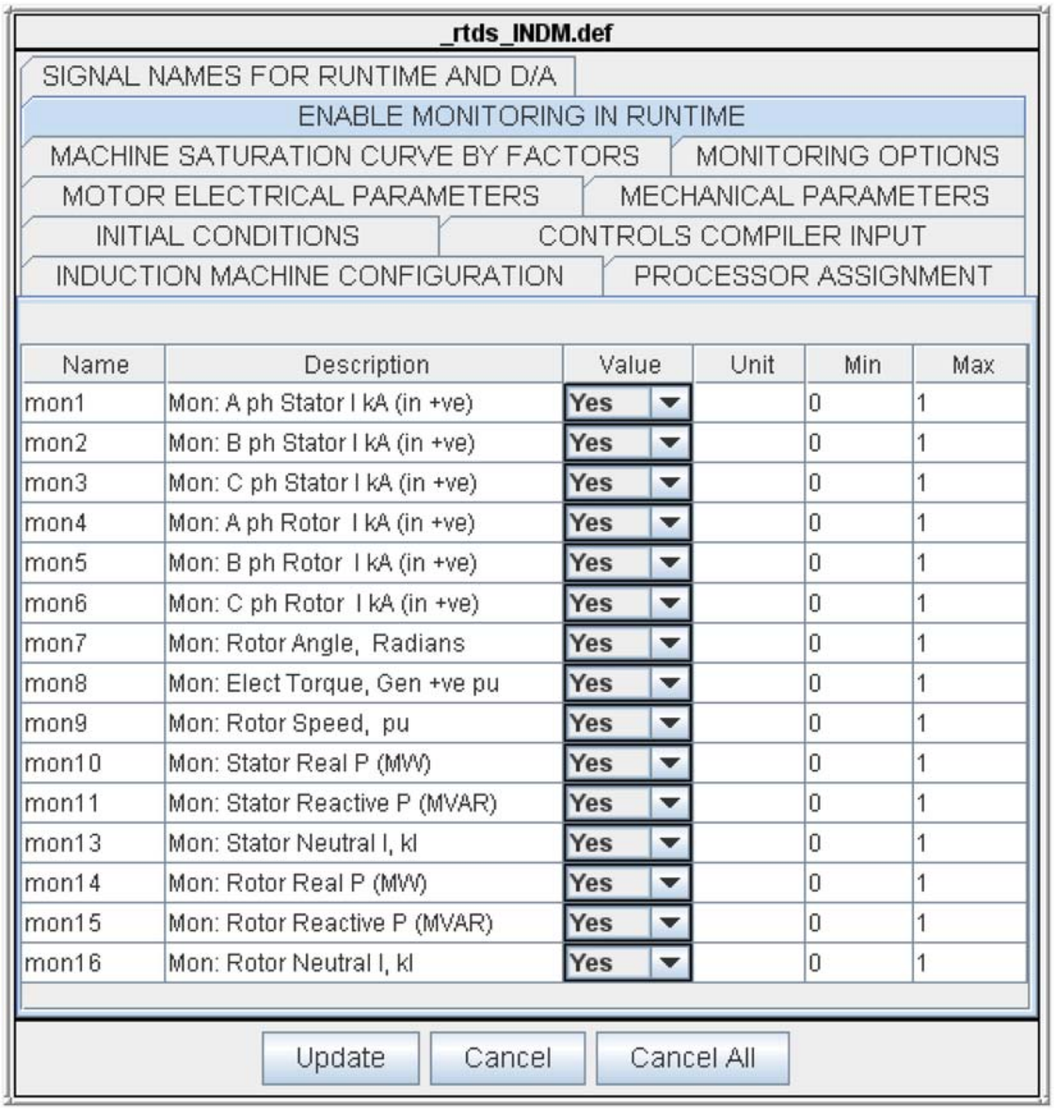
tpwr: Specifies the time constant (T) that the first order low pass filter will use on the signal for real power monitored from the machine.

Dpwr: Specifies the direction of active power monitored from the machine.

dcrt: This parameter allows the user to determine the direction of monitored current (into the winding or out of winding). The direction of monitored currents will be shown by arrows on the _rtds_INDM icon in the draft canvas.

6.12.4.12 THE ENABLE MONITORING IN RUNTIME MENU

The _rtds_INDM ENABLE MONITORING IN RUNTIME MENU appears as shown in Figure 6.12.35.



Name	Description	Value	Unit	Min	Max
mon1	Mon: A ph Stator I kA (in +ve)	Yes		0	1
mon2	Mon: B ph Stator I kA (in +ve)	Yes		0	1
mon3	Mon: C ph Stator I kA (in +ve)	Yes		0	1
mon4	Mon: A ph Rotor I kA (in +ve)	Yes		0	1
mon5	Mon: B ph Rotor I kA (in +ve)	Yes		0	1
mon6	Mon: C ph Rotor I kA (in +ve)	Yes		0	1
mon7	Mon: Rotor Angle, Radians	Yes		0	1
mon8	Mon: Elect Torque, Gen +ve pu	Yes		0	1
mon9	Mon: Rotor Speed, pu	Yes		0	1
mon10	Mon: Stator Real P (MW)	Yes		0	1
mon11	Mon: Stator Reactive P (MVAR)	Yes		0	1
mon13	Mon: Stator Neutral I, kI	Yes		0	1
mon14	Mon: Rotor Real P (MW)	Yes		0	1
mon15	Mon: Rotor Reactive P (MVAR)	Yes		0	1
mon16	Mon: Rotor Neutral I, kI	Yes		0	1

Figure 6.12.35 Enable monitoring in RUNTIME menu

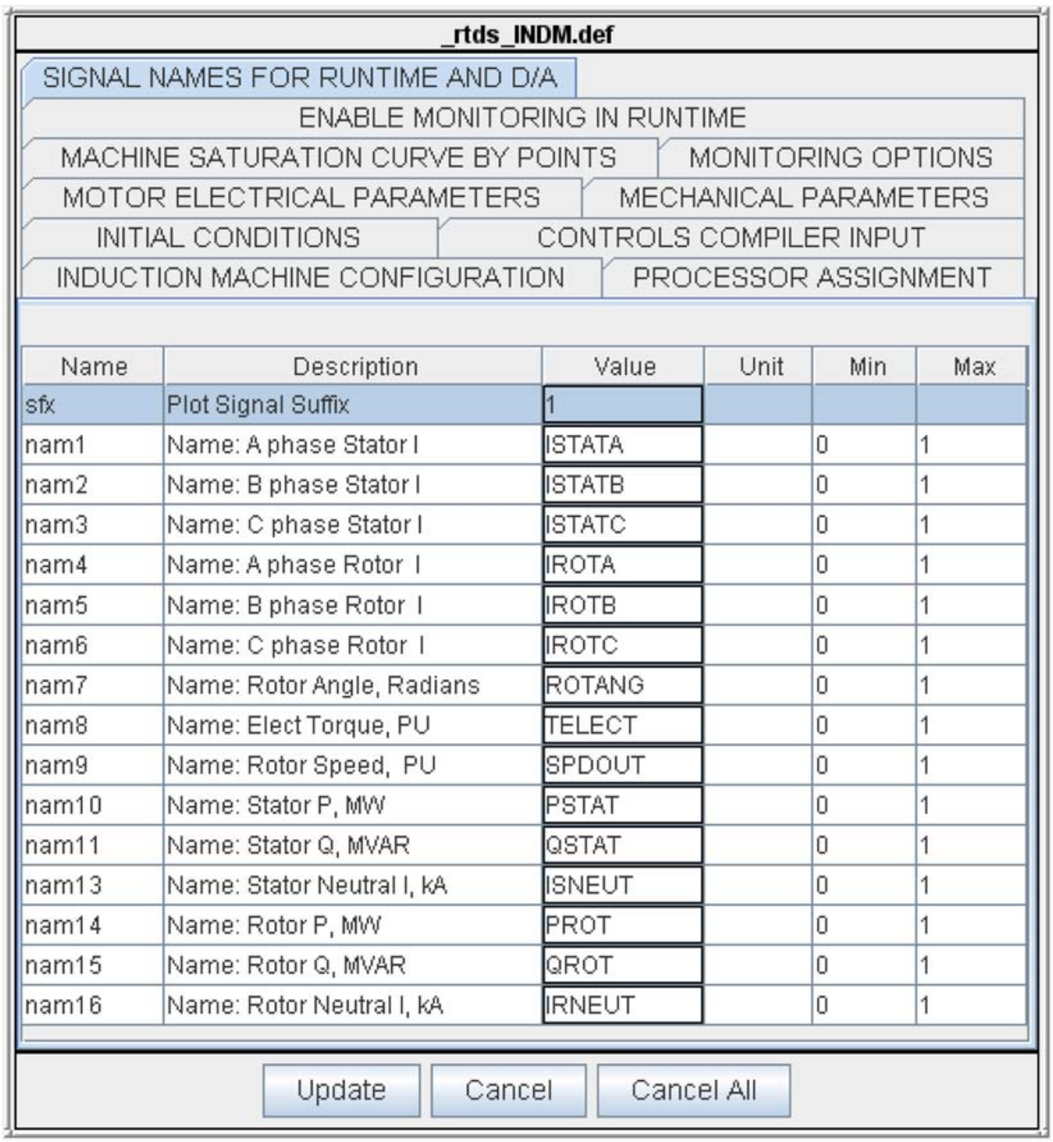
Stator and Rotor Currents: The user has the option of monitoring the stator and rotor winding and neutral currents in kA.

Rotor Angle, Electric Torque, and Rotor Speed: Mechanical quantities such as rotor angle, electric torque and rotor speed can also be monitored in Radians, pu , and pu respectively.

Active and Reactive Power of the Machine: The active and reactive power of the stator and rotor can be monitored. The direction of monitored power can be selected in the "Monitoring Options" menu.

6.12.4.13 THE SIGNAL NAMES FOR RUNTIME MENU

The SIGNAL NAMES FOR MONITORING IN RUNTIME MENU appears as shown in Figure 6.12.36. The user must dedicate a unique name for the monitored signals. A suffix can also be added to the name of signals.



Name	Description	Value	Unit	Min	Max
sfx	Plot Signal Suffix	1			
nam1	Name: A phase Stator I	ISTATA		0	1
nam2	Name: B phase Stator I	ISTATB		0	1
nam3	Name: C phase Stator I	ISTATC		0	1
nam4	Name: A phase Rotor I	IROTA		0	1
nam5	Name: B phase Rotor I	IROTB		0	1
nam6	Name: C phase Rotor I	IROTC		0	1
nam7	Name: Rotor Angle, Radians	ROTANG		0	1
nam8	Name: Elect Torque, PU	TELECT		0	1
nam9	Name: Rotor Speed, PU	SPDOUT		0	1
nam10	Name: Stator P, MW	PSTAT		0	1
nam11	Name: Stator Q, MVAR	QSTAT		0	1
nam13	Name: Stator Neutral I, kA	ISNEUT		0	1
nam14	Name: Rotor P, MW	PROT		0	1
nam15	Name: Rotor Q, MVAR	QROT		0	1
nam16	Name: Rotor Neutral I, kA	IRNEUT		0	1

Figure 6.12.36 Signal Names for RUNTIME menu

6.12.4.14 MACHINE INFORMATION WRITTEN IN THE MAP FILE

After compiling a draft case containing an _rtds_INDM machine model, the MAP file will contain information about this induction machine model. It contains the name of the machine model and electrical parameters. Also initial conditions: stator and rotor initial voltages, active and reactive power. Required initial speed and torque and initial magnetizing reactance.

```
==============================================================================

 RISC-based CModel component model of type "INDM (Induction Machine)"
   named: IM1
   in subsystem: 1

 has the following electric parameters:
   ======================================
   Rated MVA of the Machine:             1.00000      MVA
   Rated RMS Line-to-Line Voltage:       1.00000      kV
   Base Angular Frequency:               60.00000      Hz
   Rotor / Stator Turn Ratio is:         1.00000
   Stator Resistance:                    0.00300      p.u. =  0.00300      Ohm
   Stator Leakage Reactance:             0.07000      p.u. =  0.07000      Ohm
   Unsaturated Magnetizing Reactance     2.00000      p.u. =  2.00000      Ohm
   First Cage Rotor Resistance:          0.20000      p.u. =  0.20000      Ohm
   First Cage Rotor Leakage Reactance:   0.07000      p.u. =  0.07000      Ohm
   ======================================

 Machine Initial Conditions:
   ======================================

   PU Primary Voltage:                              1.00000      p.u.
   Angle of Primary Voltage( A phase sine wave ):   0.00000      Degrees
   PU Frequency of Primary Voltage:                 1.00000      p.u.

   PU Secondary Voltage:                            0.69578      p.u.
   Angle of Secondary Voltage( A phase sine wave ): 5.99180      Radians
   PU Frequency of Secondary Voltage:               0.50000      p.u.

   PU electrical torque, (generation +ve):          0.50183      p.u.
   PU required mechanical torque, (generation +ve): 0.50183      p.u.

   PU speed:                                        0.50000      p.u.

   PU real Power into stator:                       -0.50000      p.u.
   PU reactive Power into stator:                   -0.60000      p.u.

   PU real Power into rotor:                        0.57986      p.u.
   PU reactive Power into rotor:                    0.67823      p.u.

   PU Xmd (initial magnetizing inductance):         1.82080      p.u.
==============================================================================
```

Figure 6.12.37 Written information in the MAP file

6.12.5 COMPARISON WITH INDUCTION MACHINE MODELS IN PSCAD / EMTDC, ATP AND PSSE

This section describes some of the differences between the induction machine models in RTDS and induction machine models in other software packages such as PSSE, ATP and PSCAD/EMTDC. The goal is to make the process of conversion and comparison between circuits in RTDS and the above packages more convenient.
As far as we know, two main induction machine models exists in PSCAD/EMTDC library: The ”sqc100” squirrel cage induction machine model, and the ”wound_rotor” wound rotor induction machine model. Similarly, PSSE contains two induction machine model Type 1 and Type 2.

Here, main differences are divided into the following categories:

– Electrical Equivalent Circuit

– Torque and Speed Control

– Mechanical Swing Equations

– Saturation

6.12.5.1 ELECTRICAL EQUIVALENT CIRCUIT & PARAMETERS

In RTDS, the equivalent circuit for the induction machine models, whether wound–rotor or cage rotor, is as shown in Figure 6.12.4 and Figure 6.12.5. Due to the fact that path reluctance of ϕ_1 in Figure 6.12.6 is much smaller than that of ϕ_{12}, the leakage inductance of upper rotor winding is ignored in some literature [10], [23]. This feature is utilized in induction machine models provided by software packages such as PSSE (Type 2), PSCAD/EMTDC (sqc100) and ATP. In RTDS induction machine models, this leakage inductance is not ignored. However, the user has the option of entering very small values for this leakage inductance, thus making RTDS induction machine model compatible with the above software packages.

Users also need to pay attention to the menu for the base voltage: Some machine models accept rated Line–Line voltage as the base voltage and others accept rated Line–Neutral voltage of the machine.

6.12.5.2 TORQUE AND SPEED CONTROL

In RTDS and EMTDC machine models a switch decides whether the machine operates in the lock (speed) mode or in the free (torque) mode. In the speed mode, the mechanical equations are ignored, and the speed of the machine is decided by a control input. In the torque mode, the mechanical torque on the shaft is an input from a control signal and the speed of machine is decided by solving the swing equations.

– RTDS induction machine model lf_rtds_sharc_sld_INDM (available for 3PC, GPC and PB5 cards) accepts the speed in Hz, whereas other machine models in RTDS receive the speed in pu.

– In torque mode, all models in RTDS receive the input mechanical torque in pu.

– In all RTDS machine models positive torque corresponds to generating operation and negative torque corresponds to motoring operation. However in EMTDC, ”sqc100” induction machine model; positive torque means motoring operation and negative torque corresponds to generating operation of the machine.

6.12.5.3 MECHANICAL SWING EQUATIONS

In RTDS induction machine models, the “syndm” menu allows the user to decide whether the frictional torque is relative to speed ($D \cdot \omega(pu)$) by selecting “syndm = Zero” or relative to the deviation of speed from synchronous speed ($D \cdot (\omega(pu) - 1)$) by selecting “syndm = Rated”. The default value for this option is “Zero”. If the option ”syndm” is set to ”Zero”, the following equation applies:

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

If ”syndm” is set to ”Rated”, then the following equation applies:

$$T_m(pu) - T_e(pu) = 2H \cdot \frac{d}{dt}\omega(pu) + D \cdot (\omega(pu) - 1)$$

In PSCAD/EMTDC sqc100 induction machine model, the following equation applies:

$$T_e(pu) - T_m(pu) = J \cdot \frac{d}{dt}\omega(pu) + D \cdot \omega(pu)$$

6.12.5.4 SATURATION IN THE LEAKAGE PATH

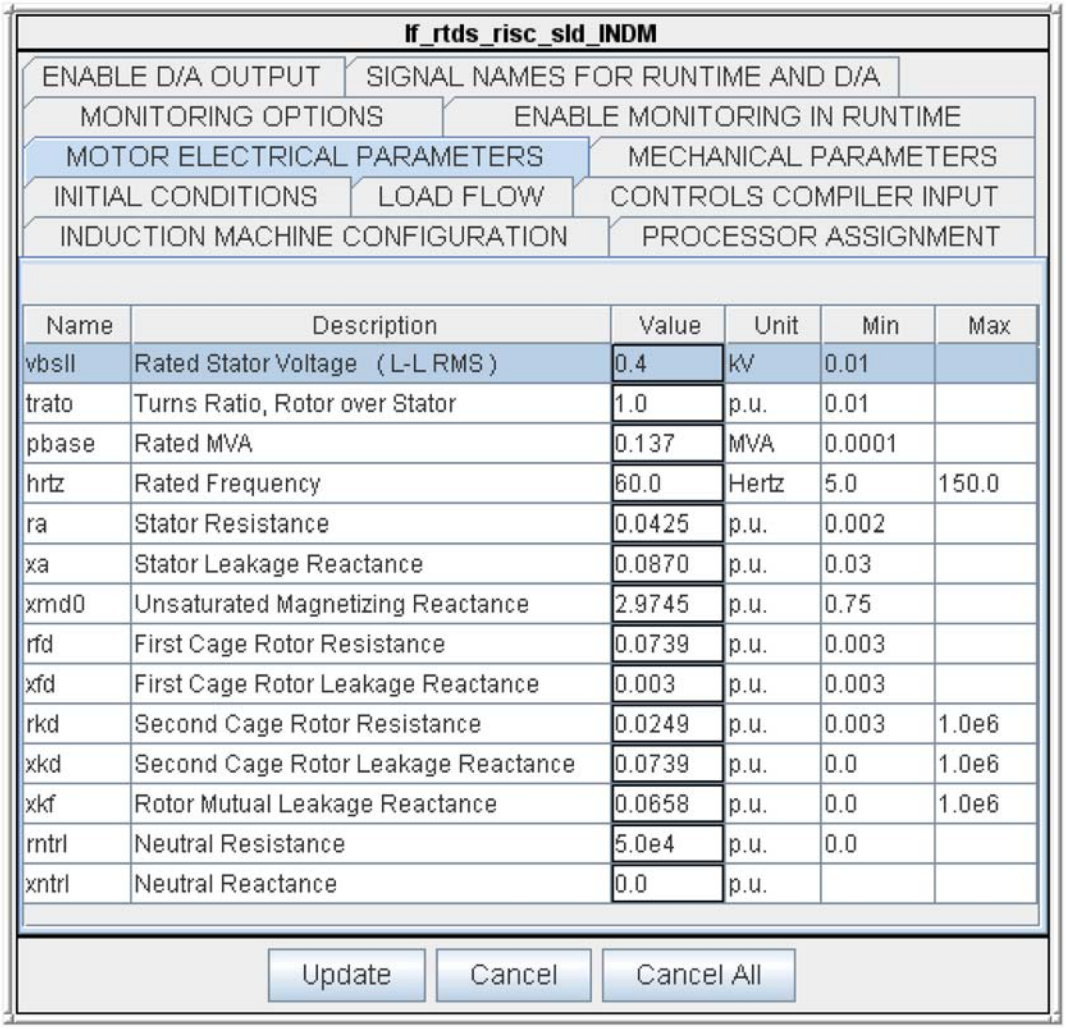
As the rotor is a cylindrical round rotor, total magnetizing MMF and magnetizing flux are aligned, therefore saturation in the magnetizing path is modeled by adjusting the magnetizing inductance as a function of peak of the total magnetizing flux in lf_rtds_risc_indm machine model [27] and peak of the total magnetizing current in _rtds_INDM phase−domain induction machine model. This is something that is common between RTDS and PSCAD/EMTDC.

During the start−up of induction machines, due to the large flow of currents in the windings, leakage paths may also saturate. PSCAD/EMTDC has an option to enable the users to include saturation in the leakage path.

As far as we know, there is no standard procedure to include this saturation phenomenon, because each phase and each slot of the machine may saturate differently based on the flow of current sheet into that particular slot. Therefore, saturation in the leakage path is not enabled in RTDS induction machine models.

6.12.6 EXAMPLE CASES

Few example cases are added to Chapter 5 of “Tutorials” directory. These examples help in understanding the analysis and operation of the three phase induction machine. These examples include start−up and torque−speed operation of induction machines. Data for this machine is taken from an example in Chapter 7.6.2 of [10]. Chapter 5 simulation cases demonstrate performance of this machine in start−up transients and various operation conditions. In [10], no leakage inductance is assumed for the first rotor cage in a double−cage induction machine model. As mentioned earlier, RTDS users has the option of entering very small values for this leakage inductance in lf_rtds_risc_INDM induction machine model. This action is shown in Figure 6.12.38 which represents the electric parameters of the induction motor in Chapter 7.6.2 of [10].



Name	Description	Value	Unit	Min	Max
vbsll	Rated Stator Voltage (L-L RMS)	0.4	kV	0.01	
trato	Turns Ratio, Rotor over Stator	1.0	p.u.	0.01	
pbase	Rated MVA	0.137	MVA	0.0001	
hrtz	Rated Frequency	60.0	Hertz	5.0	150.0
ra	Stator Resistance	0.0425	p.u.	0.002	
xa	Stator Leakage Reactance	0.0870	p.u.	0.03	
xmd0	Unsaturated Magnetizing Reactance	2.9745	p.u.	0.75	
rfd	First Cage Rotor Resistance	0.0739	p.u.	0.003	
xfd	First Cage Rotor Leakage Reactance	0.003	p.u.	0.003	
rkd	Second Cage Rotor Resistance	0.0249	p.u.	0.003	1.0e6
xkd	Second Cage Rotor Leakage Reactance	0.0739	p.u.	0.0	1.0e6
xkf	Rotor Mutual Leakage Reactance	0.0658	p.u.	0.0	1.0e6
rntrl	Neutral Resistance	5.0e4	p.u.	0.0	
xntrl	Neutral Reactance	0.0	p.u.		

Figure 6.12.38 Motor Electrical Data for the induction motor in Ch. 5 of Tutorial Examples

For the purpose of validation, the above induction machine steady−state torque−speed characteristics were calculated analytically and compared against the RTDS simulation results from RTDS induction machine model. Figure 6.12.39 shows this comparison. As can be seen there is an excellent agreement between these two graphs.

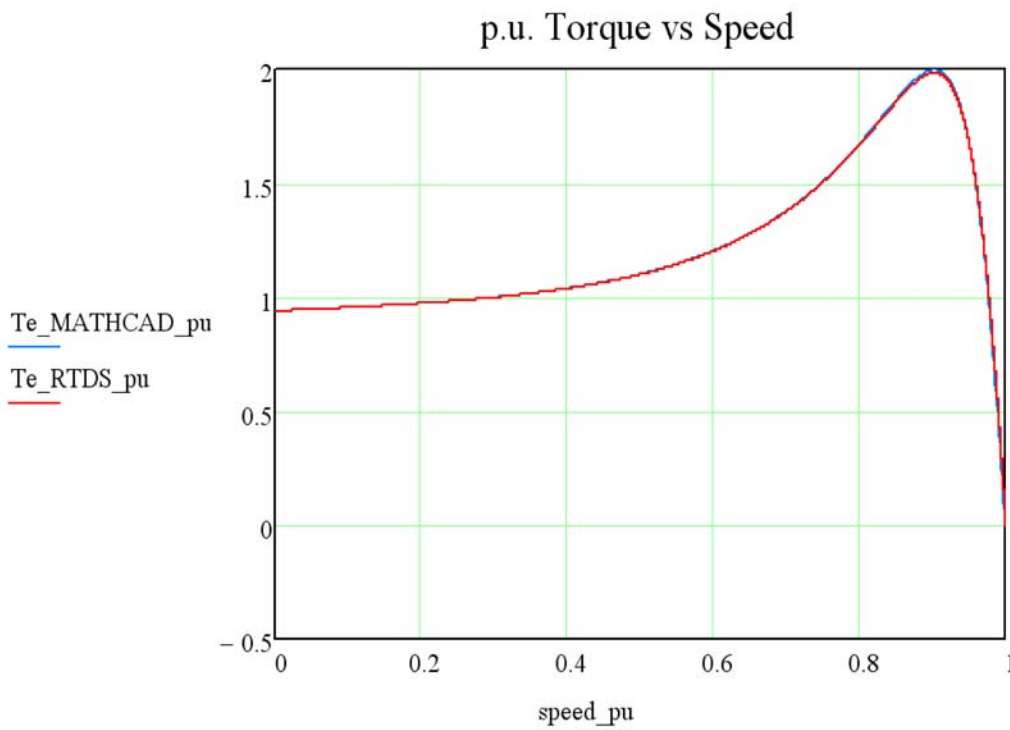


Figure 6.12.39 Induction machine steady−state torque−speed characteristics: Comparison between RTDS simulation results and analytical solution plotted in Mathcad.

6.12.7 SUMMARY

The three−phase Induction Machine Models (lf_rtds_risc_indm & _rtds_INDM) were described here. The **Interface approach** [25], [27] is used to implement this lf_rtds_risc_indm induction machine model and The **embedded approach** is used for implementation of _rtds_INDM machine model in the environment of the real−time digital simulator (RTDS). Induction machine model _rtds_INDM, provides a model that is flexible in configuration; it provides access to the stator and rotor neutral. The above models has the following assumptions and specifications:

1. It is assumed that the machine windings produce a sinusoidal MMF, thus space harmonics are ignored.
2. Similar to other machine models in RTDS, multi−pole three phase IMs are modeled as an equivalent two pole machine. Torque and speed are monitored in p.u.
3. As the rotor is a cylindrical round rotor, total magnetizing MMF and magnetizing flux are aligned, therefore saturation is modeled by adjusting the magnetizing inductance as a function of peak of the total magnetizing flux in lf_rtds_risc_indm machine model [27] and peak of the total magnetizing current in _rtds_INDM phase−domain induction machine model. Saturation in the leakage paths is ignored.

4. Five computational load units of RTDS are required for real−time simulation of an _rtds_INDM induction machine model. Two computational load units are is required for real−time simulation of an lf_rtds_risc_INDM, induction machine model.

5. For full transient modelling of induction machines, zero sequence component and zero sequence equivalent circuit need to be considered for both stator and rotor (unless rotor winding/bars are shorted). **This is especially important for correct modeling of single−phase faults**.

   In RTDS, small time−step induction machine model (rtds_vsc_INDM) assumes an open neutral for both stator and rotor, thus zero sequences are ignored.

   Induction machine model lf_rtds_risc_indm) considers stator zero sequence, also accepts values for neutral impedance. Neutral point is not accessible.

   Induction machine model (_rtds_INDM) considers zero sequence in both stator and rotor as this model is a phase−domain induction machine model.

6. For the purpose of numerical stability, the terminals of lf_rtds_risc_indm induction machine model are connected through 300 pu un−compensated resistances.

6.13 CONCLUSIONS AND REFERENCES

This chapter describes the general properties of the machine models in RTDS and outlines the references.

6.13.1 CONCLUSIONS

Various electric machine models are developed for the real−time digital simulator (RTDS). These include synchronous machines, induction machines and permanent magnet synchronous machines for both normal ($\simeq 50\,\mu s$) and small time−step modules. Additionally, a synchronous machine model capable of modeling internal faults (_rtds_PDSM_FLT_v1), a single−phase induction machine model (_rtds_SPIM) ,a DC machine model (_rtds_DCMAC) and a three−phase induction machine model (_rtds_INDM) have also been added to the power system library to be used in normal time−step ($\simeq 50\,\mu s$) module.

Some of the above models use the interfacing approach of modeling electric machines for electro−magnetic transient programs [25], [27]. Others, use the phase−domain embedded approach of modeling electric machines [4], [5].

These electric machine models have the following common specifications:

1. For each model, the computational load unit of RTDS, required for real−time simulation of that model is specified.
2. Space harmonics and slot harmonics are ignored.
3. Effects of *magnetic saturation* are included in most machine models in the library. The users have the option of entering saturation curve data using the points on the saturation curve or saturation factors.
4. Multi−pole electric machines are modeled as equivalent two pole machines. Torque and speed are monitored in p.u.
5. When the speed is positive, positive electric torque corresponds to generating operation of the machine and negative electric torque corresponds to motoring operation of the machine. When the speed is negative, positive torque corresponds to motoring operation of the machine, and negative torque corresponds to generating operation of the machine. This is shown in the following table. Note that, positive speed according to EMTDC and RTDS conventions means anti−clockwise rotation of the rotor.

Speed	Positive Torque	Negative Torque
+	Generator	Motor
−	Motor	Generator

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7 MEASUREMENT TRANSDUCERS

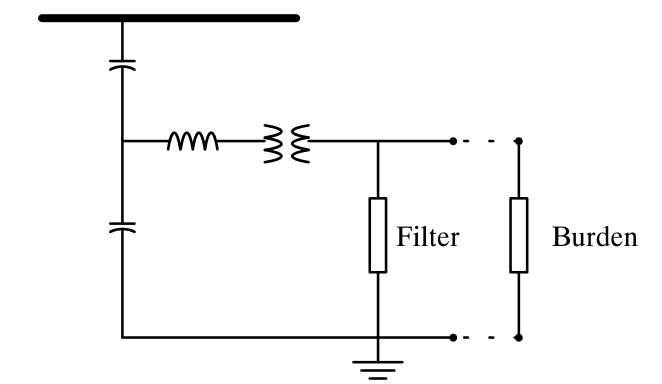
To determine or evaluate proper operation of protective relays under transient conditions, it is important to be able to reproduce the sometimes complex response of measurement transducer outputs such as current transformers (CT's) and capacitive voltage transformers (CVT's).

7.1 CAPACITIVE VOLTAGE TRANSFORMER (CVT) *[rtds_sharc_CVT3]*

Capacitive potential devices have long been used in power systems as inputs to protective relays and protective relay systems. In a digitally simulated system it is always possible to simply calculate and scale down system voltages at various points throughout the network. In fact, node voltages for every node within a system simulated on the RTDS are always available for monitoring, both on the simulators' RunTime Operator's Console and on analogue output channels. RunTime sliders associated with the analogue output channels allow the user to vary the level of output which represents the actual system voltage. This approach for voltage measurement and monitoring may be, and is, acceptable for many applications. However, under certain conditions, in particular where protective relay systems are being tested or included in the simulation, the response of the more complicated voltage measurement system as used in the physical power system will often be required.

In a real power system the voltage levels are normally many hundreds of thousands of volts and hence direct connection of voltage measurement devices for relay input is obviously not possible. Relay input levels are generally less than a few hundred volts and therefore straight potential transformation is often not economical. Capacitive potential devices such as the CVT being described here include tapped capacitor divider strings together with potential transformers. This arrangement allows the system voltage to be reduced to a more practical intermediate level before application to the potential transformer hence reducing the difficulties associated with the transformer design. As will become apparent, more than just a capacitor stack and a potential transformer are required in the make up of a typical CVT installation. Interactions between these and other components required to complete the CVT design tend to introduce various oscillatory modes under transient conditions. In particular, subsidence transients resulting from a sudden significant reduction in primary system voltage, typically caused by a nearby line to ground fault can cause significant error in the voltage waveform presented at the relay input. Ferro−resonance developed between the capacitor and the non−linear variable magnetizing inductance of the potential transformer is also a concern in physical CVT installations. Normally filter circuits are included as part of the overall CVT design to help deal with these undesirable phenomena. The model must be capable of generating this same type of ferro−resonance effect and must include filter circuitry to reduce or eliminate it as in the real system.

A typical CVT arrangement is illustrated below.



7.1.1 CVT – BASIC THEORY

The main parts making up a typical CVT installation can be categorized as follows;

i) Capacitive divider stack
ii) Tuning reactor
iii) Potential transformer
iv) Ferro−resonance filter circuitry
v) Burden

A more detailed representation of the model as implemented on the RTDS is shown in Figure 7.1. In the figure each of the main parts have been shown in the form of equivalent circuits.

The capacitive divider stack is essentially a string of capacitors which can be tapped at various points to achieve different voltage divider ratios. In Figure 7.1 the capacitive divider is shown as two capacitors C_1 and C_2. In the actual system the values of C_1 and C_2 can generally be varied by choosing appropriate tap points in order to achieve the desired voltage ratio.

The capacitor string is connected to the high voltage system bus at voltage level V_{SYS}. Depending on the ratio of C_1 to C_2 the intermediate voltage V_1 is determined. In order to determine the intermediate voltage level Equation 7.1 must be applied.

$$V_1 = V_{SYS} * C_1 / (C_1 + C_2) \qquad \text{Equation 7.1}$$

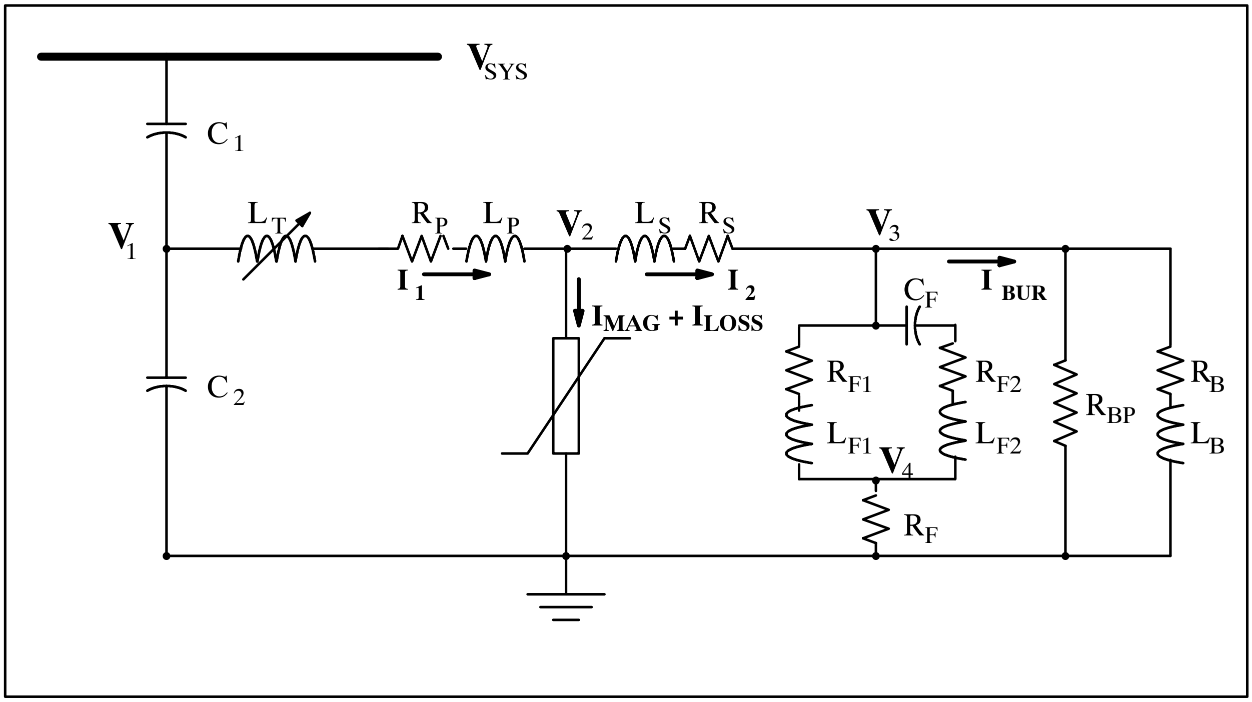


Figure 7.1 CVT Equivalent Circuit

A tuning reactor is placed on the intermediate voltage bus in order to provide impedance and phase angle compensation. In order to properly reproduce the primary or system side voltage in both phase angle and magnitude, the phase angle shift introduced by the presence of the capacitor must be compensated by an inductive reactance component. Although the potential transformer itself introduces inductance, this is not nearly enough to compensate that introduced by the capacitance. A large inductor is then typically placed at the intermediate voltage bus as shown in Figure 7.1. This forms a series resonance circuit to provide the required compensation. To calculate the approximate value of required compensation Equation 7.2 can be applied. It should be noted that Equation 7.2 does not take into account the potential transformer contribution to the inductive reactance.

$$L = 1 / (\omega_o^2 * C) \qquad \text{Equation 7.2}$$

where $\omega_o = (2\pi * \text{system frequency})$ and $C = (C1 + C2)$.

The tuning reactor is then connected to a step−down potential transformer which has a secondary side voltage rating that will be that required by the relay (typically 115 volts, line to line rms). The potential transformer model used in the RTDS CVT model includes the effects of core saturation and hysteresis.

On the low voltage side of the step−down transformer the ferro−resonance filter circuitry and the burden are connected. The ferro−resonance circuit must be present in any CVT design to avoid the undesirable and possibly damaging effects which could result if a ferro–resonance condition were excited. It should be noted that ferro–resonance is generally not a transient phenomena although it may be initiated by a transient condition on the system. In fact ferro–resonance, once initiated, may persist in steady state for an indefinite amount of time.

As already mentioned, ferro–resonance is caused by the interaction of the series capacitor and the potential transformer. It can occur in many different modes, each characterized by its own waveshapes of current , voltage and transformer flux linkage and by its frequency. The non–linear nature of the transformer core may cause inrush phenomena. Normally the extent of inrush current is effected by the flux level in the transformer core and the point on the wave at which a disturbance occurs. A single pulse of inrush current may increase, decrease, remove or reverse the charge which exists on the capacitor (again depending on the point on the wave and on the flux level). The charge then left on the capacitor by the single inrush current pulse simply acts as an additional voltage source which tends to alter the transformer flux. A positive voltage on the capacitor, for example, would cause continuous displacement of the transformer flux towards negative saturation (voltage across a capacitor is 180 degrees out of phase with that of an inductor). In the negative saturation region, inrush currents which tend to reduce or reverse the capacitor voltage would be generated. The reversal of the capacitor voltage then tends to push the transformer towards positive saturation in which positive inrush currents would result and so on. In this way it can be seen that such a phenomenon could continue with undefined and changing frequency and magnitude for an indefinite length of time.

The CVT burden is generally some combination of resistance and inductance. The burden configuration and power factor will have an effect on the shape and magnitude of the subsidence transient. For the purpose of modelling, a series R – L branch in parallel with a resistor have been provided, as can be seen in Figure 7.1.

7.1.2 CVT EQUIVALENT CIRCUIT

From the RTDS standpoint, the CVT is an auxiliary device which picks up voltages from the simulated system, applies them to a modelled CVT installation and provides an output voltage signal which accurately represents that resulting in the actual power system. The output voltage is then displayed on one of the auxiliary processor's D/A output ports for possible connection to external monitoring, control or protection devices. The user may also choose to display this quantity on the RunTime Operator's Console.

The CVT installation does not in any way contribute to, or affect the overall subsystem solution. For this reason, its internal circuitry (see Figure 7.1) can be solved independently.

Based on the CVT circuit shown in Figure 7.1, an equivalent circuit as given in Figure 7.2 can be derived. Variable current sources in parallel with fixed resistances form the basis of the CVT algorithm.

The equivalent circuit is made up of three distinct portions, these being ; capacitive potential divider ; potential transformer ; ferro−resonance filter / burden. Each portion of the equivalent circuit is solved in a unique manner, and then the solutions are combined and used to formulate the overall final solution for each time step.

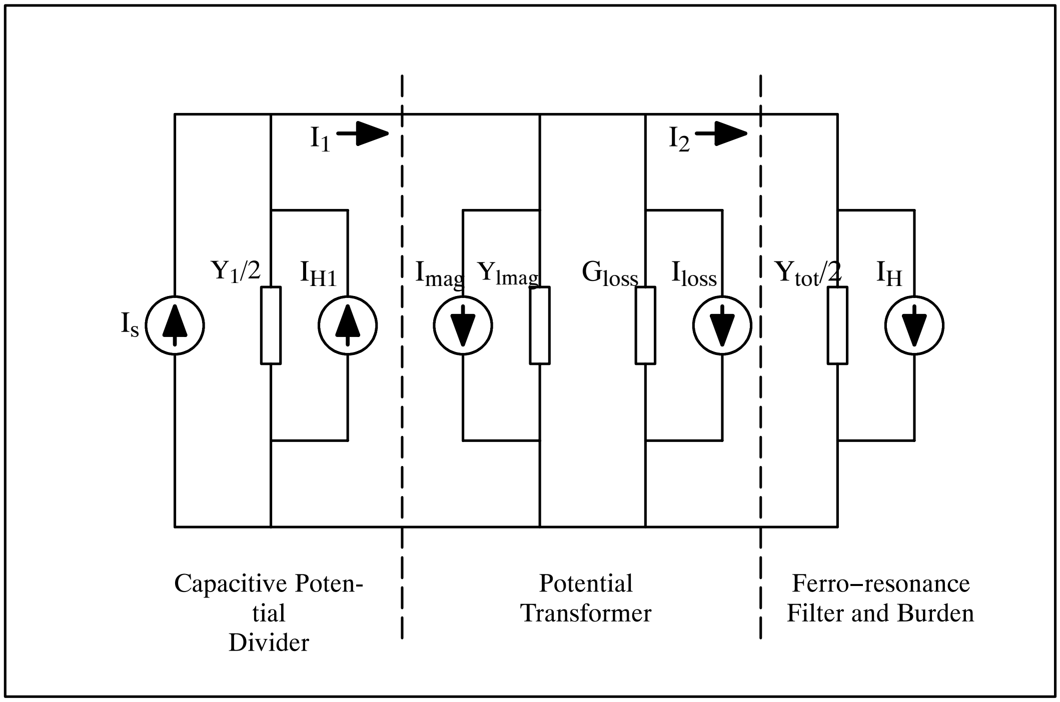


Figure 7.2 CVT Equivalent Circuit

Portion 1 of the equivalent circuit (Capacitive Potential Divider) includes the capacitor stack (C_1 and C_2), the compensating reactor (L_T) and the intermediate potential transformer primary resistance (R_P) and primary inductance (L_P).

Portion 3 of the equivalent circuit (Ferro−resonance Filter and Burden) includes the intermediate potential transformer secondary resistance (R_S) and inductance (L_S), all components associated with the filter itself (C_F, R_{F1}, L_{F1}, R_{F2}, L_{F2}, R_F) and the two parallel branches which make up the burden (R_{BP}, R_B and L_B).

By far the most involved part of the equivalent circuit is the Potential Transformer portion (ie portion 2). This part of the circuit is used to model the non−linearities associated with the core of the potential transformer. Included are core saturation effects and core losses, including both eddy current and hysteresis loss. Non−linear effects are introduced by on−line calculations of non−integer power series equations whose solution approximates the shapes of the non−linear characteristics.

The core saturation characteristic is represented by the dynamic solution of Equation 7.3.

$$H(t) = B_1 * B(t) + B_2 * B^{35}(t) \qquad \text{Equation 7.3}$$

The user, through Draft must supply pairs of points from the B−H curve (ie: magnetic flux density vs magnetic field intensity) of the transformer being modelled. In general, the B−H characteristic is a property of the core material and is quite readily available. The pairs of points then define a reference curve on which a LSE (Least Square Error) curve fitting technique is automatically applied in order to determine coefficients B_1 and B_2 of Equation 7.3.

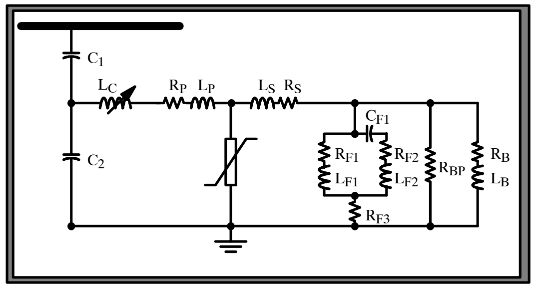
The first term of Equation 7.3 is linear and dominates the characteristic in the non saturated region when magnitude of B is low. The second term is a power term which dominates in the saturated region when magnitude of B is high. Provided that B_1 and B_2 are properly chosen, Equation 7.3 will yield a good representation of the original B−H curve.

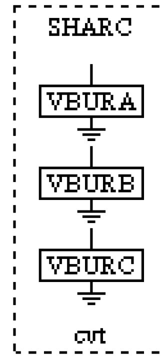
Core losses are also represented in the intermediate potential transformer. Currently, core losses can only be approximated using the CVT component. Using the approximation approach to modelling the core losses of the CVT component, the user is required to enter a loop width. The loop width is defined as a percentage of the known 1 p.u. magnetizing current.

In the case of the CVT, the user enters a value in % ranging anywhere between 0 and 100% . A value of 0% would result in a single valued B−H (and hence flux vs current) characteristic. A value other than 0% will define the major or parent loop of the flux vs current characteristic. The width of the parent loop (ie the % value entered) is defined with reference to a current called the knee point current (1 p.u. magnetizing cureent). From the B−H curve entered by the user, the knee point is automatically determined along with the corresponding knee point current. Applying the loop width to the knee point current defines the parent loop.

7.1.3 CVT INPUT DATA

CVT Model

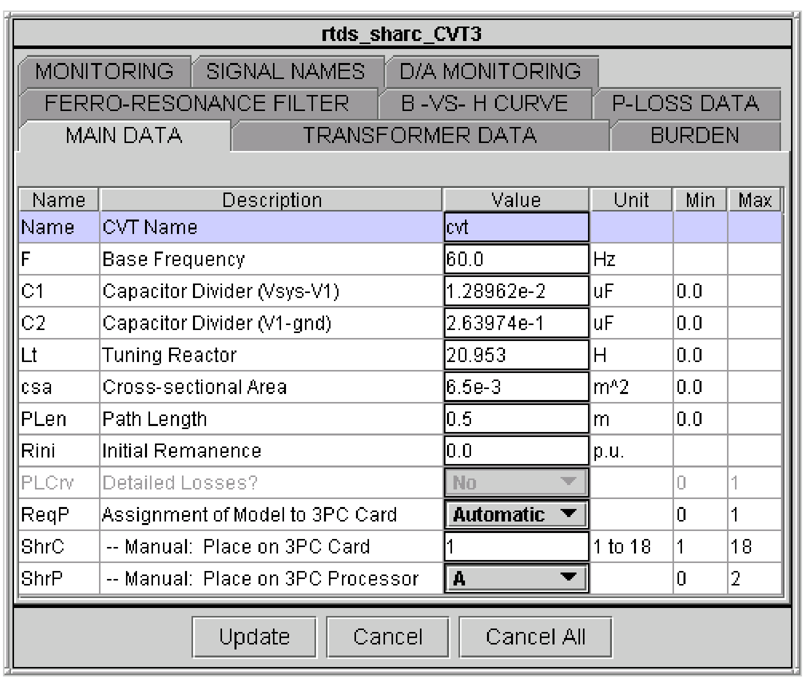




The RTDS sharc library contains a CVT model in which default values for a typical installation are already entered. If the user wishes, this default CVT can be used without modification to input parameters. The default CVT is intended for use on a 230 kV system when a desired burden voltage level of 110 to 120 volts is required (ie typical for relay input voltage level). The user may modify parameters as required to suit his or her particular application. Note however that the CVT circuit configuration cannot be changed.

Three single phase CVT models have been lumped together to create the CVT model. The user need only enter data for one phase in the menu items provided. The CVT model requires one sharc processor to perform the required computations.

Main Data Menu



rtds_sharc_CVT3

MONITORING | SIGNAL NAMES | D/A MONITORING | FERRO-RESONANCE FILTER | B -VS- H CURVE | P-LOSS DATA | MAIN DATA | TRANSFORMER DATA | BURDEN

Name	Description	Value	Unit	Min	Max
Name	CVT Name	cvt			
F	Base Frequency	60.0	Hz		
C1	Capacitor Divider (Vsys-V1)	1.28962e-2	uF	0.0	
C2	Capacitor Divider (V1-gnd)	2.63974e-1	uF	0.0	
Lt	Tuning Reactor	20.953	H	0.0	
csa	Cross-sectional Area	6.5e-3	m^2	0.0	
PLen	Path Length	0.5	m	0.0	
Rini	Initial Remanence	0.0	p.u.		
PLCrv	Detailed Losses?	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

Update | Cancel | Cancel All

Name – The CVT name can be any name beginning with a letter. Following the first letter the name can contain up to nine more alpha–numeric characters. This name is then used in all cross–referencing between Draft and RunTime. If the user fails to assign an appropriate name, an error will be issued upon compiling the circuit.

F – The user must specify the system base frequency in Hz.

C1 – This represents the capacitance of the first portion of the capacitor divider stack (see C_1 of Figure 7.1). C1 is entered in μf.

C2 – This represents the capacitance of the second portion of the capacitor divider stack. C2 is entered in μf.

Lt – This represents the CVT compensating reactor. Lc is entered in Henries (H).

csa – This is the cross–sectional area of the core in the CVT's intermediate potential transformer. The area is entered in m^2.

PLen – This is the flux path length in the potential transformer core. The path length is entered in m.

Rini – This represents the remenant flux in the potential transformer core upon starting of the simulation run. This gives the user the option of starting a simulation with an offset or non–zero core flux. Remenant flux values are entered in p.u. with base Bknee (saturation knee point). Bknee may be found by plotting the B–H loop and locating the approximate knee point value on the curve.

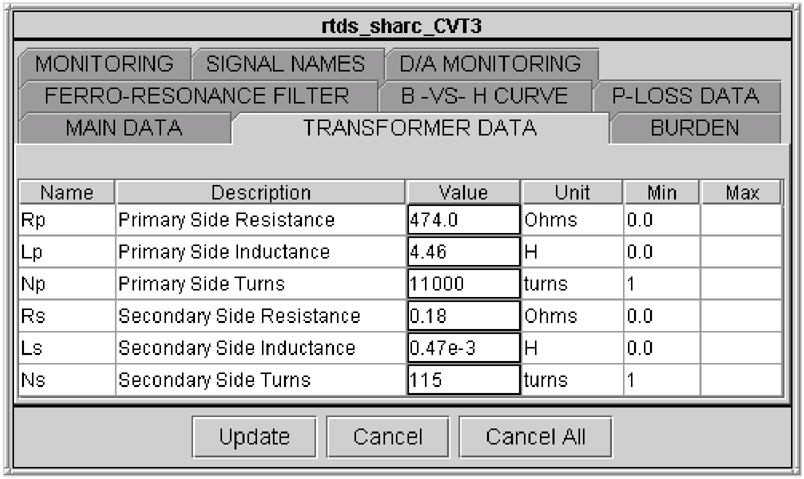
PlCrv – This parameter is disabled. Currently only approximated core losses may be modelled in the CVT component.

ReqP – The CVT model may be assigned to a sharc processor using Automatic mode or Manual mode. In Automatic mode, the processor assignment is performed by the compiler. In Manual mode, the processor assignment is specified by the user.

ShrC – In Manual mode, the 3PC card number that the CVT model is to be assigned must be specified. This parameter refers to the 3PC card number – not the card number of the RTDS rack. For example, if the CVT component is to be assigned to 3PC card1 processor A, this information would be entered into the corresponding menus. The 3PC board number entered is 1 even though the 3PC card may actually be card 17 in the RTDS rack.

ShrP – In Manual Mode, the processor that the CVT model is to be assigned must be specified. The processor selected corresponds to the 3PC card number entered above.

Transformer Data Menu



Name	Description	Value	Unit	Min	Max
Rp	Primary Side Resistance	474.0	Ohms	0.0	
Lp	Primary Side Inductance	4.46	H	0.0	
Np	Primary Side Turns	11000	turns	1	
Rs	Secondary Side Resistance	0.18	Ohms	0.0	
Ls	Secondary Side Inductance	0.47e-3	H	0.0	
Ns	Secondary Side Turns	115	turns	1	

Rp – Intermediate potential transformer primary side resistance is entered in Ω .

Lp – Intermediate potential transformer primary side inductance is entered in H.

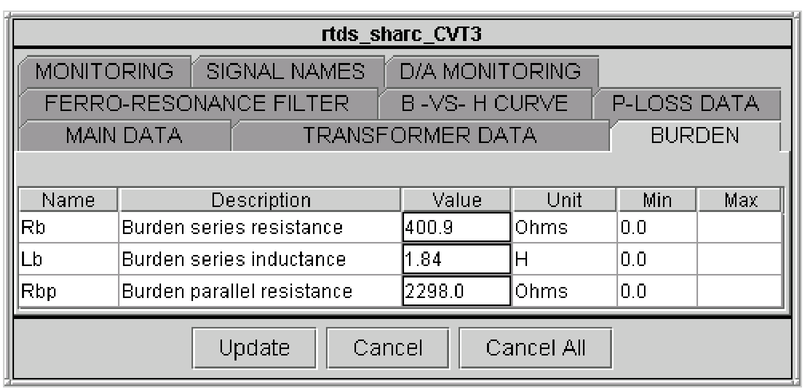
Np – Number of primary side turns on the intermediate potential transformer winding.

Rs – Intermediate potential transformer secondary side resistance is entered in Ω .

Ls – Intermediate potential transformer secondary side inductance is entered in H.

Ns – Number of secondary side turns on the intermediate potential transformer winding.

Burden Menu



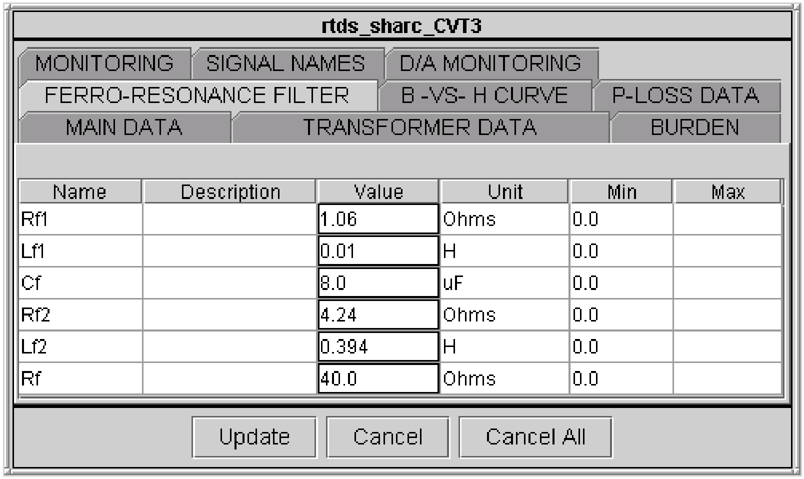
Name	Description	Value	Unit	Min	Max
Rb	Burden series resistance	400.9	Ohms	0.0	
Lb	Burden series inductance	1.84	H	0.0	
Rbp	Burden parallel resistance	2298.0	Ohms	0.0	

R_B – Burden series resistance is entered in Ω .

L_B – Burden series inductance is entered in H .

R_{BP} – Burden parallel resistance is entered in Ω .

Ferro−Resonance Filter Menu



R_{F1} – Filter branch resistance is entered in Ω .

L_{F1} – Filter branch inductance is entered in H .

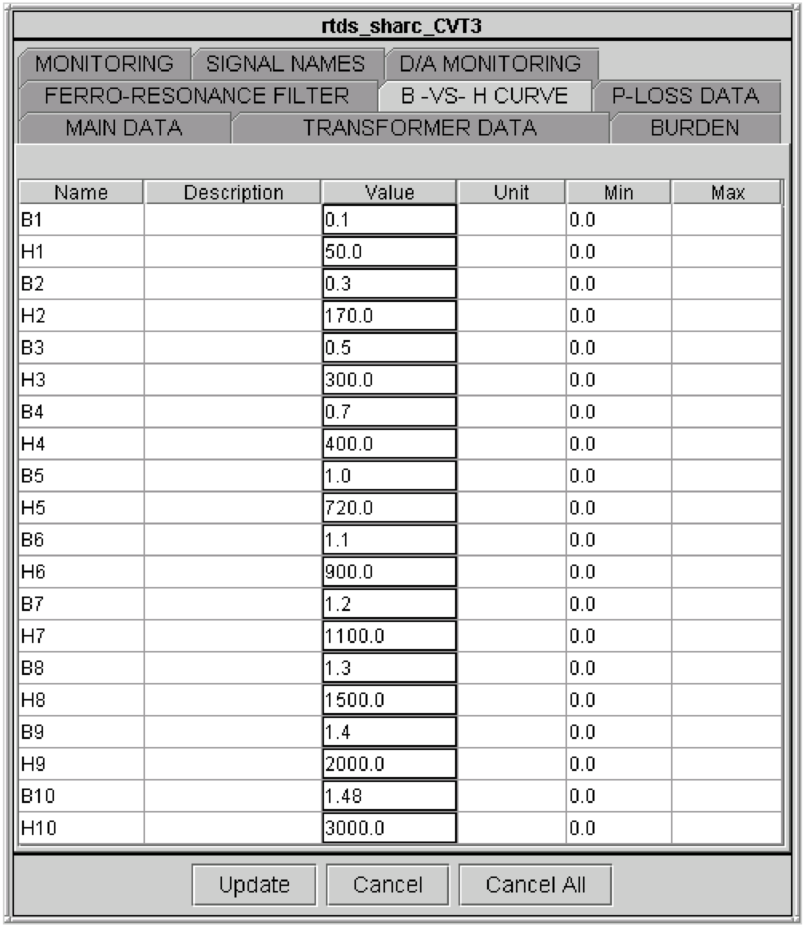
C_F – Filter branch capacitance is entered in μf.

R_{F2} – Filter branch resistance is entered in Ω .

L_{F2} – Filter branch inductance is entered in H .

R_F – Filter branch resistance is entered in Ω .

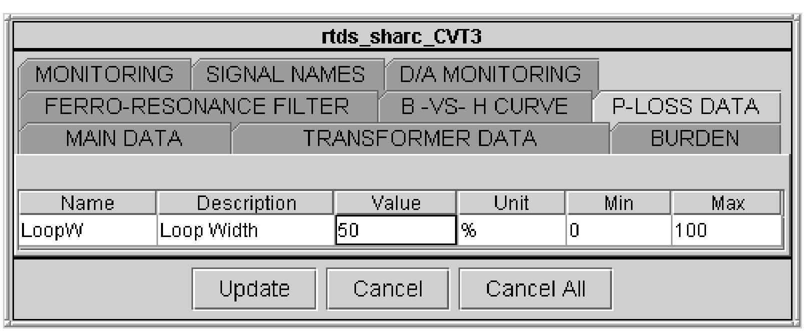
B vs H Characteristic Menu



Name	Description	Value	Unit	Min	Max
B1		0.1		0.0	
H1		50.0		0.0	
B2		0.3		0.0	
H2		170.0		0.0	
B3		0.5		0.0	
H3		300.0		0.0	
B4		0.7		0.0	
H4		400.0		0.0	
B5		1.0		0.0	
H5		720.0		0.0	
B6		1.1		0.0	
H6		900.0		0.0	
B7		1.2		0.0	
H7		1100.0		0.0	
B8		1.3		0.0	
H8		1500.0		0.0	
B9		1.4		0.0	
H9		2000.0		0.0	
B10		1.48		0.0	
H10		3000.0		0.0	

The saturation characteristic for the CVT's intermediate potential transformer is specified in terms of it's B−H (magnetic flux density vs magnetic field intensity) curve. B is entered in Tesla (T=Wb/m^2) and H is entered in Amps/m. The B−H curve representing any transformer core is primarily a function of the material used and represents data which is typically available. Ten pairs of points defining the B−H characteristic must be entered.

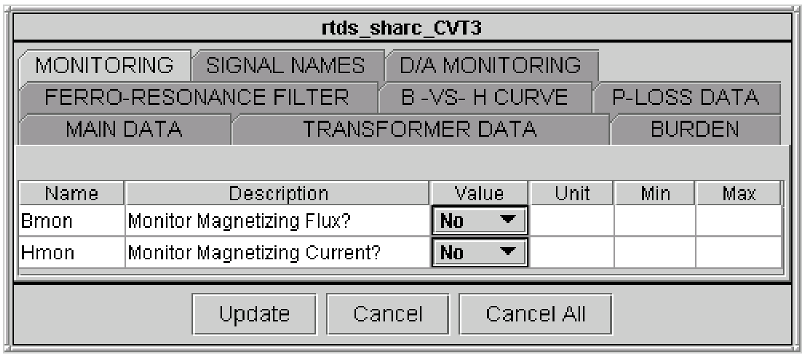
P−Loss Menu



Name	Description	Value	Unit	Min	Max
LoopW	Loop Width	50	%	0	100

As previously mentioned, core losses currently can only be approximated. For simplified or approximated loss representation the user must enter only the so−called loop width in percent (%). The % loop width is defined as a function of the knee point current from the single valued saturation characteristic.

Monitoring Menu



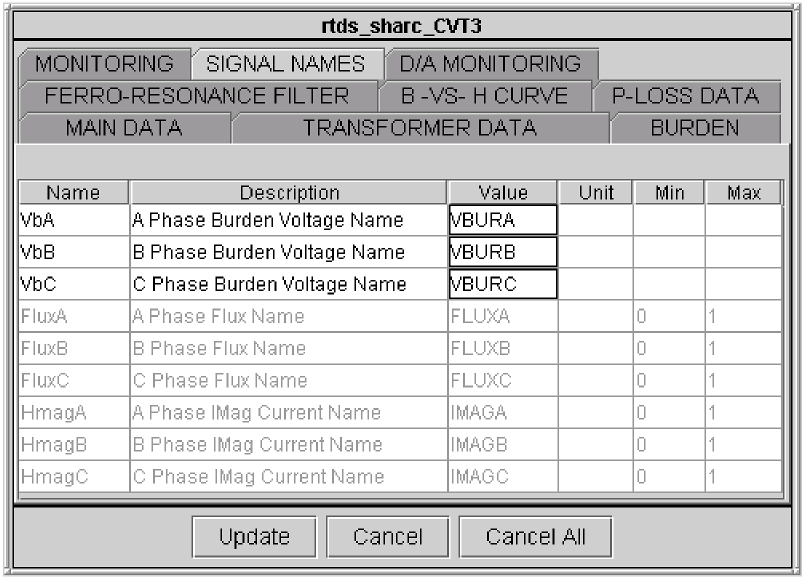
The Monitoring menu gives the user a choice as to which signals of the CVT component should be available for RunTime monitoring.

Since the Burden voltage is normally the quantity of interest in the CVT, it is always available for monitoring.

Bmon – The core flux of the CVT transformer may be monitired as either Flux (Wb) or B (Wb/m^2). Alternatively no monitoring can be selected. If monitoring is selected, signal names can be entered in the SIGNAL NAMES menu.

Hmon – The magnetizing current of the CVT transformer can be monitored as either Imag (Amps) or H (Amps/m). Alternatively no monitoring can be selected. If monitoring is selected, signal names can be entered in the SIGNAL NAMES menu.

Signal Names Menu

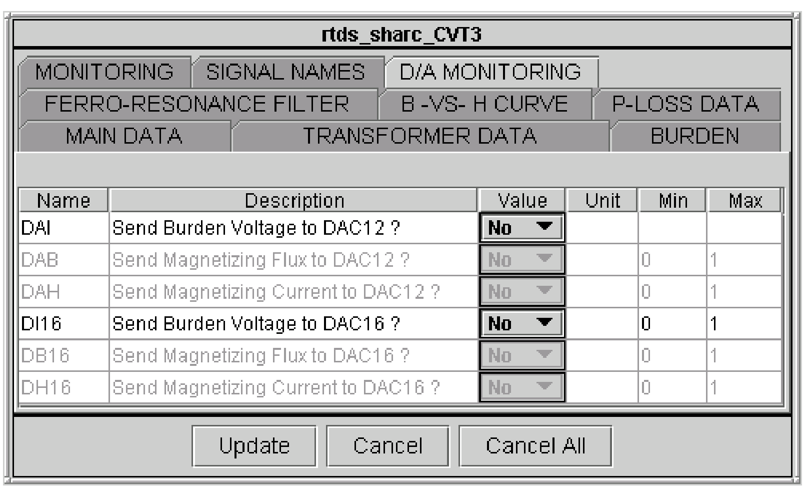


Vb* – Signals names for the burden voltage are required.

Flux* – If the flux of the CVT transformer is to be monitored, signal names for A,B and C phases are required. If Monitor Magnetizing Flux is set to “No” in the Monitoring menu, then these items will appear “greyed out”.

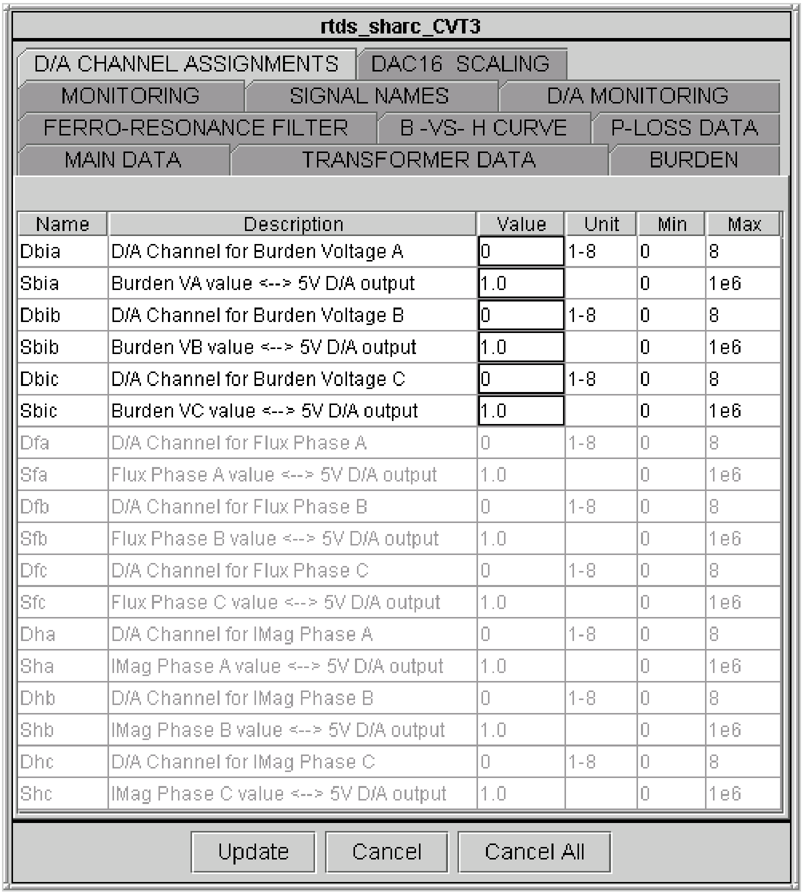
Hmag* – If the magnetizing current is to be monitored, signal names for A,B and C phases are required. If Monitor Magnetizing Current is set to “No” in the Monitoring menu, then these items will appear “greyed out”.

D/A Monitoring Menu



Monitored signals can be sent to the 12–bit D/A’s located on the front of the 3PC card. Signals can also be sent to an optional high precision 16–bit D/A card. Toggling YES in the appropriate menu will enable the selected signals to be sent to the selected destination, and will create a new menu tab: D/A Channel Assignments in the case of DAC12 monitoring, and DAC 16 Scaling in the case of DAC16 monitoring. Only one set of signals can be sent to the DAC16 at one time. The CVT component computations are performed on one processor. Each processor has one digital port available – the DAC16 cards requires the use of the digital port.

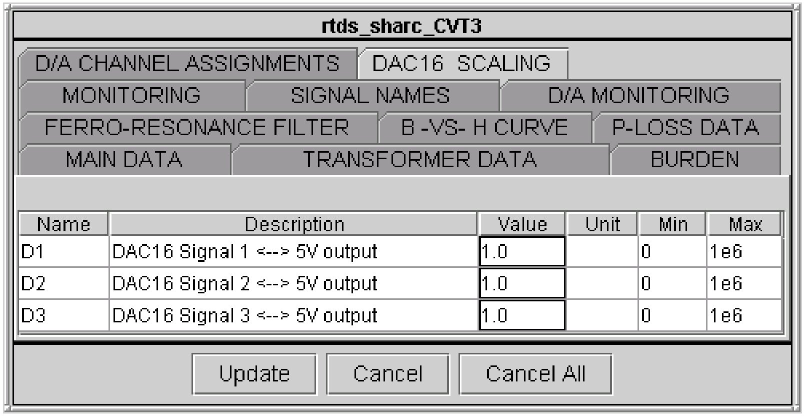
D/A Channel Assignments Menu



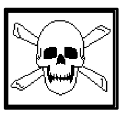
Name	Description	Value	Unit	Min	Max
Dbia	D/A Channel for Burden Voltage A	0	1-8	0	8
Sbia	Burden VA value <--> 5V D/A output	1.0		0	1e6
Dbib	D/A Channel for Burden Voltage B	0	1-8	0	8
Sbib	Burden VB value <--> 5V D/A output	1.0		0	1e6
Dbic	D/A Channel for Burden Voltage C	0	1-8	0	8
Sbic	Burden VC value <--> 5V D/A output	1.0		0	1e6
Dfa	D/A Channel for Flux Phase A	0	1-8	0	8
Sfa	Flux Phase A value <--> 5V D/A output	1.0		0	1e6
Dfb	D/A Channel for Flux Phase B	0	1-8	0	8
Sfb	Flux Phase B value <--> 5V D/A output	1.0		0	1e6
Dfc	D/A Channel for Flux Phase C	0	1-8	0	8
Sfc	Flux Phase C value <--> 5V D/A output	1.0		0	1e6
Dha	D/A Channel for IMag Phase A	0	1-8	0	8
Sha	IMag Phase A value <--> 5V D/A output	1.0		0	1e6
Dhb	D/A Channel for IMag Phase B	0	1-8	0	8
Shb	IMag Phase B value <--> 5V D/A output	1.0		0	1e6
Dhc	D/A Channel for IMag Phase C	0	1-8	0	8
Shc	IMag Phase C value <--> 5V D/A output	1.0		0	1e6

The D/A Channel Assignments menu tab will only appear if monitored signals are being sent to the DAC12. Eight D/A channels are available on the front of a 3PC card. Each signal can be assigned a D/A channel number 1–8. Entering a value of zero will cause the signal to be not to the D/A. Each D/A monitored signal must be given a unique D/A channel number. If more than one signal is assigned the same D/A channel number, an error message will be issued. Signal scaling parameters are also provided. The value entered will result in 5 volts being produced by the analogue output channel.

DAC16 Scaling Menu



The DAC16 Scaling menu tab will only appear if monitored signals are being sent to the DAC16 card.   Scale values to produce 5 volts out of the DAC16 card are required.



The MAP file should always consulted before connecting external equipment to the RTDS to avoid risk of equipment damage.

If the RTDS is interfaced to external equipment via the analogue channels, the user should ensure that the signals present on the D/A's do not unduly stress the external equipment. Particular caution should be exercised when the RTDS is interfaced via power amplifiers. Certain power system component models generate and display dc signals on the analogue output channels. These dc signals can range anywhere between the D/A output limits of +/– 10 volts. Inadvertently running a case which provides the wrong signal to the amplifiers may in turn cause damage to the amplifiers or any external equipment being supplied at their outputs.

It should be noted that whenever a simulation case is stopped, the output values of all analogue channels are forced to zero volts. Thus, if an unexpected or incorrect signal is being passed to the interfaced equipment, the case may be halted by pressing the STOP action box on the RSCAD/RunTime window. Such action will immediately zero the output of all analogue channels.

Always consult MAP file before making external connections to the RTDS !

7.2 CURRENT TRANSFORMERS (CT)   (rtds_sharc_CT2)

The other commonly used measurement transducer is the current transformer (CT). As in the case of the CVT, the CT is commonly used to transform a system quantity (in this case a current) to some lower level appropriate for a given application. A typical example is again in the area of protective relaying where the primary system current may be several hundreds or thousands of amperes, while the required relay input level would be only a few amperes (typically 5 Amps).

In the digitally simulated system running on the RTDS, any branch current can be directly monitored by the placement of a current monitoring icon in the circuit. D/A output scaling could then be used together with external voltage to current amplification hardware to achieve virtually any output level. Such an approach may be, and certainly is acceptable under some circumstances, however, situations do exist in which the transient behavior of a real CT must be included in the simulation.

An ideal current transformer, if one existed, would be able to accurately reproduce the primary system current in its secondary side circuit over any operating range. The current measurement method described in the preceeding paragraph represents such a situation. In a physical CT however, accurate duplication of the primary side current in the secondary side circuit would only occur within the linear operating region. When the CT operating point encroaches on the saturation knee point, significant measurement error is introduced.

Usually a CT is designed and dimensioned such that its normal operation is within the linear region of the flux−current plane, between the so−called ankle and knee points. Within this region, the core loss and magnetizing losses though variable, generally remain at values which do not appreciably effect the accuracy of the measurement device. However, under abnormal operating conditions, such as may exist when a fault occurs on the power system, currents may rise to many times their steady state levels hence causing the CT operating point to reach and exceed the saturation knee point. Figure 7.3 shows a typical flux (ϕ) current (I) characteristic with losses ignored in order to illustrate the sections or regions of operation.

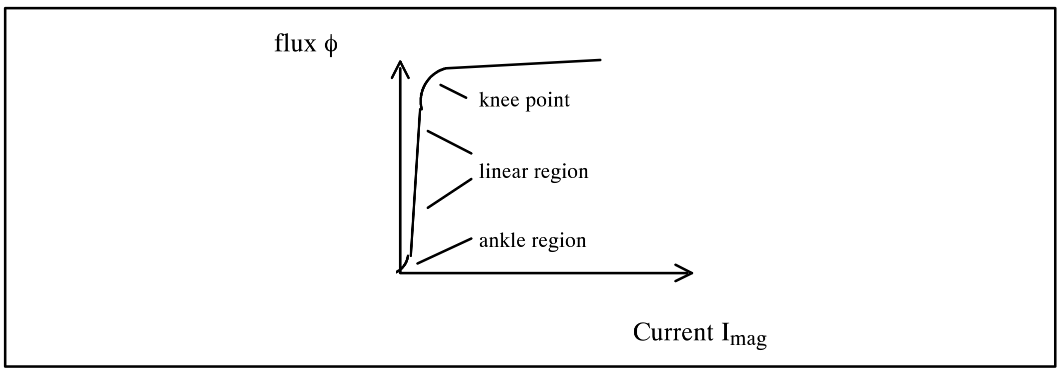


Figure 7.3 Typical CT Magnetizing Characteristic

CT's are normally designed to operate well below the saturation knee point to allow plenty of vertical movement (ie in the flux direction) in the event of high transient current conditions which may result when nearby faults occur. This type of design philosophy ensures a maximum range over which the CT can accurately reproduce primary system current conditions in its secondary circuit.

7.2.1 CT BASIC THEORY

The simplest and most widely used type of current transformer consists of a ring type core with secondary side turns toroidally wound around it The primary side consists of a single conductor passing through the centre of the ring. The flux path length and cross sectional area are then defined by the dimensions of the ring. The current transformation ratio is defined by the ratio of secondary to primary turns, where in this arrangement the number of primary turns is one. Figure 7.4 illustrates the general concept of this type of CT.

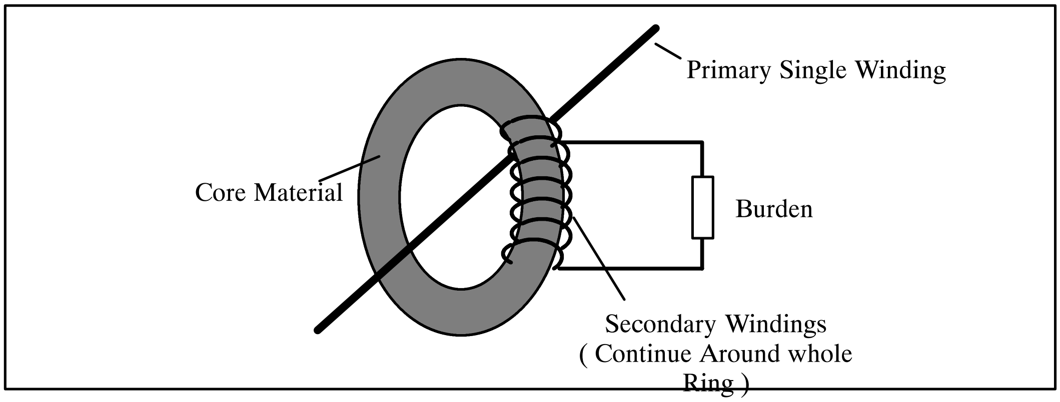


Figure 7.4 Physical CT Configuration

In general, the primary side resistance and inductance of the CT can be ignored hence resulting in the equivalent circuit representation shown in Figure 7.5.

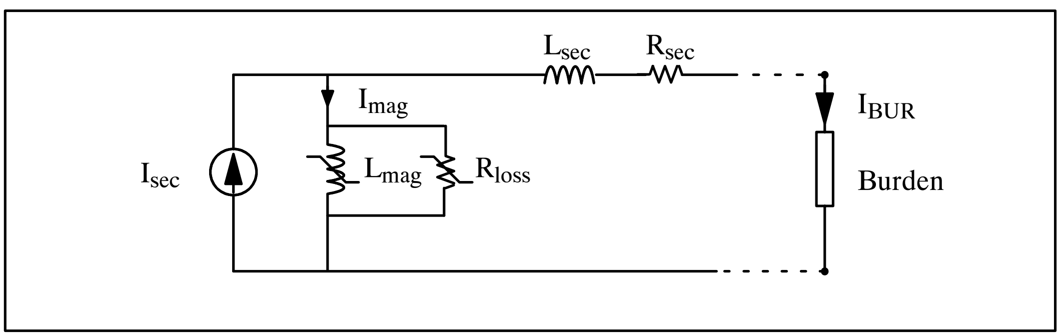


Figure 7.5 General CT Equivalent Circuit

In the equivalent circuit, the current injection represents the secondary side current as ;

$$I_{sec} = I_{prim} \; / \; N$$

where Iprim is the primary side, or line side current and N is the CT ratio.

The magnetizing branch (L_{mag} // R_{loss}) of Figure 7.5 will draw very little current as long as the CT is operated in the linear region of the flux−current characteristic.

Under such operating conditions, the secondary side current which is presented to the connected burden will be a good reproduction of the primary side current. As the operating point moves towards the saturation knee point level, the magnetizing branch begins to draw more current. The current which will now be available to flow through the burden will no longer be (I_{prim} / N), but will be this quantity minus the component that flows down the magnetizing branch. That is ;

$$I_{BUR} = I_{sec} - I_{mag}$$

The magnetizing branch shown in Figure 7.5 is composed of a non−linear reactor in parallel with a non−linear resistor. The reactor represents core saturation effects while the resistor is intended to represent core losses. Core loss is basically comprised of both hysteresis and eddy current loss components.

The model developed for the RTDS is based on the equivalent circuit shown in Figure 7.5 and includes both saturation and core loss effects.

7.2.2 CT EQUIVALENT CIRCUIT

From the RTDS standpoint, the CT is an auxiliary device which picks up currents from the simulated system, applies them to a modelled CT device and provides an output current signal which accurately represents that which would result in the actual power system. The output current (or burden current) and other internal quantities may be displayed on the RSCAD RunTime Operator's Console.

In its present form, the RTDS CT model represents a three phase unit. Each three phase CT requires one sharc processor to compute the required calculations. The CT model does not in any way contribute to, or effect the overall subsystem matrix representation or solution.

The nonlinear branches of the CT equivalent circuit (see Figure 7.5) are modelled using variable current sources. The magnetizing inductance branch and the core loss (resistance) branch are treated separately, resulting in two separate current injection components. Figure 7.6 illustrates the equivalent circuit based on the current source approach.

The CT core model is handled in exactly the same manner as that described for the intermediate potential transformer of the CVT. The single valued saturation characteristic is again represented by the dynamic solution of an integer power series equation as defined in Equation 7.5 below :

$$H(t) = B_1 * B(t) + B_2 * B^{35}(t) \qquad \text{Equation 7.5}$$

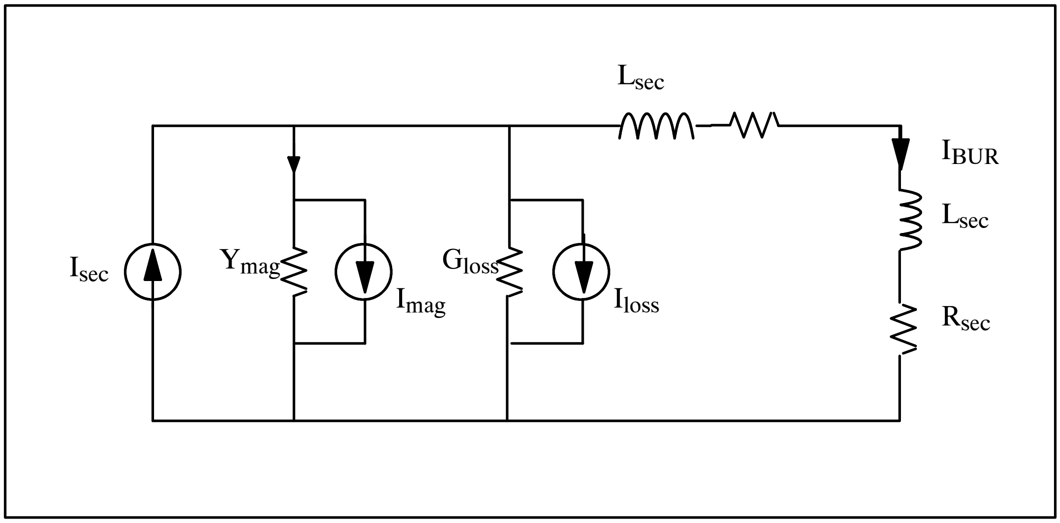


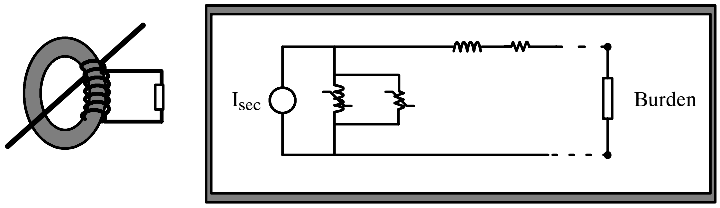
Figure 7.6 RTDS CT Equivalent Circuit

As in the case of the CVT, the user enters pairs of points from the B−H characteristic for the particular CT being represented by the model. A Least Square Error (LSE) curve fitting technique is then automatically applied to determine constants B_1 and B_2 of Equation 7.5.

Hysteresis and eddy current losses are lumped into a single component and collectively referred to as core loss. Similar to the CVT component, the core losses of the CT component can only be approximated. Using the approximation approach to modelling core losses, the user is required to enter a loop width. The loop width is defined as a percentage of the known 1 p.u. magnetizing current.

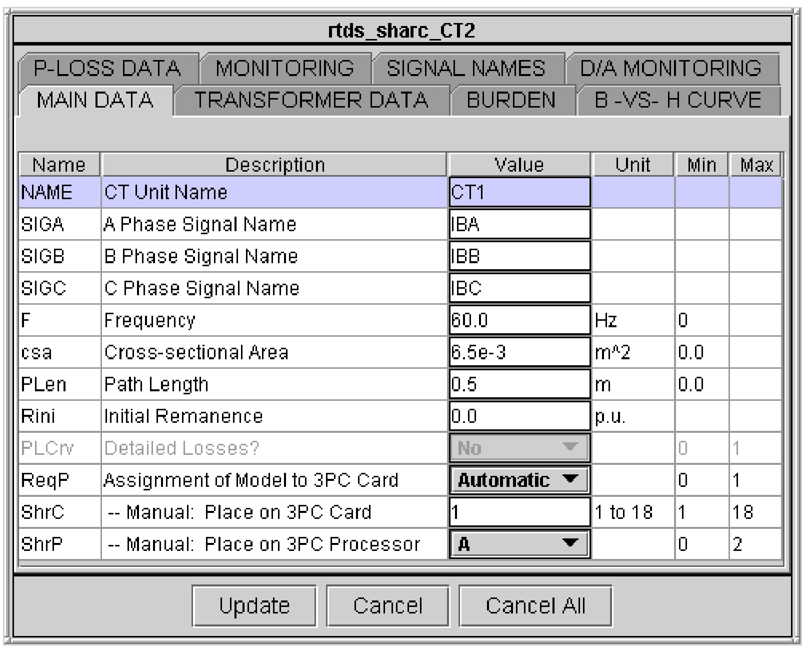
7.2.3 CT INPUT DATA

CT Model



The RTDS sharc library contains a CT model in which default values for a typical installation are already entered. If the user wishes, this default CT can be used without modification to input parameters. The default CT has a turns ratio of 100. The user may modify parameters as required to suit his or her particular application.

Main Data Menu



Name	Description	Value	Unit	Min	Max
NAME	CT Unit Name	CT1			
SIGA	A Phase Signal Name	IBA			
SIGB	B Phase Signal Name	IBB			
SIGC	C Phase Signal Name	IBC			
F	Frequency	60.0	Hz	0	
csa	Cross-sectional Area	6.5e-3	m^2	0.0	
PLen	Path Length	0.5	m	0.0	
Rini	Initial Remanence	0.0	p.u.		
PLCrv	Detailed Losses?	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

NAME – Each CT component must be given a unique name.

SIG* – The phase A,B and C signal names are required. The entered signal names must have the same name as assigned to a breaker or branch current. The CT component requires a current as input. If the entered signal names do not reference a branch or breaker current name, an error will be issued by the compiler.

F – The system base frequency in Hz.

csa – Cross−sectional area of the CT core. The area is entered in m^2.

PLen – The flux path length of the CT core is required in meters.

Rini – The initial remenant flux density is required in p.u. with a base of Bknee (saturation knee point). This gives the option of starting a simulation with an offset or non−zero core flux. PlCrv – This parameter has been disabled. Currently only approximated core losses may be modelled in the CT component.

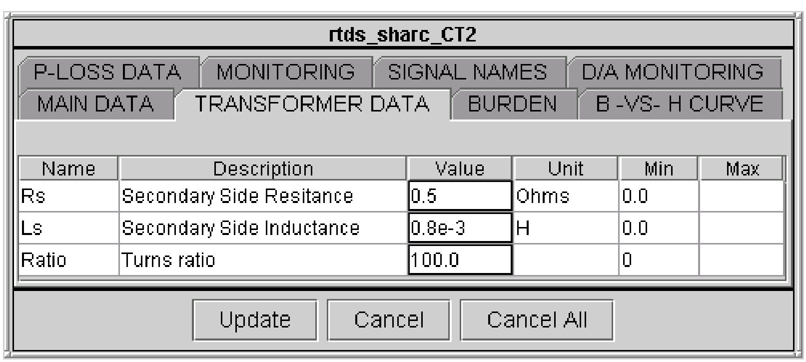
PlCrv – This parameter is disabled. Currently only approximated core losses may be modelled in the CT component.

ReqP – The CT model may be assigned to a sharc processor using Automatic mode or Manual mode. In Automatic mode, the processor assignment is performed by the compiler. In Manual mode, the processor assignment is specified by the user.

ShrC – In Manual mode, the 3PC card number that the CT model is to be assigned must be specified. This parameter refers to the 3PC card number and the card number of the RTDS rack. For example, if the CT component is to be assigned to 3PC card 1 processor A, this information would be entered into the corresponding menus. The 3PC board number entered is 1 even though the 3PC card is actually card 17 in the RTDS rack.

ShrP – In Manual mode, the processor that the CT model is to be assigned must be specified. The processor selected corresponds to the 3PC card number entered above.

Transformer Data Menu



rtds_sharc_CT2

P-LOSS DATA | MONITORING | SIGNAL NAMES | D/A MONITORING
MAIN DATA | TRANSFORMER DATA | BURDEN | B -VS- H CURVE

Name	Description	Value	Unit	Min	Max
Rs	Secondary Side Resitance	0.5	Ohms	0.0	
Ls	Secondary Side Inductance	0.8e-3	H	0.0	
Ratio	Turns ratio	100.0		0	

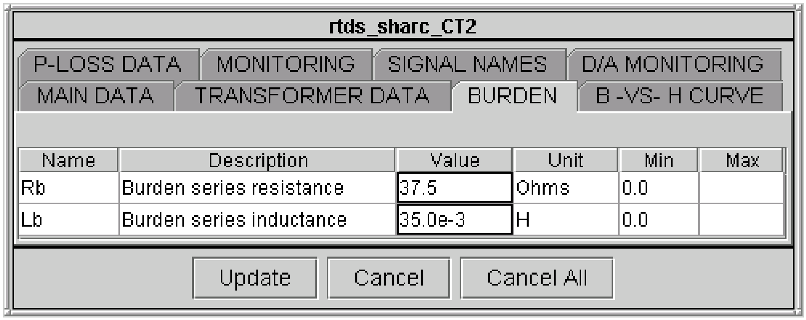
Update | Cancel | Cancel All

Rs – CT secondary side resistance is entered in Ω .

Ls – CT secondary side inductance is entered in H.

Ratio – CT ratio.

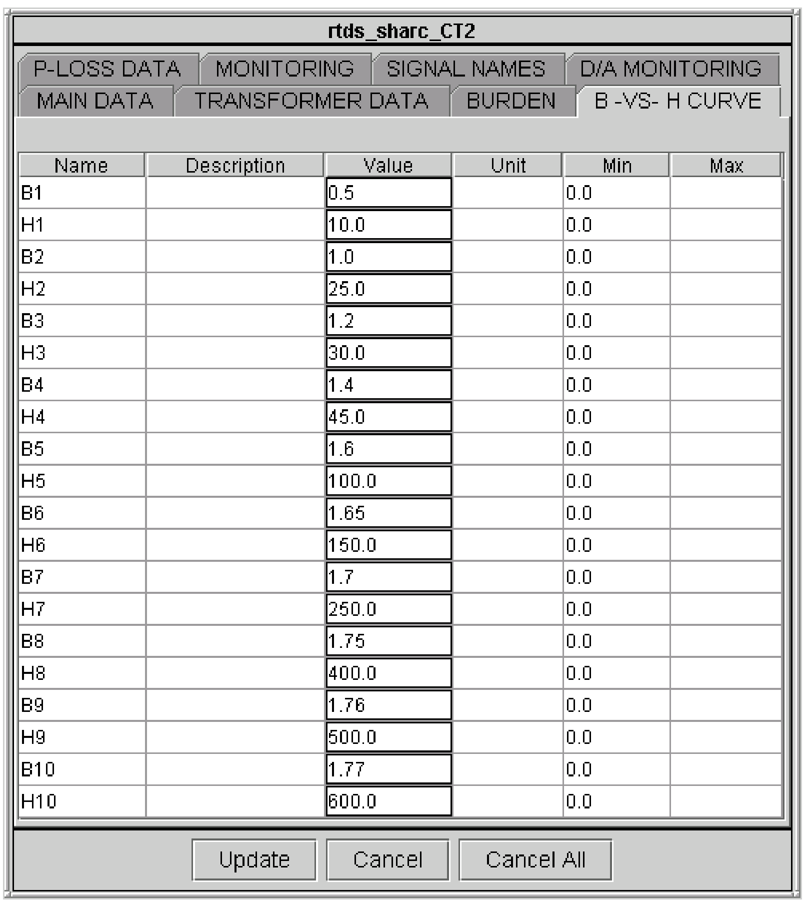
Burden Menu



R_B – Burden series resistance is entered in Ω .

L_B – Burden series inductance is entered in H .

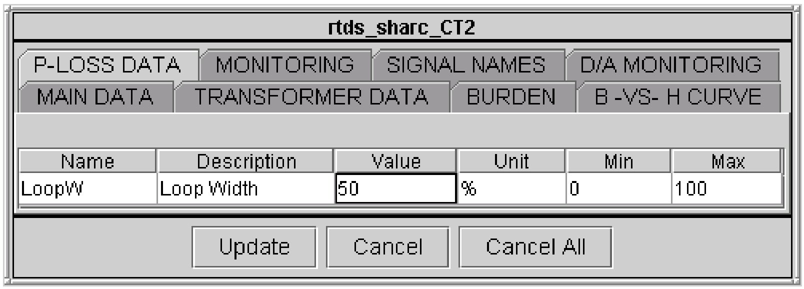
B vs H Characteristic Menu



The saturation characteristic for the CT is specified in terms of it's B–H (magnetic flux density vs magnetic field intensity) curve. B is entered in Tesla ($T=Wb/m^2$) and H is entered in (Amps.m). The B–H curve representing any transformer core is primarily a function of the material used and represents data which is typically available. Ten pairs of points defining the B−H characteristic must be entered.

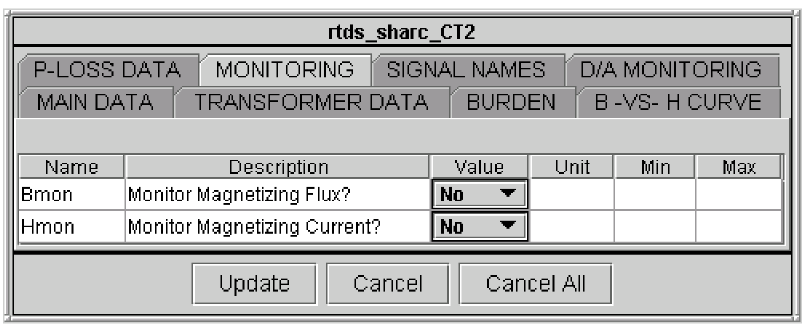
P−Loss Menu

As already mentioned, core losses currently can only be approximated.



For simplified or approximated loss representation the so−called loop width in percent (%) must be entered. The % loop width is defined as a function of the knee point current from the single valued saturation characteristic.

Monitoring Menu

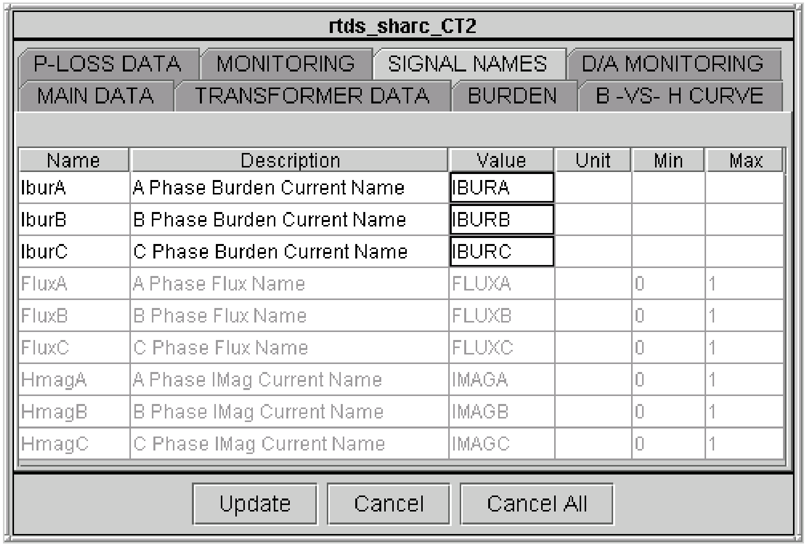


Since the burden current is normally the quantity of interest in the CT, it is always available for monitoring.

Bmon − The core flux of the CT may be monitored as either PHI(Wb) or B (Wb/ m^2). Alternatively no monitoring can be selected. If monitoring is selected, signal names can be entered in the SIGNAL NAMES menu.

Hmon − The magnetizing current of the CT can be monitored as either Imag(Amps) or H(Amps/m). Alternatively no monitoring can be selected. If monitoring is selected, signal names can be entered in the SIGNAL NAMES menu.

Signal Names Menu



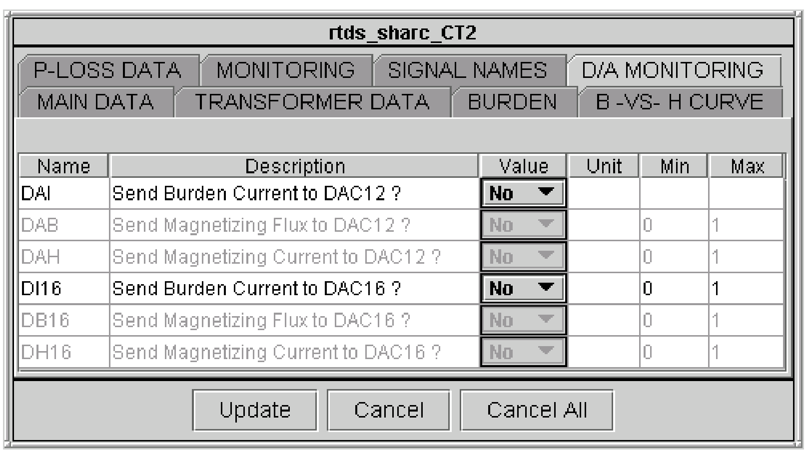
Name	Description	Value	Unit	Min	Max
IburA	A Phase Burden Current Name	IBURA			
IburB	B Phase Burden Current Name	IBURB			
IburC	C Phase Burden Current Name	IBURC			
FluxA	A Phase Flux Name	FLUXA		0	1
FluxB	B Phase Flux Name	FLUXB		0	1
FluxC	C Phase Flux Name	FLUXC		0	1
HmagA	A Phase IMag Current Name	IMAGA		0	1
HmagB	B Phase IMag Current Name	IMAGB		0	1
HmagC	C Phase IMag Current Name	IMAGC		0	1

Ibur* – Signal names for the burden currents are required.

Flux* – If the flux of the CT is to be monitored, signal names for A,B and C phases are required.

Hmag* – If the magnetizing current is to be monitored, signal names for A,B and C phases are required.

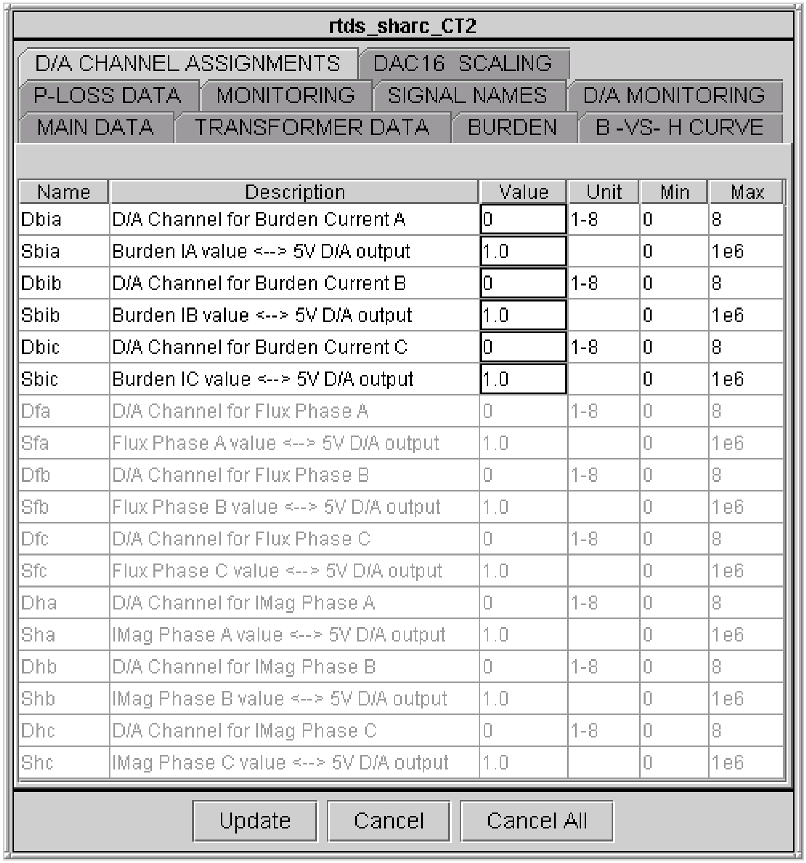
D/A Monitoring Menu



Name	Description	Value	Unit	Min	Max
DAI	Send Burden Current to DAC12 ?	No			
DAB	Send Magnetizing Flux to DAC12 ?	No		0	1
DAH	Send Magnetizing Current to DAC12 ?	No		0	1
DI16	Send Burden Current to DAC16 ?	No		0	1
DB16	Send Magnetizing Flux to DAC16 ?	No		0	1
DH16	Send Magnetizing Current to DAC16 ?	No		0	1

Monitored signals can be sent to the 12–bit D/A's located on the front of the 3PC card. Signals can also be sent to an optional high precision 16–bit D/A card. Toggling YES in the appropriate menu will enable the selected signals to be sent to the selected destination and will create a new menu tab: D/A Channel Assignments in the case of DAC12 monitoring, and DAC 16 Scaling in the case of DAC16 monitoring. Only one set of signals can be sent to the DAC16 at one time. The CT component computations are performed on one processor. Each processor has one digital port available, the DAC16 card requires the use of the digital port.

D/A Channel Assignments Menu


rtds_sharc_CT2

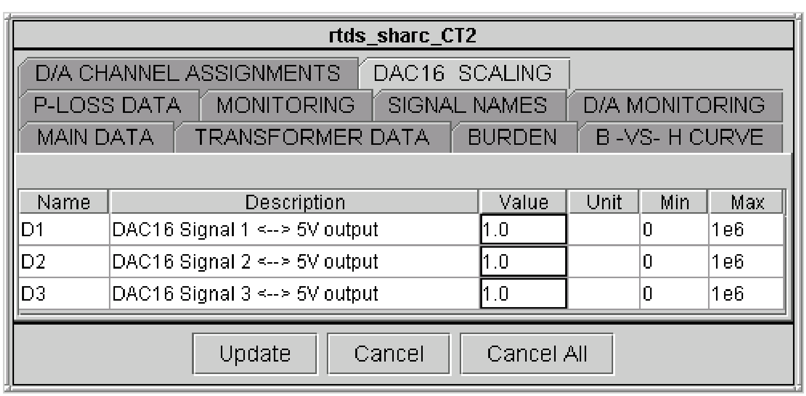
D/A CHANNEL ASSIGNMENTS | DAC16 SCALING
P-LOSS DATA | MONITORING | SIGNAL NAMES | D/A MONITORING
MAIN DATA | TRANSFORMER DATA | BURDEN | B -VS- H CURVE

Name	Description	Value	Unit	Min	Max
Dbia	D/A Channel for Burden Current A	0	1-8	0	8
Sbia	Burden IA value <--> 5V D/A output	1.0		0	1e6
Dbib	D/A Channel for Burden Current B	0	1-8	0	8
Sbib	Burden IB value <--> 5V D/A output	1.0		0	1e6
Dbic	D/A Channel for Burden Current C	0	1-8	0	8
Sbic	Burden IC value <--> 5V D/A output	1.0		0	1e6
Dfa	D/A Channel for Flux Phase A	0	1-8	0	8
Sfa	Flux Phase A value <--> 5V D/A output	1.0		0	1e6
Dfb	D/A Channel for Flux Phase B	0	1-8	0	8
Sfb	Flux Phase B value <--> 5V D/A output	1.0		0	1e6
Dfc	D/A Channel for Flux Phase C	0	1-8	0	8
Sfc	Flux Phase C value <--> 5V D/A output	1.0		0	1e6
Dha	D/A Channel for IMag Phase A	0	1-8	0	8
Sha	IMag Phase A value <--> 5V D/A output	1.0		0	1e6
Dhb	D/A Channel for IMag Phase B	0	1-8	0	8
Shb	IMag Phase B value <--> 5V D/A output	1.0		0	1e6
Dhc	D/A Channel for IMag Phase C	0	1-8	0	8
Shc	IMag Phase C value <--> 5V D/A output	1.0		0	1e6

Update | Cancel | Cancel All

Eight D/A channels are available of the front of a 3PC card. Each signal can be assigned a D/A channel number 1–8. Entering a value of zero will cause the signal not to be sent to the D/A. Each D/A monitored signal must be given a unique D/A channel number. If more than one signal is assigned the same D/A channel number, an error message will be issued. Signal scaling parameters are also provided. The value entered will result in 5 volts being produced by the analogue output channel.

DAC16 Scaling Menu

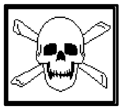

rtds_sharc_CT2

D/A CHANNEL ASSIGNMENTS | DAC16 SCALING
P-LOSS DATA | MONITORING | SIGNAL NAMES | D/A MONITORING
MAIN DATA | TRANSFORMER DATA | BURDEN | B -VS- H CURVE

Name	Description	Value	Unit	Min	Max
D1	DAC16 Signal 1 <--> 5V output	1.0		0	1e6
D2	DAC16 Signal 2 <--> 5V output	1.0		0	1e6
D3	DAC16 Signal 3 <--> 5V output	1.0		0	1e6

Update | Cancel | Cancel All

The DAC16 Scaling menu item will only appear if monitored signals are being sent to the DAC16 card. Scale values to produce 5 volts out of the DAC16 card are required.



The MAP file should always be consulted before connecting external equipment to the RTDS to avoid risk of equipment damage.

If the RTDS is interfaced to external equipment via the analogue channels, the user should ensure that the signals present on the D/A's do not unduly stress the external equipment. Particular caution should be exercised when the RTDS is interfaced via power amplifiers. Certain power system component models generate and display dc signals on the analogue output channels. These dc signals can range anywhere between the D/A output limits of +/− 10 volts. Inadvertently running a case which provides the wrong signal to the amplifiers may in turn cause damage to the amplifiers or any external equipment being supplied at their outputs.

It should be noted that whenever a simulation case is stopped, the output values of all analogue channels are forced to zero volts. Thus, if an unexpected or incorrect signal is being passed to the interfaced equipment, the case may be halted by pressing the STOP icon on the RSCAD/RunTime window. Such action will immediately zero the output of all analogue channels.

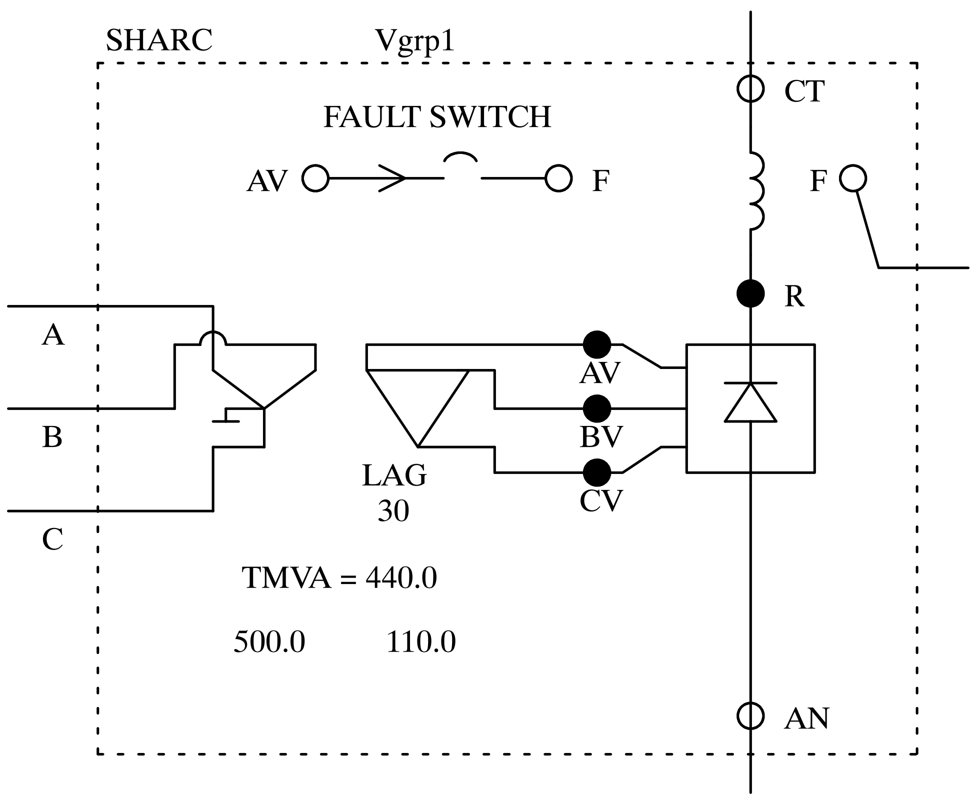
Always consult MAP file before making external connections to the RTDS !

8 SIX–PULSE HVDC VALVE GROUP

This chapter discusses the model represented by the icon: rtds_sharc_VGP6V4.

8.1 INTRODUCTION

The Six–Pulse Valve Group model has been developed for use with the Sharc Network Solution (reference Chapter 2) and with the RPC network solution. The model implements the improved firing accuracy algorithm first introduced with the rtds_sharc_vgrp6 model. The new model continues to support a broad range of valve faults, both between internal nodes and also to external nodes.



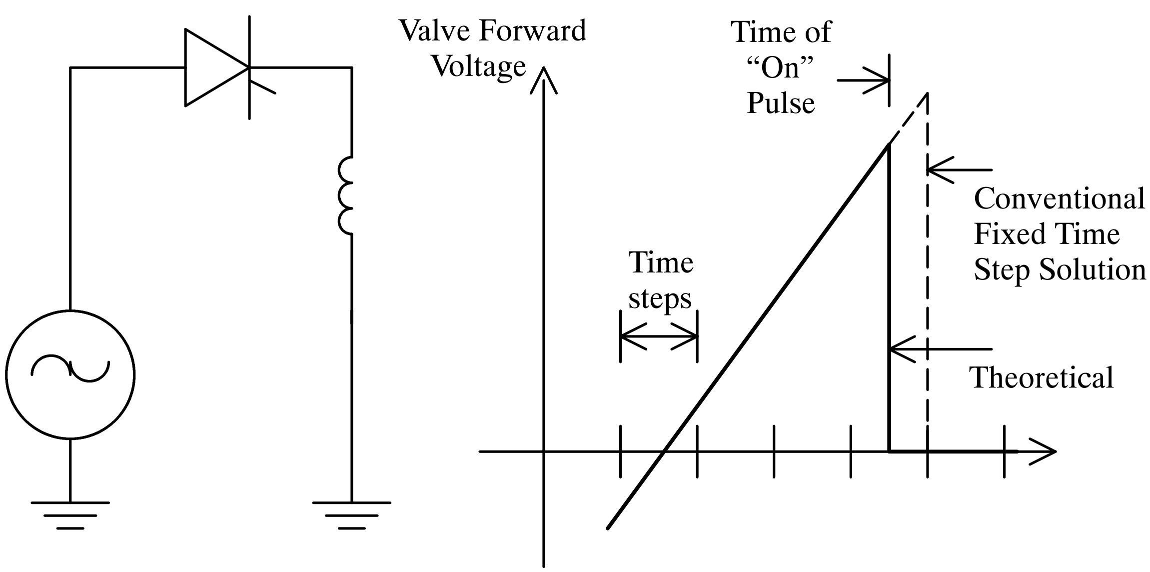
One Sharc processor is required for the Six–Pulse Valve Group model when transformer saturation is not enabled.

The Sharc Valve Group model has several features:

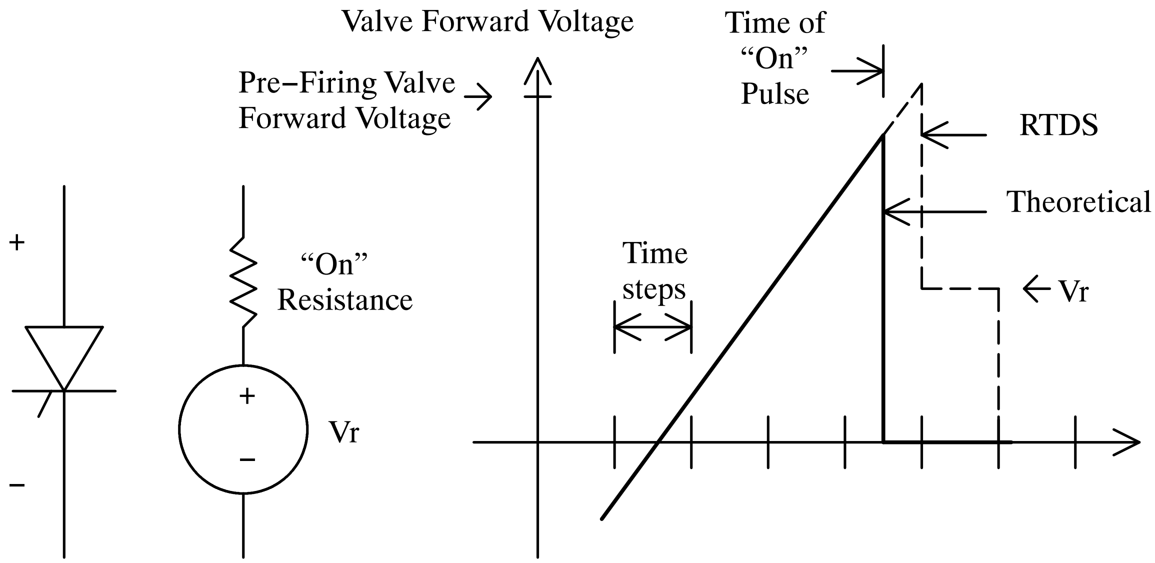
1. The valves have been implemented in the Valve Group model to provide improved firing accuracy. The signals required by the Valve Group model in support of improved firing can come either from the Digital Input Time Stamp (DITS) card when external HVDC controls are used, or from a control system modeled in the RTDS Controls Compiler.

   The DITS card samples a 6−bit firing−pulse word from external HVDC controls every 60 nanoseconds in each time−step. Based on this sampling rate, the DITS card generates information for the Valve Group model as to the exact time of arrival of firing pulses in the time−step. This information is used by the valves to correct for late sampling of firing pulses. In general, the use of the DITS card is described in more detail in the TCSC Chapter 11. However, the DITS card can now be connected directly to the digital I/O port of the valve group processor for model rtds_sharc_VGP6V4.

   As illustrated in the following diagram, the voltage on a valve in a conventional valve group model can be made to collapse at the end of a time−step by changing the representation of the Valve from a high resistance value to a low resistance value.



   In the Sharc Valve Group model, the voltage on the valve is made to collapse in a controlled manner by including a voltage source (Vr) in series with the “On” resistance during the first time−step of “On” conduction as illustrated in the figure below.



The voltage source Vr during the first time–step of conduction is selected as "fraction" times "Pre–Firing Valve Forward Voltage". "Fraction" is the fractional position into the previous time–step where the firing pulse change was recorded. The voltage source is set to zero in subsequent time–steps.

The error in firing of a valve <u>without improved firing</u> is inconsistent between 0 and 1 time–steps and there is no continuous response to small changes in firing angle.

The error in firing of a valve <u>with improved firing</u> is consistently about 1 time–step and there is continuous response to small changes in firing angle. This consistent 1 time–step error is an improvement because most control systems are not seriously degraded by small fixed delays such as that introduced by bus voltage transducers. In addition, the continuous response to changes in firing delay angle makes the model much more suitable for such applications as SSR (sub–synchronous resonance) studies.

<u>With or without improved firing</u>, the use of the trapezoidal integration method in the Dommel algorithm introduces an additional 0.5 time–step delay in the effective collapse of the valve voltage. This delay occurs even if a firing pulse arrives exactly at the beginning of a time–step. In that case, the 0.5 time–step delay occurs because the commutating inductance is affected in the next time–step by the average of the pre–firing voltage on the inductance (zero kV) and the voltage on the inductance at the end of the time–step (V line–to–line).

If the firing pulse input from external physical controls is brought from a DITS (Digital Input Time Stamp) card through a controls processor and passed on the backplane to the valve group model, then an additional 0.5 time−steps of delay can be expected associated with the communication time. This additional 0.5 time−step delay does not occur if firing pulse information is generated internally in the RTDS using the Controls Compiler firing pulse generation block: rtds_sharc_ctl_FPGEN. Also, this delay can be eliminated when using the rtds_sharc_VGP6V4 valve group model by connection of the DITS card directly to the digital I/O port of the valve group processor rather than to the digital I/O of a CC controls processor.

Consequently, when firing pulses are generated by an internal RTDS controls block, (example: rtds_sharc_ctl_FPGEN), it is appropriate to increase the angle provided to the firing pulse generation block from the Phase Phase Locked loop block (example: rtds_sharc_PLLT2) by an angle corresponding to approximately 1.5 time−steps at fundamental frequency. Alternatively, in order to cause the correct firing angle to occur effectively in the simulation, the firing delay angle order provided to the firing pulse generator could be temporarily reduced by an angle which corresponds to 1.5 time−steps at fundamental frequency.

In the case where firing pulses are generated by external physical controls and the firing pulse information created by the DITS card is connected to the digital I/O port of valve group processor, then the net delay due to all factors is approximately 1.5 time−steps: 0.5 time−steps due to trapezoidal integration; and 1.0 time−step of consistent delay due to the improved firing algorithm. Consequently, in order to cause the correct firing angle to occur effectively in the simulation, either the output angle of the phase locked oscillator in the external controls can be temporarily increased by an angle corresponding to 1.5 time−steps at fundamental frequency, or the firing delay angle in the external controls can be temporarily decreased by an angle which corresponds to 1.5 time−steps at fundamental frequency.

To provide commutating bus voltages to external controls, the DDAC or FDAC cards (discussed in the Hardware Manual) can be used respectively with the rtds_sharc_DAOVR2 or rtds_sharc_FDACOVR2 icons (discussed in the Interfacing Manual). In each case, the STEPSADV slider in RunTime should be set to 1.0 in order to avoid effective delay in providing commutating bus voltages to the external controls.

2. There is no interface between the Valve Group and the Sharc Network. The Valve Group and the Network are solved as one seamless Dommel trapezoidal network solution.

   The technique used to solve the Valve Groups as additional embedded networks is similar to that described in Chapter 2 on the Sharc Network Solution. The use of the embedded network concept can easily be explained by reference to the following figure:

$$\begin{bmatrix} G \end{bmatrix}\begin{bmatrix} V \end{bmatrix} = \begin{bmatrix} I \end{bmatrix} \Rightarrow \left[\begin{array}{c|c} A & B \\ \hline C & D \end{array}\right]\begin{bmatrix} V1 \\ \hline V2 \end{bmatrix} = \begin{bmatrix} I1 \\ \hline I2 \end{bmatrix}$$

$$A\,V1 + B\,V2 = I1 \qquad \text{Eqn 1}$$

$$C\,V1 + D\,V2 = I2 \qquad \text{Eqn 2}$$

$$V1 = A^{-1}\left(I1 - BV2 \right) \qquad \text{Eqn 3}$$

$$\left(D - CA^{-1}B \right) V2 = \left(I2 - CA^{-1}\, I1 \right) \qquad \text{Eqn 4}$$

The Dommel algorithm requires the solution of the basic equation [G] [V] = [I] for the node voltage vector [V]. The G matrix can be partitioned into portions for one or more embedded sets of nodes (such as A) and a portion for connector nodes (D). A few simple matrix operations yield the equations which must be solved for handling the embedded networks.

Eqn. 3, which defines V1, can be produced from Eqn. 1 by a simple inversion and some re−arrangement. Eqn. 3 can then be substituted into Eqn. 2 to produce Eqn. 4 after some additional re−arrangement.

Note that the dimension of the left−hand matrix in Eqn. 4 is reduced to the dimension of V2, the number of connector nodes. This reduction in dimension makes it practical to apply LU decomposition to the matrix in Eqn. 4 in each time−step in order to solve for the voltage vector V2. Subsequently, V2 can be substituted back into Eqn. 3 to solve for the voltage vector V1.

Of course, the matrix products within Eqns. 3 and 4 (e.g. $CA^{-1}B$) can be pre–calculated before a simulation for each combination of switch states in the embedded Valve Group.

This rigorous solution of the overall [G] [V] = [I] equation allows for the elimination of any interface. The removal of the interface will produce slightly improved representation of harmonic impedances looking into the valve group.

The removal of the interface also allows both internal valve faults and faults from internal nodes to external Sharc Network Connector nodes and ground.

3. The transformer model allows the User to separately specify the positive–sequence and zero–sequence resistance and inductance of the transformer. The transformer may also be replaced by series inductances with resistance between the AC bus terminal and the AC valve nodes.

4. The Valve Group model produces it's own signal for Measured Gamma. The noise in the Gamma signal due to time–step effects is very low because the reversal of current in the valve and subsequent application of forward voltage are both located with precision by interpolation. The Gamma signal is available for use in RTDS based HVDC control systems or as a D/A output.

5. The User can choose from among 24 possible signals for D/A and RunTime monitoring. Of course, discretion should be applied in selecting only those signals which are required in order to keep the communication load on the backplane at a minimum and thus to keep the time–step from growing needlessly.

6. Each 3PC Network solution (see Chapter 2) can accommodate a maximum of 4 embedded valve groups. Similarly, each RPC network solution can accommodate 12 embedded valve groups. When using the valve group with the 3PC Network Solution, the embedded Valve Groups must connect to Connector type nodes or to ground. This latter requirement has been eliminated when using the RPC network solution in which all nodes are effectively connector nodes.

7. A Valve Group can optionally include a dc reactor with specifiable resistance as shown on page –8.1– of this Chapter. A back–to–back link with no reactor can be created by connecting four Sharc Valve

Groups without reactors in series.

Several other features are described in the detailed explanations which follow.

8.2 USE OF THE VALVE GROUP MODEL WITH THE SHARC NETWORK SOLUTION

The valve group model must be used with the 3PC Network Solution discussed in Chapter 2 or with the RPC network solution. In addition to the network solution, two 3PC cards in an a RTDS rack are required to model the valve groups in a 12−pulse back−to−back HVDC link. If the 3PC network solution is to be used then two 3PC cards must be connected together to create a DUAL 3PC unit.

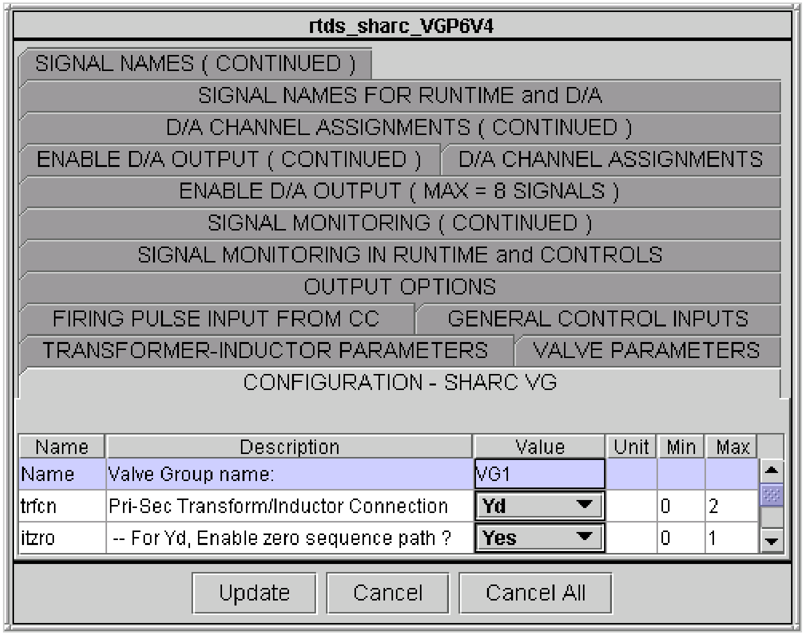
At present, the transformer saturation model is “rtds_sharc_SA−SAT” (see Chapter 4).

It is possible to use the valve group model with external HVDC controls, with or without a DITS card. However, firing accuracy will be degraded if the DITS card is not used.

The Valve Group model must be attached to Connector type nodes in the Sharc Network Solution or to ground nodes. An ERROR message will be issued if this rule is not followed. The RPC network solution does not impose this requirement.

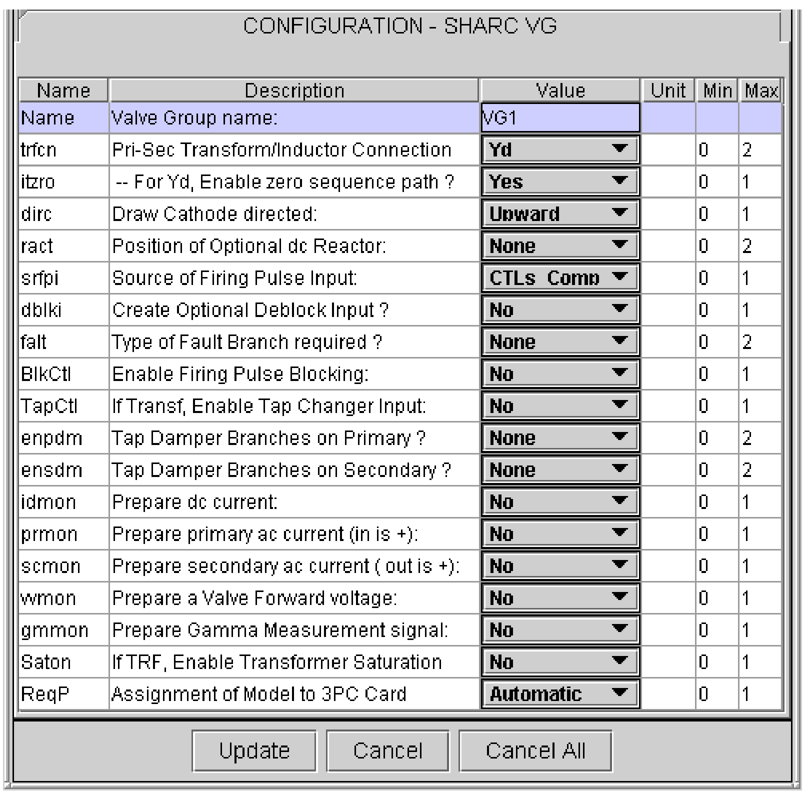
8.3 PARAMETER ENTRY FOR THE VALVE GROUP MODEL

Due to the large number of menu tabs for the rtds_sharc_VGP6V4 valve group model, the menu tabs will not be displayed in the menus throughout this chapter. The complete set of menu tabs available by default, as well as the partial CONFIGURATION menu appear below:



The various menus are described in the following sections.

8.4 THE CONFIGURATION MENU



Name	Description	Value	Unit	Min	Max
Name	Valve Group name:	VG1			
trfcn	Pri-Sec Transform/Inductor Connection	Yd		0	2
itzro	-- For Yd, Enable zero sequence path ?	Yes		0	1
dirc	Draw Cathode directed:	Upward		0	1
ract	Position of Optional dc Reactor:	None		0	2
srfpi	Source of Firing Pulse Input:	CTLs Comp		0	1
dblki	Create Optional Deblock Input ?	No		0	1
falt	Type of Fault Branch required ?	None		0	2
BlkCtl	Enable Firing Pulse Blocking:	No		0	1
TapCtl	If Transf, Enable Tap Changer Input:	No		0	1
enpdm	Tap Damper Branches on Primary ?	None		0	2
ensdm	Tap Damper Branches on Secondary ?	None		0	2
idmon	Prepare dc current:	No		0	1
prmon	Prepare primary ac current (in is +):	No		0	1
scmon	Prepare secondary ac current (out is +):	No		0	1
vvmon	Prepare a Valve Forward voltage:	No		0	1
gmmon	Prepare Gamma Measurement signal:	No		0	1
Saton	If TRF, Enable Transformer Saturation	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1

The CONFIGURATION menu is shown above. The CONFIGURATION menu prompts for a name (Name) for the Valve Group being modeled. This name appears on the icon after being specified.

According to the "trfcn" item in the CONFIGURATION menu, the valves can be connected to the ac system through a transformer (either wye−wye or wye−delta) or through inductors. When a transformer is chosen, as opposed to inductors, the transformer is always connected in wye on the primary.

The "itzro" item allows the Y neutral point to be connected to ground so as to provide a zero sequence path in the wye−delta (Yd) connected transformer. The valve−side connection of the transformer is specified by selecting the wye (Yy) or delta (Yd) response to the "trfcn" menu item. The lag in degrees for the connection is requested in the TRANSFORMER−INDUCTOR PARAMETERS menu.

The direction (dirc) of the valve group in the icon, must be selected as either Upward or Downward. The Upward side of the Icon is closest to the AV node shown in the Valve Group icon. The Downward side of the Icon is closest to the CV node shown in the Valve Group icon.

The menu requests the specification of whether there is a DC reactor to be modeled in the Valve Group (ract) or not, and whether it is located at the Top of the icon (by node AV) or at the Bottom of the icon (by node CV). When a DC reactor is requested, a node "R" appears on the Valve Group icon between the valves and the reactor, and a REACTOR PARAMETERS menu tab is added.

The rtds_sharc_VGP6V4 valve group can receive firing pulse information as specified by the "srfpi" menu item from the controls compiler (CTLs_Comp) or directly from a DITS card (Local_DITS) connected to the digital I/O port on the back of the valve group processor. When "CTLs_Comp" is selected, then a "FIRING PULSE INPUT FROM CC" menu tab is available for specifying the names of firing pulse input. When "Local_DITS" is selected, then a "FIRING PULSE INPUT FROM LOCAL DITS" menu tab appears for specifying the input from the DITS and for monitoring firing pulse input.

The item "dblki" allows the User to request that a valve group deblocking signal should be included in the general inputs for the model. The input signal must be named in the GENERAL CONTROL INPUTS menu.

The type of fault branch that should be included in the model (falt) is then requested. This can be "None", "Internal" or "External". An "Internal" fault branch can be located between two (2) nodes in the set A, B, C, AV, BV, CV, CT, AN and R, shown on the Valve Group icon. An External fault branch can be connected between one of the foregoing nodes and an external node connection, "F" which appears when an "External" fault branch is requested. The resulting external connection point shown in the icon must be connected to a Connector type node or a Ground node when using the 3PC Network Solution. In an RPC Network Solution the external fault connection point can be connected to any node. The actual fault nodes and the fault impedances are specified in the FAULT BRANCH CONNECTION menu which becomes available when a fault branch is requested.

The Valve Group model allows specified firing pulses to be blocked for a specified period of time in response to a signal from the Controls Compiler. The parameter “BlkCtl” allows the User to enable this feature. When firing pulse blocking is enabled, a FIRING PULSE BLOCKING menu tab appears.

The Valve Group model allows for a tap changer “TapCtl” to be included within the Valve Group transformer. When this feature is enabled, a per unit tap factor (0.6 to 1.4) must be provided from the Controls Compiler into the model. The input signal must be named in the GENERAL CONTROL INPUTS menu.

The valve group is solved as an embedded part of the main Dommel network. Consequently, there is no interface between the network and the valve group. However, when the tap changer function is requested, then a supplementary series voltage source and shunt current source are used to implement an effective change of turns ratio for the transformer. The presence of these supplementary sources is similar in some aspects to an interfaced model which depends completely on interfacing sources. However, when working at nominal tap these sources have zero output.

The optional presence of the tap changer supplementary sources makes it prudent to provide interface stabilizing methods within the model. The CONFIGURATION menu allows the user to request Y−connected damper branches on the primary side of the transformer and delta−connected damper branches on the secondary side. The damper branches on each side consist of a resistive branch in parallel with an RC series branch.

When the User specifies “Default” in response to the “enpdm” item in the above CONFIGURATION menu, then a 500.0 per unit resistance is connected to ground on the transformer primary. The “Default” RC branch on the primary is determined according to a well−known interface stabilizing technique [REF 1] which is referred to as the compensated conductance method. The compensated conductance method involves adding a small conductance (G) at the terminals of the model (i.e. the transformer) and compensating the G in each time−step with a parallel current source. The current source is set to precisely offset the current through the G in the previous time−step. For the “Default” selection, the conductance G is chosen according to the equation G = 0.5 *delt/L where L is the leakage inductance of the transformer and delt is the time−step size. It is less well−known that the compensated conductance branch is equivalent to a series resistor−capacitor (RC) branch where 2R = 1/G and C = G*delt. The impedance of the RC branch is effectively that of the capacitance C for frequencies to a few kiloHertz because the RC time constant is 0.5*delt and thus R is relatively small. In order to inform the User of the size of the damper branches, entries are made in the MAP file which describe the per unit resistance of the parallel R and the per unit Xc of the RC branch. The R value in the RC branch is described in the MAP file according to the RC time constant expressed in time−steps.

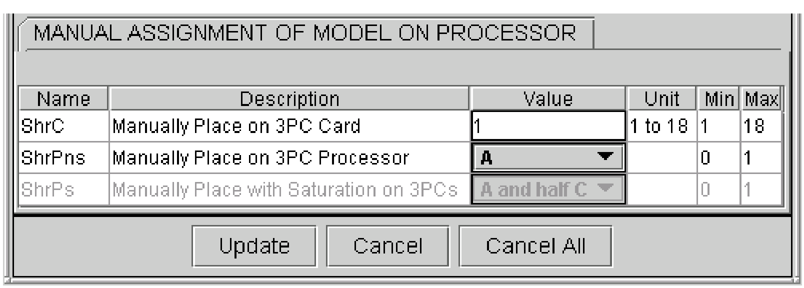
When the User specifies “Default” in response to the “ensdm” item in the above CONFIGURATION menu, then a delta−connected 4500.0 per unit resistance is connected on the transformer secondary. The base impedance is the line−to−ground base impedance on the secondary. The “Default” RC branch (in parallel to the 4500 per unit R) consists of a capacitor C with Xc = 4500.0 per unit in series with an resistor R where the RC time constant is equal to 0.5*delt.

If the User selects “Specify” in response to either the “enpdm” or “ensdm” items, then a DAMPER BRANCH PARAMETERS menu tab becomes available. The DAMPER BRANCH PARAMETERS menu and the entries therein are discussed below.

The CONFIGURATION menu also asks if the model should prepare certain output signals for D/A or RunTime monitoring. These include dc current in the valve group; primary ac currents into the valve group transformer; secondary ac currents out of the valve group transformer; a selected forward valve voltage; and the Gamma signal. The Gamma signal is the angle in radians between valve turn−off and the re−application of forward valve voltage. The details concerning output of these signals is specified in later menus.

The CONFIGURATION menu also asks if saturation is to be enabled in the transformer model. At present, the saturation model planned for the model is not enabled. Therefore, the saturation model (Saton = Yes) should not be requested. If it is requested then an ERROR message will appear.

The CONFIGURATION menu also asks if the model should be automatically placed on an available Sharc processor or manually placed. If Manual placement is requested, then an additional menu tab (MANUAL ASSIGNMENT OF MODEL ON PROCESSOR) will appear. The MANUAL ASSIGNMENT OF MODEL ON PROCESSOR menu appears as follows:


MANUAL ASSIGNMENT OF MODEL ON PROCESSOR

Name	Description	Value	Unit	Min	Max
ShrC	Manually Place on 3PC Card	1	1 to 18	1	18
ShrPns	Manually Place on 3PC Processor	A		0	1
ShrPs	Manually Place with Saturation on 3PCs	A and half C		0	1

For Manual placement, a specific Card must be requested using the “ShrC” item in the above menu. A 3PC card number of 1 means the first 3PC card in a rack. The 3PC card number is not the same as the slot number. For instance, slot number 1 may contain a NEC−based card in mixed NEC/Sharc racks.

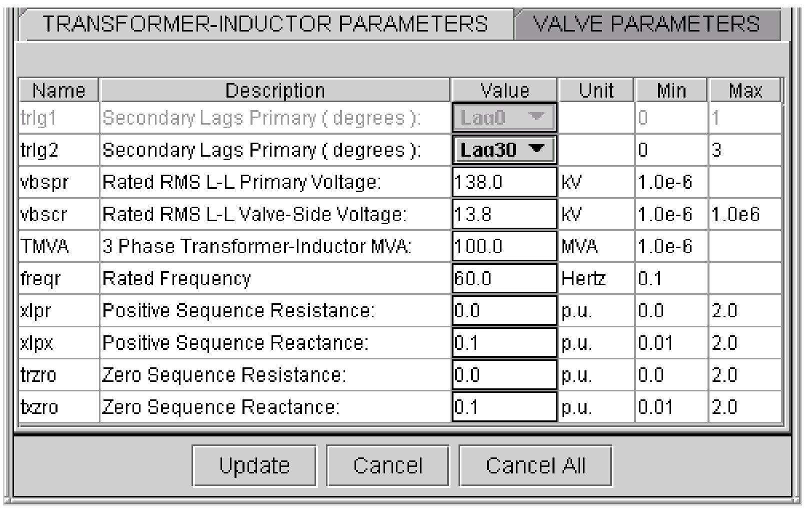
Depending on the saturation request in the CONFIGURATION menu, either the “ShrPns” item or the “ShrPs” item in the above menu, will be grey and inaccessible.

If saturation has not enabled, the item “ShrPns” item will be accessible. In that case, the model may be placed on the A or B processor. Alternatively, if saturation has been enabled, the “ShrPs” item will be accessible and either “A and half C” or ”B and half C” may be chosen. The “half C” part means that the C processor will contain the detailed saturation model. In this way, 2 Valve Groups on 1 card can share the C processor for solving the saturation routine.

It is noted above that the saturation Model is not yet enabled (Saton must = No) so that the “ShrPs” item is not yet useful. These menus are included to accommodate continuing development.

8.5 THE TRANSFORMER–INDUCTOR PARAMETERS MENU

The TRANSFORMER–INDUCTOR PARAMETERS menu appears as follows:


TRANSFORMER-INDUCTOR PARAMETERS | VALVE PARAMETERS

Name	Description	Value	Unit	Min	Max
trlg1	Secondary Lags Primary (degrees):	Lag0		0	1
trlg2	Secondary Lags Primary (degrees):	Lag30		0	3
vbspr	Rated RMS L-L Primary Voltage:	138.0	kV	1.0e-6	
vbscr	Rated RMS L-L Valve-Side Voltage:	13.8	kV	1.0e-6	1.0e6
TMVA	3 Phase Transformer-Inductor MVA:	100.0	MVA	1.0e-6	
freqr	Rated Frequency	60.0	Hertz	0.1	
xlpr	Positive Sequence Resistance:	0.0	p.u.	0.0	2.0
xlpx	Positive Sequence Reactance:	0.1	p.u.	0.01	2.0
trzro	Zero Sequence Resistance:	0.0	p.u.	0.0	2.0
txzro	Zero Sequence Reactance:	0.1	p.u.	0.01	2.0

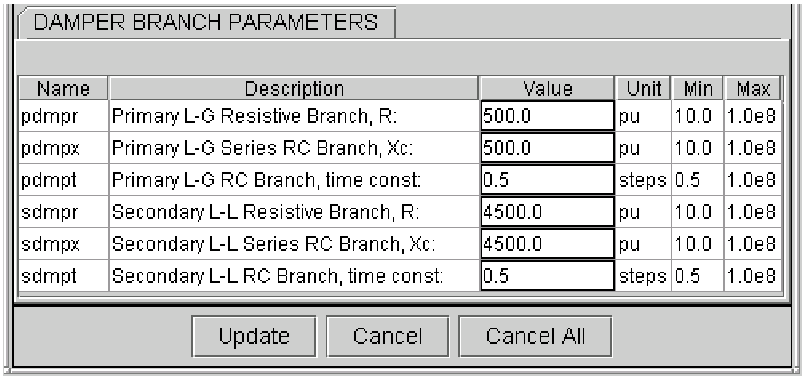
Update | Cancel | Cancel All

The six (6) possible Yy and Yd connections can be selected by the 1^{st} and 2^{nd} items concerning lag (trlg1 and trlg2) in the TRANSFORMER–INDUCTOR PARAMETERS menu. The 1^{st} item will be greyed out if a wye–grounded–delta (Yd) transformer is requested in the CONFIGURATION menu. The 2^{nd} item will be greyed out if a wye–wye (Yy) transformer is requested in the CONFIGURATION menu. Both the 1^{st} and 2^{nd} items will be greyed out if “Inductors” is selected in the CONFIGURATION menu.

The remaining eight (8) items in the TRANSFORMER–INDUCTOR PARAMETERS menu are basically self–explanatory. The “vbsrc” item will be greyed out if “Inductors” is selected in the CONFIGURATION menu. The “trzro” and “txzro” items relating to zero sequence will be greyed out in the menu unless a wye–delta (Yd) transformer with a zero–sequence path is requested in the CONFIGURATION menu.

8.6 THE DAMPER BRANCH PARAMETERS MENU

The DAMPER BRANCH PARAMETERS menu tab appears when “Specify” is selected in response the “enpdm” or “ensdm” items in the CONFIGURATION menu:


DAMPER BRANCH PARAMETERS

Name	Description	Value	Unit	Min	Max
pdmpr	Primary L-G Resistive Branch, R:	500.0	pu	10.0	1.0e8
pdmpx	Primary L-G Series RC Branch, Xc:	500.0	pu	10.0	1.0e8
pdmpt	Primary L-G RC Branch, time const:	0.5	steps	0.5	1.0e8
sdmpr	Secondary L-L Resistive Branch, R:	4500.0	pu	10.0	1.0e8
sdmpx	Secondary L-L Series RC Branch, Xc:	4500.0	pu	10.0	1.0e8
sdmpt	Secondary L-L RC Branch, time const:	0.5	steps	0.5	1.0e8

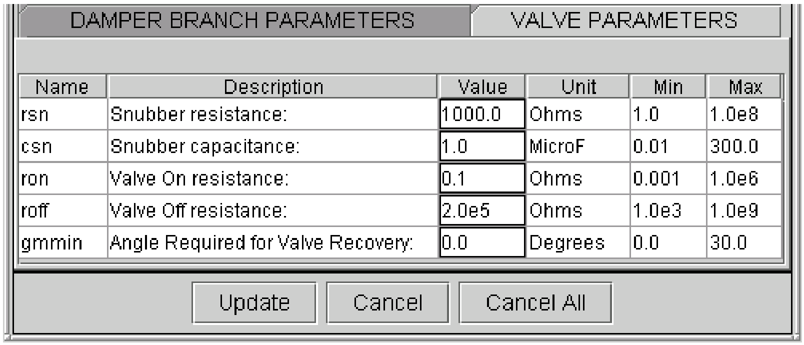
Update Cancel Cancel All

The first three items in the menu are available if “Specify” is selected in response to the “Tap Damper Branches on Primary ?” item (“enpdm”) in the CONFIGURATION menu. The first menu item allow the User to specify a resistance to ground connected on the primary of the transformer. The 2^{nd} and 3^{rd} items allow the User to specify a damped RC branch connected to ground on the transformer primary side. The “pdmpx” item allows the User to specify the fundamental frequency impedance of the capacitor C. The “pdmpt” item allows the User to specify the RC time constant of the damped RC branch. An RC time constant of less than 0.5 time−steps in not permitted.

The last three items in the menu are available if “Specify” is selected in response to the “Tap Damper Branches on Secondary ?” item (“ensdm”) in the CONFIGURATION menu. The “sdmpr” item allows the User to specify a line−to−line resistance connected on the secondary of the transformer. The base impedance for use with items “sdmpr” and “sdmpx” is the normal line−to−ground secondary−side base impedance. The “sdmpx” and “sdmpt” items allow the User to specify a damped RC branch connected line−to−line on the transformer secondary side. The “sdmpx” item allows the User to specify the fundamental frequency impedance of the capacitor C. The “sdmpt” item allows the User to specify the RC time constant of the damped RC branch. An RC time constant of less than 0.5 time−steps in not permitted.

8.7 THE VALVE PARAMETERS MENU

The VALVE PARAMETERS menu appears as follows:



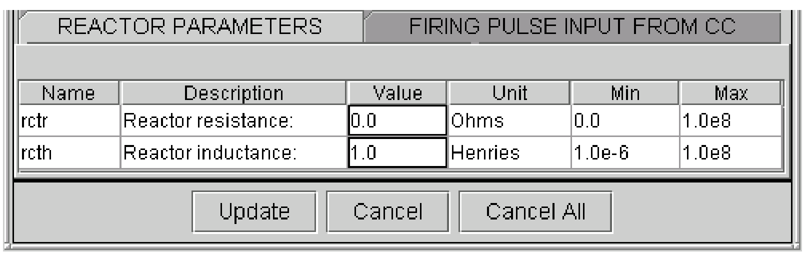
Name	Description	Value	Unit	Min	Max
rsn	Snubber resistance:	1000.0	Ohms	1.0	1.0e8
csn	Snubber capacitance:	1.0	MicroF	0.01	300.0
ron	Valve On resistance:	0.1	Ohms	0.001	1.0e6
roff	Valve Off resistance:	2.0e5	Ohms	1.0e3	1.0e9
gmmin	Angle Required for Valve Recovery:	0.0	Degrees	0.0	30.0

The first four items in the menu are self−explanatory. However, the time constant of the snubber (rsn * csn) should be maintained at about 2 time−steps in duration or longer.

The final entry in the menu allows valve recovery time to be expressed as a number of degrees for recovery at fundamental frequency.

8.8 THE REACTOR PARAMETERS MENU

The REACTOR PARAMETERS menu appears as follows:

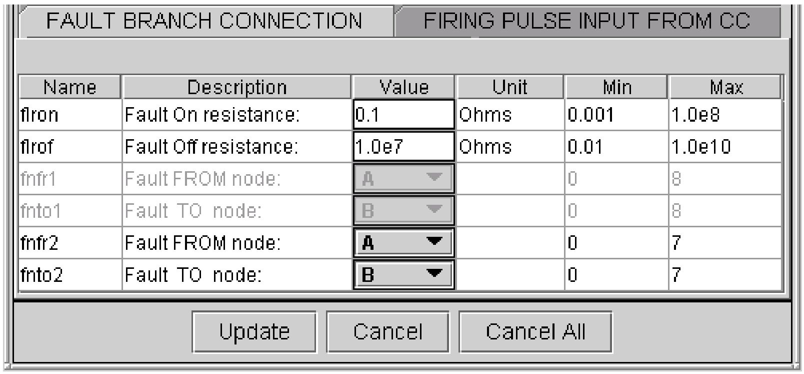


Name	Description	Value	Unit	Min	Max
rctr	Reactor resistance:	0.0	Ohms	0.0	1.0e8
rcth	Reactor inductance:	1.0	Henries	1.0e-6	1.0e8

If a dc reactor is requested in the CONFIGURATION menu, then this menu becomes available. The entries are self−explanatory. The reactor resistance may be made equal to zero if desired.

8.9 THE FAULT BRANCH CONNECTION MENU

The FAULT BRANCH CONNECTION menu appears as follows:



Name	Description	Value	Unit	Min	Max
flron	Fault On resistance:	0.1	Ohms	0.001	1.0e8
flrof	Fault Off resistance:	1.0e7	Ohms	0.01	1.0e10
fnfr1	Fault FROM node:	A		0	8
fnto1	Fault TO node:	B		0	8
fnfr2	Fault FROM node:	A		0	7
fnto2	Fault TO node:	B		0	7

This menu appears if an “Internal” or “External” fault branch type is requested in the CONFIGURATION menu.

If a dc reactor has been specified within the model, the 5th and 6th lines of the above menu are greyed out. Alternatively, if no dc reactor has been specified, then lines 3 and 4 of the menu are greyed out. This corresponds with the absence or presence of the “R” node in the model.

In the case where an “Internal” fault branch type has been specified, both the TO node and the FROM node must be selected using the toggle boxes.

In the case where an “External” fault branch type has been specified, only the FROM node may be selected from the toggle box. The TO node item will be greyed out in that situation.

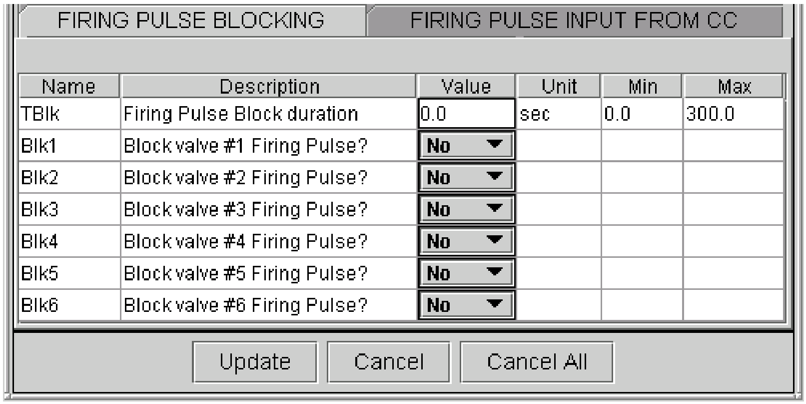
When a fault is requested, the FROM node and TO node will be identified at either end of a FAULT SWITCH on the Valve Group icon along with the fault current reference direction arrow. In the case of an “External” fault type, the TO node will be shown as node “F” on the icon and a conductor connection will be provided on the icon for connecting from the “F” node to any external Connector type node or to a Ground node.

The switching of the fault branch is controlled from the Controls Compiler as discussed in Section 8.13 in relation to the GENERAL CONTROLS INPUTS menu.

Fault branch current can be monitored in RunTime or using a D/A channel, as discussed below.

8.10 THE FIRING PULSE BLOCKING MENU

The FIRING PULSE BLOCKING menu appears as follows:



FIRING PULSE BLOCKING | FIRING PULSE INPUT FROM CC

Name	Description	Value	Unit	Min	Max
TBlk	Firing Pulse Block duration	0.0	sec	0.0	300.0
Blk1	Block valve #1 Firing Pulse?	No			
Blk2	Block valve #2 Firing Pulse?	No			
Blk3	Block valve #3 Firing Pulse?	No			
Blk4	Block valve #4 Firing Pulse?	No			
Blk5	Block valve #5 Firing Pulse?	No			
Blk6	Block valve #6 Firing Pulse?	No			

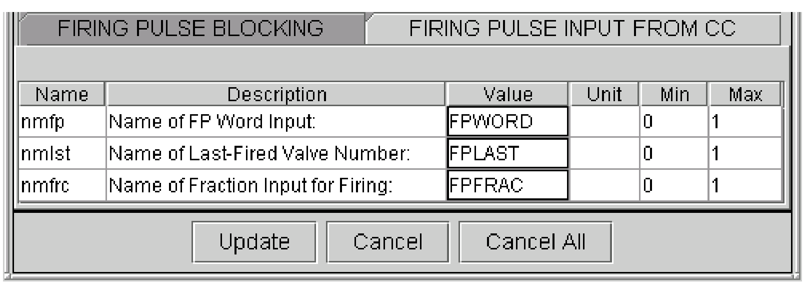
Update | Cancel | Cancel All

This menu appears only if Firing Pulse Blocking is requested in the CONFIGURATION menu.

The above menu allows one or more valves to be specified to which the firing pulse will be blocked for a specified period. The initiation of the firing pulse blocking period is triggered from the Controls Compiler as discussed below in the Section 8.13 describing the GENERAL CONTROLS INPUTS menu.

8.11 THE FIRING PULSE INPUT FROM CC MENU

The FIRING PULSE INPUT menu appears when “CTLs_Comp” is selected in response to the “srfpi” item in the CONFIGURATION menu. The FIRING PULSE INPUT FROM CC appears as follows:



FIRING PULSE BLOCKING | FIRING PULSE INPUT FROM CC

Name	Description	Value	Unit	Min	Max
nmfp	Name of FP Word Input:	FPWORD		0	1
nmlst	Name of Last-Fired Valve Number:	FPLAST		0	1
nmfrc	Name of Fraction Input for Firing:	FPFRAC		0	1

Update | Cancel | Cancel All

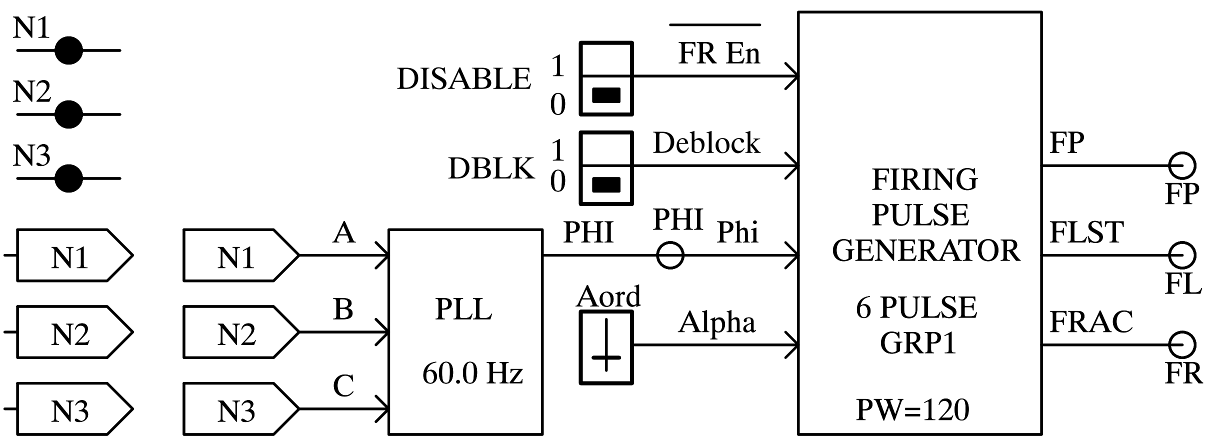
This menu enables the external source of firing pulse information to be specified for the Valve Group model, as three named words passed on the backplane in the RTDS rack. The three named words may be generated in Control Blocks described below.

The first word (“nmfp”) is the integer firing pulse word, having a permitted range of values from binary 000000 to binary 111111. Each bit represents a firing pulse bit, the least significant bit (LSB) corresponding to the firing pulse bit for valve number 1. A one bit asserts firing a valve.

The second word (“nmlst”) is an integer identifying the last bit in the firing pulse word to transition ON in the last time−step. If no bit transitioned ON, then the word “nmlst” should contain zero. However, if a bit did transition ON, then that bit number should be contained within “nmlst”. For instance, if firing pulse bit 4 transitioned ON 2/3 of the way through the last time−step, then the integer 4 would be passed on the backplane in the “nmlst” word. In this last case, the third named word (“nmfrc”) should contain a floating point number, between 0.0 and 1.0, which describes the fractional position in the time−step when the ON transition occurred (Example: 0.66667).

The firing of 1 out of 6 valves can be improved in each time−step.

The set of three firing−pulse words may come from a control system simulated in the RTDS as illustrated below, or from a Digital Input Time Stamp (DITS) card, as described in the next section.



The Phase Locked Loop (PLL) in the above Controls Compiler schematic is controls component rtds_sharc_ctl_PLL. The Firing Pulse Generator is controls block rtds_sharc_ctl_FPGEN. In the above schematic, a constant angle corresponding to 1.5 time−steps at fundamental frequency could be added to the output of the PLL in order to remove delay inherent to the trapezoidal integration method and the improved firing method as discussed in section 8.1 above.

The Firing Pulse Generator must be set to produce a <u>firing pulse width of 120 degrees</u> duration rather than 180 degrees.

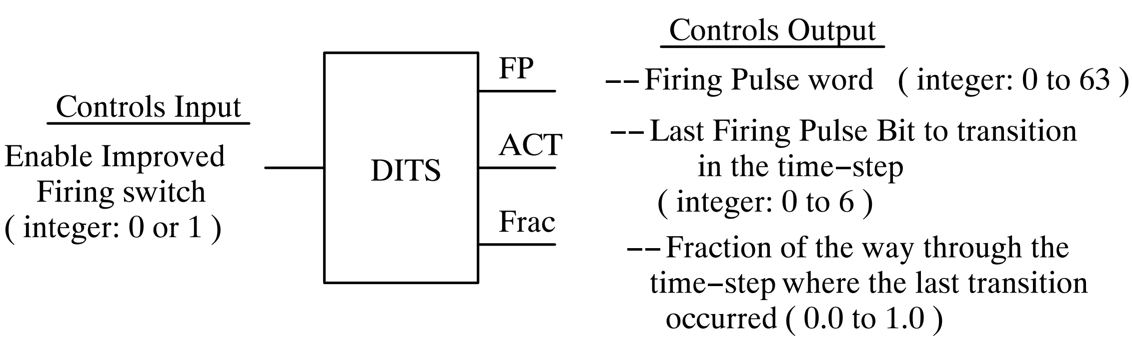
These components represent basic control blocks which are not optimized for any particular purpose. More detailed control systems may be assembled using the lower level control blocks which are available in the Controls Compiler library.

Setting the DISABLE switch to 1 disables the improved firing output words FLST and FRAC. Therefore, for operation with improved firing, the DISABLE switch must be set to 0. FLST is the number (1 to 6) of the last firing pulse to transition ON in the time−step. The switch DBLK (in the 1 position) causes firing pulses to be generated. FRAC is the fraction of the way through the time−step where the ON transition occurred. When there is no firing−pulse ON transition in the time−step or when DISABLE = 1, then FLST will be equal to integer 0 and FRAC will be equal to floating−point 0.0. With the latter outputs for FLST and FRAC, the Valve Group will obey the firing pulses in FP, but no improvement in firing accuracy will occur. FLST and FRAC may be monitored in RunTime.

8.12 THE DIGITAL INPUT TIME STAMP CARD

Access of DITS Card Using Component: rtds_sharc_ctl_DITS

Use of the Digital Input Time Stamp (DITS) card is required in support of improved firing accuracy for the Valve Group during testing of physical HVDC controls. The DITS card can be connected by a ribbon cable to the digital I/O port on the back of a Controls Compiler processor or it can be similarly connected by a ribbon cable to the digital I/O port on the back of the valve group processor. Starting with the rtds_sharc_VGP6V4 valve group model, it is recommended that the connection be made to the back of the valve group processor. Connection to the back of the valve group processor eliminates about 1/2 time−steps of delay in obtaining the firing pulse information as explained in Section 8.1. However, it is still possible to use the rtds_sharc_ctl_DITS component executed on a controls processor to obtain the firing pulse information from the DITS card.



When using the rtds_sharc_ctl_DITS component on a controls processor, it is useful to force the DITS control component to be serviced late in the time−step. In this way, the firing information is not unnecessarily delayed before being passed on the backplane to the valve group model at the end of the time−step.

The use of the DITS card is explained in detail in Chapter 11 which discusses the TCSC model.

Access of DITS Card directly through the digital I/O on the VG processor

As noted above, the recommended method of using the DITS card with the rtds_sharc_VGP6V4 valve group model is to connect the DITS card by ribbon cable to the digital I/O port on the back of the valve group processor. In that case the User must specify in the CONFIGURATION menu that the "Source of the Firing Pulse Input:" is "Local_DITS". With that selection made a menu tab "FIRING PULSE INPUT FROM LOCAL DITS" appears. This menu allows the User to make certain choices for receiving the firing pulse input into the valve group model and to monitor the usual firing pulse word (FP), active valve number (FL), and fraction (FRC). The menu appears as follows:

FIRING PULSE BLOCKING | FIRING PULSE INPUT FROM LOCAL DITS

Name	Description	Value	Unit	Min	Max
ledmd	Conducting DITS LED means an FP bit:	Active			
IMPF	Create Improved Firing ON/OFF Input ?	No		0	1
IMPN	-- If Yes: Name of ON/OFF Word:	IMPFWD		0	0
IMPB	-- If Yes: Bit No. in ON/OFF Word:	1	1 to 15	1	15
fpmon	Monitor DITS FP Input in RT and CC ?	No		0	1
fpnam	-- If Yes: Name of DITS FP input	DITSFP		0	0
flmon	Monitor DITS FL Input in RT and CC ?	No		0	1
flnam	-- If Yes: Name of DITS FL input	DITSFL		0	0
frmon	Monitor DITS FRC Input in RT and CC ?	No		0	1
frnam	-- If Yes: Name of DITS FRC input	DITSFRC		0	0

Update | Cancel | Cancel All

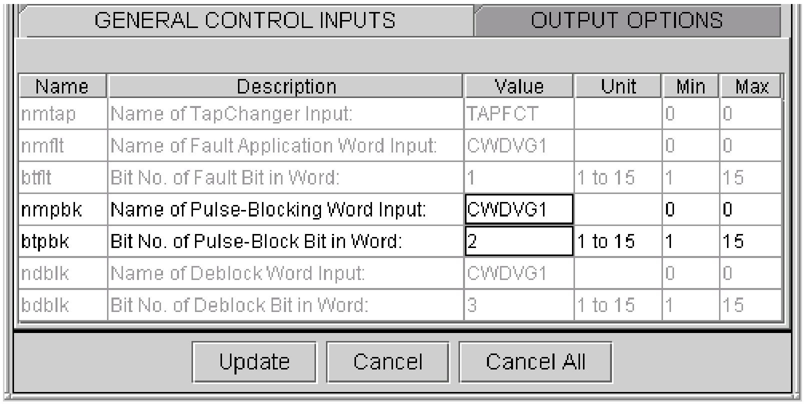
In Section 11.5 there is a simple functional schematic of the DITS card showing the terminal connections, resistors for limiting current, and light emitting diodes. As explained in that section, the resistors can be replaced by the User and should be adequate in power and resistance rating for the voltage levels applied on the terminals of the DITS card. Depending on whether the User wishes an "On" pulse to correspond to a conducting or non−conducting LED, the User makes the appropriate selection in response to the 1^{st} item (" ledmd") in the above menu.

If the User wishes to be able to turn improved firing off, then an optional input can be created for that purpose according to the 2^{nd}, 3^{rd}, and 4^{th} items ("IMPF", "IMPN", and "IMPB") in the above menu. There is no need to create this input if the User intends to leave improved firing ON at all times.

The final 6 items in the above menu allow the User to optionally monitor the usual output words of the DITS card in RunTime and the Controls Compiler.

8.13 THE GENERAL CONTROL INPUTS MENU

The GENERAL CONTROL INPUTS menu appears as follows:



Name	Description	Value	Unit	Min	Max
nmtap	Name of TapChanger Input:	TAPFCT		0	0
nmflt	Name of Fault Application Word Input:	CWDVG1		0	0
btflt	Bit No. of Fault Bit in Word:	1	1 to 15	1	15
nmpbk	Name of Pulse-Blocking Word Input:	CWDVG1		0	0
btpbk	Bit No. of Pulse-Block Bit in Word:	2	1 to 15	1	15
ndblk	Name of Deblock Word Input:	CWDVG1		0	0
bdblk	Bit No. of Deblock Bit in Word:	3	1 to 15	1	15

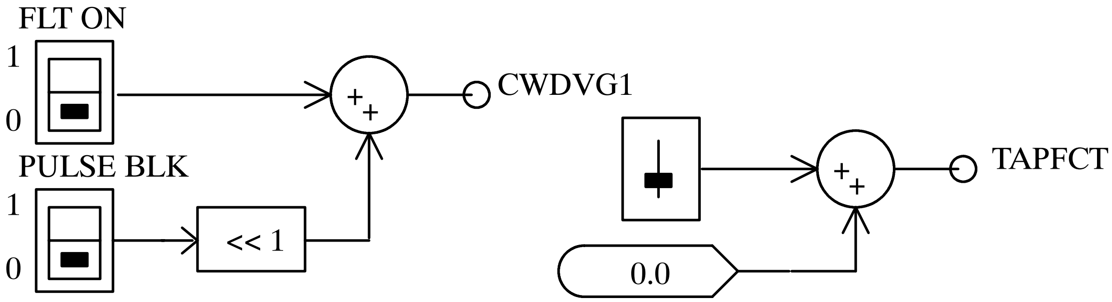
Based on selections in the CONFIGURATION menu, four items of input may be needed from the Controls Compiler. In particular, the CONFIGURATION menu allows requests for Tapchanger operation, for the presence of a fault branch, for the ability to block selected firing pulses for a specified period, and/or the presence of a deblock input.

In the case of Tapchanger operation, the name of a floating point word to be communicated on the backplane must be provided for the Controls Compiler. If Tapchanger operation is not requested, then the first item in the menu will be greyed out and the floating point number is not required.

The GENERAL CONTROL INPUTS menu allows the name of an integer word containing the fault application control bit to be specified. The menu prompts for the bit that should be monitored in the integer word. A one bit causes the fault branch to physically closed. A zero bit causes the fault branch to physically open. However, a physically open fault will not extinguish until a current zero. Lines 2 and 3 of the menu are greyed out when no fault branch has been requested.

The GENERAL CONTROL INPUTS menu allows the name of an integer word containing the pulse blocking control bit to be specified. The menu prompts for the bit that should monitor in the integer word. A transition of the control bit from zero to one causes the beginning of the pulse blocking period to commence. Lines 4 and 5 of the menu are greyed out when no pulse blocking has been requested.

The GENERAL CONTROL INPUTS menu allows the name of an integer word containing the valve group deblock control bit to be specified. The menu prompts for the bit that should monitor in the integer word. A transition of the control bit from zero to one causes the valve group to deblock. Lines 6 and 7 of the menu are greyed out when no deblock input has been requested in the CONFIGURATION menu.
The following DRAFT diagram illustrates, by example, the creation of various control words:

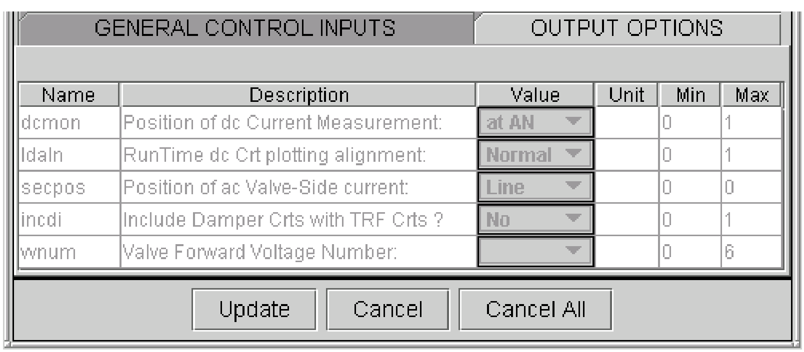


In the above diagram, the Control inputs are shown as switches and sliders accessible in RunTime. However, the integer inputs could have been brought into the controls processor through a Controls Compiler digital input port icon. Alternatively, the slider and switches could be replaced by the output of a more complicated controls circuit containing timers, pulse counters, and similar devices.

The Valve Group model passes the Tap Changer per unit factor through a real−pole lag filter with a time constant of 20 milliseconds in order to avoid step changes in the applied per unit factor.

8.14 THE OUTPUT OPTIONS MENU

The OUTPUT OPTIONS menu appears as follows:



GENERAL CONTROL INPUTS | OUTPUT OPTIONS

Name	Description	Value	Unit	Min	Max
dcmon	Position of dc Current Measurement:	at AN		0	1
Idaln	RunTime dc Crt plotting alignment:	Normal		0	1
secpos	Position of ac Valve-Side current:	Line		0	0
incdi	Include Damper Crts with TRF Crts ?	No		0	1
wnum	Valve Forward Voltage Number:			0	6

Update | Cancel | Cancel All

Preparation of a valve group dc current may be requested in the CONFIGURATION menu. If a fault branch is enabled in the Valve Group, the current out of the node CT is not necessarily equal to the current into node AN (see page 8.1). In that case, the OUTPUT OPTIONS menu must be used to select the position for monitoring the Valve Group dc current. It should be noted that the position of measurement of the dc current is on the outside of the CT and AN node.

Generally, the calculation of currents in the Valve Group appear in RunTime with a one time−step delay. This delay can be avoided in the case of the dc current signal by specifying that the “RunTime dc Crt plotting alignment” should be “Early”.

If preparation of dc current is not enabled in the CONFIGURATION menu, then the first and second line of this menu will be greyed out.

The CONFIGURATION menu allows transformer secondary current to be prepared for output. If the transformer is connected wye−wye (Y−Y) then the secondary currents into the valve group (line currents) can be monitored. If the transformer is connected wye−delta then secondary current can be monitored. However, in the wye−delta case, the User must make a selection in the OUTPUT OPTIONS menu to choose whether to monitor the phase currents into the valve (Line) or the currents in the delta connected winding (Winding). If secondary current is not to be monitored, or if the transformer is wye−wye connected, the 3rd line in the OUTPUT OPTIONS menu will be greyed out.

When Tap Damper Branches are enabled in the CONFIGURATION menu (items "enpdm" and "ensdm"), these branches have a small effect on the ac currents which effectively flow into and out of the valve group transformer. The User can choose whether the damper branch currents should be included in the actual transformer currents for purposes of monitoring using the item "incdi".

The CONFIGURATION menu allows a Valve Forward voltage to be monitored. In this case, the valve number must be indicated using the "vvnum" toggle in the OUTPUT OPTIONS menu.

8.15 THE SIGNAL MONITORING IN RUNTIME & CONTROLS MENU

These menus (SIGNAL MONITORING IN RUNTIME and CONTROLS and SIGNAL MONITORING (CONTINUED))list the signals which can be produced by the Valve Group model. If "YES" is selected for a particular entry, that signal will be available for input to the Controls Compiler and for monitoring in RunTime. All of the signals are floating point numbers except for the "Valve Turn−Off Word" and the "Bitwise Word for Valve−Off" which are integers. If "YES" is given for monitoring a signal, or the signal is to be output through a D/A (as discussed below), a name must be specified in the SIGNAL NAMES FOR RUNTIME and D/A menus.

The two Signal Monitoring menus appear as follows:

SIGNAL MONITORING IN RUNTIME and CONTROLS

Name	Description	Value	Unit	Min	Max
mon1	Monitor Valve Group DC Current:	No		0	1
mon2	Monitor Valve Ph A Voltage (AV):	No			
mon3	Monitor Valve Ph B Voltage (BV):	No			
mon4	Monitor Valve Ph C Voltage (CV):	No			
mon5	Monitor Reactor Node Voltage (R):	No		0	1
mon6	Monitor Reactor dc Current:	No		0	1
mon7	Monitor Fault Current (from -> to):	No		0	1
mon8	Monitor Gamma Measured:	No		0	1
mon9	Monitor Valve Turn-Off Word:	No			
mon10	Monitor Max Abs Valve Phase I:	No		0	1

Update Cancel Cancel All

SIGNAL MONITORING (CONTINUED)

Name	Description	Value	Unit	Min	Max
mon11	Monitor Transf. I primary (A Phase):	No		0	1
mon12	Monitor Transf. I primary (B Phase):	No		0	1
mon13	Monitor Transf. I primary (C Phase):	No		0	1
mon14	Monitor Transf. I sec (A Phase):	No		0	1
mon15	Monitor Transf. I sec (B Phase):	No		0	1
mon16	Monitor Transf. I sec (C Phase):	No		0	1
mon17	Monitor Transf. I wind (B to A):	No		0	1
mon18	Monitor Transf. I wind (C to B):	No		0	1
mon19	Monitor Transf. I wind (A to C):	No		0	1
mon20	Monitor Valve Forward Voltage:	No		0	1
mon21	Monitor Fraction in Valve-Off Step:	No		0	1
mon22	Monitor Bitwise Word for Valve-Off:	No		0	1
mon23	Monitor Valve Node AN Voltage:	No		0	1
mon24	Monitor Valve Node CT Voltage:	No		0	1

Update Cancel Cancel All

The electrical signals listed in the above menus are in units of kA and kV. The reference direction for dc current and transformer currents are illustrated on page 8.1 when output is enabled.

The Valve Group DC current is measured either outside of node CT or node AN of the Valve Group depending on a selection in the OUTPUT OPTIONS menu.

The reactor and fault currents are only available for monitoring if a reactor or fault is requested in the CONFIGURATION menu.

The “Valve Turn−Off Word” is a 6 bit integer word which indicates all the valves which turn Off in a given time−step. Valve 1 is indicated by the least significant bit (LSB). Valve 6 is indicated by the most significant bit of the six (6).

The “Max Abs Valve Phase I” is the maximum of the absolute values of the phase currents out of the transformer on the valve−side.

Transformer primary phase currents can be monitored when they are specified for preparation in the CONFIGURATION menu. The reference direction of the Transformer primary phase currents is into the transformer.

Transformer secondary phase currents may be monitored when they are specified for preparation in the CONFIGURATION menu and, in the case of a wye−delta transformer, that the Position of ac Valve−Side current is “Line” (see OUTPUT OPTIONS menu). The reference direction of the Transformer secondary phase currents is out of the transformer and into the valves. The reference direction is shown on the icon when “Line” is selected.

Transformer delta winding currents may be monitored when “Prepare secondary ac currents” is specified for preparation in the CONFIGURATION menu and the Position of ac Valve−Side current is “Winding” in the OUTPUT OPTIONS menu. The reference direction of the winding currents is shown on the icon when “Winding” is selected.

The valve number which provides the Valve Forward Voltage can be specified in the OUTPUT OPTIONS menu when “Prepare Valve Forward Voltage” is specified in the CONFIGURATION menu.

The Gamma signal produced by the Valve Group can be monitored by responding to the “mon8” prompt. The Gamma Measured output signal is based on the shortest available measured recovery period among the six valves in the Valve Group model. Therefore, the Gamma Measured signal is updated 6 times per cycle. For each valve, a recovery timer is set to zero whenever the valve is conducting. When the valve current zero−crossing occurs, then the timer begins to ramp toward PI radians. When the zone of possible commutation ends for the valve (determined from commutating bus voltages), then the timer for the valve is sampled to determine Gamma for the valve. If the recovery period ends while the valve is still conducting, then Gamma for the valve and the valve group will be 0.0.

Other algorithms for calculating Gamma can be created in the Controls Compiler. Three output signals are available for that purpose (see entries mon9, mon21 and mon22). The “Valve Turn−Off Word” (mon9) indicates all valves that turned Off in a time−step. The “Bitwise Word for Valve−Off” signal (mon22) provides a 6−bit integer word which indicates a single valve which turned Off in the time−step (with a 1 bit). The LSB corresponds with Valve 1. A one bit indicates a turn−off. The “Fraction in Valve−Off Step” (mon21) is a floating point number which indicates the fraction of the time−step which occurred <u>after</u> the valve turned off. This value is generated by interpolating the valve current signal to the turn off point. The “Valve Turn−Off Word” (mon9) and the “Fraction in Valve−Off Step” (mon21) are the values typically passed to the DOPTO card icon for improved accuracy output of zero crossing pulses.

8.16 SPECIFYING D/A OUTPUT ON 3PC FACEPLATES

The ENABLE D/A OUTPUT menus list the signals which may be assigned to D/A output channels located on the faceplate of the 3PC card. These signals include all of the signals in the SIGNAL MONITORING IN RUNTIME and CONTROLS menu except for the two integer signals: "Valve Turn−Off Word" and the "Bitwise Word for Valve−Off".

There are only 8 D/A output channels on a Sharc processor, 24 per 3PC card. If more than 8 are needed, the additional signals can be passed to a Controls Compiler processor and routed to a D/A output channel on the controls processor. In order to pass a signal on the RTDS backplane, it must be selected in the SIGNAL MONITORING IN RUNTIME and CONTROLS menu discussed in the preceding section.

For requested D/A signals, the D/A CHANNEL ASSIGNMENTS menu must specify unique D/A channel numbers between 1 and 8. Signal magnitude, which corresponds with a 5 Volt D/A output level, must also be supplied.

In the menu SIGNAL NAMES FOR RUNTIME and D/A discussed below, a unique Name must be supplied for each signal that is either assigned to a D/A channel or passed on the backplane for monitoring in RunTime, or in the Controls Compiler.

In the case of signals assigned to D/A channels, Offset and Unity Gain sliders can be created in RunTime based on signal names. In addition, for each signal name, a switch can be created in RunTime for lighting an LED on the faceplate of the 3PC card. The LED for a named signal is located immediately above the output pin for the signal.

8.17 THE SIGNAL NAMES FOR RUNTIME & D/A MENU

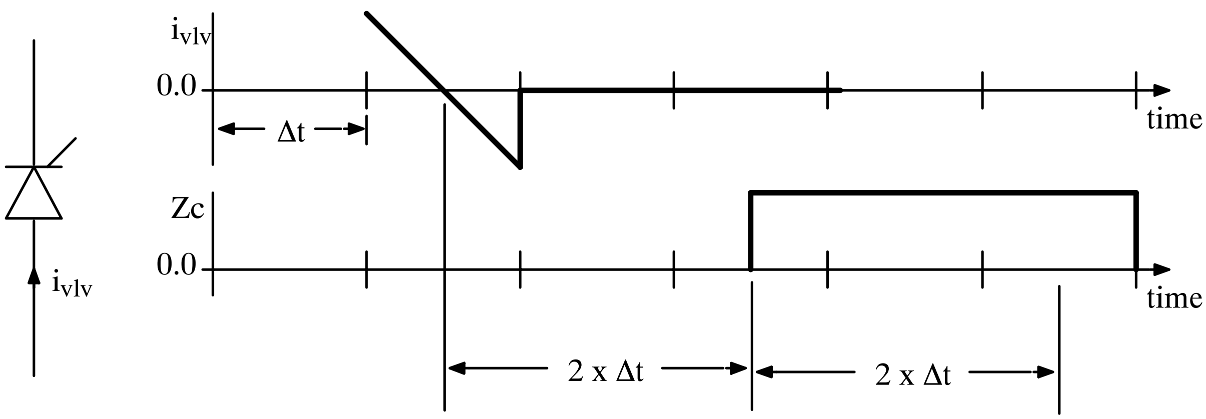
In this menu, a name must be specified for all signals which have been requested in either the SIGNAL MONITORING IN RUNTIME and CONTROLS menu or in the ENABLE D/A OUTPUT menu as discussed above. An example of this type of menu may be seen in Chapter 11 on the TCSC model.

The signals which can be accessed using the specified signal names are discussed in the previous two sections above.

8.18 INTERPOLATED ZERO CROSSING COMPONENT

RSCAD/Draft components are available to write interpolated zero−crossing pulses as digital output, either directly to a 3PC digital output port, or optionally using a DOPTO card (see RTDS Hardware Manual Ch. 12 for DOPTO documentation).

The zero−crossing pulse information is produced by the Valve Group model and passed to the zero−crossing component. The required zero−crossing information produced by the Valve Group model is provided in two parts: “Valve Turn−Off Word” (item “mon9”) and “Fraction in Valve−Off Step” (item “mon21”). The fraction describes the portion of the time−step after the zero−crossing. The zero−crossing component uses the information to generate a pulse whose rising edge represents the time at which the valve current became zero and is accurate to within a few microseconds, but delayed by two time−steps as illustrated below.



Generally, Gamma (extinction margin angle) is determined by comparing the relative phase of the zero−crossing pulses and the commutating bus voltages. The delay of the zero−crossing pulses by two time−steps will cause the Gamma measured by external controls to be two time−steps too small if there is no effective delay in the output of the commutating bus voltages. There will be no effective delay in the output of commutating bus voltages if the “rtds_sharc_FDACOVR2” model is used with an FDAC card with the STEPSADV slider set to 1.0 in RunTime. If there is effective delay in providing analog output of the commutating bus voltages for use in the gamma calculation, then the error would be reduced. For instance, if the “rtds_sharc_FDACOVR2” model is used to provide an oversampled analog output of the voltages, and if a step advance of zero (STEPSADV=0.0) is used, then there will be a delay in the analog output voltages of 1.0 time−steps. For an explanation of the “rtds_sharc_FDACOVR2” model, see Section 1.2 of the INTERFACING Portion of the RTDS USER’s MANUAL SET. The delay of analog output voltages by 1.0 time−step would result in the external HVDC controller hardware computing a Gamma which is 1.0 time−step (not 2.0 times−steps) too small. This error would be a fixed, constant error equal to 1 time−step (eg. 1.08 degrees at 60 Hz. with a time−

step of 50 μs) in steady−state.

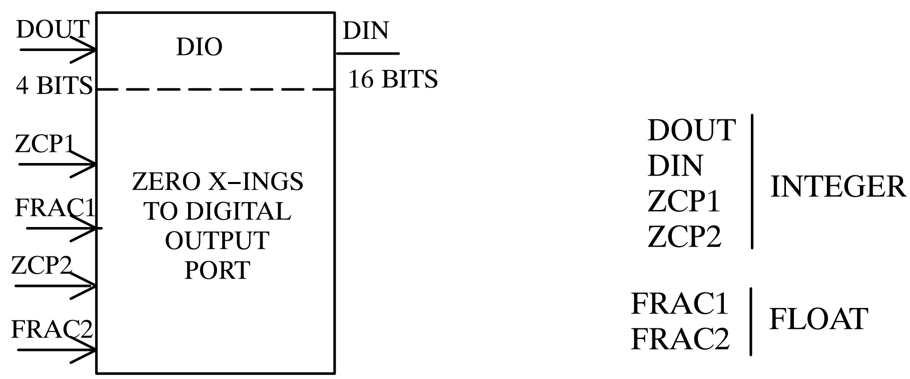
8.19 ZERO CROSSING DIGITAL OUTPUT PORT COMPONENT

The zero−crossing component used to write zero−crossing pulses to a 3PC digital port is named “rtds_sharc_ZCPDIG”. This component must be assigned to either the A or B processor on a 3PC card. No other power system or control system components may be allocated to the processor to which the ZCPDIG component is assigned.

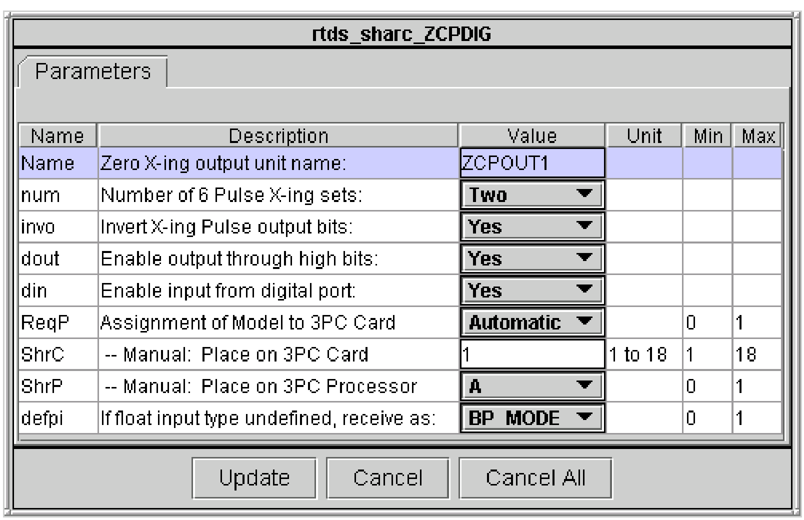
Each ZCPDIG component can handle the zero−crossing pulse sets (6 pulses per set) for either one or two valve groups. Each 12 pulse inverter requires only one ZCPDIG component.

In order to permit maximum usage of the processor’s digital I/O port the user may optionally specify that unused digital port output bits, as well as, the digital input port can be used for other signals.

Parameters associated with the ZCPDIG component are described below.



rtds_sharc_ZCPDIG



rtds_sharc_ZCPDIG

Parameters

Name	Description	Value	Unit	Min	Max
Name	Zero X-ing output unit name:	ZCPOUT1			
num	Number of 6 Pulse X-ing sets:	Two			
invo	Invert X-ing Pulse output bits:	Yes			
dout	Enable output through high bits:	Yes			
din	Enable input from digital port:	Yes			
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	1
defpi	If float input type undefined, receive as:	BP_MODE		0	1

Update Cancel Cancel All

Name: A unique name identifying the ZCPDIG component is required. The name is used to identify signals associated with the ZCPDIG component when selecting signals for monitoring in RSCAD/RunTime.

num: The number of zero−crossing sets, either one six−pulse set or two six−pulse sets. If two is selected, then input signals ZCP2 and FRAC2 become active.

invo: If yes, then all the bits in the zero−crossing pulse digital output are inverted. If no, then there is no inversion.

dout: If yes, the DOUT input signal to the icon becomes active. The user can use this signal to write either 10 bits (num=1) or 4 bits (num=2) to the digital output port on the processor to which the ZCPDIG component is allocated. Digital output port pin allocation is as follows:

num=1: pins 2−7 used for zero−crossing pulses corresponding to thyristors 1,2 ... 6 respectively.

pins 8−17 used for DOUT signal

num=2: pins 2−7 used for zero−crossing pulses corresponding to ZCP1 thyristors 1,2 ... 6 respectively.
pins 8−13 used for zero−crossing pulses corresponding to ZCP2 thyristors 1,2 ... 6 respectively.
pins 14−17 used for DOUT signal.

As an example, if an integer '3' was written to the DOUT signal and num=1, then digital output port pins 8 and 9 would be high and pins 10 through 17 would be 0. If num=2 then pins 14 and 15 would be high and pins 16 and 17 low.

din: Specifies whether the digital input port signals are to be used. Since the ZCPDIG component does not actually make use of the digital input port, a feature is included in the component which allows the digital input port to be read and the signal written to the DIN output signal. All 16 digital input port bits (pins 2−17) may be used. When din is specified as yes, then the DIN signal becomes active on the icon.

ReqP: Allows the RTDS compiler to automatically allocate the processor to which the ZCPDIG component is allocated, or alternatively specifies that the ShrC and ShrP parameters are to be used to manually specify the processor. Since external hardware will be connected to the processor's digital I/O port it is recommended that the Manual option be chosen.

ShrC: The Sharc processor card allocated to run the ZCPDIG component. Active only if ReqP set to Manual.

ShrP: The A or B processor on the allocated sharc processor card to be used to run the ZCPDIG component. Active only if ReqP set to Manual.

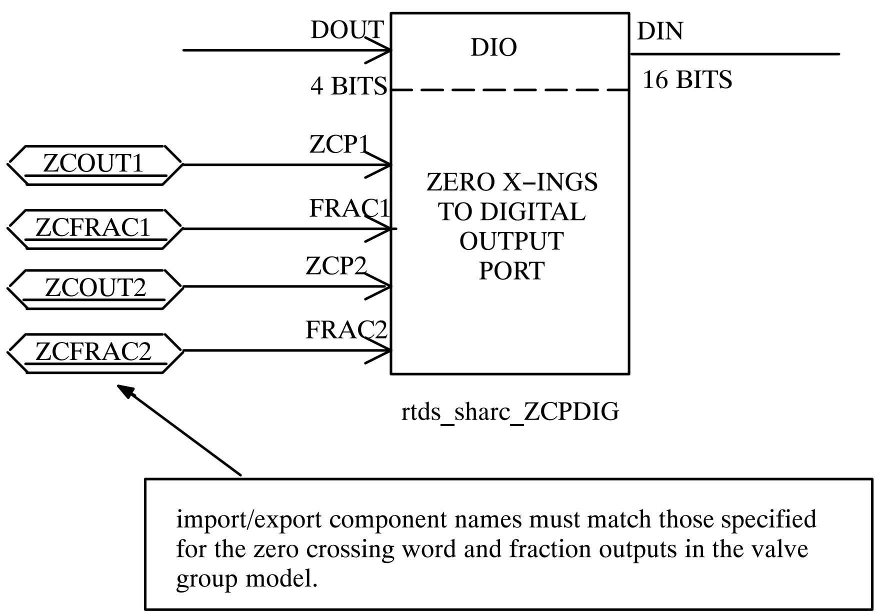
defpi: This parameter is only pertinent when the ZCPDIG component is allocated to an RTDS rack which contains both TPC and 3PC cards. In this case BP_MODE sets the floating point format used by the ZCPDIG model to that determined by the RTDS compiler or forces the floating point format to be IEEE.

INPUT SIGNALS

Two input signals are required for each six−pulse zero−crossing set. The ZCP1 and the optional ZCP2 signals are integer and are produced as output by the valve−group models (rtds_sharc_vgrp6 and rtds_sharc_vgrp6i). The necessary Zero−Crossing signal is obtained from the valve group model by specifying ‘Yes’ for parameter mon9 under the valve group’s SIGNAL MONITORING IN RUNTIME and CONTROLS menu. The corresponding signal name is then specified for parameter “nam9” under the SIGNAL NAMES FOR RUNTIME and D/A menu.

The FRAC1 and the optional FRAC2 ZCPDIG component input signals are Floating Point and are also obtained from the valve−group model. The FRAC signal is enabled using parameter mon21 located under the SIGNAL MONITORING (CONTINUED) menu and its name specified as parameter nam21 under the SIGNAL NAMES (CONTINUED) menu.

Use IMPORT/EXPORT signals to transfer the signal names from the valve−group model to the ZCPDIG component as shown below.



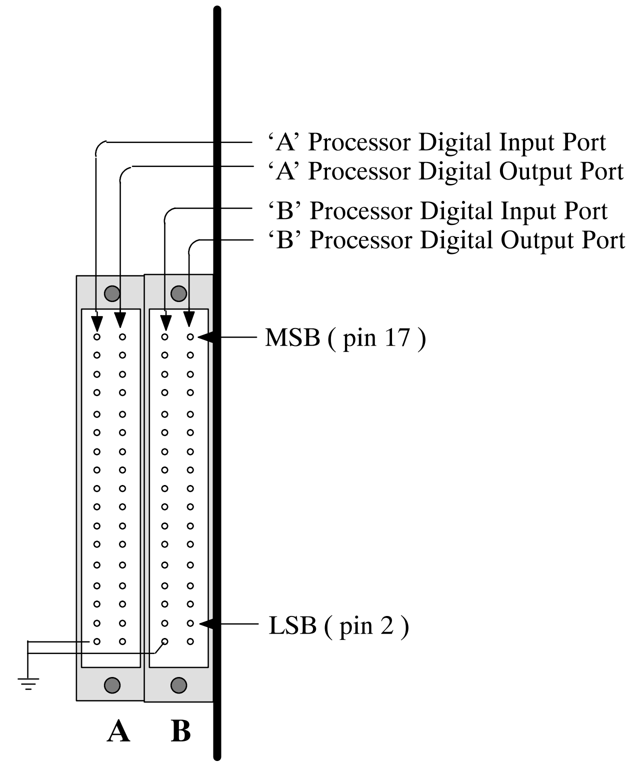
OUTPUT SIGNALS

Zero−crossing pulses are written to the digital output port of the processor to which the ZCPDIG component is allocated. Zero crossing pulses associated with ZCP1 are allocated to digital output port pins 2−7 corresponding to thyristors 1−6 respectively. Zero crossing pulses associated with ZCP2 are allocated to digital output port pins 8−13 corresponding to thyristors 1−6 respectively. DOUT signals are allocated to digital output port pins immediately above the last used zero crossing pin.

Connection from the 3PC digital I/O port is usually via ribbon cable to a MUX card installed in the rear of the RTDS cubicle. From the MUX card signals may be transferred to terminal blocks for connection to the user’s external equipment.

Note that the maximum source current for each digital output port signal is 15 mA and maximum sink current is 24 mA.

The 3PC digital output port pin locations are shown below.



3PC Digital Input/Output Port (View from rear of Cubicle)

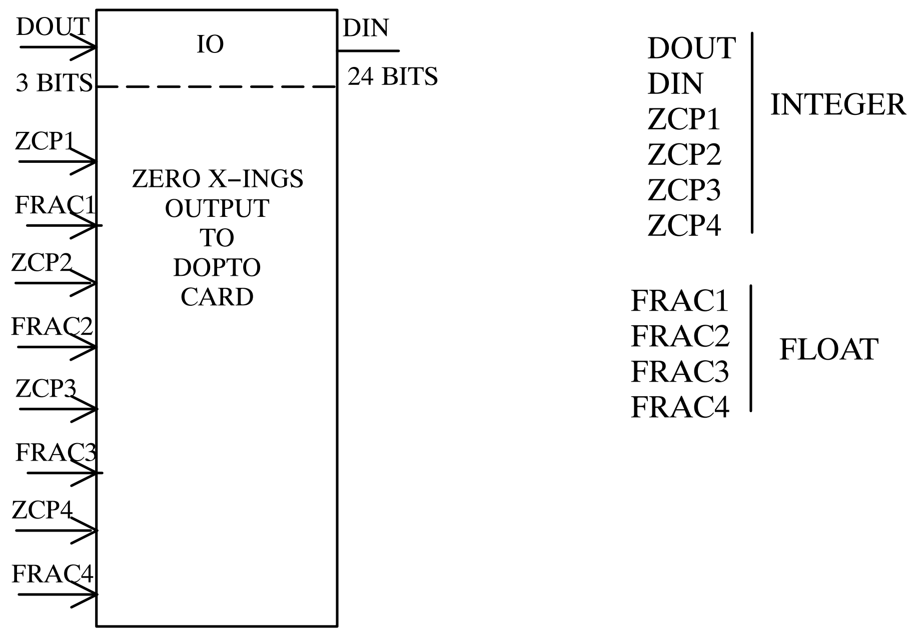
8.20 ZERO CROSSING DOPTO COMPONENT

The zero−crossing component used to write zero−crossing pulses to a DOPTO card is named "rtds_sharc_ZCPDOPT". This component must be assigned to the C processor on a 3PC card which is connected via link ports to a DOPTO card. No other power system or control system components may be allocated to the processor to which the ZCPDOPT component is assigned.

Each ZCPDOPT component can handle the zero−crossing pulse sets (6 pulses per set) for up to four valve groups. Two 12 pulse inverters require only one ZCPDOPT component.

In order to permit maximum usage of the processor's digital I/O port, the user may optionally specify that unused digital port output bits, as well as, the digital input port can be used for other signals.

Parameters associated with the ZCPDOPT component are described below.



rtds_sharc_ZCPDOPT

rtds_sharc_ZCPDOPT

Parameters

Name	Description	Value	Unit	Min	Max
Name	Zero X-ing output unit name:	ZCPDOPT1			
num	Number of 6 Pulse X-ing sets:	One			
invo	Invert X-ing Pulse output bits:	No			
dout	Enable output through high bits:	No			
doutn	-- Number of high bits:	6	1 to 18	1	18
din	Enable DOPTO digital input path:	No			
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on Proc C on Card	1	1 to 18	1	18
defpi	If float input type undefined, receive as:	BP MODE		0	1

Update | Cancel | Cancel All

Name: A unique name identifying the ZCPDOPT component. The name is used to identify signals associated with the ZCPDOPT component in RSCAD/RunTime.

num: The number of zero–crossing sets. Either one, two, three or four six–pulse sets. Input signal pairs ZCP2 – FRAC2, ZCP3 – FRAC3 and ZCP4 – FRAC4 become active only when "num" is set to 2, 3 or 4 respectively.

invo: If yes, then all the bits in the zero–crossing pulse digital output are inverted. If no, then there is no inversion.

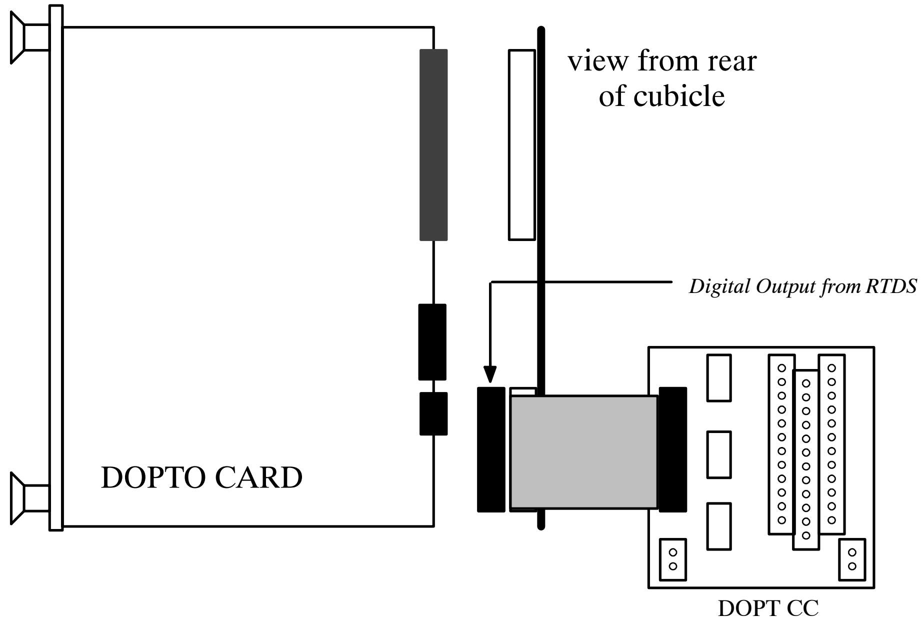
dout: If yes, the DOUT input signal to the icon becomes active. The user can use this signal to write either 18 bits (num=1) or 12 bits (num=2) or 6 bits (num=3) to the DOPTO card's output port. If num=4 no additional digital output port signals are available. Typically the DOPTO's digital output port is connect via ribbon cable to a DOPTO Connector Card (CC). Terminal block allocation for the DOPTO CC is shown below.

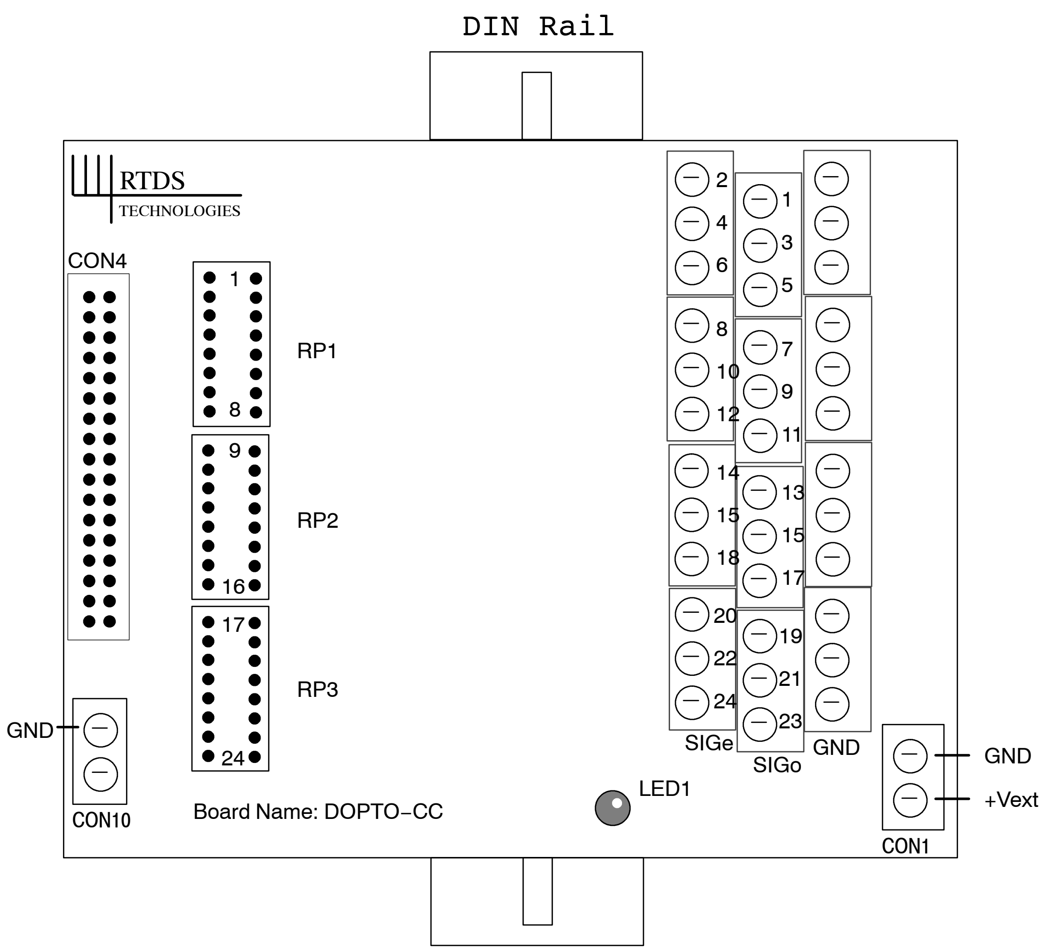
num=1: terminal blocks 1−6 used for zero−crossing pulses corresponding to thyristors ZC1: 1,2 ... 6 respectively.
terminal blocks 7−24 used for DOUT signal

num=2: terminal blocks 1−6 used for zero−crossing pulses corresponding to thyristors ZC1: 1,2 ... 6 respectively.
terminal blocks 7−12 used for zero−crossing pulses corresponding to thyristors ZC2: 1,2 ... 6 respectively.
terminal blocks 13−24 used for DOUT signal

num=3: terminal blocks 1−6 used for zero−crossing pulses corresponding to thyristors ZC1: 1,2 ... 6 respectively.
terminal blocks 7−12 used for zero−crossing pulses corresponding to thyristors ZC2: 1,2 ... 6 respectively.
terminal blocks 13−18 used for zero−crossing pulses corresponding to thyristors ZC3: 1,2 ... 6 respectively.
terminal blocks 18−24 used for DOUT signal

num=4: terminal blocks 1−6 used for zero−crossing pulses corresponding to thyristors ZC1: 1,2 ... 6 respectively.
terminal blocks 7−12 used for zero−crossing pulses corresponding to thyristors ZC2: 1,2 ... 6 respectively.
terminal blocks 13−18 used for zero−crossing pulses corresponding to thyristors ZC3: 1,2 ... 6 respectively.
terminal blocks 19−24 used for zero−crossing pulses corresponding to thyristors ZC4: 1,2 ... 6 respectively.


view from rear
of cubicle
Digital Output from RTDS
DOPTO CARD
DOPT CC


DIN Rail
RTDS
TECHNOLOGIES
CON4
RP1
RP2
RP3
GND
CON10
Board Name: DOPTO-CC
LED1
SIGe
SIGo
GND
GND
+Vext
CON1

As an example, if an integer ‘3’ was written to the DOUT signal and num=1 then DOPTO CC terminal blocks 7 and 8 would be high and terminal blocks 9 through 24 would be 0. If num=2 then terminal blocks 13 and 14 would be high and terminal blocks 15 through 17 low.

doutn: Specify the number of additional digital output bits to use. If num=1 and dout set to “Yes” then this value can be set between 1 and 18; if num=2 then between 1 and 12; if num=3 then between 1 and 6; and if num=4 then dout must be set to No. Unused bits are set to 1 so that the user may optionally use the DOPTO front panel inputs for available signals.

din: Specify whether the digital input signals are to be used. Since the ZCPDOPT component does not actually make use of the digital input signals, a feature is included in the component which allows digital input to be read and the signal written to the DIN icon output signal. All 24 digital input bits may be used. When din is specified as yes the DIN signal becomes active.

ReqP: Allow the RTDS compiler to automatically allocated the card to which the ZCPDOPT component is allocated, or alternatively specify that the ShrC parameters be used to manually specify the processor. Since the DOPTO will be connected to a specific C processor’s link port it is recommended that the Manual option be chosen.

ShrP: The 3PC card to which the ZCDOPT component is allocated. The selected 3PC must be connected to a DOPTO card via the C processor’s link port Active only if ReqP set to Manual.

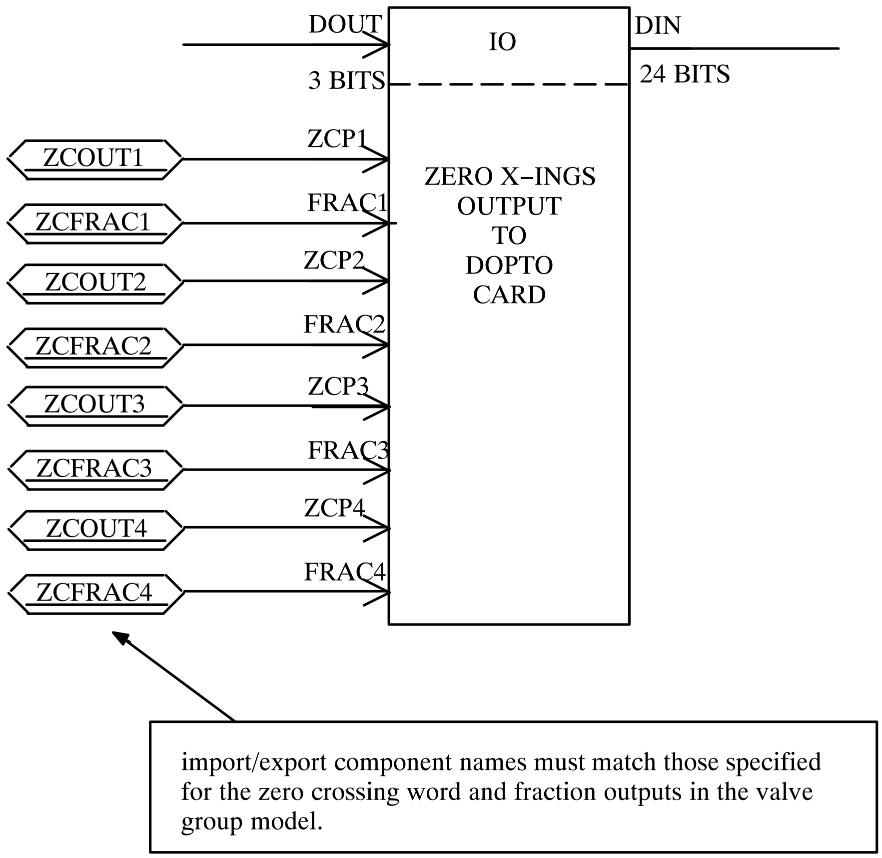
defpi: The parameter is only pertinent when the ZCPDOPT component is allocated to an RTDS rack which contains both TPC and 3PC cards. In this case selecting BP_MODE sets the floating point format used by the ZCPDOPT model to that determined by the RTDS compiler. Selecting IEEE forces the floating point format to be IEEE.

INPUT SIGNALS

Two input signals are required for each six−pulse zero−crossing set. The ZCP1 and the optional signals ZCP2, ZCP3 and ZCP4 which are integer and are produced as output by the valve group models (rtds_sharc_vgrp6 and rtds_sharc_vgrp6i). The necessary Zero−Crossing signal is obtained from the valve group model by specifying ‘Yes’ for item “mon9” under the valve group’s SIGNAL MONITORING IN RUNTIME and CONTROLS menu. The corresponding signal name is then specified for parameter “nam9” under the SIGNAL NAMES FOR RUNTIME and D/A menu.

The FRAC1 and optionally FRAC2, FRAC3 and FRAC4 ZCPDOPT component input signals are Floating Point and are also obtained from the valve group model. The FRAC signal is enabled using the item “mon21” located under the SIGNAL MONITORING (CONTINUED) menu and its name specified as parameter “nam21” under the SIGNAL NAMES (CONTINUED) menu.

Use IMPORT/EXPORT signals to transfer the signal names from the valve group model to the ZCPDIG component as shown below.



OUTPUT SIGNALS

Zero−crossing pulses are written DOPTO output port and transferred via ribbon cable to a DOPTO CC card. Zero−crossing pulses associated with ZCP1 are allocated to DOPTO CC terminal blocks 1−6 corresponding to thyristors 1−6 respectively. Zero−crossing pulses associated with ZCP2 are allocated to DOPTO CC terminal blocks 7−12 corresponding to thyristors 1−6 respectively. Zero−crossing pulses associated with ZCP3 are allocated to DOPTO CC terminal blocks 13−18 corresponding to thyristors 1−6 respectively. Zero−crossing pulses associated with ZCP4 are allocated to DOPTO CC terminal blocks 19−24 corresponding to thyristors 1−6 respectively. DOUT signals are allocated to DOPTO CC terminal blocks numbered immediately higher than the last allocated zero−crossing terminal block.

Note that the maximum source current for each DOPTO output port signal is 5 mA and maximum sink current is 250 mA.

8.21 REFERENCES

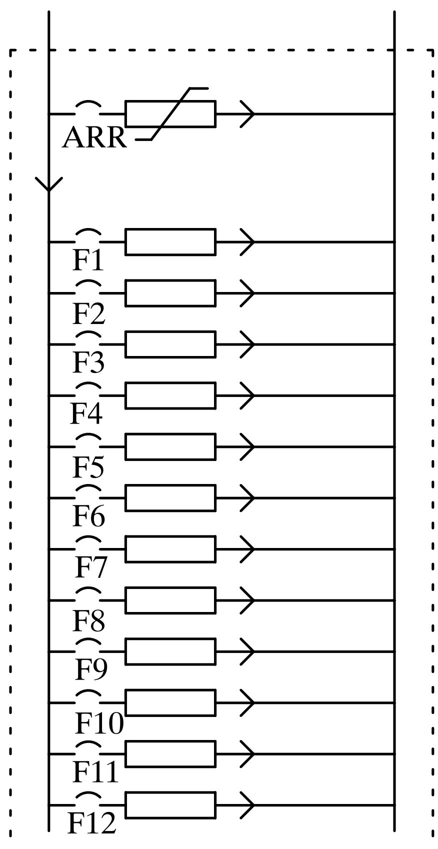
1. “Improved Interfacing of Electrical Machine Models in Electromagnetic Transients Programs”, A.M. Gole, R.W. Menzies, D.A. Woodford, and H. Turanli, I.E.E.E. Trans. on Power Apparatus and Systems, Vol. PAS−103, No. 9, September 1984, pp. 2446−2451

9 SWITCHED FILTER BRANCH

9.1 SWITCHED FILTER BRANCH USAGE IN A SUBSYSTEM (rtds_sharc_SWBRC)

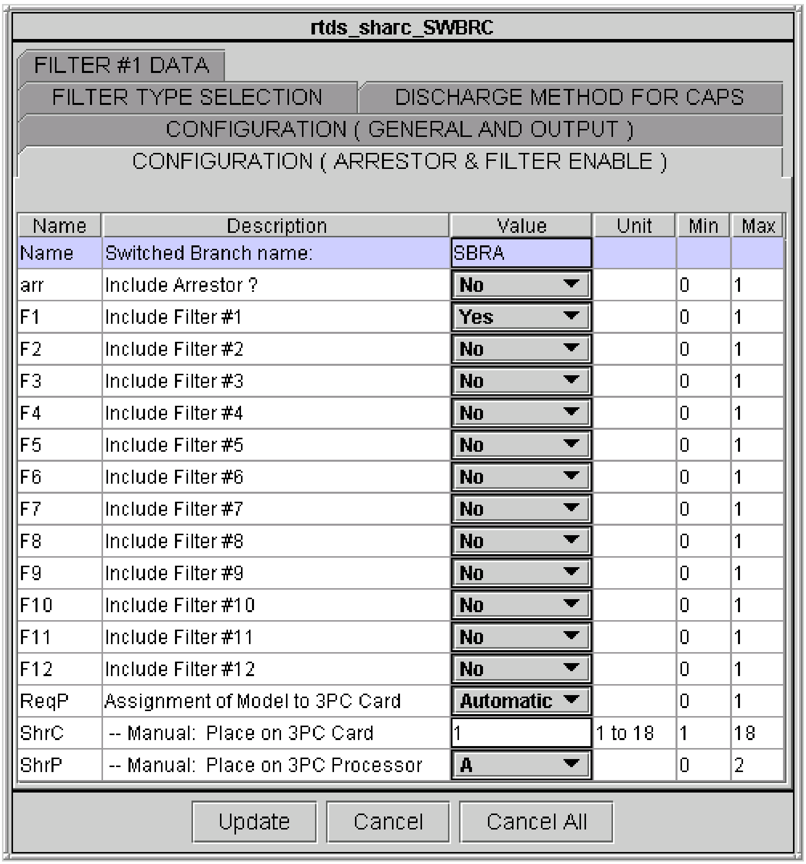
The switched filter branch model can be used with the Sharc−based or RISC−based Network Solutions in order to permit the switching of many shunt filter branches which are commonly connected to HVDC system commutating buses. The switched filter branch model provides up to 12 parallel single−phase filters which may be dynamically switched. Any filter branch can be used to provide a fault branch. The model also permits the inclusion of a bus arrestor model.

The single−phase Sharc filter branch requires the use of one Sharc processor. Therefore, one 3PC card is required in order to simulate a three−phase switched filter bank consisting of 3 switched filter branch models. The switched filter branch may also be used on a GPC/PB5 processor. A single phase switched filter branch requires 1 unit of load. The model icon is as illustrated below except that filter types and current names have been omitted from the illustration.



The model may only be used in conjunction with a Sharc−based or RISC−based Network solutions. When used with Sharc−based Network Solution, the switched branch model must only be connected between two Connector nodes or between a Connector node and Ground. Please refer to Chapter 2 for an explanation of the Sharc–based Network solution. The model will issue an error message if a Sharc–based Network solution does not exist or if the model is not connected to Connector type nodes or ground nodes in the Sharc–based Network Solution. The model can be connected between any nodes in the RISC–based network solution.

9.2 SWITCHED FILTER BRANCH PARAMETER ENTRY


rtds_sharc_SWBRC

FILTER #1 DATA

FILTER TYPE SELECTION | DISCHARGE METHOD FOR CAPS

CONFIGURATION (GENERAL AND OUTPUT)

CONFIGURATION (ARRESTOR & FILTER ENABLE)

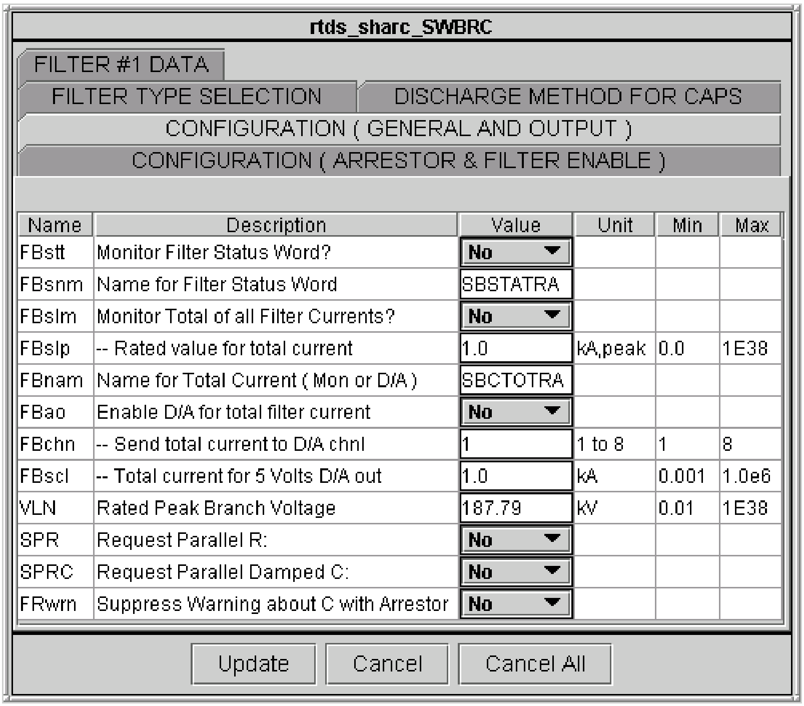
Name	Description	Value	Unit	Min	Max
Name	Switched Branch name:	SBRA			
arr	Include Arrestor ?	No		0	1
F1	Include Filter #1	Yes		0	1
F2	Include Filter #2	No		0	1
F3	Include Filter #3	No		0	1
F4	Include Filter #4	No		0	1
F5	Include Filter #5	No		0	1
F6	Include Filter #6	No		0	1
F7	Include Filter #7	No		0	1
F8	Include Filter #8	No		0	1
F9	Include Filter #9	No		0	1
F10	Include Filter #10	No		0	1
F11	Include Filter #11	No		0	1
F12	Include Filter #12	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

Update | Cancel | Cancel All

The above figure illustrates the CONFIGURATION (ARRESTOR & FILTER ENABLE) menu. Each of the twelve filter branches and the arrestor branch may be enabled by selecting 'Yes' in the appropriate item in the CONFIGURATION (ARRESTOR & FILTER ENABLE) menu. The filters may be enabled or disabled in the model, independently of each other. Filter data for disabled filters are preserved, though not used. In this way, data previously entered for filters which are not required for the given simulation can be saved, and used in future simulations.

The last 3 entries in the CONFIGURATION menu shown above, allow the model to be automatically assigned to a processor (Automatic) or manually assigned to a specified processor. If automatic assignment is requested, the subsequent two entires in the menu are ignored. If manual assignment is requested, a specific processor can be requested by indicating a 3PC card number, beginning with 1, and whether the model will be on processor A, B, or C. A 3PC card number of 1 means the first 3PC card in a rack.

There is a second configuration menu named CONFIGURATION (GENERAL AND OUTPUT) as illustrated below. The menu covers two main areas.

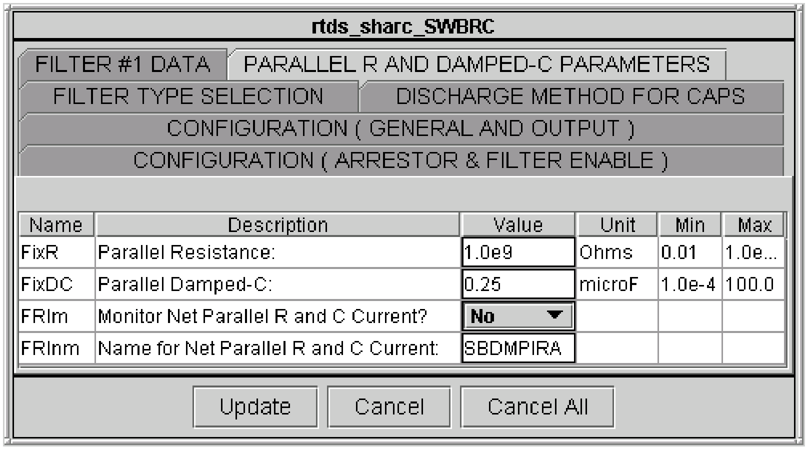


Name	Description	Value	Unit	Min	Max
FBstt	Monitor Filter Status Word?	No			
FBsnm	Name for Filter Status Word	SBSTATRA			
FBslm	Monitor Total of all Filter Currents?	No			
FBslp	-- Rated value for total current	1.0	kA,peak	0.0	1E38
FBnam	Name for Total Current (Mon or D/A)	SBCTOTRA			
FBao	Enable D/A for total filter current	No			
FBchn	-- Send total current to D/A chnl	1	1 to 8	1	8
FBscl	-- Total current for 5 Volts D/A out	1.0	kA	0.001	1.0e6
VLN	Rated Peak Branch Voltage	187.79	kV	0.01	1E38
SPR	Request Parallel R:	No			
SPRC	Request Parallel Damped C:	No			
FRwrn	Suppress Warning about C with Arrestor	No			

This menu specifies output from the overall model which does not relate to any particular filter or the arrestor. For example, the total of all filter currents can be monitored in RunTime and the controls, as a single signal. Also, the calculation of total reactive power flow can be calculated, without passing all of the individual filter currents on the backplane. This is an important advantage because it allows the model to be used without causing a large increase in communication traffic and a corresponding significant increase in time−step size. The total current may be sent to a D/A channel on the front of the Sharc card. The model also allows a filter status integer word to be passed on the backplane. Within this word, bit 1 will be high when filter 1 conducts, bit 2 will be high when filter 2 conducts and so on. Note that the arrestor on/off status is not included within the filter status word. The menu also allows a Rated Peak Branch Voltage to be specified to set the default minimum and maximum of Plots in RunTime when monitoring voltages within individual filters.

The CONFIGURATION (GENERAL AND OUTPUT) menu also allows a parallel resistance branch and a parallel damped capacitance branch to be individually requested, using the items labelled SPR and SPRC. If either is requested, the PARALLEL R AND DAMPED−C PARAMETERS menu tab will appear. If a significant damped−C branch is not specified when an arrestor is requested, a Warning message will be given in Draft during compilation. If a capacitor bank exists already, the Warning message may be suppressed using the "FRwrn" item in the above menu.

The PARALLEL R AND DAMPED−C PARAMETERS menu appears as follows:



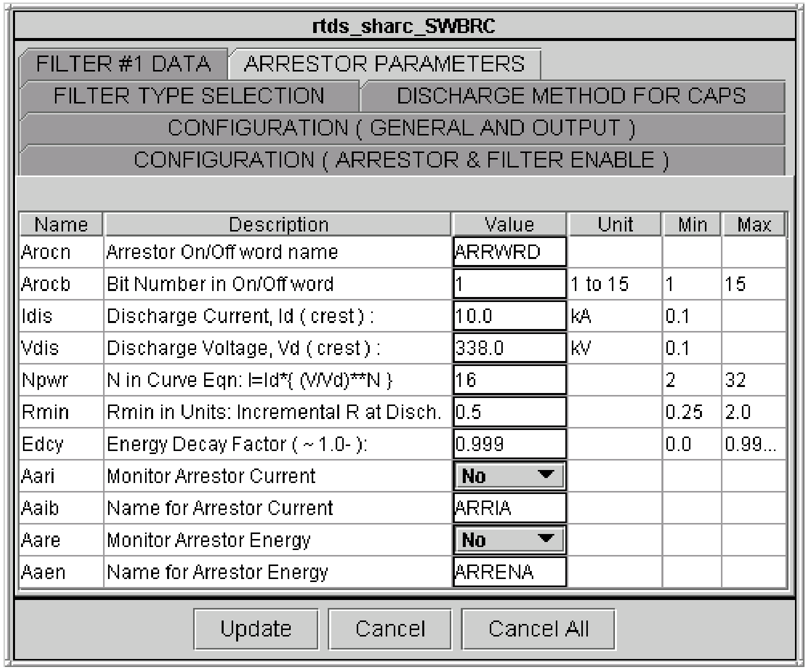
The Damped−C branch is simply a capacitor in series with a small resistance. The use of the Damped−C branch is recommended when using the arrestor branch, as is discussed below. The size of the series resistance R is chosen to be equal to the Dommel resistance of the capacitor C, namely, delt / (2 C). The variable "delt" is the time−step size used in the simulation. This Damped−C branch is equivalent to a compensated resistive branch with resistance of 2R in which the current through the resistance, 2R, is compensated in every time−step according to the current through the 2R resistance in the previous time−step. Such a compensated resistance branch has been discussed in the literature[Ref.1]. The impedance of the Damped−C branch is determined essentially by the capacitance C for the first few kiloHertz because of the relatively small value of the series resistance. Therefore, for estimating current flow through the Damped−C branch, it is possible to ignore the series resistance. In order to confirm the level of current through the parallel resistance and damped−C branches, the current sum may be monitored in RunTime.

The ARRESTOR PARAMETERS menu is available if an arrestor is requested in the CONFIGURATION (ARRESTOR & FILTER ENABLE) menu. The ARRESTOR PARAMETERS menu allows an arrestor to be specified by the following equation:

I = Id * V/Vd * abs((V/Vd)**(N−1))

where Id and Vd are the crest discharge current and voltage.

It is recommended that the arrestor model be used with caution, as numerical instability is highly likely.



Name	Description	Value	Unit	Min	Max
Arocn	Arrestor On/Off word name	ARRWRD			
Arocb	Bit Number in On/Off word	1	1 to 15	1	15
Idis	Discharge Current, Id (crest) :	10.0	kA	0.1	
Vdis	Discharge Voltage, Vd (crest) :	338.0	kV	0.1	
Npwr	N in Curve Eqn: I=Id*((V/Vd)**N)	16		2	32
Rmin	Rmin in Units: Incremental R at Disch.	0.5		0.25	2.0
Edcy	Energy Decay Factor (~ 1.0-):	0.999		0.0	0.99...
Aari	Monitor Arrestor Current	No			
Aaib	Name for Arrestor Current	ARRIA			
Aare	Monitor Arrestor Energy	No			
Aaen	Name for Arrestor Energy	ARRENA			

The Arrestor branch is controlled by a bit in a word provided to the backplane by the Controls Compiler. The above menu specifies the word name and bit number. When the arrestor is switched off, the arrestor energy is reset to zero. A switch is physically in the closed position when the bit is set to 1 and in the open position when the bit is set to 0.

“N” in the arrestor curve equation can be any integer between 2 and 32. However, a high value of N means that the curvature of the curve at the knee point is very high. This can lead to numerical difficulties if the bus consists of inductive nodes (i.e. nodes connected only to inductive branches or high resistance branches). Therefore, it is important to experiment with the circuit being simulated in order to select a suitable value for N.

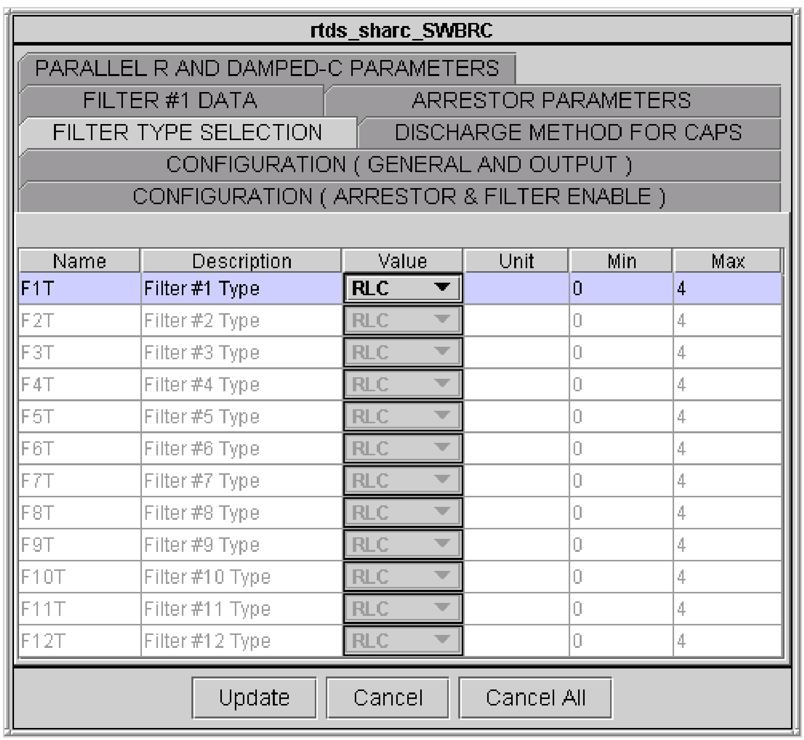
The resistance at the discharge point of the characteristic is Vd / (N * Id). The incremental resistance of the curve drops rapidly as voltage rises above Vd. The Rmin item in the above menu allows a lower limit on resistance to be specified. Rmin is specified as a fraction of the incremental resistance at the discharge point. At low values of voltage, the incremental resistance of the arrestor characteristic can be quite high. Thus, when the arrestor comes out of conduction, it can be numerically similar to opening a breaker. For inductive nodes, this can lead to a numerical oscillation which can cause the arrestor model to malfunction. The SPRC item in the CONFIGURATION (GENERAL AND OUTPUT) menu allows the compensated conductance technique to be employed for damping numerical oscillations, as discussed above. This technique causes a resistance and a current source to be placed in parallel with the arrestor. The current source is set in each time−step to supply the current which went through the resistor in the previous time−step. The compensated conductance can be specified in the PARALLEL R AND DAMPED−C

PARAMETERS menu (which becomes available when YES is chosen for SPRC) according to the apparent capacitance.

In the case where capacitive filters are connected to the bus, it may be possible to omit the Damped−C branch even when using an arrestor branch. In that case, the resulting Warning message may be suppressed by making a suitable selection in the CONFIGURATION (GENERAL AND OUTPUT) menu. It is desirable to avoid using the Damped−C branch when possible because it will have an effect on harmonic impedances, as would any capacitance. A Damped−C value of 0.5 microFarads used in conjunction with the parameters in the above menu provided a stable arrestor model on a purely inductive 230 kV bus with a 2000 MVA fault level. The capacitance provided approximately 10 MVAR of capacitive support to the bus.

The Edcy item in the above menu is a factor which is used to multiply the accumulated arrestor energy in each time step. This is a basic method for providing arrestor cooling.

The final entries in the ARRESTOR PARAMETERS menu enable monitoring of arrestor current and energy in RunTime. Arrestor Energy is in megajoules.



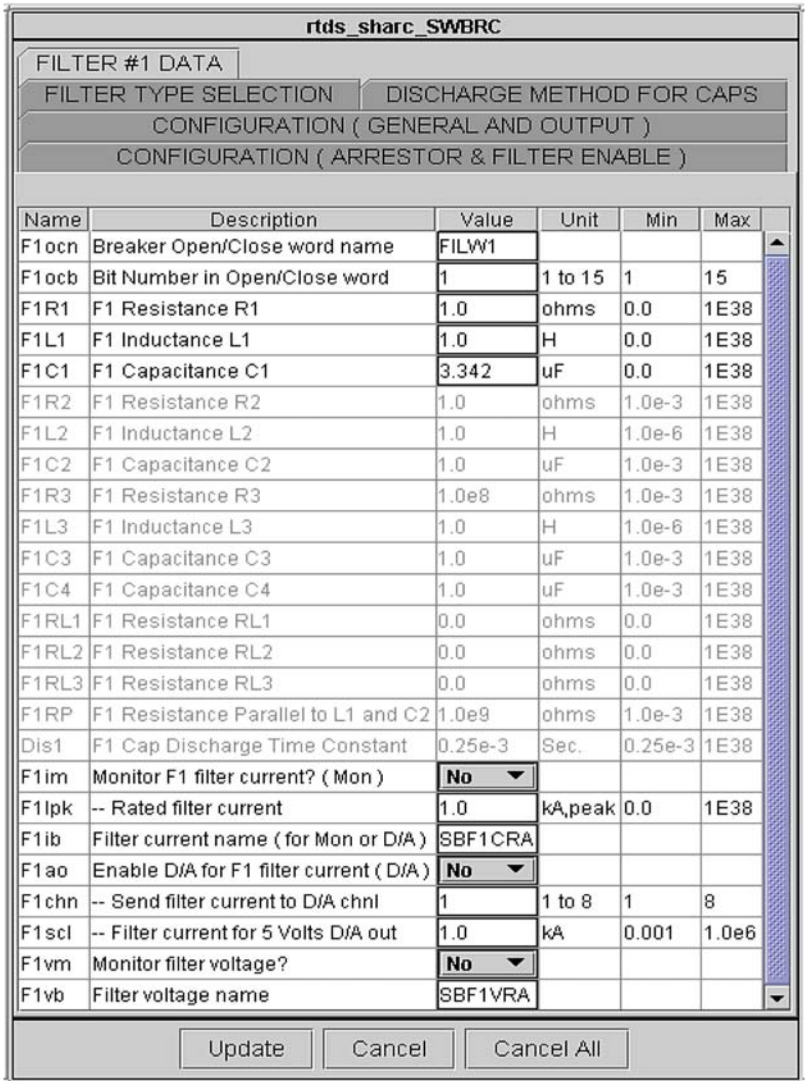
For each active filter branch, the type of filter may be selected in the FILTER TYPE SELECTION menu, shown above. RLC (Series R−L−C), HP (High Pass), C−Type, Double (Double−Damped), Triple (Triple−Tuned), D−type, Quad (Quadruple−Tuned), D2−type and T2−Type filters may be selected. For the RLC type, the R, L, C, RL, RC, or LC combinations may be selected by setting the appropriate parameters to 0.0 in the FILTER # N DATA menus. For example, a resistive fault branch may be created using filter number 3 by selecting RLC for the F3T item and then specifying the L1 and C1 parameters equal to 0.0 in the FILTER #3 DATA menu discussed below.

In the case of filters which include parallel resistive elements, the resistance of the elements can be set large (Example: 1.0E9 Ohms) in order to eliminate the resistive element.

Some filter types contain a capacitor with no parallel path within the filter for capacitor discharge. These filter types retain a charge for some time when the filter breaker is opened during normal operation. These types include the RLC filter when C is not equal to zero, the High−Pass filter; the C−type filter; the Double−Damped, the Triple−Tuned filter, the D−Type filter and the Quadruple−Tuned filter. The DISCHARGE METHODS FOR CAPS menu specifies for each enabled filter, whether it will discharge instantaneously when the filter breaker opens, or according to an RC time constant. If “Instant” discharge is selected, the filter is reset to zero immediately when the breaker opens. If the RC discharge is selected, an appropriate discharge R is placed in parallel with the C, when the breaker is opened. In case of the selection of RC discharge, the time constant can be specified in the FILTER #N DATA menus.

If the RC discharge time constant is very large (> a few seconds), the discharge rate should be checked to verify that it is correct. The discharge within a single time−step must be within the extended precision of the Sharc processors.

A FILTER #N DATA menu is available for each filter branch enabled in the CONFIGURATION (ARRESTOR & FILTER ENABLE) menu. The FILTER #1 DATA menu is shown below.



rtds_sharc_SWBRC

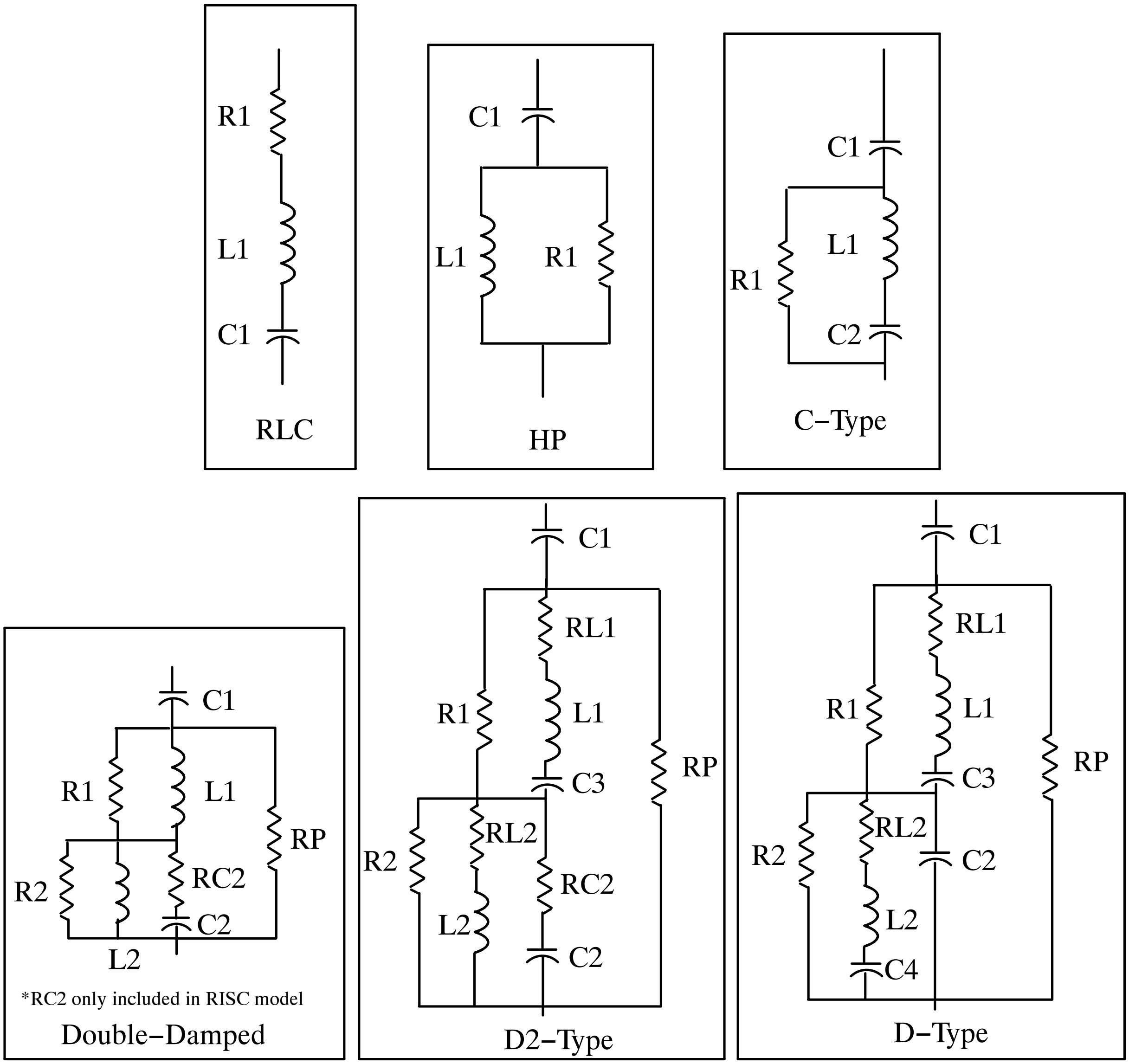
FILTER #1 DATA | FILTER TYPE SELECTION | DISCHARGE METHOD FOR CAPS | CONFIGURATION (GENERAL AND OUTPUT) | CONFIGURATION (ARRESTOR & FILTER ENABLE)

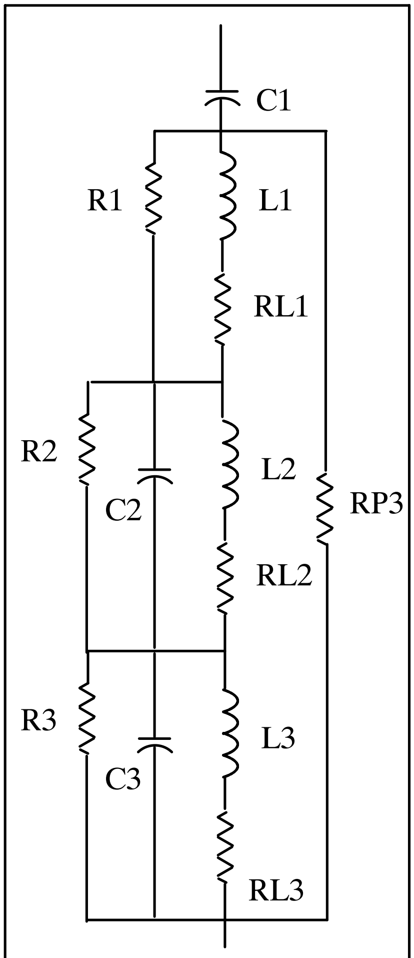
Name	Description	Value	Unit	Min	Max
F1ocn	Breaker Open/Close word name	FILW1			
F1ocb	Bit Number in Open/Close word	1	1 to 15	1	15
F1R1	F1 Resistance R1	1.0	ohms	0.0	1E38
F1L1	F1 Inductance L1	1.0	H	0.0	1E38
F1C1	F1 Capacitance C1	3.342	uF	0.0	1E38
F1R2	F1 Resistance R2	1.0	ohms	1.0e-3	1E38
F1L2	F1 Inductance L2	1.0	H	1.0e-6	1E38
F1C2	F1 Capacitance C2	1.0	uF	1.0e-3	1E38
F1R3	F1 Resistance R3	1.0e8	ohms	1.0e-3	1E38
F1L3	F1 Inductance L3	1.0	H	1.0e-6	1E38
F1C3	F1 Capacitance C3	1.0	uF	1.0e-3	1E38
F1C4	F1 Capacitance C4	1.0	uF	1.0e-3	1E38
F1RL1	F1 Resistance RL1	0.0	ohms	0.0	1E38
F1RL2	F1 Resistance RL2	0.0	ohms	0.0	1E38
F1RL3	F1 Resistance RL3	0.0	ohms	0.0	1E38
F1RP	F1 Resistance Parallel to L1 and C2	1.0e9	ohms	1.0e-3	1E38
Dis1	F1 Cap Discharge Time Constant	0.25e-3	Sec.	0.25e-3	1E38
F1im	Monitor F1 filter current? (Mon)	No			
F1lpk	-- Rated filter current	1.0	kA,peak	0.0	1E38
F1ib	Filter current name (for Mon or D/A)	SBF1CRA			
F1ao	Enable D/A for F1 filter current (D/A)	No			
F1chn	-- Send filter current to D/A chnl	1	1 to 8	1	8
F1scl	-- Filter current for 5 Volts D/A out	1.0	kA	0.001	1.0e6
F1vm	Monitor filter voltage?	No			
F1vb	Filter voltage name	SBF1VRA			

Update | Cancel | Cancel All

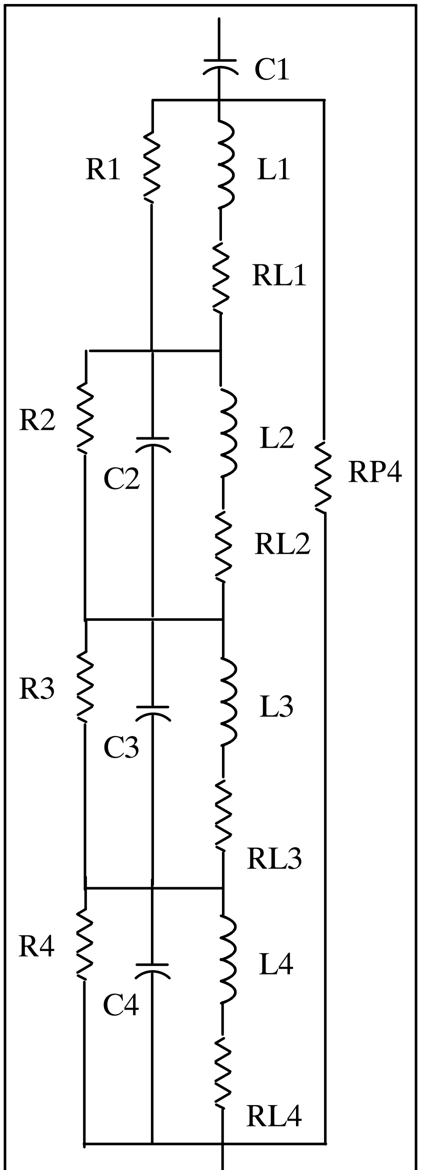
Each filter branch is controlled by a bit in a word provided to the backplane by the Controls Compiler. The first two entries in the FILTER #N DATA menu prompts for the word name and bit number for filter N. A switch is physically in the closed position when the bit is set to 1 and in the open position when the bit is set to 0.

Depending on the filter type selected in the FILTER TYPE SELECTION menu, the parameters R1, L1, C1, R2, L2, C2, R3, L3, C3, R4, L4, C4, RL1, RL2, RL3,RL4, RP, RP3,RP4 and RC2 are defined as illustrated in the following figure. Only R1, L1, and C1 will be accessible in the FILTER #N DATA menus for RLC and High−Pass filters. For RLC filters, an R1, L1 or C1 parameter set to 0.0 causes the resistance, inductance or capacitance to be dropped from the branch model. C2 becomes accessible for C−type filters. R2 and L2 become accessible in the menu for Double−Damped, D−Type, D2−Type, Quad, Triple, and T2−Type filters. RP is available for Double−Damped and D−Type filters. R3, L3, C3, RL1, RL2, RL3 and RP3 parameters are available for Triple−Tuned, Quad and T2−Type filters. Note: The RP3 parameter of the triple tuned filter is only enabled when the component is assigned to a GPC processor. If the triple tuned filter is assigned to a 3PC processor, the RP3 parameter is set to 1.0e9 Ω. The R4, L4, C4, RL4 and RP4 parameters are available for the Quadruple−Tuned and T2−Type filter. The RC2 parameter is available in the Double−Damped, D2−Type and T2−Type filters. Note: The Quadruple−Tuned, D2−Type and T2−Type filters are only available for use on a GPC/PB5 processor.

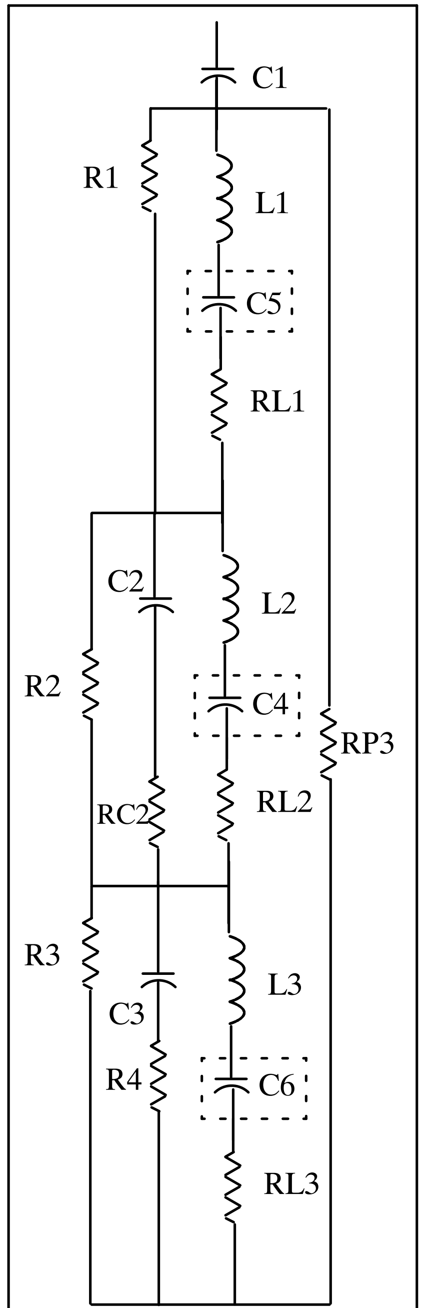




Triple−Tuned



Quadruple−Tuned (Quad)



T2−Type

*Note – capacitors C4, C5, and C6 are optional.

Any combination of these capacitors can be included/excluded from the filter

As discussed above, the FILTER #N DATA menu allows a capacitor discharge time constant to be specified when an RC discharge has been selected in the DISCHARGE METHOD FOR CAPS menu for an enabled filter.

The FILTER #N DATA menu permits an individual filter current to be made available for monitoring in RunTime and controls processors. Monitoring many filter currents should be avoided because each monitored quantity will add 100 or 125 nanoseconds to the time−step. The model creates a signal for the total filter current through all filters in case the total filter reactive power needs to be calculated in a controls processor.

The FILTER #N DATA menu permits an individual filter current to be made available through a D/A channel. If two signals are specified for one D/A channel, an ERROR message will be issued.

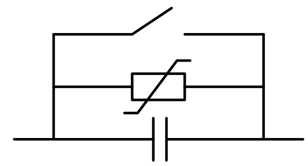
The FILTER #N DATA menu permits an individual filter voltage signal to be made available for monitoring in RunTime and the controls processors. When the filter breaker is closed, this signal will be equal to the voltage at the terminals of the model. When the filter breaker is open, the voltage will be branch voltage behind the breaker. and will be zero for branches which discharge instantly. It will be the decaying branch voltage for branches which discharge C1 according to an RC time−constant.

9.3 REFERENCES

1. “Improved Interfacing of Electrical Machine Models in Electromagnetic Transients Programs”, A.M. Gole, R.W. Menzies, D.A. Woodford, and H. Turanli, I.E.E.E. Trans. on Power Apparatus and Systems, Vol. PAS−103, No. 9, June 1984, pp. 2446−2451.

10 MOV PROTECTED SERIES CAPACITOR

(rtds_sharc_SCAP)



In order to enhance stability and maximize power transfer capability on long, heavily loaded transmission lines, series compensation is often used. This compensation is in the form of series capacitors, either at the ends of the line or at an intermediate point. During fault conditions, very large currents may flow in the transmission line and hence produce very high voltages across the terminals of the capacitors. In order to limit these voltages, Metal Oxide Varistors (MOV) are often included.

An MOV is a device which is placed in parallel with the series capacitor compensation to protect it against overvoltages. It is a non−linear device which for all practical purposes appears as an open circuit to the line current when the voltage across it (and hence across the capacitor) is low. At higher voltages, it begins to conduct more current, hence preventing a large voltage from being developed across the capacitor.

The MOV itself is protected by a parallel by−pass switch that can be closed when the energy absorbed by the MOV exceeds some predetermined limit. The energy absorbed by the MOV will be a function of the voltage across, and the current through the device. During high current fault conditions, the energy build up in the MOV may be very fast. In order to protect it against permanent damage, it can be removed from the circuit by closing its parallel by−pass switch. When this happens, the series capacitor compensation is also removed from the circuit.

Figure 10.1 below shows the basic arrangement of an MOV protected series capacitor. The RTDS model is based on this configuration.

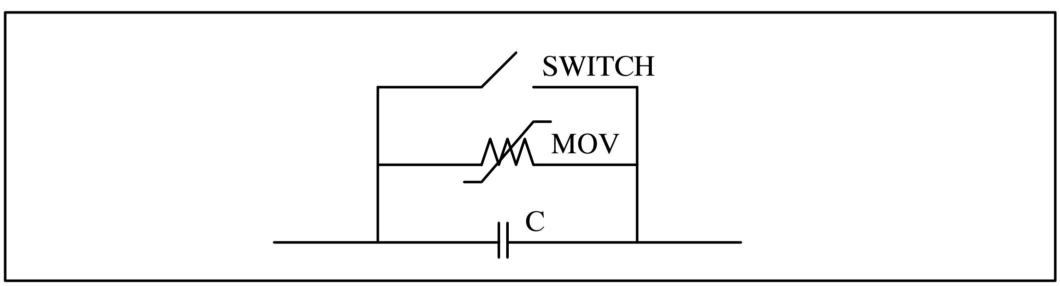


Figure 10.1 Series Capacitor Arrangement

The apparent impedance of a series compensated transmission line may vary depending on the level of voltage across the MOV protected series capacitor. If for example, the voltage level is normal and the MOV is not conducting, the series capacitor will compensate the inductive reactance of the line. However, if the voltage increases to levels where the MOV begins to conduct, its resistance effect will influence the apparent impedance. Furthermore, if energy within the MOV builds up to such a level that the by–pass switch closes, the capacitor and the MOV will be shorted out. This completely removes the compensating effect of the series capacitor. The change in impedance with voltage and energy level presents interesting challenges for protection design and coordination engineers. For this reason, substantial effort has gone into the development of not only an accurate model for the non–linear MOV, but also the coordinated operation of the capacitor, MOV and by–pass switch modelling.

Recent advances in power electronics have seen the introduction of so–called Advanced Series Compensation systems. In such systems, controlled high speed switching of thyristors is used to alter the line impedance dynamically. An additional branch consisting of anti–parallel thyristors in series with an inductive impedance is placed across the series capacitor branch. By controlling the angle at which the thyristors are fired, the impedance and hence the current flowing in the transmission line can be controlled.

A model for representing advanced series compensation is provided. All of the features associated with the MOV protected series capacitor model have been included in the advanced series compensation model.

Chapter 11 deals with the advanced series compensation model.

10.1 MOV / SERIES CAPACITOR EQUIVALENT CIRCUIT REPRESENTATION

An RTDS model has been written to represent a series capacitor element with a parallel connected MOV and by–pass switch. Figure 10.1 of the preceding section illustrates the circuit upon which the model has been based.

On the RTDS, the MOV protected series capacitor element can be connected between any two electrical nodes within a subsystem. It is generally associated with the modelling of long transmission lines and is placed either at one, or both ends of the line, or at some intermediate point along the line. To place the compensation along the line, the transmission line itself (if represented as a travelling wave model) must be split into two or more sections to introduce the necessary connection nodes.

The MOV protected series capacitor element is a three phase model. Each three phase model requires one processor.

In its non–conducting state the MOV will appear as an open circuit and hence the parallel connected MOV, capacitor and open by–pass switch will together appear as a simple capacitive branch. The overall branch solution will under these conditions comprise just the Dommel equations for a capacitive branch (ie. parallel resistor and current source). If the MOV device begins to conduct, then an additional current injection (ie. current source) will also contribute to the solution. The non−linear effects of the MOV are represented by a non−integer power series equation. Finally, the status of the by−pass switch must also be known and considered when the overall branch solution from the auxiliary processor is formulated.

The MOV protected capacitor algorithm is therefore three−fold;

i) Solution for non−linear MOV using power series equation

ii) Solution for capacitor element (according to Dommel representation)

iii) Check switch status – if open then no effect, if closed then short circuit

An illustration of the overall branch equivalent circuit is given in Figure 10.2 .

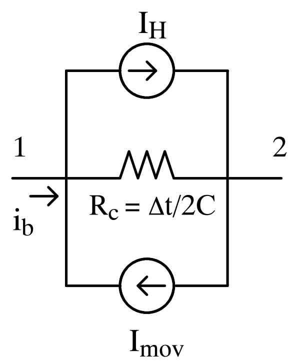


Figure 10.2 Basic Equivalent Circuit For MOV / Capacitor Branch

10.1.1 METAL OXIDE VARISTOR SOLUTION

The V−I relationship of the MOV device is non−linear and has been modelled using the non−integer power series approach common to a number of RTDS algorithms. A single term power series such as that shown in equation 10.1. was found to be suitable. An advantage of the power series representation for non−linear devices is that it provides a smooth (continuous), dynamically calculated solution. No curve storage or iterative procedures are required. For real−time operation, these features are essential.

$$I_{mov} = (V_n)^{32} \qquad 10.1$$

In this equation V_n represents the normalized voltage across the MOV and is defined as illustrated in equation 10.2.

V_{mov} represents the measured voltage across the MOV / capacitor parallel combina-

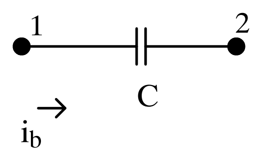
$$V_n = V_{mov} / V_{const} \qquad 10.2$$

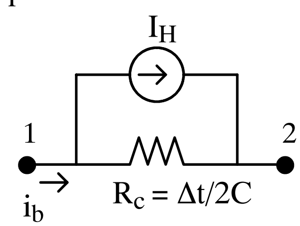
tion and V_{const} is defined based on the user specified 10kA discharge voltage (ie : the user specified clipping voltage).

The MOV contribution to the auxiliary processors solution is then a variable current injection as calculated from equation 10.1 above. When the by−pass switch is closed the value of I_{mov} is always forced to 0.0.

10.1.2 CAPACITOR SOLUTION

A current injection history term I_H is calculated for the capacitor according to the standard Dommel equations and is combined with the MOV current injection within the auxiliary processor. The standard solution for a capacitor element is as shown below.





$$i_b(t) = (1/R_c) * (V_1(t) - V_2(t)) + I_H(t - \Delta t)$$
$$I_H(t) = (-1/R_c) * (V_1(t) - V_2(t)) - i_b(t) \qquad 10.3$$

10.1.3 BY−PASS SWITCH

A by−pass switch is placed across the terminals of the series capacitor for the purpose of protecting the MOV. The by−pass switch is normally open and in the real system would only close if the MOV was in danger of being thermally damaged. During a fault, when the current is high and the voltage across the series capacitor approaches the MOV discharge or clipping level, the MOV begins to conduct and the energy stored within the device builds up. If this process exceeds some critical level, there is a danger of damaging or even destroying the MOV. When the known safe level of stored energy is exceeded, a switch closure is triggered and both the series capacitor and the MOV are simultaneously by−passed. The MOV protected series capacitor model designed for use on the RTDS includes this by−pass feature.

An internal energy calculation is performed as part of the overall algorithm. The instantaneous value of energy calculated in each time−step is based on the voltage and current within the MOV and on the energy value calculated in the previous time step. Equation 10.4 illustrates this internal energy calculation as coded for the RTDS model.

$$WZnO(t) = df * WZnO(t-\Delta t) + \Delta t * V_{mov}(t) * I_{mov}(t) \qquad 10.4$$

The term df in the above equation is the so called energy decay factor and represents the rate of energy loss within the MOV device (ie rate of cooling). In the actual system, the rate of cooling or energy loss may be such that many minutes or even hours would be required between the instant of by−pass and the point in time when the MOV could safely be re−inserted. The energy decay factor in the RTDS model allows the energy dissipation rate to be accelerated in order to allow repetitive cases to be run without the long delay time which would be required to cool the physical device.

Triggering of the by−pass switch can be done in one of two ways. When building the case in the RSCAD based DRAFT module, one of the items (BOP) in the CONFIGURATION menu (shown below) relates to how the by−pass switch should be triggered. The first choice (Internal) involves the internal energy calculation based on equation 10.4. If this option is chosen, two energy limits and the energy decay factor must be specified (items Df, Ebp and Eopen). The first limit (Ebp) represents the energy level at which the by−pass switch should close. The second energy limit (Eopen) represents the level at which the by−pass switch should re−open (note that re−opening will occur at the first branch current zero crossing after the energy limit condition is met).

The second by−pass switch triggering option (CC) allows control over the status of the switch using controls components to operate it dynamically from RunTime or externally. The MOV requires a signal generated from the controls component to operate the breaker.

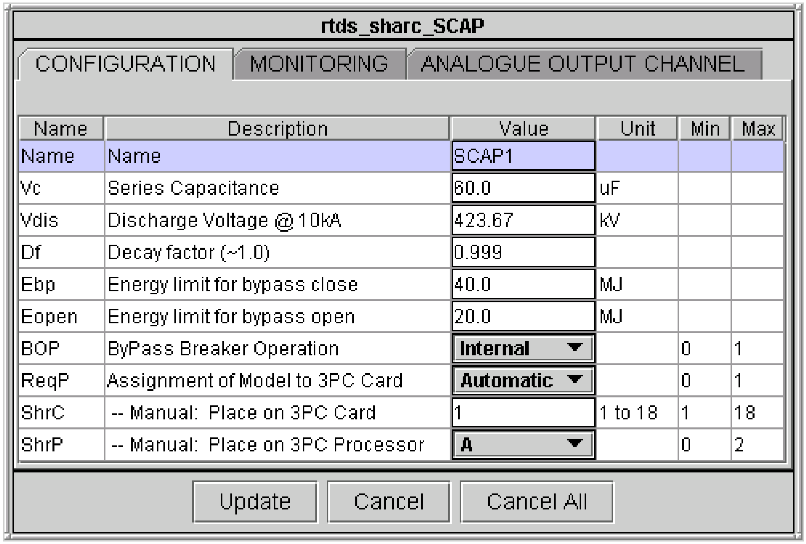
A ZERO signal should be provided when the switch is to be OPEN and a ONE when the switch is to be CLOSED.

Again, re−opening of the switch will occur on the first branch current zero crossing following the open command.

10.2 INPUT DATA

The required input data for a three phase MOV protected series capacitor model is summarized below.

CONFIGURATION MENU



Name	Description	Value	Unit	Min	Max
Name	Name	SCAP1			
Vc	Series Capacitance	60.0	uF		
Vdis	Discharge Voltage @ 10kA	423.67	kV		
Df	Decay factor (~1.0)	0.999			
Ebp	Energy limit for bypass close	40.0	MJ		
Eopen	Energy limit for bypass open	20.0	MJ		
BOP	ByPass Breaker Operation	Internal		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

Name – The MOV–branch name can be any name beginning with a letter. Following the first letter the name can contain up to nine more alpha–numeric characters. This name is used in all cross–referencing between Draft and RunTime for the particular unit being defined. If an appropriate name is not assigned to the MOV, the Draft compiler will issue an error.

Vc – The value of capacitance is entered in μf.

Vdis – The 10kA discharge voltage level must be specified. This information is used to formulate the point at which the MOV is to start conducing. The quantity is entered in kV.

Df – The decay factor defines how quickly the energy is dissipated within the MOV device. The number should be quite close to 1.0 since it is used simply as a reduction or multiplication factor in each calculation time step. A value of 1.0 means no energy dissipation while a value of 0.0 means total energy dissipation within one simulation time step. Since a physical MOV may take minutes or hours to cool, this feature has been added to allow accelerated cooling for practical reasons.

Ebp – This represents the energy threshold for by–pass switch operation. When the internally calculated energy level within the MOV exceeds this user defined level the by–pass switch will close. The energy level is entered in megajoules.

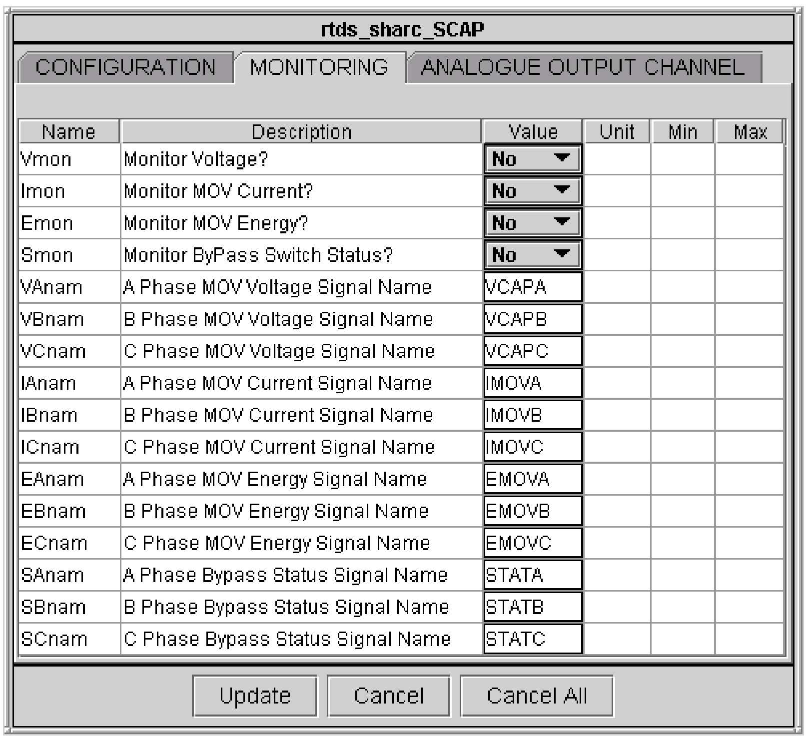
Eopen – This represents the a second energy threshold, this time for by–pass switch re–opening. When the internally calculated energy level within the MOV drops below this second user specified level, the MOV can be safely re–inserted into the circuit. The energy level is entered in MJ.

BOP – The by–pass breaker can be operated internally or by using controls components to generate a signal. If “Internal” is selected the by–pass breaker operation is determined by the internal energy calculation. If “CC” is selected a control signal is used to operate the breaker. If ’CC’ is selected a new menu tab becomes available labelled “BY–PASS BREAKER OPERATION SIGNAL NAMES”.

ReqP – The MOV component can be assigned to a user defined sharc processor. If “Manual” is selected, the MOV component will be assigned to the sharc processor defined by the two menu items below, ShrC and ShrP. If “Automatic” is selected, the compiler will assign the component to an available processor.

ShrC/ShrP – If “Manual” 3PC assignment was selected above, the user is required to enter the 3PC card number and select the processor to compute the MOV model. If “Automatic” is selected, these two menu items are not used.

MONITORING MENU



Name	Description	Value	Unit	Min	Max
Vmon	Monitor Voltage?	No			
Imon	Monitor MOV Current?	No			
Emon	Monitor MOV Energy?	No			
Smon	Monitor ByPass Switch Status?	No			
VAnam	A Phase MOV Voltage Signal Name	VCAPA			
VBnam	B Phase MOV Voltage Signal Name	VCAPB			
VCnam	C Phase MOV Voltage Signal Name	VCAPC			
IAnam	A Phase MOV Current Signal Name	IMOVA			
IBnam	B Phase MOV Current Signal Name	IMOVB			
ICnam	C Phase MOV Current Signal Name	IMOVC			
EAnam	A Phase MOV Energy Signal Name	EMOVA			
EBnam	B Phase MOV Energy Signal Name	EMOVB			
ECnam	C Phase MOV Energy Signal Name	EMOVC			
SAnam	A Phase Bypass Status Signal Name	STATA			
SBnam	B Phase Bypass Status Signal Name	STATB			
SCnam	C Phase Bypass Status Signal Name	STATC			

Up to four quantities can be monitored from each phase of the MOV protected series capacitor unit.

Vmon – The voltage across the MOV protected series capacitor branch can be monitored on the RunTime Operators Console. Branch voltage calculation is determined as the difference in node voltage between the two nodes to which the model is connected. Voltage is displayed in kV. “Yes” must be selected to monitor this quantity.

Imon – The current through the MOV element can also be monitored on the RunTime screen. Current is displayed in kA. “Yes” must be selected in order to monitor MOV current.

Emon – The energy build up within the MOV can be displayed. Each time the MOV conducts current the energy absorbed increases and if the internal energy calculation option is used, this quantity can be displayed. Units for MOV energy are MJ. "Yes" must be selected to monitor this quantity.

Smon – The open/close status of the by–pass switch can be monitored in RunTime. The status signal is an integer signal where a 1 represents open and a 0 represents close. "Yes" must be selected to monitor this quantity.

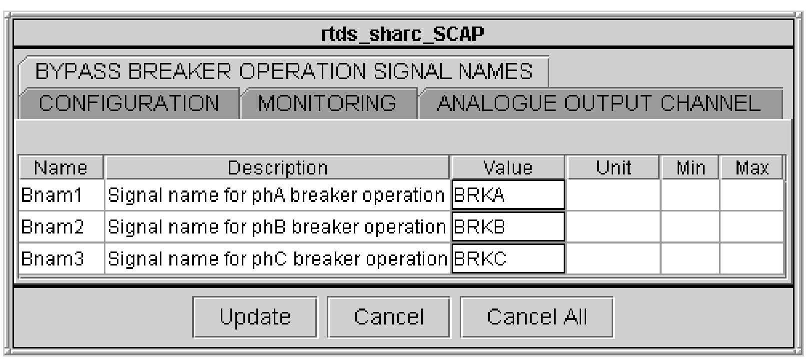
V*name – If the voltage across the MOV protected series capacitor branch is to be monitored from RunTime. A voltage signal name must be given for each phase. This signal name if used for cross–referencing between Draft and RunTime.

I*name – If the current through the MOV is to be monitored, a current signal name for each phase must be supplied.

E*name – If the energy is to be monitored from RunTime, an energy signal name must be supplied for each phase.

S*name – If the by–pass switch status is to be monitored, a signal name must be supplied for each of the three phases.

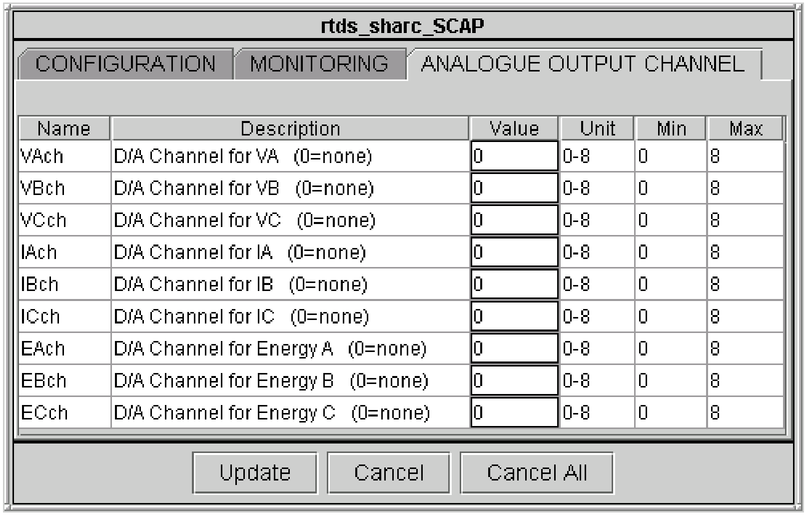
BY–PASS BREAKER OPERATION SIGNAL NAMES MENU



This menu item will only appear if the by–pass breaker is to be operated using the controls components.

Bnam* – A signal name is required to operate the by–pass breaker. The signal is generated using the controls components. For proper operation, an integer signal is required, a value of zero will open the by–pass breaker and a value of one will close the by–pass breaker.

ANALOGUE OUTPUT MENU



Name	Description	Value	Unit	Min	Max
VAch	D/A Channel for VA (0=none)	0	0-8	0	8
VBch	D/A Channel for VB (0=none)	0	0-8	0	8
VCch	D/A Channel for VC (0=none)	0	0-8	0	8
IAch	D/A Channel for IA (0=none)	0	0-8	0	8
IBch	D/A Channel for IB (0=none)	0	0-8	0	8
ICch	D/A Channel for IC (0=none)	0	0-8	0	8
EAch	D/A Channel for Energy A (0=none)	0	0-8	0	8
EBch	D/A Channel for Energy B (0=none)	0	0-8	0	8
ECch	D/A Channel for Energy C (0=none)	0	0-8	0	8

In addition to monitoring the MOV signals from RunTime, these signals may also be sent to the analogue output channels. An analogue channel number can be entered for each signal. Each sharc processor has eight analogue channels available. The MOV component is computed on one sharc processor, therefore each signal must be assigned a unique channel number. If the MOV component has been assigned to a sharc processor using the 'Automatic' feature, please consult the .map file to determine which processor the analogue output signals are available for monitoring. Entering a non−zero channel value will produce RunTime scale and offset sliders to modify the analogue output signal.

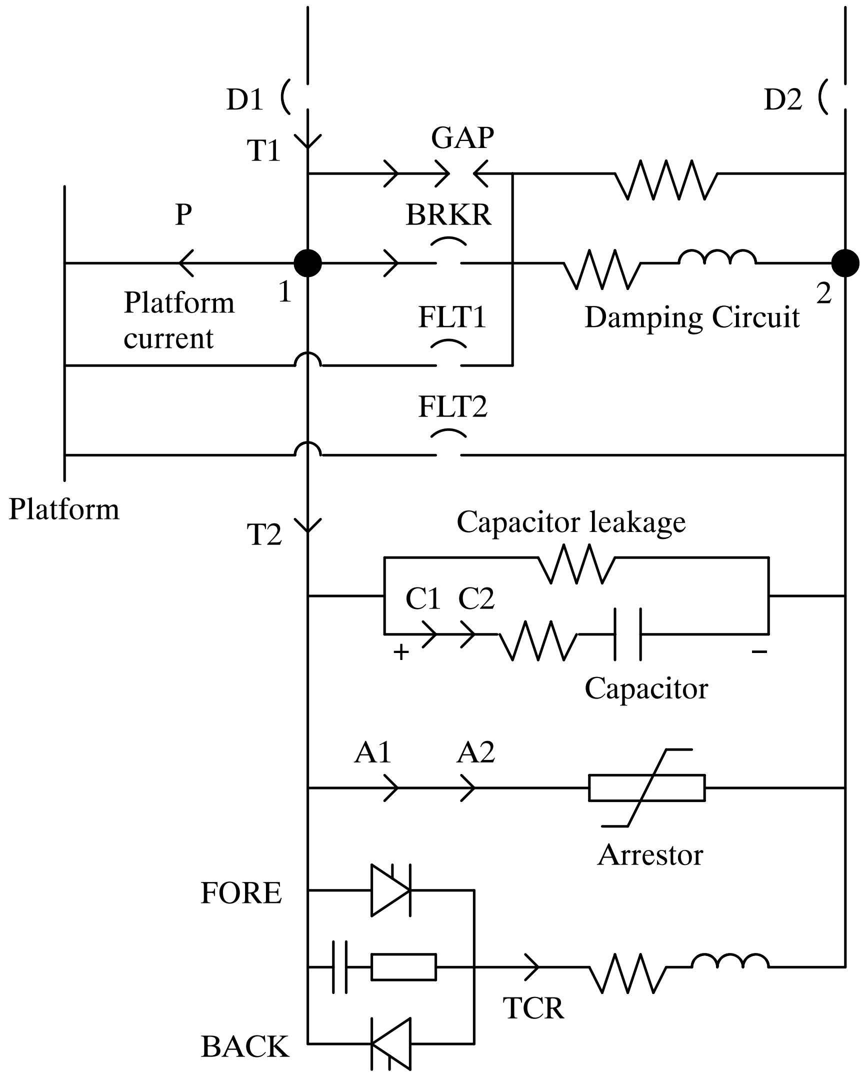
11 THYRISTOR CONTROLLED SERIES COMPENSATION

(rtds_sharc_TCSC)

11.1 INTRODUCTION

The Thyristor Controlled Series Compensation (TCSC) model was developed to bring advanced testing of TCSC control systems to the RTDS simulator.

The single−phase TCSC model requires the use of one Sharc processor. Therefore, one 3PC card is required in order to simulate a three−phase TCSC bank.



The Sharc TCSC model has several features:

1. The Thyristor Controlled Reactor (TCR) has been implemented in the TCSC model to provide improved firing accuracy. The signals required by the TCSC model in support of improved firing can come from the Digital Input Time Stamp (DITS) card or from a control system modelled in the RTDS Controls Compiler.

   The DITS card samples a 6–bit firing–pulse word from external TCSC controls every 60 nanoseconds in each time–step. Based on this sampling rate, the DITS card generates information for the TCSC model as to the exact time of arrival of firing pulses in the time–step. This information is used by the TCR to correct for late sampling of firing pulses. Use of the DITS card will be discussed below.

   The TCR supports BOD firing as discussed below. Briefly, the TCR valves will only fire in the presence of a firing pulse and a User specifiable level of forward voltage.

2. The TCSC model includes two Platform Disconnects shown as D1 and D2 in the icon. Including these disconnects in the model creates two additional nodes, shown as “1” and “2”. These nodes are internal to the model and do not count as Sharc Network Solution nodes.

   It is intended that a Bypass breaker will be added on each phase (not shown above), using a single–phase breaker.

3. Two fault switches are included in the model shown as FLT1 and FLT2 in the icon. These two fault switches are connected from either side of the damping reactor to the platform. A measurement of current to the platform through a measuring device is illustrated at “P” in the above icon.

4. Two measurements of Arrestor Current are created, shown as A1 and A2 in the icon. Each can be multiplied internally by a User specified factor before output. Parameter named ’farr1’ is used to scale signal A1 and parameter ’farr2’ is used to scale signal A2. The signals can be provided to D/A output channels or monitored in RunTime. Complete lists of signals available for D/A output and monitoring in RunTime are provided below.

5. Two measurements of Capacitor Current are created, shown as C1 and C2 in the above icon. The second output is multiplied by a factor that is passed on the backplane. This factor can be varied dynamically by the Controls Compiler components.

6. The Arrestor model has the ability to calculate energy accumulation. It is also possible to switch the Arrestor model ON and OFF. When the Arrestor is switched OFF, the accumulated energy is reset to zero.

7. The Main Gap (GAP) includes a Damping Circuit which damps current oscillations when the GAP is fired.

   The GAP will not fire unless the voltage on the GAP is more than a User specified magnitude. The GAP will not recover until the GAP current is lower than a User specified level for more than a User specified time period.

   The GAP, Bypass Breaker (BRKR), and Fault No. 1 (FLT1) are all in parallel. If more than one of these units is conducting at a given time, then the current through the damper circuit is assigned completely to one unit with a priority order of BRKR, FLT1, and GAP. For example, if the GAP is fired, it will conduct all of the current until either the BRKR or FLT1 is closed. When the BRKR or FLT1 is closed, the BRKR or FLT1 will conduct all of the current and the GAP will conduct none. If the BRKR is closed, then neither the FLT1 nor the GAP will conduct any current.

11.2 USE OF THE TCSC MODEL WITH THE NETWORK SOLUTION

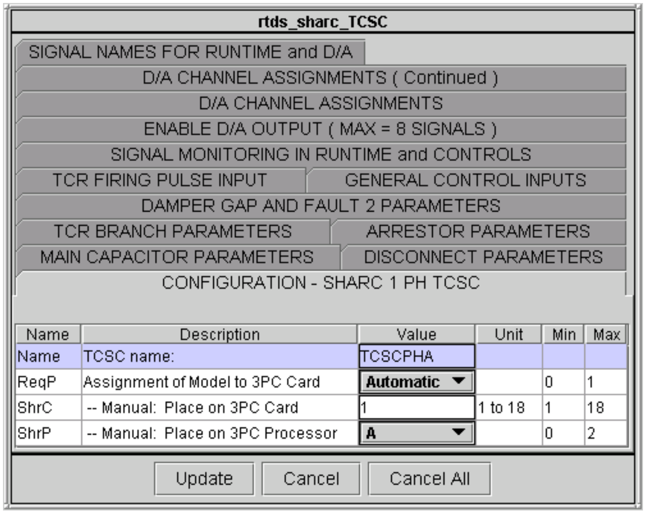
The TCSC model can be used with the Sharc or RISC Network Solution, discussed in Chapter 2. The TCSC model can be assigned to a sharc or risc processor. To model a single−phase TCSC requires one 3PC processor or 2 units of RISC processing power.

The models can be used with external TCSC controls, with or without a DITS card. However, firing accuracy will be degraded if no DITS card is used.

The TCSC model must be attached to Connector type nodes in the Sharc Network Solution. An ERROR message will be issued if this rule is not followed. All nodes in the RISC network solution are Connector type nodes.

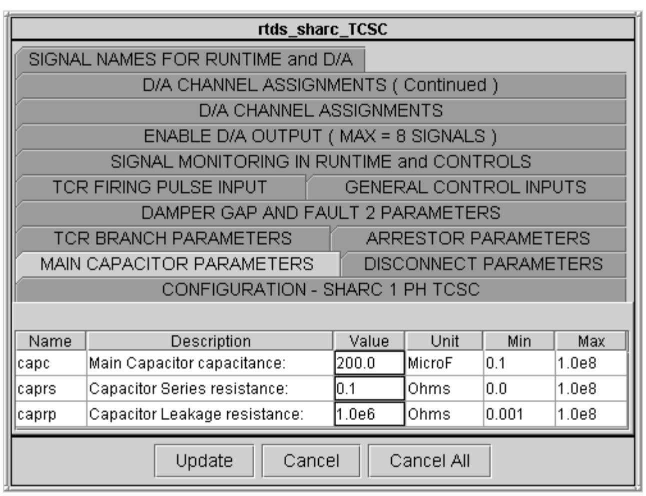
The models can be used with external TCSC controls, with or without a DITS card. However, firing accuracy will be degraded if no DITS card is used.

11.3 PARAMETER ENTRY FOR THE TCSC MODEL

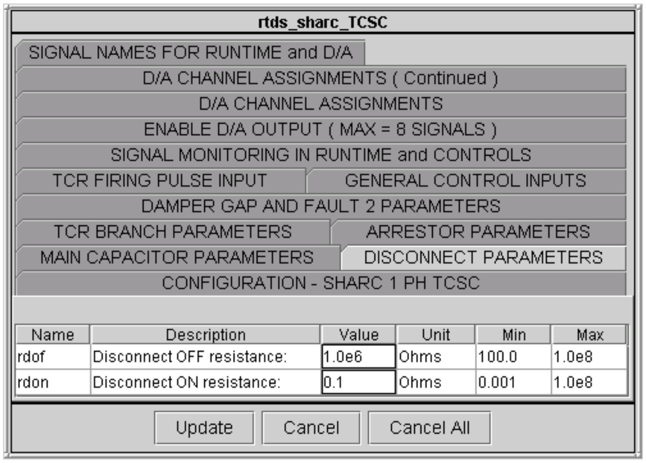


The CONFIGURATION menu (shown above) asks for a Name for the TCSC model. This name will appear on the icon.

The CONFIGURATION menu allows the model to be automatically or manually assigned to a processor. If automatic assignment is requested, the subsequent two entries in the menu are ignored. If manual assignment is requested, a specific processor can be indicated by 3PC card number (beginning with 1) and processor A, B, or C. A 3PC card number of 1 means the first 3PC card in a rack.



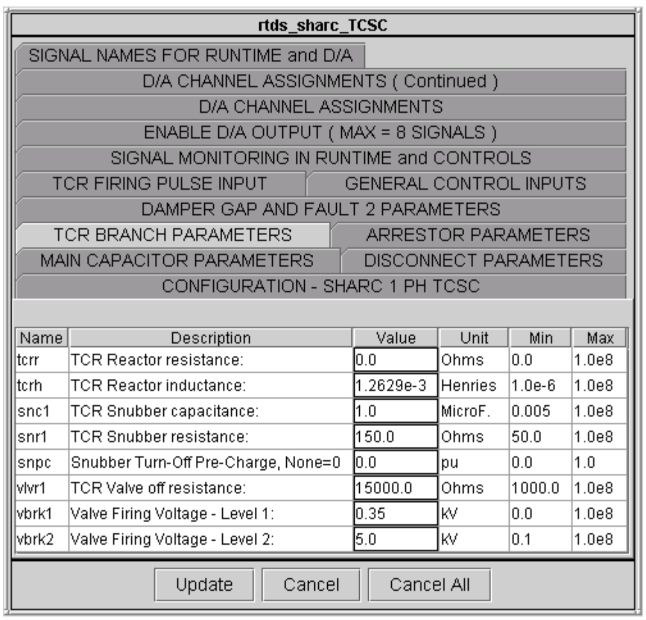
The MAIN CAPACITOR PARAMETERS menu prompts for the capacitance and series resistance of the Main Capacitor and a parallel capacitor leakage resistance. When specifying the leakage resistance, it is appropriate to consider the OFF resistance of FLT2 and the Valves. The OFF resistance of the BRKR, FLT1 and the GAP is infinite. The resistance of the Arrestor is also infinite when it is OFF.



Name	Description	Value	Unit	Min	Max
rdof	Disconnect OFF resistance:	1.0e6	Ohms	100.0	1.0e8
rdon	Disconnect ON resistance:	0.1	Ohms	0.001	1.0e8

The DISCONNECT PARAMETERS menu prompts for the ON and OFF resistance of the Platform Disconnects.

The TCR BRANCH PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
tcrr	TCR Reactor resistance:	0.0	Ohms	0.0	1.0e8
tcrh	TCR Reactor inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
snc1	TCR Snubber capacitance:	1.0	MicroF.	0.005	1.0e8
snr1	TCR Snubber resistance:	150.0	Ohms	50.0	1.0e8
snpc	Snubber Turn-Off Pre-Charge, None=0	0.0	pu	0.0	1.0
vlvr1	TCR Valve off resistance:	15000.0	Ohms	1000.0	1.0e8
vbrk1	Valve Firing Voltage - Level 1:	0.35	kV	0.0	1.0e8
vbrk2	Valve Firing Voltage - Level 2:	5.0	kV	0.1	1.0e8

The RC time constant of the snubber should be maintained equal to about 2 time−steps.

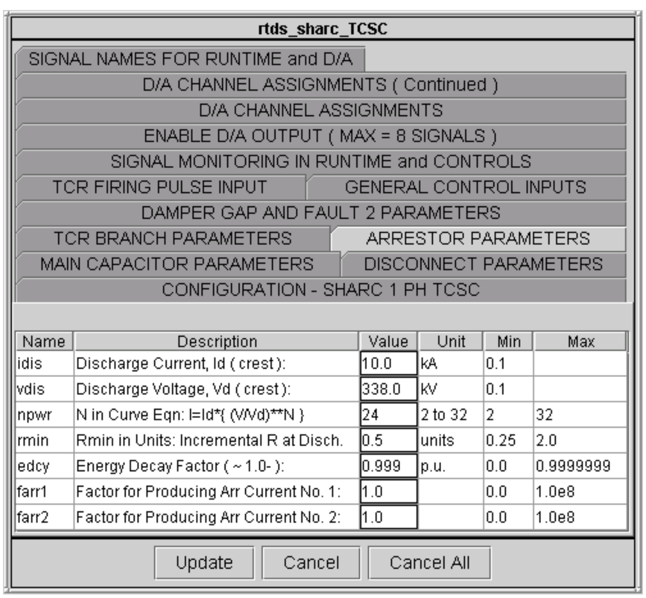
Valve turn−off in the TCSC always interpolates back to a zero−crossing of current in the turn−off time−step. Charge lost through reverse current in the valve after the zero−crossing is recovered and placed back on the main TCSC capacitor. The reactor current is set to zero at the zero−crossing point.

The item “Snubber Turn−Off Pre−Charge” in the above menu provides an option concerning the turn−off of valves in the TCSC model. The default is to place no charge on the snubber capacitor (Snubber Turn−Off Pre−Charge = 0.0) after interpolating back to the current zero−crossing point. When this is done, the snubber will ring in the normal way and provide an increase in voltage applied to the valve during the valve recovery.

However, the snubber is modelled simply, as shown in the icon of the TCSC. Therefore, it may known through detailed study of the actual valve and snubber, that the recovery voltage overshoot will be less than seen in the simulation. The item “Snubber Turn−Off Pre−Charge” allows the valve voltage overshoot to be reduced by pre−charging the snubber capacitor with a fraction (0.0 to 1.0) of the main capacitor voltage, after interpolating back to the zero−crossing point. The charge placed on the snubber is taken from the main capacitor so as to conserve charge. The presence of the charge reduces ringing in the snubber.

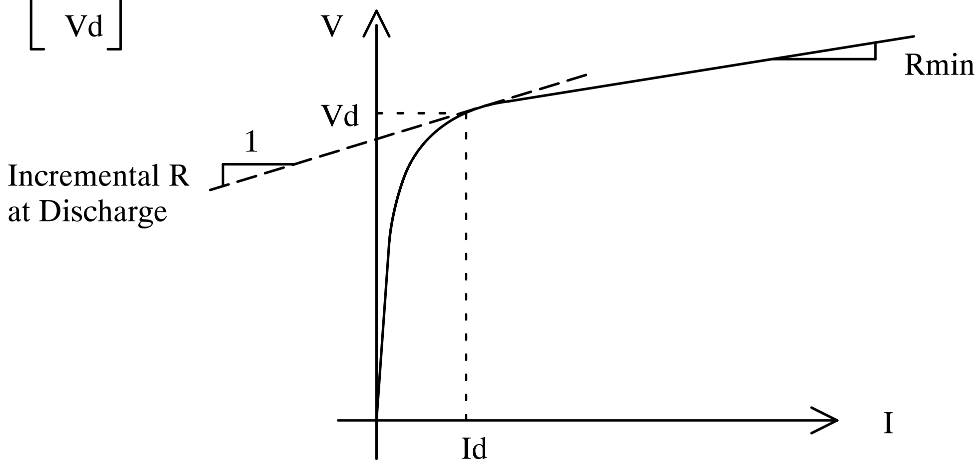
The final two entries in the TCR BRANCH PARAMETERS menu require some explanation. The TCR valve model in the TCSC is configured so that it will only turn−on if it receives both a firing pulse and a specified level of forward voltage (BOD voltage) on the valve. In fact, as may be noted in the TCR BRANCH PARAMETERS menu, that there are two specifiable levels of BOD voltage. The User may switch between these two levels dynamically during a simulation using a bit in a control word passed on the backplane. This is discussed below in conjunction with the GENERAL CONTROL INPUTS menu below.

The ARRESTOR PARAMETERS menu appears as follows:



The Arrestor model operates according to the following V−I characteristic equation (in Quadrant 1) where Id and Vd are the crest discharge current and voltage.

$$I = Id \left[\frac{V}{Vd} \right]^N$$



The above equation may be fitted to an Arrestor characteristic by choosing appropriate values of Vd, Id, and N. The presence of the large capacitance in the main capacitor bank is beneficial to the proper numerical operation of this arrestor model.

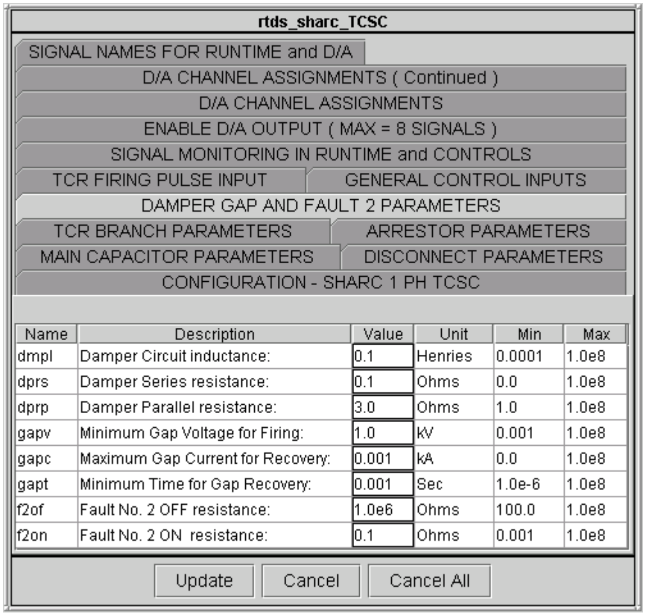
The icon allows the selection of values of N between 2 and 32. However, a very high value of N means that the curvature of the arrestor characteristic at the knee point is very high. This can lead to numerical difficulties if the capacitance of the main capacitor is small. In this case, it may be necessary to experiment with the circuit being simulated in order to select a suitable N.

For high values of N, the incremental resistance of the characteristic reduces quickly as voltage rises above Vd. The minimum resistance (rmin) item in the above menu allows the specification of a lower limit on resistance. Rmin is a fraction of the incremental resistance at the discharge point. The resistance at the discharge point of the characteristic is Vd / (N * Id).

The Energy Decay Factor in the above table is used to multiply the accumulated arrestor energy in each time step. This is a basic method for providing arrestor cooling. It is normally selected in the range of 0.999 to 0.999999.

Monitoring arrestor energy and current in RunTime and sending arrestor energy and current to D/A output is discussed below. The Arrestor is permitted to switch ON and OFF as will be discussed below.

The DAMPER GAP AND FAULT 2 PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
dmpl	Damper Circuit inductance:	0.1	Henries	0.0001	1.0e8
dprs	Damper Series resistance:	0.1	Ohms	0.0	1.0e8
dprp	Damper Parallel resistance:	3.0	Ohms	1.0	1.0e8
gapv	Minimum Gap Voltage for Firing:	1.0	kV	0.001	1.0e8
gapc	Maximum Gap Current for Recovery:	0.001	kA	0.0	1.0e8
gapt	Minimum Time for Gap Recovery:	0.001	Sec	1.0e-6	1.0e8
f2of	Fault No. 2 OFF resistance:	1.0e6	Ohms	100.0	1.0e8
f2on	Fault No. 2 ON resistance:	0.1	Ohms	0.001	1.0e8

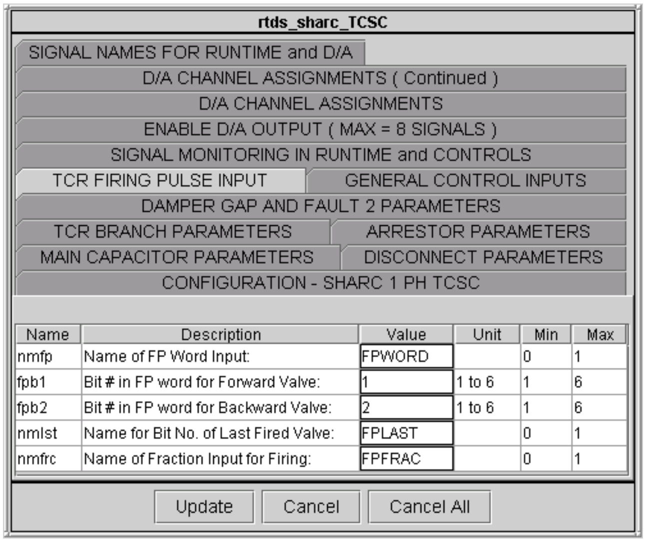
As may be noted in the above menu, the bypass GAP in the model will only fire in the presence of both a User specifiable level of voltage (“gapv”) and the trigger pulse.

The GAP will recover current blocking capability only if the current has been smaller in magnitude than a specifiable level (“gapc”) continuously for more than a specifiable period of time (“gapt”). Please note that the GAP current falls to zero any time that the Bypass breaker (BRKR) or Fault No. 1 (FLT1) are conducting.

The other parameters in the above menu are self−explanatory. There is no need to specify the ON and OFF resistances of the BRKR, FLT1 and GAP because they are mathematically modelled as ideal switches (zero Ohms when closed, infinite Ohms when open).

11.4 THE TCR FIRING PULSE INPUT MENU

The TCR FIRING PULSE INPUT menu for the A−phase of a TCSC model is in the following form:



rtds_sharc_TCSC

SIGNAL NAMES FOR RUNTIME and D/A
D/A CHANNEL ASSIGNMENTS (Continued)
D/A CHANNEL ASSIGNMENTS
ENABLE D/A OUTPUT (MAX = 8 SIGNALS)
SIGNAL MONITORING IN RUNTIME and CONTROLS
TCR FIRING PULSE INPUT | GENERAL CONTROL INPUTS
DAMPER GAP AND FAULT 2 PARAMETERS
TCR BRANCH PARAMETERS | ARRESTOR PARAMETERS
MAIN CAPACITOR PARAMETERS | DISCONNECT PARAMETERS
CONFIGURATION - SHARC 1 PH TCSC

Name	Description	Value	Unit	Min	Max
nmfp	Name of FP Word Input:	FPWORD		0	1
fpb1	Bit # in FP word for Forward Valve:	1	1 to 6	1	6
fpb2	Bit # in FP word for Backward Valve:	2	1 to 6	1	6
nmlst	Name for Bit No. of Last Fired Valve:	FPLAST		0	1
nmfrc	Name of Fraction Input for Firing:	FPFRAC		0	1

Update | Cancel | Cancel All

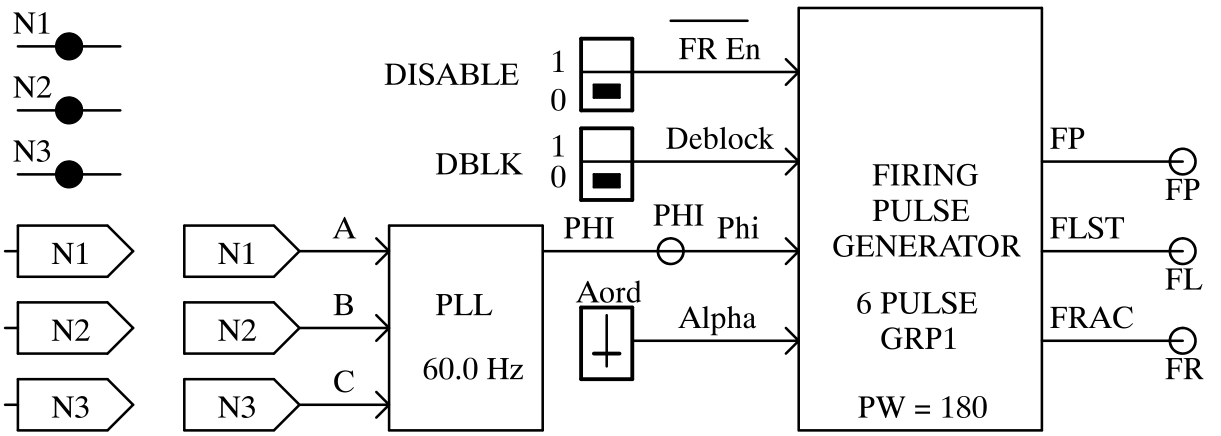
This menu enables the external source of firing pulse information to be specified for the single−phase TCSC model as three named words passed on the backplane in the RTDS rack. The 3 named words may be generated in Control Blocks described below.

The first word (“nmfp”) is the firing pulse word. This is an integer word having a permitted range of values from binary 000000 to binary 111111. Each bit represents a firing pulse bit, the least significant bit (LSB) corresponds to the firing pulse bit for valve number 1. The menu enables the selection of two bits from the firing pulse word for firing the forward and backward facing valves. A “1” bit asserts firing. The forward and backward facing valves are identified in the icon as FORE and BACK respectively.

The second word (“nmlst”) is an integer identifying the last bit in the firing pulse word to transition ON in the last time−step. If no bit transitioned ON, the word “nmlst” should contain zero. Otherwise, that bit number should be contained within “nmlst”. For example, if firing pulse bit 4 transitioned ON 2/3 of the way through the last time−step, then the integer 4 would be passed on the backplane in the “nmlst” word. In this latter case, the third named word (“nmfrc”) should contain a floating point number, between 0.0 and 1.0, which describes the fractional position in the time−step when the ON transition occurred (Example: 0.66667).

Each of the single−phase TCSCs required to simulate a three−phase TCSC may monitor the same set of named words. For example, the phase “A” TCSC may monitor bits 1 and 4, phase “B” may monitor bits 2 and 5, and phase “C” may monitor bits 3 and 6. The firing of 1 out of 6 valves can be improved in each time−step when the single−phase TCSCs monitor the same 3 words. This is usually adequate, given that the valves in a three−phase TCSC typically transition ON at 60 degree intervals. However, a different set of three words may be monitored for each single−phase TCSC. In that case, each valve turn−on will be with improved accuracy because two valves in a single−phase TCSC cannot turn on in the same time−step.

The firing−pulse word set may come from a control system simulated in the RTDS as illustrated below, or from a Digital Input Time Stamp (DITS) card as described in the next section.



The Phase Locked Loop (PLL) in the above schematic is controls component rtds_sharc_ctl_PLL. The Firing Pulse Generator is rtds_sharc_ctl_FPGEN.

The Firing Pulse Generator must be set to produce a <u>firing pulse width of 180 degrees</u> duration rather than 120 degrees.

These components represent basic control blocks which are not optimized for any particular purpose. More detailed control systems may be assembled using the lower level control blocks which are available in the Controls Compiler library.

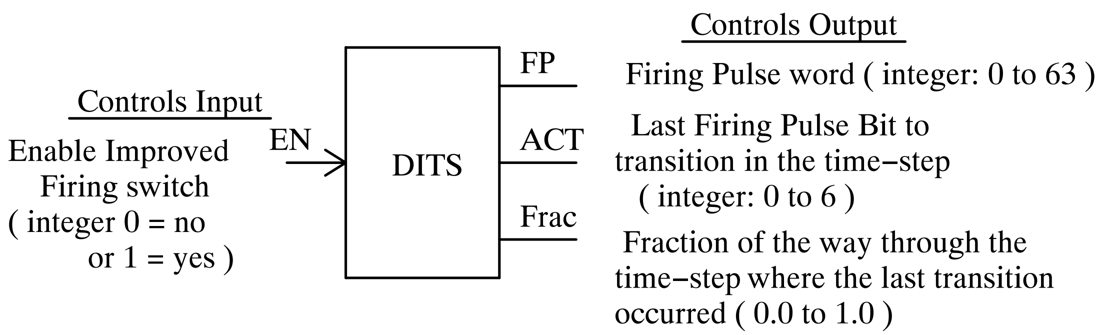
Setting the DISABLE switch to 1 disables the improved firing output words FLST and FRAC. Therefore, for operation with improved firing, the DISABLE switch must be set to 0. FLST is the number (1 to 6) of the last firing pulse to transition ON in the time−step. The switch DBLK (in the 1 position) causes firing pulses to be generated. FRAC is the fraction of the way through the time−step where the ON transition of a firing−pulse occurred. When there is no firing−pulse ON transition in the time−step or when DISABLE = 1, then FLST will be equal to integer 0 and FRAC will be equal to floating−point 0.0. With the latter outputs for FLST and FRAC, the

TCSC will obey the firing pulses in FP but no improvement in firing accuracy will occur. The User may monitor FLST and FRAC in RunTime.

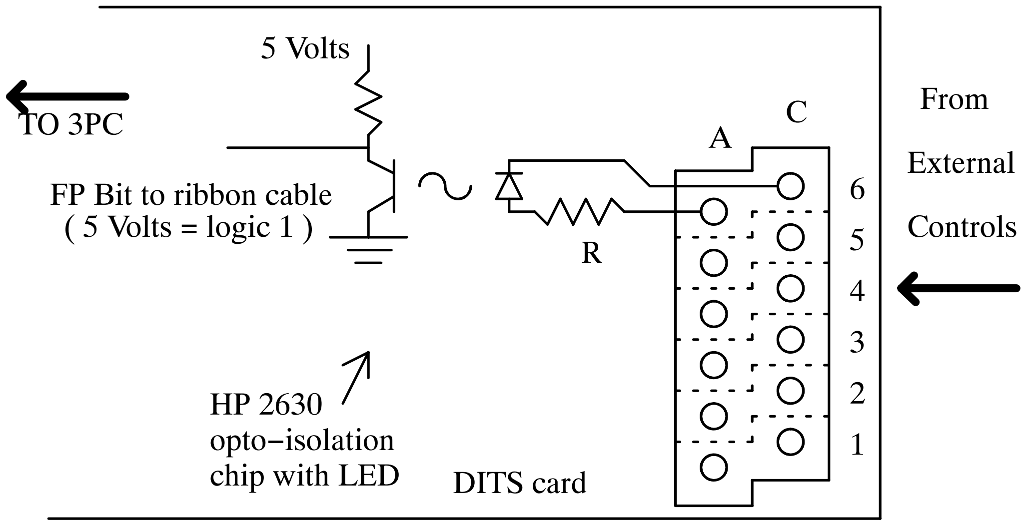
11.5 THE DIGITAL INPUT TIME STAMP CARD

Access of DITS Card Using Component: rtds_sharc_ctl_DITS

The Digital Input Time Stamp (DITS) card can be used in support of improved firing accuracy for the TCR during testing of physical TCSC controls. The DITS card may be accessed using the Controls Compiler component icon (“rtds_sharc_ctl_DITS”) illustrated below:

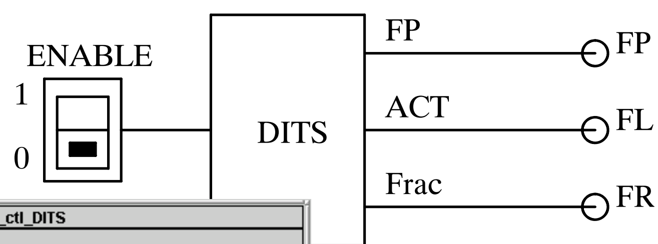


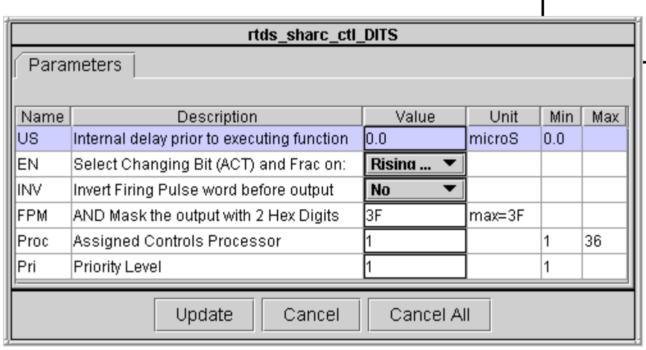
The selection of PARAMETERS in the above icon depends upon the method of connection of the firing pulses to the DITS card. The following diagram illustrates the circuit for a firing pulse bit passing through the DITS card opto−isolation.



The firing pulse bit on the RTDS side of the opto–isolation goes to 5 Volts (logic 1) when the LED in the opto–isolation chip is not conducting. The anode "A" and cathode "C" of each LED are brought out to terminal blocks. Each LED circuit is completely isolated from the others and active firing pulses can be represented by a non–conducting or a conducting LED.

In the case where a 6–bit firing pulse word is to be represented by non–conducting LEDs, the Draft circuit for the DITS control component and the associated PARAMETERS menu should appear as follows:





rtds_sharc_ctl_DITS

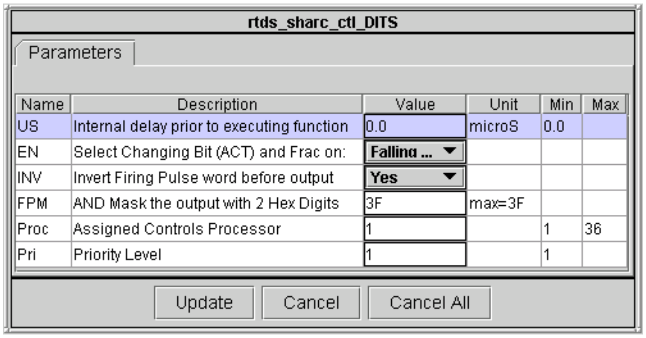
Parameters

Name	Description	Value	Unit	Min	Max
US	Internal delay prior to executing function	0.0	microS	0.0	
EN	Select Changing Bit (ACT) and Frac on:	Rising ...			
INV	Invert Firing Pulse word before output	No			
FPM	AND Mask the output with 2 Hex Digits	3F	max=3F		
Proc	Assigned Controls Processor	1		1	36
Pri	Priority Level	1		1	

Update   Cancel   Cancel All

The first item in the above menu allows retrieval of the firing–pulse information from the DITS card to be delayed until late in the time–step. The length of this delay can be seen using the DRAFT menu OPTIONS –> Show Processor Usage (No / Yes) selection, after the case has been compiled.

In the case where a 6−bit firing pulse word is to be represented by conducting LEDs, the Draft circuit for the DITS component is unchanged. The PARAMETERS menu should appear as follows:


rtds_sharc_ctl_DITS

Parameters

Name	Description	Value	Unit	Min	Max
US	Internal delay prior to executing function	0.0	microS	0.0	
EN	Select Changing Bit (ACT) and Frac on:	Falling ...			
INV	Invert Firing Pulse word before output	Yes			
FPM	AND Mask the output with 2 Hex Digits	3F	max=3F		
Proc	Assigned Controls Processor	1		1	36
Pri	Priority Level	1		1	

Update | Cancel | Cancel All

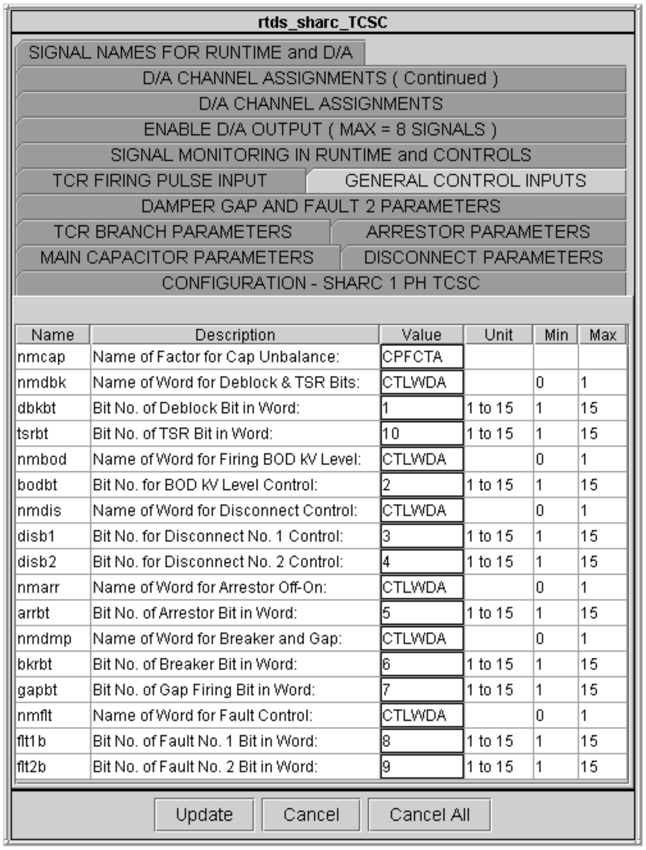
In the conducting LEDs case, it is necessary to invert the firing logic. It is also necessary to specify that the DITS icon should pass out fraction information concerning “Falling Edges” instead of “Rising Edges”.

In either case, it is useful to force the DITS control component to be serviced late in the time−step by giving it a higher priority level and if necessary by specifying a delay using the menu item “US”. In this way, the firing information is not delayed before being passed on the backplane to the TCSC model at the end of the time−step.

Details describing the connection of the DITS card to the 3PC are given the RTDS Hardware Manual.

11.6 THE GENERAL CONTROL INPUTS MENU

The GENERAL CONTROL INPUTS menu appears as in the diagram illustrated below. Each single−phase TCSC requires 1 floating−point control word and 10 control bits. The 10 control bits are selected from one or more integer control words passed on the backplane. This menu allows the source of the inputs to be specified by name and bit number.



rtds_sharc_TCSC

SIGNAL NAMES FOR RUNTIME and D/A
D/A CHANNEL ASSIGNMENTS (Continued)
D/A CHANNEL ASSIGNMENTS
ENABLE D/A OUTPUT (MAX = 8 SIGNALS)
SIGNAL MONITORING IN RUNTIME and CONTROLS
TCR FIRING PULSE INPUT | GENERAL CONTROL INPUTS
DAMPER GAP AND FAULT 2 PARAMETERS
TCR BRANCH PARAMETERS | ARRESTOR PARAMETERS
MAIN CAPACITOR PARAMETERS | DISCONNECT PARAMETERS
CONFIGURATION - SHARC 1 PH TCSC

Name	Description	Value	Unit	Min	Max
nmcap	Name of Factor for Cap Unbalance:	CPFCTA			
nmdbk	Name of Word for Deblock & TSR Bits:	CTLWDA		0	1
dbkbt	Bit No. of Deblock Bit in Word:	1	1 to 15	1	15
tsrbt	Bit No. of TSR Bit in Word:	10	1 to 15	1	15
nmbod	Name of Word for Firing BOD kV Level:	CTLWDA		0	1
bodbt	Bit No. for BOD kV Level Control:	2	1 to 15	1	15
nmdis	Name of Word for Disconnect Control:	CTLWDA		0	1
disb1	Bit No. for Disconnect No. 1 Control:	3	1 to 15	1	15
disb2	Bit No. for Disconnect No. 2 Control:	4	1 to 15	1	15
nmarr	Name of Word for Arrestor Off-On:	CTLWDA		0	1
arrbt	Bit No. of Arrestor Bit in Word:	5	1 to 15	1	15
nmdmp	Name of Word for Breaker and Gap:	CTLWDA		0	1
bkrbt	Bit No. of Breaker Bit in Word:	6	1 to 15	1	15
gapbt	Bit No. of Gap Firing Bit in Word:	7	1 to 15	1	15
nmflt	Name of Word for Fault Control:	CTLWDA		0	1
flt1b	Bit No. of Fault No. 1 Bit in Word:	8	1 to 15	1	15
flt2b	Bit No. of Fault No. 2 Bit in Word:	9	1 to 15	1	15

Update | Cancel | Cancel All

The first line in the GENERAL CONTROL INPUTS menu requests the name of a signal representing the Capacitor Unbalance current. Capacitors are usually arranged in parallel strings, with monitoring at intermediate points to detect failures and imbalance in the strings. This input multiplies the main capacitor current to simulate an imbalance for protection. The factor can come from the Controls Compiler.

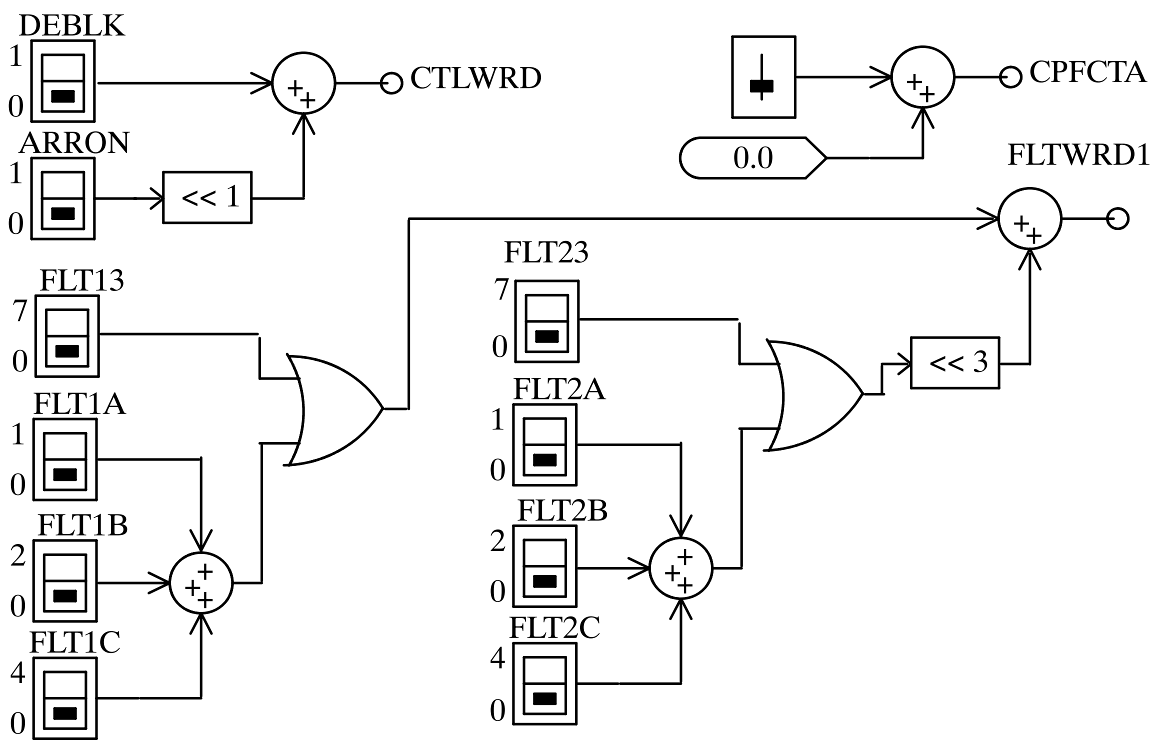
The remaining entries in the GENERAL CONTROL INPUTS menu relate to control bits for various purposes as follows;

1. A deblock bit must be set to 1 to enable firing pulses to the TCR valve.
2. A bit is provided for forcing TSR firing mode as discussed below.
3. A BOD control bit must be set to “1” in order to select the second Valve Firing Voltage Level as discussed in section 11.3 above. A “0” for this bit selects the first Valve Firing Voltage Level.
4. Two control bits in one word must be passed for controlling the Platform Disconnects. A “1” bit closes a Disconnect.
5. An Arrestor control bit allows the Arrestor model to be Off and On. The transition between Off and On or On and Off, only occur at a current zero. A “1” bit enables the Arrestor. When the Arrestor is turned Off, the accumulated Arrestor energy is reset to 0.0.

6. The Bypass Breaker control bit and the Main Gap firing bit are selected from the same word. The Breaker is closed by a “1” bit. Similarly, the Main Gap is fired by a transitory “1” bit in the presence of sufficient voltage as discussed in section 11.3 above.

7. The Fault No. 1 and No. 2 control bits are selected from the same word. A “1” bit applies the fault. Faults clear on current zeroes as do the breaker and disconnects.

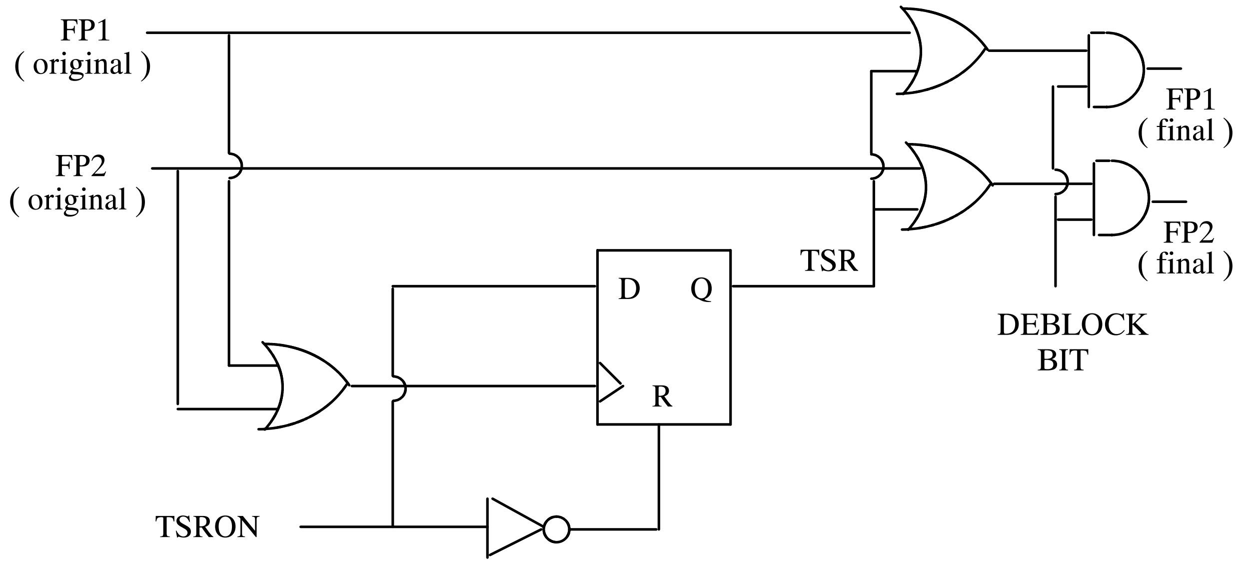
The following DRAFT diagram illustrates, by example, the creation of various control words using the controls compiler:



In the above diagram, the Control inputs are shown as switches and sliders accessible in RunTime. However, any of the individual inputs could have been brought into the controls processor through a Controls Compiler digital input port icon. As an alternative, the slider and switches could be replaced by a more complicated controls circuit containing timers, threshold detectors, and similar devices.

TSR Firing Mode

Firing Pulses taken into the TCSC model are processed within the TCSC model as illustrated in the following diagram before use. The signal TSRON is set to 1 to enable TSR firing mode.

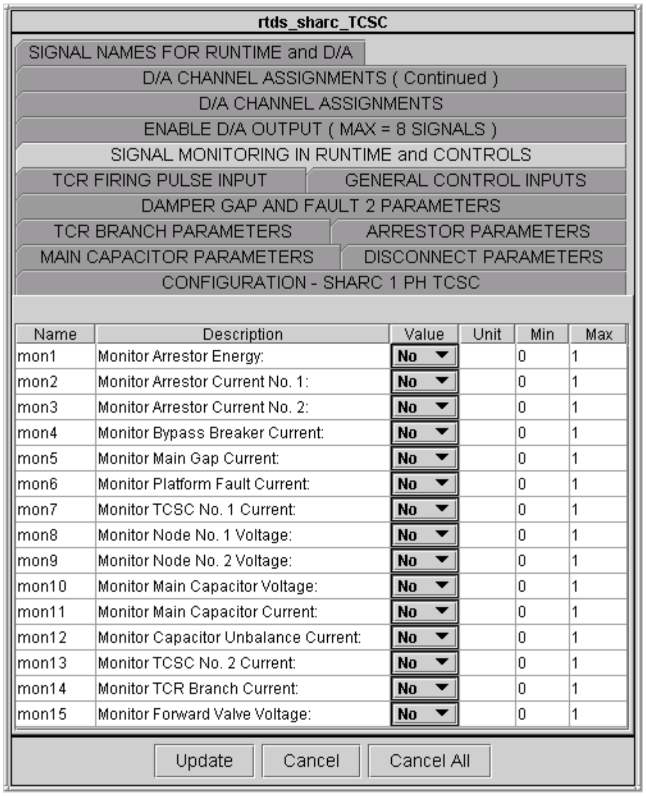


When TSRON is asserted (logic 1), the arrival of the next firing pulse causes both final firing bits, FP1 and FP2 on the right, to be asserted (logic 1) until TSRON is reset back to 0.

11.7 SIGNAL MONITORING IN RUNTIME & CONTROLS MENU

This menu lists the floating−point signals which are produced by the single−phase TCSC model. If "YES" is selected with respect to a particular entry, then that signal will be available both as an input to the Controls Compiler and for monitoring in Run-Time. If "YES" is given for a signal or a D/A output of the signal is requested as discussed below, a Name for the signal must be supplied in the SIGNAL NAMES FOR

RUNTIME and D/A menu.



rtds_sharc_TCSC

SIGNAL NAMES FOR RUNTIME and D/A
D/A CHANNEL ASSIGNMENTS (Continued)
D/A CHANNEL ASSIGNMENTS
ENABLE D/A OUTPUT (MAX = 8 SIGNALS)
SIGNAL MONITORING IN RUNTIME and CONTROLS
TCR FIRING PULSE INPUT | GENERAL CONTROL INPUTS
DAMPER GAP AND FAULT 2 PARAMETERS
TCR BRANCH PARAMETERS | ARRESTOR PARAMETERS
MAIN CAPACITOR PARAMETERS | DISCONNECT PARAMETERS
CONFIGURATION - SHARC 1 PH TCSC

Name	Description	Value	Unit	Min	Max
mon1	Monitor Arrestor Energy:	No		0	1
mon2	Monitor Arrestor Current No. 1:	No		0	1
mon3	Monitor Arrestor Current No. 2:	No		0	1
mon4	Monitor Bypass Breaker Current:	No		0	1
mon5	Monitor Main Gap Current:	No		0	1
mon6	Monitor Platform Fault Current:	No		0	1
mon7	Monitor TCSC No. 1 Current:	No		0	1
mon8	Monitor Node No. 1 Voltage:	No		0	1
mon9	Monitor Node No. 2 Voltage:	No		0	1
mon10	Monitor Main Capacitor Voltage:	No		0	1
mon11	Monitor Main Capacitor Current:	No		0	1
mon12	Monitor Capacitor Unbalance Current:	No		0	1
mon13	Monitor TCSC No. 2 Current:	No		0	1
mon14	Monitor TCR Branch Current:	No		0	1
mon15	Monitor Forward Valve Voltage:	No		0	1

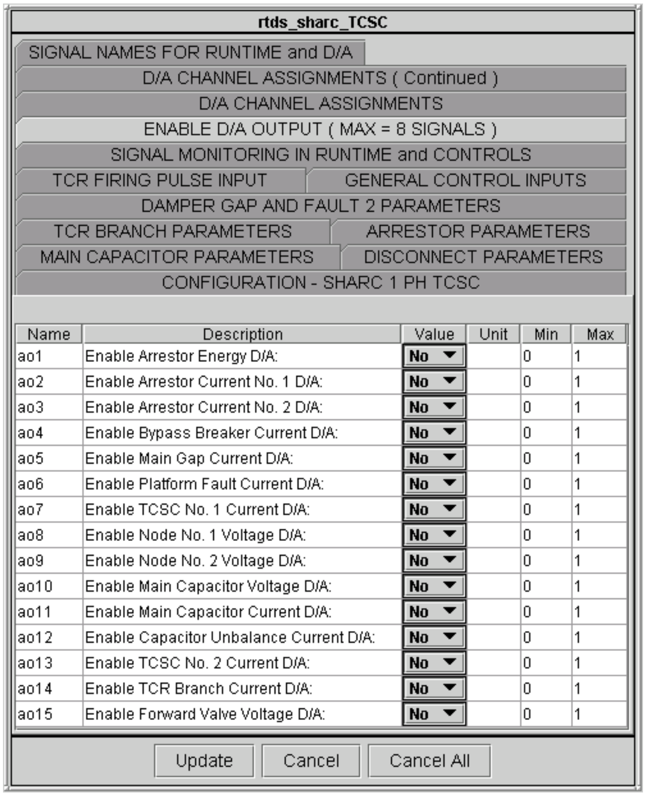
Update | Cancel | Cancel All

The signals listed in the above table are in units of kA, kV and MW−sec. The reference direction for all currents and the main capacitor voltages are illustrated in the icon shown on page 11.1 of this chapter. TCSC currents No. 1 and No. 2 are shown as T1 and T2 in the icon. Please note the reference direction for the platform current P which is into the platform.

11.8 SPECIFYING D/A OUTPUT

The menu ENABLE D/A OUTPUT (MAX = 8 SIGNALS) below lists the signals which may be assigned to D/A output channels located on the faceplate of the 3PC processor.

There are only 8 D/A output channels on a processor, 24 per 3PC card. If more than 8 D/A analog output signals per single−phase TCSC model are desired, the additional signals can be passed to a Controls Compiler processor and routed to a D/A output channel on the controls processor. In order to pass a signal on the RTDS backplane, it must be selected in the SIGNAL MONITORING IN RUNTIME and CONTROLS menu discussed in the preceding section.



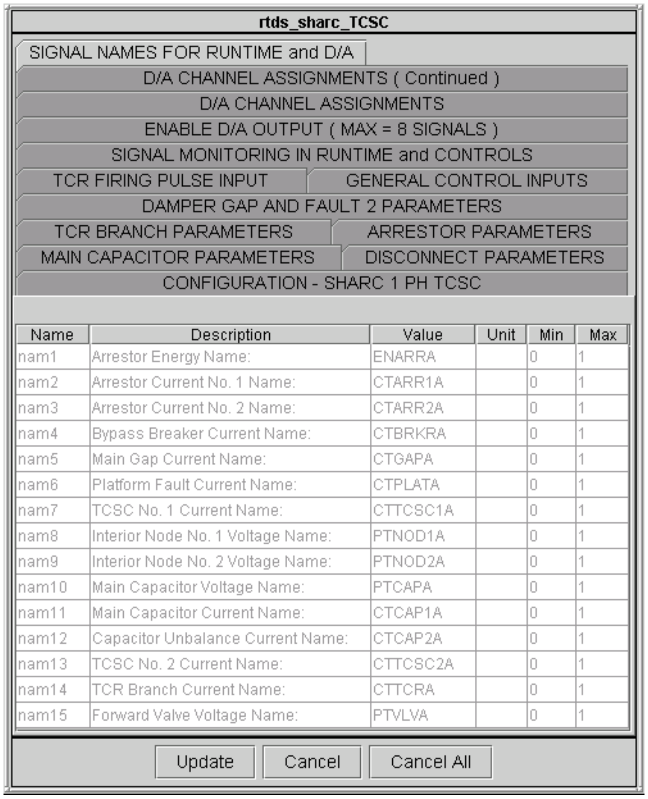
For requested signals, the D/A CHANNEL ASSIGNMENTS menu must be used to specify unique D/A channel numbers between 1 and 8. The signal magnitude which corresponds with a 5 Volt D/A output level must also be supplied.

In the menu SIGNAL NAMES FOR RUNTIME and D/A discussed below, a unique Name must be specified for each signal that is either assigned to a D/A channel or passed on the backplane for monitoring in RunTime or in the Controls Compiler processors.

In the case of signals assigned to D/A channels, Offset and Unity Gain sliders can be created in RunTime according to signal names. In addition, for each signal name, a switch can be created in RunTime for lighting an LED on the faceplate of the 3PC card. The LED for a named signal is located immediately above the output pin for the signal.

11.9 SPECIFYING SIGNAL NAMES

The SIGNAL NAMES FOR RUNTIME and D/A menu is illustrated below:

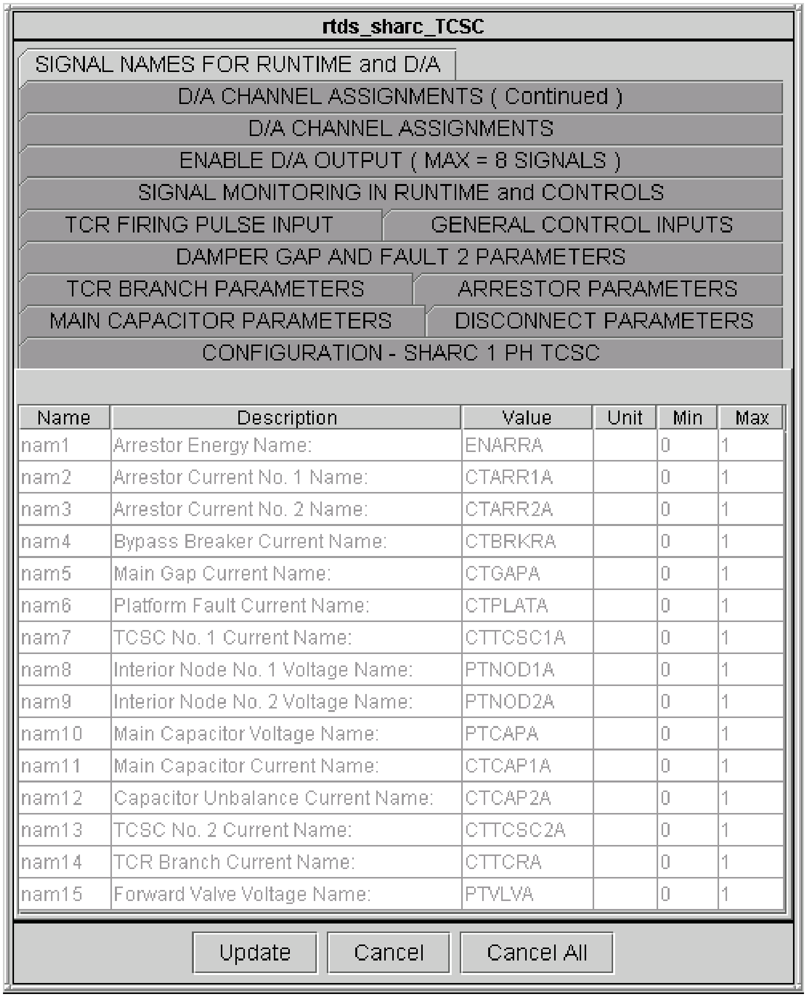


In this menu, a name must be specified for all signals which have been requested in either the SIGNAL MONITORING IN RUNTIME and CONTROLS menu or in the ENABLE D/A OUTPUT (MAX = 8 SIGNALS) menu as discussed above.

The signals and facilities which can be accessed using the specified signal names are discussed in the last two sections above.

11.9 SPECIFYING SIGNAL NAMES

The SIGNAL NAMES FOR RUNTIME and D/A menu is illustrated below:



Name	Description	Value	Unit	Min	Max
nam1	Arrestor Energy Name:	ENARRA		0	1
nam2	Arrestor Current No. 1 Name:	CTARR1A		0	1
nam3	Arrestor Current No. 2 Name:	CTARR2A		0	1
nam4	Bypass Breaker Current Name:	CTBRKRA		0	1
nam5	Main Gap Current Name:	CTGAPA		0	1
nam6	Platform Fault Current Name:	CTPLATA		0	1
nam7	TCSC No. 1 Current Name:	CTTCSC1A		0	1
nam8	Interior Node No. 1 Voltage Name:	PTNOD1A		0	1
nam9	Interior Node No. 2 Voltage Name:	PTNOD2A		0	1
nam10	Main Capacitor Voltage Name:	PTCAPA		0	1
nam11	Main Capacitor Current Name:	CTCAP1A		0	1
nam12	Capacitor Unbalance Current Name:	CTCAP2A		0	1
nam13	TCSC No. 2 Current Name:	CTTCSC2A		0	1
nam14	TCR Branch Current Name:	CTTCRA		0	1
nam15	Forward Valve Voltage Name:	PTVLVA		0	1

In this menu, a name must be specified for all signals which have been requested in either the SIGNAL MONITORING IN RUNTIME and CONTROLS menu or in the ENABLE D/A OUTPUT (MAX = 8 SIGNALS) menu as discussed above.

The signals and facilities which can be accessed using the specified signal names are discussed in the last two sections above.

12 INTERFACED SVC MODEL

(rtds_sharc_SVC3)

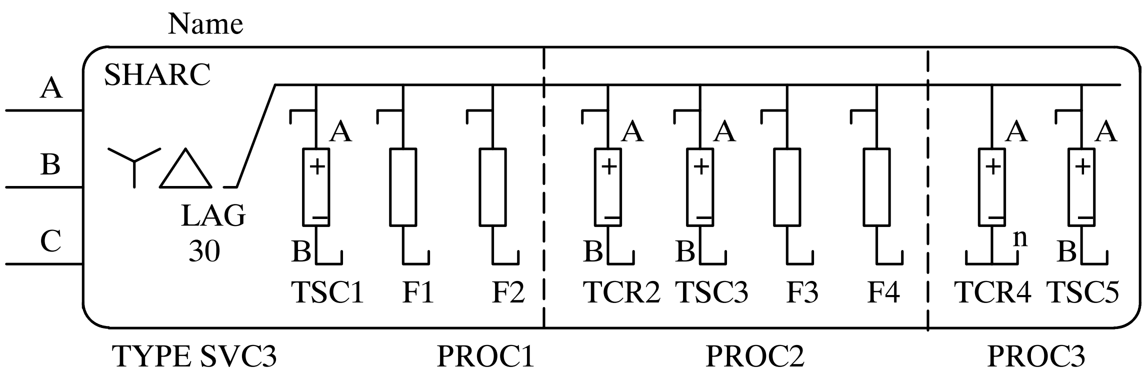
12.1 INTRODUCTION

There are two SVC models which are available for use with the 3PC Card, the SVC3 and SVC4.

The SVC3 model described in this Chapter is the first created for the 3PC card. The SVC3 model can be used with the Real Time Network Solution based on 3PC cards (Chapter 2). The model may be connected to either Connector type nodes or Embedded type nodes when used with the Real Time Network Solution. One to three Sharc processors on one 3PC card are required for using the SVC3 model, depending on the number of processors enabled in the CONFIGURATION menu. The model can provide up to 5 TSC or TCR banks connected in Wye or Delta with up to 4 filter banks and an SVC transformer on the one card.

Alternatively, Chapter 13 describes an embedded SVC bank model (SVC4) which is solved as part of the main network as one seamless Dommel trapezoidal network. The model described in Chapter 13 uses 1 Sharc processor per bank. The SVC4 model must be connected to Connector type nodes in a Real Time Network Solution. The SVC4 model has improved turn−off performance so that BOD firing can be more properly simulated. The SVC4 model also allows for valve, reactor, capacitor and low−side bus faults. The increased performance of the SVC4 model comes at the cost of generally using more hardware for the SVC4 solution. Presently, the SVC4 model can only accommodate Delta connected SVC banks.

SVC3

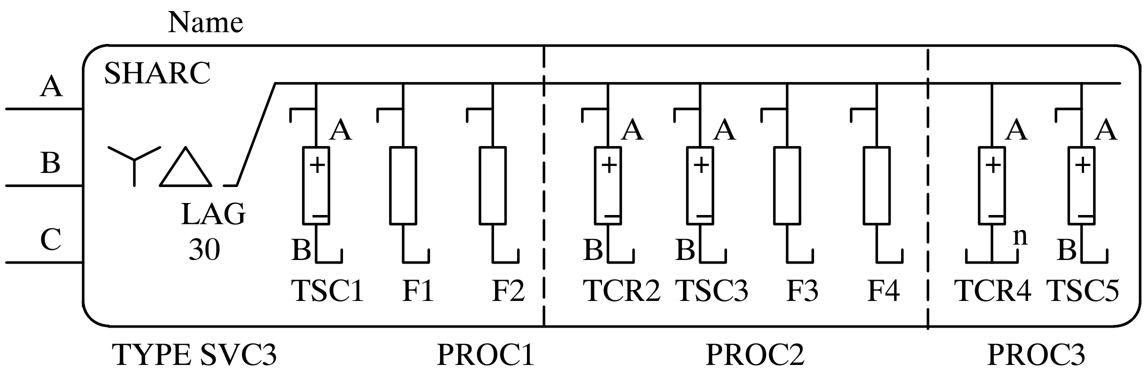


The SVC3 Model

As with the Voltage Type Bridge (Chapter 14), the TCSC (Chapter 11), and the HVDC Valve Group (Chapter 8), each TCR bank within the SVC3 model includes an improved firing accuracy capability, described below. Of course, the TCR in the

SVC4 model (Chapter 13) also includes the improved firing accuracy capability.

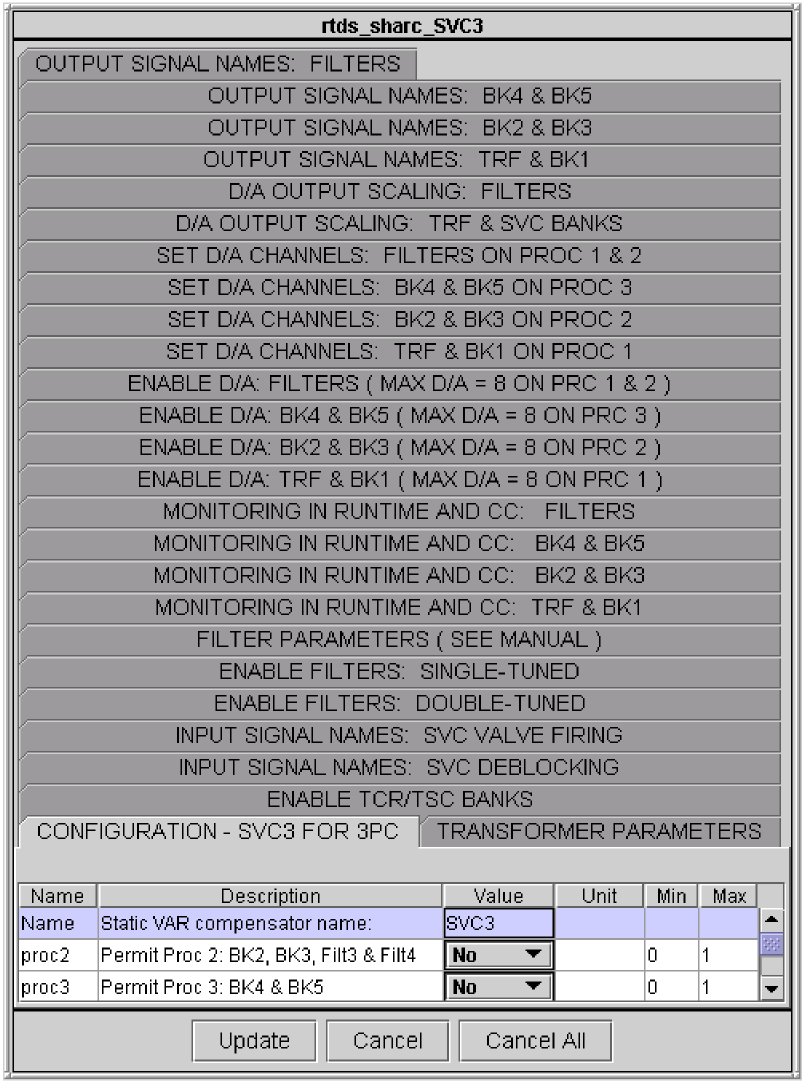
The icon for the model appears as shown in the Figure below. The icon is labeled "TYPE SVC3" in the lower left–hand corner to distinguish it from earlier versions which had no such label. The 5 possible SVC banks are labelled as TCR or TSC in the icon according to the User's specification.



The transformer for the SVC3 model can represent all six (6) possible lags in Yy, Yd, Dy and Dd transformer connections. Winding resistance is also included in the SVC3 transformer model.

The first processor (PROC1) in the above icon is always enabled. Processor PROC1 models the SVC transformer and optionally: one TSC or TCR bank and two single–tuned filters or one double–tuned filter. Enabling processor PROC2 allows two more TSC or TCR banks and two more single–tuned filters or one more double–tuned filter to be modeled. Enabling processor PROC3 permits two more TSC or TCR banks as shown above.

Each of the five possible SVC banks can be either a TCR bank or a TSC bank and each SVC bank can be connected in either Wye or Delta. In the above Figure, SVC bank 4 is shown as connected in Wye with a floating neutral star point. SVC banks 1, 2, 3, and 5 are shown as connected in Delta. The individual SVC banks are labelled as TCR# or TSC# in the icon, depending on whether the bank has been selected to be a TCR bank or a TSC bank.

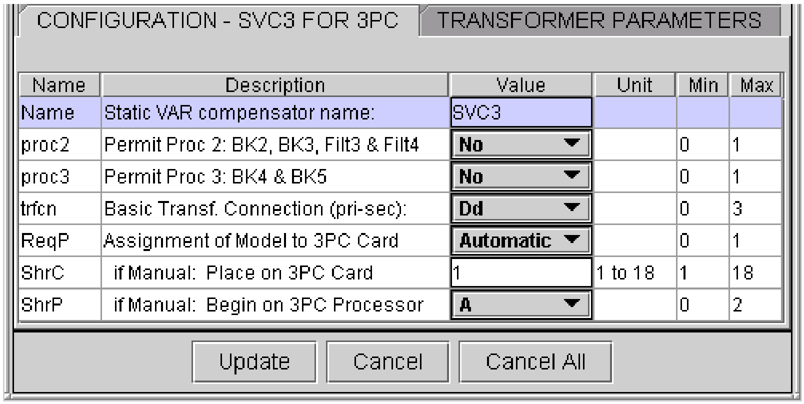


12.2 STATIC VAR COMPENSATOR MENU TABS

Due to the large number of menu tabs, images of the the various menus throughout this chapter will not show all of the menu tabs. The partial CONFIGURATION – SVC3 FOR 3PC menu, and all of the tabs which are available by default appears above.

12.3 CONFIGURATION – SVC3

The CONFIGURATION – SVC3 FOR 3PC menu appears below.



CONFIGURATION - SVC3 FOR 3PC | TRANSFORMER PARAMETERS

Name	Description	Value	Unit	Min	Max
Name	Static VAR compensator name:	SVC3			
proc2	Permit Proc 2: BK2, BK3, Filt3 & Filt4	No		0	1
proc3	Permit Proc 3: BK4 & BK5	No		0	1
trfcn	Basic Transf. Connection (pri-sec):	Dd		0	3
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	if Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	if Manual: Begin on 3PC Processor	A		0	2

Update | Cancel | Cancel All

As usual, the first entry is a name. An Error message will be issued if any other SVC is given the same name.

The first processor (PROC1) shown in the icon is always enabled. That processor models the SVC transformer and optionally; one TSC or TCR bank, and two single–tuned filters or one double–tuned filter. An SVC3 model using one processor can be run on processor A, B or C on a card. If additional SVC or filter banks are to be modelled, processor 2 (PROC2) or processor 3 (PROC3) or both must be enabled using the second and third entries in the above menu.

If only one of PROC2 and PROC3 are enabled, then the model will always use two consecutive processors on a card. For example, the model might run on the A and B processors on a 3PC card or on the B and C processors. The model will never run using the A and C processors without also using the B processor.

If both PROC2 and PROC3 are enabled, then the model will always use all three processors (A, B and C) on a single 3PC card.

The fourth entry in the CONFIGURATION menu specifies the basic transformer connection. The primary and secondary can each be Y–connected or Delta–connected. "Y" or "y" in the choices means Y–connected. "D" or "d" in the choices means Delta–connected. The primary winding connection is indicated by the capital letter and the secondary winding connection is indicated by the lower case letter. Additional transformer data including primary neutral connection is requested in the next menu below named TRANSFORMER PARAMETERS.

The fifth entry in the CONFIGURATION menu enables Automatic or Manual assignment to specified processors. If Automatic assignment is requested, the subsequent two entries in the menu are ignored. If Manual assignment is requested, a specific processor can be selected by indicating 3PC card number and processor. If two models request the same processor, an Error message will be given. Manual assignment is useful where external equipment is being connected through I/O to a given 3PC processor. In that case, Manual assignment ensures that the selected processor will continue to be used as the case is modified.

12.4 TRANSFORMER PARAMETERS

The TRANSFORMER PARAMETERS menu is shown below.

CONFIGURATION - SVC3 FOR 3PC | TRANSFORMER PARAMETERS

Name	Description	Value	Unit	Min	Max
t3mvr	3 Phase Transformer MVA:	100.0	MVA	1.0e-6	
vbspr	Rated RMS L-L Primary Voltage:	138.0	kV	1.0e-6	
vbscr	Rated RMS L-L SVC-side Voltage:	13.8	kV	1.0e-6	
xlkpr	Transformer Winding Resistance:	0.002	p.u.	0.002	2.0
xlkpx	Transformer Leakage Reactance:	0.1	p.u.	0.01	2.0
freqr	Rated Frequency	60.0	Hertz	0.1	
trlg1	Secondary Lags Primary (degrees):	L...		0	1
trlg2	Secondary Lags Primary (degrees):			0	3
prygd	Is the Primary Y grounded ?	No		0	1
xzrpr	Ygrounded-Delta 0 Seq. Resistance:	0.01	p.u.	0.001	2.0
xzrpx	Ygrounded-Delta 0 Seq. Reactance:	0.05	p.u.	0.01	2.0
xrdmp	Damping branch series R (valve-side)	500.0	p.u.	0.5	
xcdmp	Damping branch series Xc (valve-side)	500.0	p.u.	50.0	

Update | Cancel | Cancel All

Items 1 to 6 are always visible (not “greyed out”) . They prompt for transformer data that is always required.

Item 7 (“trlg1”) is visible if the Basic Transformer Connection in the CONFIGURATION menu is specified as either “Yy” or “Dd”. This specifies whether the SVC bank−side voltages will be in phase with the primary voltages or 180 degrees out of phase for these connections.

Item 8 (“trlg2”) is available if the Basic Transformer Connection in the CONFIGURATION menu is specified as either “Yd” or “Dy”. This specifies whether the SVC bank side voltages will be lagging the primary voltages by 30 degrees, 150 degrees, 210 degrees, or 330 degrees for these connections.

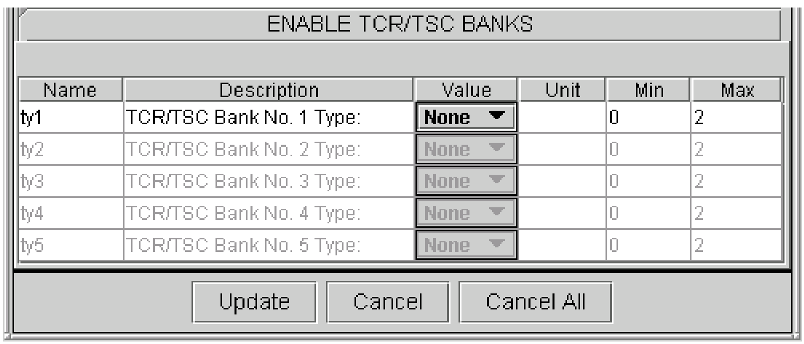
Item 9 (“prygd”) is available if the Basic Transformer Connection in the CONFIGURATION menu is specified as either “Yy” or “Yd”. This item specifies whether or not the neutral point on the transformer primary is grounded for these connections.

Items 10 and 11 (“xzrpr” and “xzrpx”) are available if the Basic Transformer Connection in the CONFIGURATION menu is specified as “Yd”. If item 9 indicates that there is a neutral connection to ground, zero−sequence impedance must be specified in response to items 10 and 11. Otherwise, values entered for items 10 and 11 will not be used.

It is well−known in electromagnetic simulation that switching events can cause two time−step numerical oscillations. These oscillations are often damped by the resistances in the network. However, in this model, items 12 and 13 provide an optional series RC circuit for this purpose. The default values of 500 p.u. resistance in series with 500 p.u. capacitive reactance are usually adequate for controlling numerical oscillations. The p.u. base is that of the transformer secondary. These values can be made larger or smaller than 500 p.u. if desired.

12.5 ENABLE TCR / TSC BANKS

The next menu is ENABLE TCR/TSC BANKS, shown below.



ENABLE TCR/TSC BANKS

Name	Description	Value	Unit	Min	Max
ty1	TCR/TSC Bank No. 1 Type:	None		0	2
ty2	TCR/TSC Bank No. 2 Type:	None		0	2
ty3	TCR/TSC Bank No. 3 Type:	None		0	2
ty4	TCR/TSC Bank No. 4 Type:	None		0	2
ty5	TCR/TSC Bank No. 5 Type:	None		0	2

Update Cancel Cancel All

This menu allows possible SVC banks to be either TCR banks or TSC banks. The items for Bank No. 2 and Bank No. 3 will only be visible if processor number 2 (PROC2) has been enabled in the CONFIGURATION menu as discussed above. Similarly, the items for Bank No. 4 and Bank No. 5 will only be visible if processor number 3 (PROC3) has been enabled.

12.6 TCR / TSC PARAMETERS

Depending on which SVC banks are enabled in the above menu, the next three menus allow the parameters of the individual enabled banks to be specified. The items for Bank No. 1 are contained in a menu called TCR / TSC PARAMETERS: BANK NO. 1, illustrated below. Identical items must be answered for each enabled SVC bank.

TCR/TSC PARAMETERS: BANK NO. 1

Name	Description	Value	Unit	Min	Max
cnct1	TCR/TSC No. 1 Connection:	Delta		0	1
tsc1r	TCR/TSC No. 1 Reactor resistance:	0.0	Ohms	0.0	1.0e8
tsc1h	TCR/TSC No. 1 Reactor inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
tsc1c	TCR/TSC No. 1 Capacitor capacitance:	222.86	MicroF.	0.005	1.0e8
snc1	TCR/TSC No. 1 Snubber capacitance:	1.0	MicroF.	0.005	1.0e8
snr1	TCR/TSC No. 1 Snubber resistance:	200.0	Ohms	50.0	1.0e8
vlvr1	TCR/TSC No. 1 Valve off resist:	5000.0	Ohms	1000.0	1.0e8
vbrk1	TCR/TSC No. 1 Valve Break-Over kV:	1.0e6	kV	0.1	1.1e6
pt1v1	BNK No. 1 Vout1 selection (See Manual)	0	0 to 8	0	8
pt1v2	BNK No. 1 Vout2 selection (See Manual)	0	0 to 8	0	8

Update | Cancel | Cancel All

Item 1 prompts for the TCR or TSC bank, Delta or Wye connection. There can be a mixture of Delta and Wye connected banks. Wye connected banks have a floating neutral.

Items 2 and 3 prompt for the resistance and inductance of the reactor in the SVC bank.

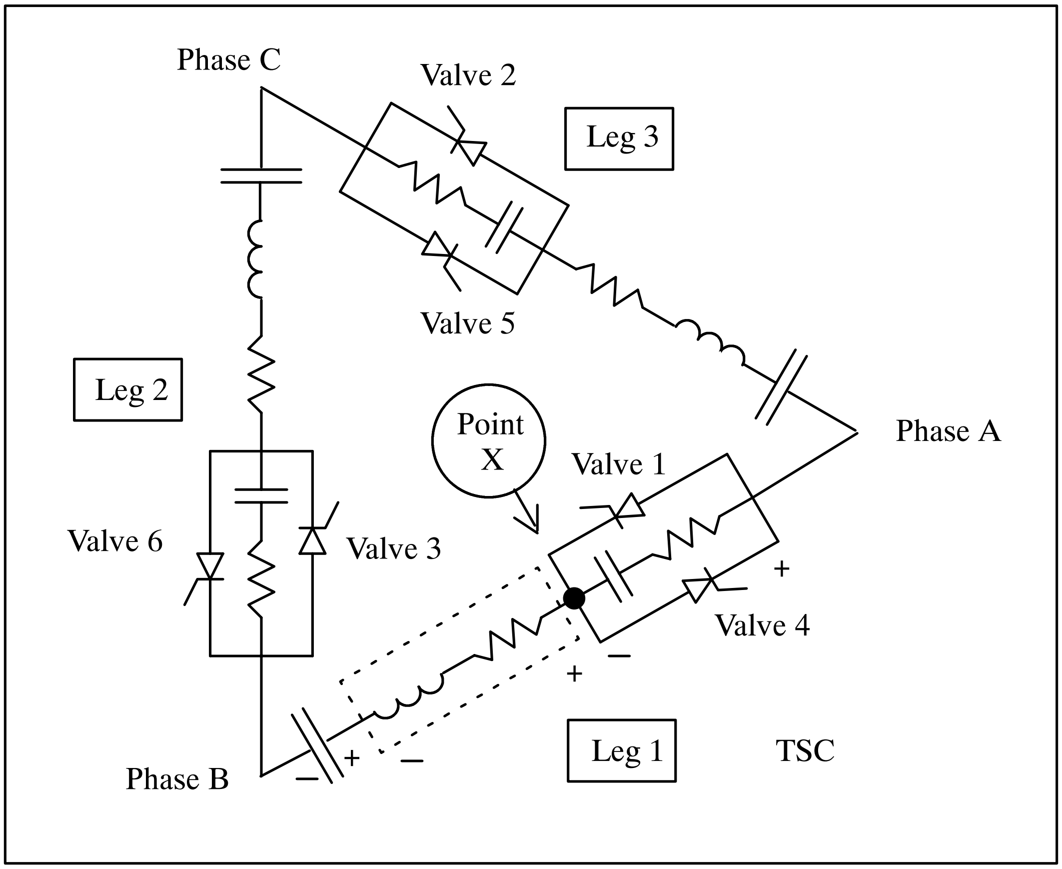
Item 4 (“tsc1c”) will be visible only if the bank has been specified as a TSC bank (not a TCR bank). This item prompts for the size of the main TSC capacitor. It is often the case that the series LC in a TSC bank is tuned to the 5^{th} or 7^{th} harmonic of the fundamental frequency.

Items 5 and 6 (“snc1” and “snr1”) request the parameters of the series RC snubber used on the valve. It is sometimes necessary to provide a snubber circuit which has more snubbing effect than the actual snubber, for numerical reasons. This is due to the reversal of current in the valve continuing until the end of the time−step at which point it is cut−off. This can cause a larger shut−off voltage spike than would be expected in the real valve. In particular, a larger snubber circuit may be required when the BOD (break−over diode) feature is enabled, as discussed below. The parameters of the snubber should be optimized to obtain good numerical performance. The RC time constant should always be greater than 2 time−steps in magnitude.

Item 7 (“vlvr1”) prompts for valve “Off” resistance. The valve “On” resistance is always exactly zero. If some valve “On” resistance needs to be represented, the resistance of the reactor can be increased artificially.

Item 8 (“vbrk1”) prompts for valve break−over voltage. When the absolute value of the valve voltage exceeds the specified break−over voltage, then the valve with positive forward voltage will turn−on, as if it had received an external firing pulse. This feature may be disabled by specifying a high break−over valve voltage such as 1.0e6 kV (illustrated in the above table). There are limitations in using the break−over feature. When a valve in a TCR leg shuts “Off”, then a forward voltage spike will be created on the reverse valve in the TCR leg. This is due to the reversal of current in the TCR leg which occurs in the valve before the end of the turn–off time–step. The magnitude of this spike is dependent on the point in the time–step when the valve turns "Off" and the size of the snubber circuit. Therefore, the spike is not consistent in magnitude. One limitation of using BOD is that the snubber circuit must be made overly large to control the effects of the spike. If control of this spike is important, consideration should be given to the use of SVC4.

Items 9 and 10 ("pt1v1" and "pt1v2") prompt for two three–phase voltage output quantities to be calculated. For reference, a typical TSC bank (connected in Delta) may be configured as follows:



Each TCR leg has a valve and a reactor. Each TSC leg also has a capacitor. The polarity of the voltages on these components are as shown on Leg 1 in the above Figure. Of course, the order of the components may be different in a Leg of the actual hardware. Therefore, the model allows the voltage components to be combined so as to obtain an appropriate voltage signal for the actual arrangement of components.

Items 9 and 10 ("pt1v1" and "pt1v2") select one of nine combinations of output quantities (0 to 8) for each three–phase output. The combination of components are described in the Table below for Leg1. Of course, Tables for Leg2 and Leg3 are similar except that the Phase A voltage is replaced with the Phase B or Phase C voltage. The table also applies for Wye connected banks.

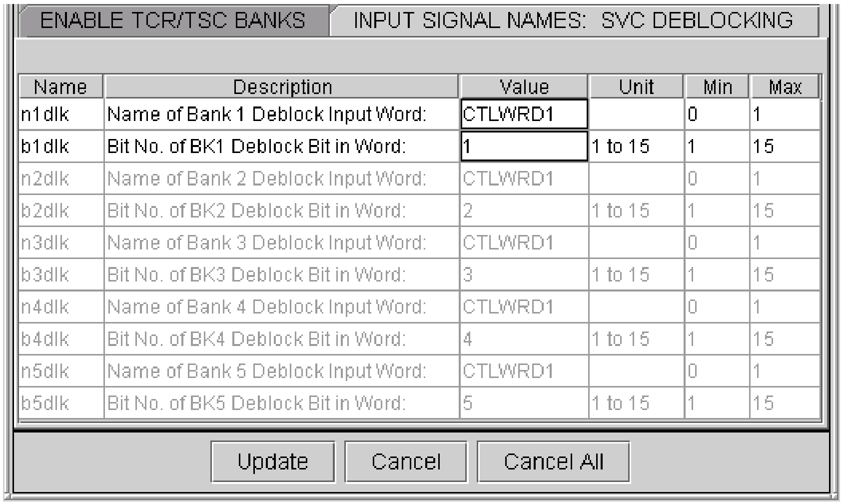
"pt1v1" and "pt1v2" Selection	Components of Output Voltage			
	Phase "A"	Capacitor	Valve	Reactor
0.0 output --> 0	0	0	0	0
capacitor output --> 1	0	+	0	0
valve output --> 2	0	0	+	0
3	+	−	0	0
4	+	0	−	0
5	+	0	0	−
6	+	−	−	0
7	+	−	0	−
8	+	0	−	−

For example, if the components of the actual hardware are configured as shown for the TSC bank illustrated above, and if the voltage is to be monitored at point X, "pt1v1" or "pt1v2" would be equal to 4. This selection would cause a three−phase signal to be calculated where the signal for each Leg consists of the node voltage for the phase minus the valve voltage for the respective Leg.

Output of the calculated voltage signals to RunTime, the controls compiler, and/or D/A are described below.

12.7 INPUT SIGNAL NAMES: SVC DEBLOCKING

The next menu is INPUT SIGNAL NAMES: SVC DEBLOCKING, as shown below. This menu is used to specify the source of the deblock bit for each enabled SVC bank. This is done by specifying the name of an integer control word and the bit number within the control word. The least significant bit (LSB) is referred to as bit 1. If desired, the same control word can be used for all banks and a different control bit specified for the separate banks.

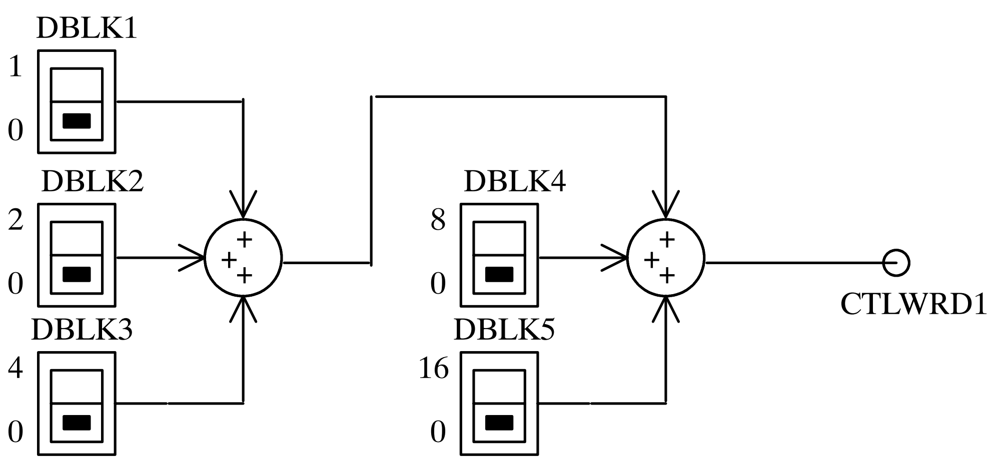


ENABLE TCR/TSC BANKS | INPUT SIGNAL NAMES: SVC DEBLOCKING

Name	Description	Value	Unit	Min	Max
n1dlk	Name of Bank 1 Deblock Input Word:	CTLWRD1		0	1
b1dlk	Bit No. of BK1 Deblock Bit in Word:	1	1 to 15	1	15
n2dlk	Name of Bank 2 Deblock Input Word:	CTLWRD1		0	1
b2dlk	Bit No. of BK2 Deblock Bit in Word:	2	1 to 15	1	15
n3dlk	Name of Bank 3 Deblock Input Word:	CTLWRD1		0	1
b3dlk	Bit No. of BK3 Deblock Bit in Word:	3	1 to 15	1	15
n4dlk	Name of Bank 4 Deblock Input Word:	CTLWRD1		0	1
b4dlk	Bit No. of BK4 Deblock Bit in Word:	4	1 to 15	1	15
n5dlk	Name of Bank 5 Deblock Input Word:	CTLWRD1		0	1
b5dlk	Bit No. of BK5 Deblock Bit in Word:	5	1 to 15	1	15

Update | Cancel | Cancel All

The integer control word may be created in the Controls Compiler (CC). The signal can depend on digital input, RunTime switches, and/or the output of some control system modelled in the CC. An example Draft schematic showing the generation of a control word in the CC is shown below. This circuit provides switches in RunTime.



12.8 INPUT SIGNAL NAMES: SVC VALVE FIRING

The next menu is INPUT SIGNAL NAMES: SVC VALVE FIRING, as shown below. This menu enables specification of the external source of firing pulse information as three words passed on the backplane in the RTDS rack. The 3 named words may be generated in the Controls Compiler blocks as described below.

The top 3 entries in the menu are for SVC Bank No. 1. The next 3 entries are for Bank No. 2, et cetera.

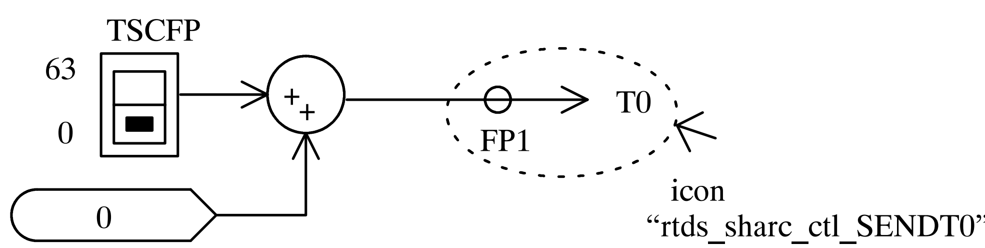
If an SVC Bank is specified as a TCR , then it will require all three of the Firing Pulse, Flast, and Fraction input words. If an SVC Bank is specified as a TSC, then it will require only the Firing Pulse input word. Words will be "greyed out" if they are not required for the the banks which have been enabled.

INPUT SIGNAL NAMES: SVC VALVE FIRING

Name	Description	Value	Unit	Min	Max
n1fp	Name of Bank1 Firing Pulse Input:	BK1FP		0	1
n1fl	Name of Bank1 Flast Input:	BK1FLST		0	1
n1frc	Name of Bank1 Fraction Input:	BK1FRAC		0	1
n2fp	Name of Bank2 Firing Pulse Input:	BK2FP		0	1
n2fl	Name of Bank2 Flast Input:	BK2FLST		0	1
n2frc	Name of Bank2 Fraction Input:	BK2FRAC		0	1
n3fp	Name of Bank3 Firing Pulse Input:	BK3FP		0	1
n3fl	Name of Bank3 Flast Input:	BK3FLST		0	1
n3frc	Name of Bank3 Fraction Input:	BK3FRAC		0	1
n4fp	Name of Bank4 Firing Pulse Input:	BK4FP		0	1
n4fl	Name of Bank4 Flast Input:	BK4FLST		0	1
n4frc	Name of Bank4 Fraction Input:	BK4FRAC		0	1
n5fp	Name of Bank5 Firing Pulse Input:	BK5FP		0	1
n5fl	Name of Bank5 Flast Input:	BK5FLST		0	1
n5frc	Name of Bank5 Fraction Input:	BK5FRAC		0	1

Update | Cancel | Cancel All

For a TSC type SVC bank, a very simple control system for turning on the TSC would be as illustrated below. This provides a switch in RunTime for the TSC.



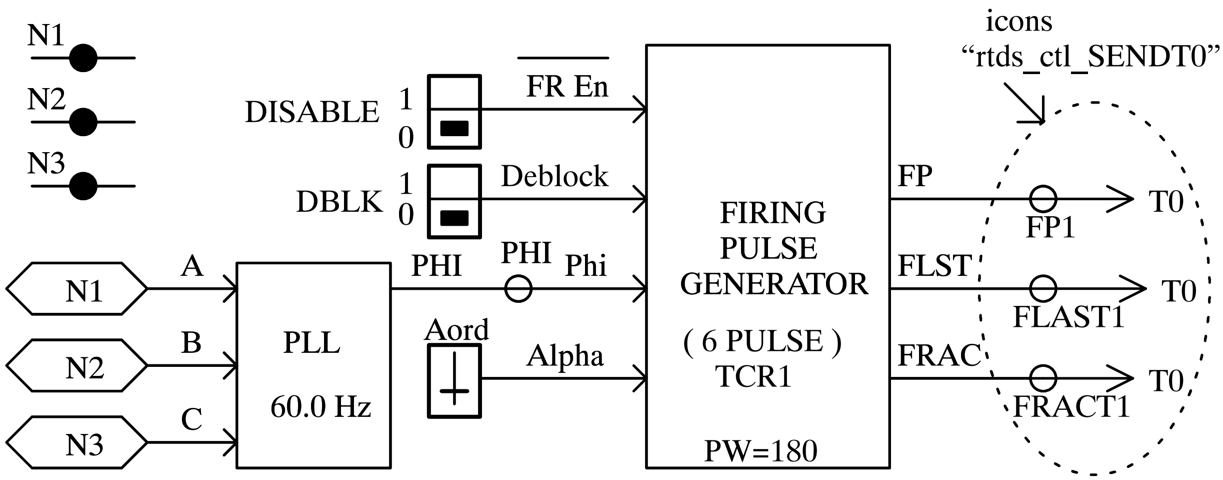
As an alternative to the switch, the firing pulse information for the TSC can be brought into the Controls Compiler processor using a CC digital input icon. The output of the digital input icon would be sent to the "rtds_sharc_ctl_SENDT0" icon.

It is important to note how the icon "rtds_sharc_ctl_SENDT0" is used in the above diagram. This icon causes the firing information to be passed on the backplane at the mid−point of the time−step (T0) rather than at the end of the time−step (T2). The banks in the SVC3 model (an interfaced model) must obtain the firing information in the middle of the time−step, just in time for use after T0.

In order to use the "rtds_sharc_ctl_SENDT0" icon as shown, Control Component ordering must be selected as "Auto" (which is the default setting), rather than the optional "Priority" mode. The "Auto" selection can be made by right−clicking on the circuit canvas, and choosing "Options". The "Circuit Options" menu will appear, in which "Auto" as opposed to "Priority" should be selected. Save and compile the case. Open the processor−usage page. Confirm that control blocks are organized so that the T0 transfer is indicated to occur at a time which is less than about 20 microseconds. If more than 20 microseconds, then re−organize control blocks to reduce time before T0. This will avoid unnecessarily extending the time−step size due to delay of T0.

For details on passing signals at T0 in "Priority" mode, please see the Controls Compiler documentation. For details on the T0 and T2 transfers, see Chapter 2.

For a TCR type SVC bank, a simple RTDS control system for firing the TCR would be as illustrated below. It creates the 3 backplane transfers, mentioned above, which must be transferred at the T0 transfer opportunity using "rtds_sharc_ctl_SENDT0" icons.



The first word ("n#fp") is the Firing Pulse Input word. This is an integer word having a permitted range of values from binary 000000 to binary 111111. Each bit represents a firing pulse bit, the least significant bit (LSB) corresponding to the firing pulse bit for valve number 1. A one (1) bit asserts firing of a valve.

The second word ("n#fl") is an integer identifying the last bit in the firing pulse word to transition ON in the last time−step. If no bit transitioned ON, then the word "n#fl" should contain the integer 0. However, if a bit did transition ON, then that bit number should be contained within "n#fl". For example, if firing pulse bit 4 transitioned ON 2/3 of the way through the last time−step, the integer 4 would be passed on the backplane in the "n#fl" word.

In this latter case, the third named word ("n#frc") should contain a floating point number, between 0.0 and 1.0, which describes the fractional position in the time−step when the ON transition occurred (Example: 0.66667).

The firing of 1 out of 6 valves can be improved in each time−step.

The Phase Locked Loop (PLL) in the above Controls Compiler schematic is controls component icon “rtds_sharc_ctl_PLL”. The Firing Pulse Generator is icon “rtds_sharc_ctl_FPGEN”.

The Firing Pulse Generator must be set to produce a <u>firing pulse width of 180 degrees</u> duration rather than 120 degrees.

More information is provided in Chapter 11 on the TCSC. These components represent basic control blocks which are not optimized for any particular purpose. More detailed control systems may be assembled using the lower level control blocks which are available in the Controls Compiler library.

Firing pulse information may be acquired from external SVC control hardware with the DITS (Digital Input Time Stamp) card. Chapter 11, on the TCSC model, describes the use of the DITS and it’s control icon, “rtds_sharc_ctl_DITS”. If using this component, the “rtds_sharc_ctl_SENDT0” component should also be used as discussed above, to pass the firing information at T0 in the middle of the time−step.

12.9 ENABLING AND SPECIFYING FILTERS

There are three menus for enabling and specifying filters as follows:

ENABLE FILTERS: DOUBLE−TUNED
ENABLE FILTERS: SINGLE−TUNED
FILTER PARAMETERS (SEE MANUAL)

The ENABLE FILTERS: DOUBLE−TUNED menu may be used to enable Filter 1 on processor 1 as a double−tuned filter connected in Delta. In that case, neither Filter 1 nor Filter 2 are usable on processor 1 as single−tuned filters.

If a double−tuned Filter is not requested on processor 1, the ENABLE FILTERS: SINGLE−TUNED menu can be used to request 1 or 2 series−RLC or High−pass filters connected in delta on processor 1.

The ENABLE FILTERS: DOUBLE−TUNED menu can also be used to enable Filter 3 on processor 2 as a double−tuned filter, connected in Delta. In that case, neither Filter 3 nor Filter 4 can be used on processor 2 as single−tuned filters.

If a double−tuned Filter is not requested on processor 2, the ENABLE FILTERS: SINGLE−TUNED menu can be used to request 1 or 2 series−RLC or High−pass filters connected in delta on processor 2.

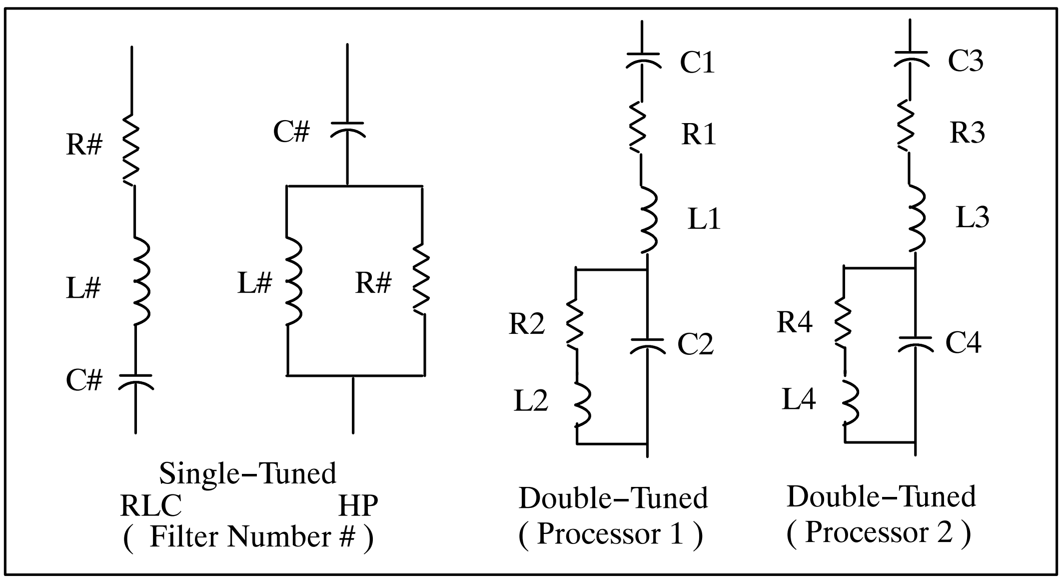
The FILTER PARAMETERS menu appears as shown below.

FILTER PARAMETERS (SEE MANUAL)

Name	Description	Value	Unit	Min	Max
p1fr1	Processor 1, R1 resistance:	0.0	Ohms	0.0	1.0e8
p1fh1	Processor 1, L1 inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
p1fc1	Processor 1, C1 capacitance:	222.86	MicroF.	0.005	1.0e8
p1fr2	Processor 1, R2 resistance:	0.0	Ohms	0.0	1.0e8
p1fh2	Processor 1, L2 inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
p1fc2	Processor 1, C2 capacitance:	222.86	MicroF.	0.005	1.0e8
p2fr1	Processor 2, R3 resistance:	0.0	Ohms	0.0	1.0e8
p2fh1	Processor 2, L3 inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
p2fc1	Processor 2, C3 capacitance:	222.86	MicroF.	0.005	1.0e8
p2fr2	Processor 2, R4 resistance:	0.0	Ohms	0.0	1.0e8
p2fh2	Processor 2, L4 inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
p2fc2	Processor 2, C4 capacitance:	222.86	MicroF.	0.005	1.0e8

Update Cancel Cancel All

The use of the parameters on each processor depends on the type of filter selected in the ENABLE FILTERS: DOUBLE−TUNED and ENABLE FILTERS: SINGLE−TUNED menus. The types of filters available are shown in the Figure below.



If a double−tuned filter is enabled on processor 1 or processor 2, then the quantities in the FILTER PARAMETERS menu correspond to the R, L, and C elements shown in the above Figure for the double−tuned filter.

If a single−tuned filter is enabled on processor 1 or processor 2, then the corresponding set of R, L, and C quantities in the FILTER PARAMETERS menu corresponds to R, L and C components of either an RLC−tuned filter or a High−pass filter as shown in the above Figure.

12.10 ENABLING MONITORING IN RUNTIME AND CONTROLS

There are four menus for enabling monitoring of available output quantities in Run-Time and the Controls Compiler (CC) as follows:

MONITORING IN RUNTIME AND CC: TRF & BK1
MONITORING IN RUNTIME AND CC: BK2 & BK3
MONITORING IN RUNTIME AND CC: BK4 & BK5
MONITORING IN RUNTIME AND CC: FILTERS

Each of the menus has essentially the same function but for different parts of the model. The first menu covers the transformer (“TRF”) and SVC Bank No. 1 (“BK1”). The second menu covers SVC Banks No. 2 and 3. The third menu covers SVC Banks No. 4 and 5. The final menu covers the Filters.

These menus are used to specify if various possible output signals from the model will be transferred on the backplane. Signals passed on the backplane can be monitored in RunTime, used in the Controls Compiler, or picked up for analog output by 16 bit optically isolated D/A cards (ODAC). Signals do NOT need to be passed on the backplane in order to be passed out of D/A channels on the front of the model processor card. The menus enable transfers of single−phase signals in the following list:

1) Primary currents into the transformer;
2) Voltages on the transformer valve−side bus;
3) The currents calculated in each of the SVC banks;
4) The 2 sets of three−phase voltages calculated in each bank; and
5) The filter currents.

12.11 ENABLING D/A OUTPUT

There are four menus for enabling D to A output of available output quantities, as follows:

ENABLE D/A: TRF & BK1 (MAX D/A = 8 ON PRC 1)
ENABLE D/A: BK2 & BK3 (MAX D/A = 8 ON PRC 2)
ENABLE D/A: BK4 & BK5 (MAX D/A = 8 ON PRC 3)
ENABLE D/A: FILTERS (MAX D/A = 8 ON PRC 1 & 2)

Each of the menus has essentially the same function but for different parts of the model. The first menu covers the transformer (“TRF”) and SVC Bank No. 1 (“BK1”). The second menu covers SVC Banks No. 2 and 3. The third menu covers SVC Banks No. 4 and 5. The final menu covers the Filters.

These menus are used to specify which output signals from the model will be passed through D/A output channels on the front of the processor card. The menus enable local D/A output of all single−phase signals listed in the previous section.

Each processor on a processor card has 8 dedicated D/A channels. In the SVC model, only quantities calculated on a given processor can be passed to the 8 D/A channels on that processor. If more D/A outputs per processor are required, then quantities must be passed on the backplane to the Controls Compiler (CC) where they can be passed out of D/A channels on the CC processor. Alternatively, additional D/A output signals can be passed from the backplane to optically isolated D/A cards (ODAC).

12.12 SPECIFYING D/A OUTPUT CHANNELS

There are four menus for specifying the D to A output channels to be used for the D to A signals enabled in the previous section. The menus are as follows:

SET D/A CHANNELS: TRF & BK1 ON PROC 1
SET D/A CHANNELS: BK2 & BK3 ON PROC 2
SET D/A CHANNELS: BK4 & BK5 ON PROC 3
SET D/A CHANNELS: FILTERS ON PROC 1 & 2

Each of the menus has essentially the same function but for different parts of the model. The first menu covers the transformer ("TRF") and SVC Bank No. 1 ("BK1") which are calculated on processor PROC1. The second menu covers SVC Banks No. 2 and 3 which are calculated on processor PROC2. The third menu covers SVC Banks No. 4 and 5 which are calculated on processor PROC3. The final menu covers the Filters which are calculated on processors PROC1 and PROC2.

The menus described in section 12.11 allow certain signals produced on a processor to be passed out of D/A channels on that processor. The menus in this section allow specification of which 8 D/A channels on the processor should be used for a given signal. If more than one signal is assigned to a given channel on the same processor, an error message will be given.

12.13 SPECIFYING SCALING OF D/A OUTPUT SIGNALS

There are two menus for specifying the scaling of the D to A signals enabled in Section 12.11 as follows:

D/A OUTPUT SCALING: TRF & SVC BANKS
D/A OUTPUT SCALING: FILTERS

The first menu covers scaling of D/A signals for the transformer, secondary bus and

SVC banks. The second menu covers scaling of D/A signals for the filters.

The signals calculated in the model for output are individual signals in three−phase groups. This menu specifies the signal magnitude for each three−phase group which will correspond to 5 Volts D/A output. Unity sliders are provided in RunTime for circumstances in which it is necessary to provide different scaling for individual signals in a three−phase group. Switches are also provided in RunTime to light an LED over the output channel on the front of 3PC card according to signal name (see section 12.14 below). Signal Offset adjustment sliders are also available in RunTime.

12.14 SPECIFYING OUTPUT SIGNAL NAMES

There are four menus for specifying the names of output signals, as follows:

OUTPUT SIGNAL NAMES: TRF & BK1
OUTPUT SIGNAL NAMES: BK2 & BK3
OUTPUT SIGNAL NAMES: BK4 & BK5
OUTPUT SIGNAL NAMES: FILTERS

If output signals are requested in either the MONITORING IN RUNTIME AND CC menus or the ENABLE D/A MONITORING menus, a unique signal name must be provided for each output signal. The specified name will be used if the signal is passed on the backplane. The specified name will also be used to identify the D/A scaling and offset adjustment sliders in RunTime and also the LED On/Off switch in RunTime.

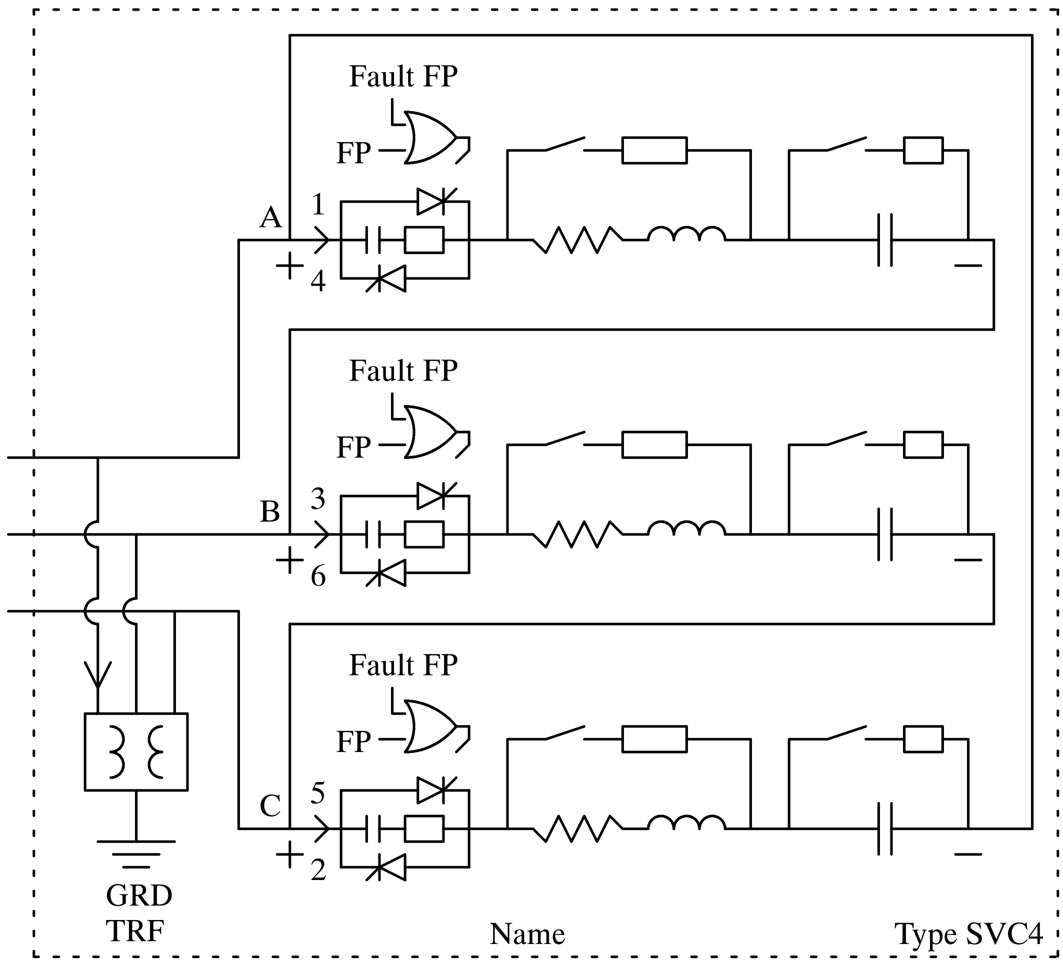
13 EMBEDDED SVC BANK MODEL

(rtds_sharc_SVC4)

13.1 INTRODUCTION

There are two SVC models which are available for modelling on the 3PC card: SVC3 and SVC4. This Chapter describes model type SVC4 while Chapter 12 describes SVC3. The icon for the model (rtds_sharc_SVC4) is shown below with optional Grounding Transformer and optional faults visible.

SVC4



The SVC3 model described in Chapter 12 was the first SVC model created for the 3PC card. The SVC3 model may be connected to either Connector type nodes or Embedded type nodes when used with the Real Time Network Solution. From one to three Sharc processors on one 3PC card are required for using the SVC3 model depending on the number of banks modelled. The model can provide up to 5 TSC or TCR banks connected in Wye or Delta with up to 4 filter banks and an SVC transformer on the one 3PC card.

As an alternative, this Chapter describes an embedded SVC bank model (SVC4) which is solved as part of the main network solution as one seamless Dommel trapezoidal network. The SVC4 model can be configured either as a TCR bank or a TSC bank. The SVC4 model uses one Sharc processor per bank.

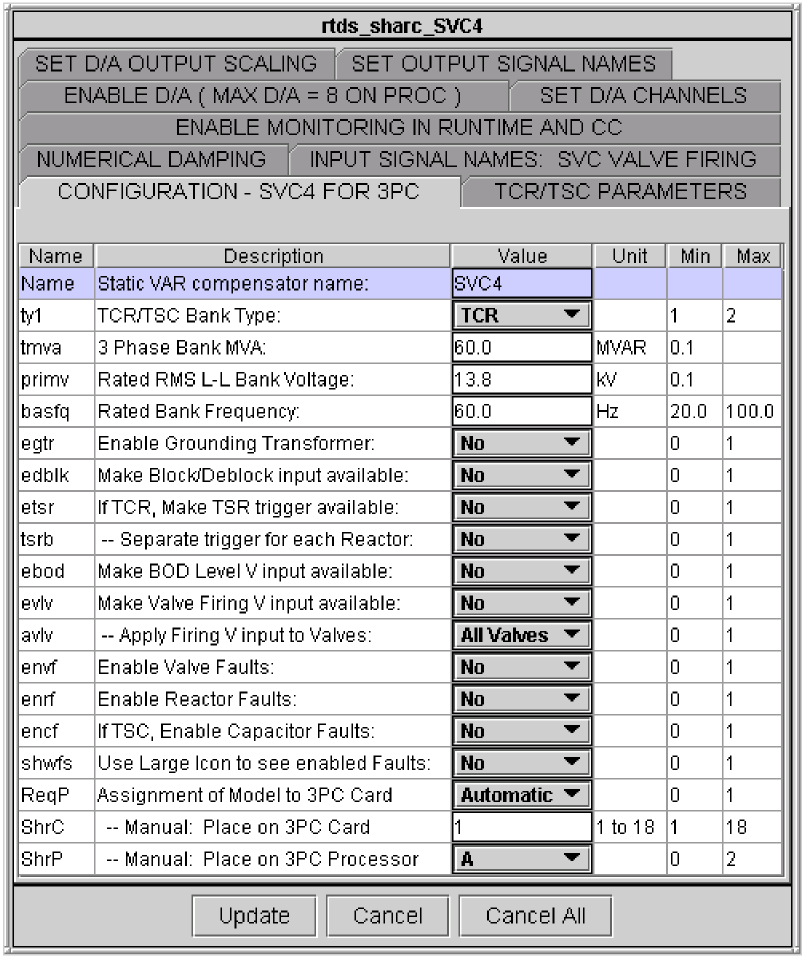
The SVC4 model must be connected to Connector type nodes in a Real Time Network Solution.

The model has improved turn−off performance so that Break−Over Diode (BOD) firing can be properly simulated. The model also allows for valve, reactor, capacitor and low−side bus faults. The increased capability and performance of the SVC4 model comes at the cost of generally using more hardware for the SVC4 solution. At present, the SVC4 model can only accommodate Delta−connected SVC banks.

As with the TCSC (Chapter 11) and the HVDC Valve Group (Chapter 8), and the SVC3 type model (Chapter 12), each TCR bank within the SVC4 model includes an improved firing accuracy feature.

13.2 CONFIGURATION – SVC4 FOR 3PC

The CONFIGURATION – SVC4 FOR 3PC menu, including the menu tabs available by default appears below.



Name	Description	Value	Unit	Min	Max
Name	Static VAR compensator name:	SVC4			
ty1	TCR/TSC Bank Type:	TCR		1	2
tmva	3 Phase Bank MVA:	60.0	MVAR	0.1	
primv	Rated RMS L-L Bank Voltage:	13.8	kV	0.1	
basfq	Rated Bank Frequency:	60.0	Hz	20.0	100.0
egtr	Enable Grounding Transformer:	No		0	1
edblk	Make Block/Deblock input available:	No		0	1
etsr	If TCR, Make TSR trigger available:	No		0	1
tsrb	-- Separate trigger for each Reactor:	No		0	1
ebod	Make BOD Level V input available:	No		0	1
evlv	Make Valve Firing V input available:	No		0	1
avlv	-- Apply Firing V input to Valves:	All Valves		0	1
envf	Enable Valve Faults:	No		0	1
enrf	Enable Reactor Faults:	No		0	1
encf	If TSC, Enable Capacitor Faults:	No		0	1
shwfs	Use Large Icon to see enabled Faults:	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

As usual, the first entry is a User specified name. An Error message will be issued if any other SVC4 is also given the same name.

The next entry in the CONFIGURATION menu allows the User to specify either that the model will represent a TCR bank or a TSC bank.

The SVC transformer is modelled using a normal transformer model. Therefore, the User does not specify the transformer data in the SVC4 model menus. However, various quantities such as default plot limits and numerical damping reactances are based on the per unit base values of the SVC bank. Therefore, it is necessary to specify the base values for bank MVAR, bank line−to−line RMS kV, and base bank fundamental frequency in Hz for the SVC bank. The next three items in the CONFIGURATION menu request this data.

The SVC4 model has several optional features enabled by the next 11 items in the CONFIGURATION menu. Depending on the selections made, the icon will change in appearance and additional menu tabs will appear.

The model may have a grounding transformer as shown above in the icon. In that case, a menu tab called GROUNDING TRANSFORMER will appear.

The model may have a Block/Deblock control bit input. In that case, a menu tab will appear asking for the name of the Backplane word and the bit number of the controlling bit in the word. This word can come from the Controls Compiler.

For the case of a TCR bank, the model may have a TSR (thyristor switched reactor) control input bit. When the TSR operation mode is enabled, assertion of the TSR bit will cause both valves in a leg (AB, BC, or CA) to fire upon the arrival of the next firing pulse for that leg. The continuous firing of both valves in the leg will continue until the TSR bit is taken to zero. The TSR menu is shown below.

Each TCR / TSR bank has a default break–over diode (BOD) voltage specified in the TCR / TSC PARAMETERS menu. However, using menu item “ebod”, it is also possible for the User to request the dynamic input of a BOD level signal from the Controls Compiler to over–ride the default value. This might be a Controls Compiler RunTime slider output which passes a BOD level value to the model. The slider could be adjusted by the User dynamically during a simulation.

Each valve in the TCR/TSC banks by default requires a forward voltage which is only greater than 0.0 in order to fire when a firing pulse is received. The “evlv” item in the CONFIGURATION menu enables the User to substitute for the required 0.0 level with a higher level brought in from the Controls Compiler. If the option in item “evlv” is selected, then the higher level is used for those valves indicated by the next item, “avlv”. The “avlv” item enables the use of the higher input voltage level on “All Valves” or only on those valves indicated by a 6 bit “CC Word” to be received from the Controls Compiler. For example, a binary number of 001001 (integer 9) would indicate that valves 1 and 4 should use the higher level for firing. The menu INPUT SIGNAL: VALVE BOD AND FWD V LEVELS”, discussed below, enables the User to specify names for receiving the optional control signals from the Controls Compiler. See Section 12.10 for further clarification.

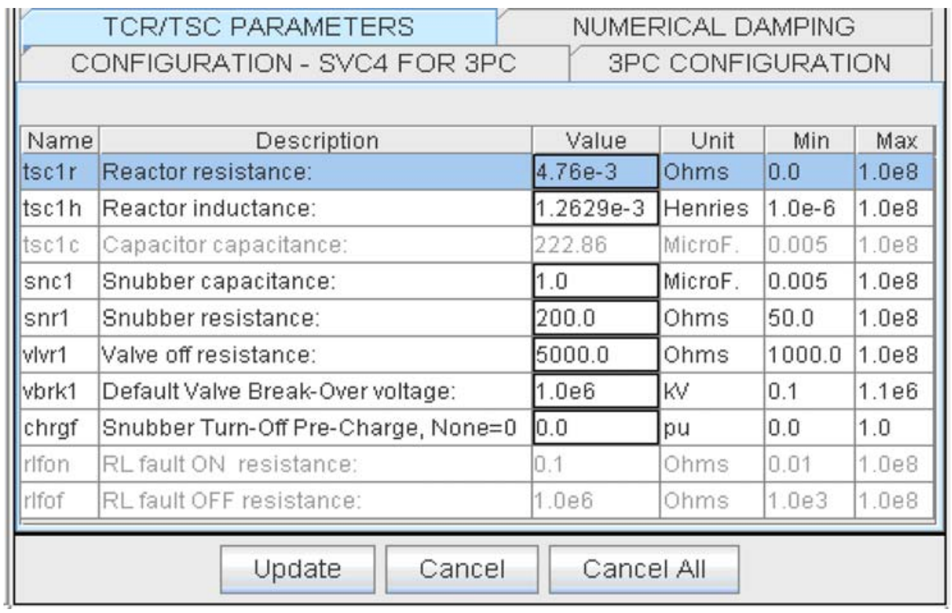
The next three items in the CONFIGURATION menu allow the User to request certain valve, reactor, and capacitor faults as shown in the model icon above. When using the large icon option (also in the CONFIGURATION menu), the requested valve, reactor or capacitor faults will be visible in the model icon. When a fault type is requested then an INPUT SIGNALS: FAULTS menu tab will appear. If a reactor fault is requested, then the reactor fault data will be requested in the TCR / TSC PARAMETERS menu as described below.

The last three entries in the CONFIGURATION menu (shown above) allow the User to specify either that the model will be automatically assigned to a processor (Automatic) or manually assigned to a User specified processor. If the User requests automatic assignment of the model to a 3PC processor, then the subsequent two entries in the menu are ignored. If the User requests manual assignment of the model to a processor, then the User can request a specific processor by indicating a 3PC card number (beginning with 1) and whether the model will be on processor

A, B, or C on the card. A 3PC card number of 1 means the 1st 3PC card in a rack. If two models request the same processor, then an Error message will be given. Manual assignment is useful in the case where a User is connecting external equipment through I/O to a given 3PC processor. In that case, Manual assignment assures the User that the model calculated on that processor will continue to be calculated on that processor as the case is modified.

13.3 TCR / TSC PARAMETERS

This menu allows the User to specify the parameters of the TCR / TSC bank.



Name	Description	Value	Unit	Min	Max
tsc1r	Reactor resistance:	4.76e-3	Ohms	0.0	1.0e8
tsc1h	Reactor inductance:	1.2629e-3	Henries	1.0e-6	1.0e8
tsc1c	Capacitor capacitance:	222.86	MicroF.	0.005	1.0e8
snc1	Snubber capacitance:	1.0	MicroF.	0.005	1.0e8
snr1	Snubber resistance:	200.0	Ohms	50.0	1.0e8
vlvr1	Valve off resistance:	5000.0	Ohms	1000.0	1.0e8
vbrk1	Default Valve Break-Over voltage:	1.0e6	kV	0.1	1.1e6
chrgf	Snubber Turn-Off Pre-Charge, None=0	0.0	pu	0.0	1.0
rlfon	RL fault ON resistance:	0.1	Ohms	0.01	1.0e8
rlfof	RL fault OFF resistance:	1.0e6	Ohms	1.0e3	1.0e8

The default main data is for a TSC bank with 11.43 Ohm delta−connected Legs with the LC elements tuned to the 5th harmonic (of 60 Hz) and a reactor with a Q of 100. The data will need to be re−entered to represent any realistic TCR. The third item (“tsc1c”) will be available to the User only if the bank has been specified as a TSC bank (not a TCR bank).

Items 5 and 6 (“snc1” and “snr1”) request the parameters of the series RC snubber used on the valve. The User may sometimes need to experiment with the snubber circuit for numerical reasons. However, in this model this should not often be necessary because the current in the TCR or TSC leg is interpolated back to zero at turn−off to avoid unrealistic numerical effects. Previously, the reversal of current in the valve continued until the end of the time−step at which point the current was cut−off. This could cause a larger shut−off voltage spike than would be expected in the real valve. This difficulty has been overcome in the present model.

Item 7 (“vlvr1”) asks the User to specify valve “Off” resistance. The valve “On” resistance is always exactly zero. If the User would like to represent some valve "On" resistance, then perhaps the resistance of the reactor could be increased artificially.

Item 8 ("vbrk1") asks the User to specify Default Valve Break−Over voltage. When the absolute value of the valve voltage exceeds the specified break−over voltage, then the valve with positive forward voltage will turn−on (as if it had received an external firing pulse). The User may disable this feature by specifying a high break−over valve voltage such as 1.0e6 kV (as illustrated in the above table).

The User may over−ride the default valve Break−Over voltage by enabling the BOD level input option in the CONFIGURATION menu. When this option is enabled, then the User can control the BOD firing level from the Controls Compiler (or the Sequencer) by setting a floating−point value for a name. The name of the BOD voltage signal is specified in the INPUT SIGNAL: VALVE BOD AND FWD V LEVELS menu of the SVC4 model.

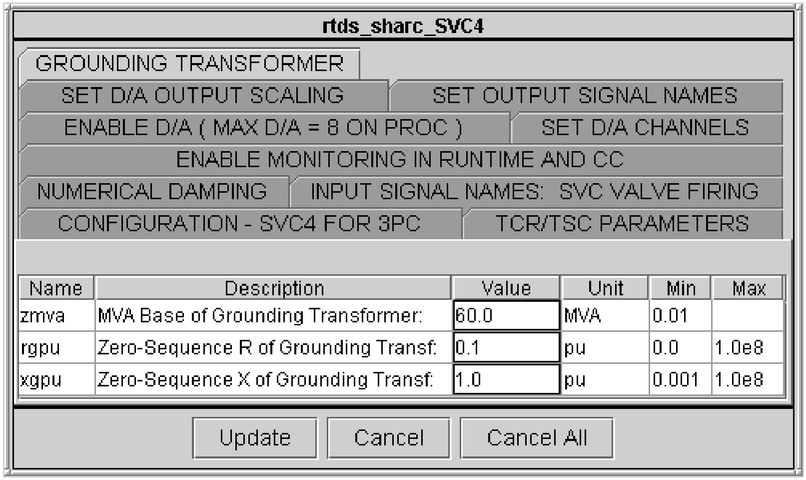
The item "Snubber Turn−Off Pre−Charge" in the above menu provides an option concerning the turn−off of valves in the SVC4 model. The default is to place no charge on the snubber capacitor (Snubber Turn−Off Pre−Charge = 0.0) after interpolating back to the current zero−crossing point. When this is done, the snubber will ring in the normal way and provide an increase in voltage applied to the valve during the valve recovery.

However, the snubber is modelled simply, as shown in the icon of the SVC4. Therefore, the User may know, through detailed study of the actual valve and snubber, that the recovery voltage overshoot will be less than seen in the simulation. The item "Snubber Turn−Off Pre−Charge" allows the User to reduce the valve voltage overshoot by pre−charging the snubber capacitor with a fraction (0.0 to 1.0) of the recovery voltage after interpolating back to the zero−crossing point. The presence of the charge reduces ringing in the snubber.

The final two items in the TCR / TSC PARAMETERS menu are available when the Enable Reactor Faults option is enabled in the CONFIGURATION menu. These items prompt for the ON and OFF resistance of the RL (resistor−reactor) fault branch. The primarily resistive fault branch contains a series L element which is automatically sized to L = 2 * Delt * R. This means that the L / R time constant of the fault branch elements have a time constant of 2.0. At 60 Hz, a typical fault resistance of 0.1 Ohm would contain a series inductive reactance of 0.00377 Ohms. This approach has been taken to assist numerical stability during faults.

13.4 GROUNDING TRANSFORMER

The GROUNDING TRANSFORMER menu tab appears when the Grounding Transformer is enabled in the CONFIGURATION menu. The menu appears as follows:

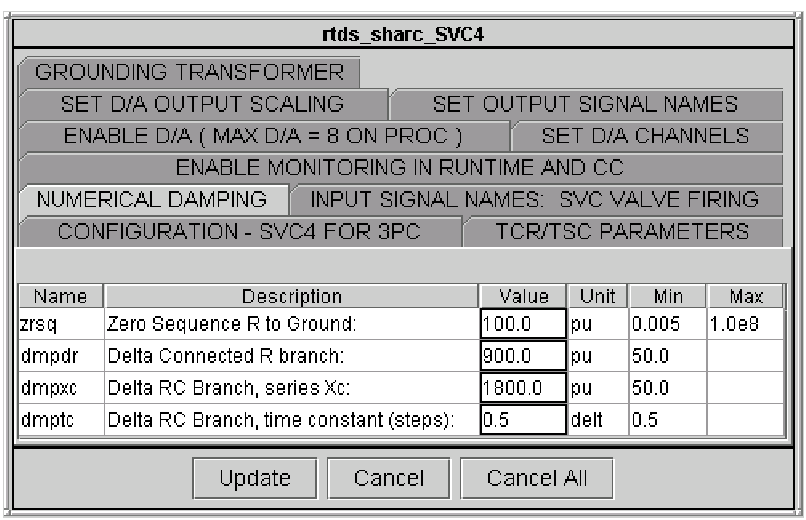


The base MVA of the Grounding transformer is specified separately from the Bank MVA described in the CONFIGURATION menu. The Rated RMS L−L Bank Voltage and the Rated Bank Frequency are taken directly from the CONFIGURATION menu and used also as base values for the Grounding Transformer.

The User can monitor the per−phase current out of the power system into the Grounding Transformer as shown in the icon for the model above. The signal can be sent to RunTime, the Controls Compiler and also to D/A output. See the ENABLE MONITORING... and ENABLE D/A... menus.

13.5 NUMERICAL DAMPING

The next menu allows the User to modify various default parameters in order to improve some aspects of numerical performance.



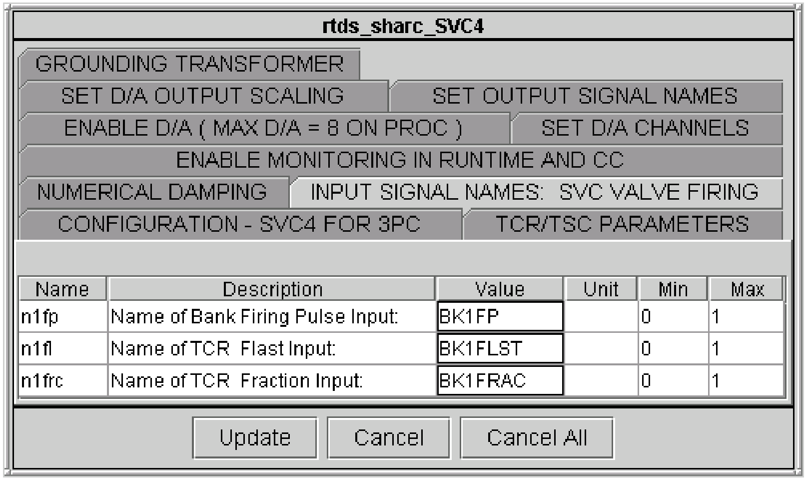
The banks of an SVC are often connected on the Delta side of a Wye−Delta transformer. If there is no connection to ground on the Delta−side of a transformer then in reality the zero−sequence component of the Delta bus voltages is determined only by stray conductances to ground. These cannot be exactly modelled in a transients program. Therefore, in the RTDS, if there is no connection to ground (example: grounding transformer, grounded load, et cetera) on the Delta side of the transformer then the User should optionally specify a Zero−Sequence resistance to ground (Zero Sequence R to Ground). The base value for the resistance is according to the rated values in the CONFIGURATION menu. The per unit value of this zero−sequence resistance can be quite large. The default values shown above tend to work well. If there is no other connection between the Delta bus and ground, then the zero−sequence content of the Delta bus voltages will be zero. If there is a fault on the Delta side bus, then only zero−sequence current will flow through this zero−sequence resistance.

It is well−known in electromagnetic simulation that switching events can cause two (2) time−step numerical oscillations. These oscillations are often damped by the resistances in the network. However, in this model, the SVC banks may be isolated on the inductive nodes of the SVC−side of the transformer. Therefore, techniques are made available to suppress erroneous two time−step numerical oscillations. Essentially, two branches are connected in parallel with each Delta−connected leg of the SVC. The first is a resistive branch which can be specified using the “dmpdr” item in the above menu (Delta Connected R branch:). The second is an RC snubber−like branch.

The default value for the Delta Connected R branch is 900 pu. The default RC branch is 1800 pu with a time constant of 0.5 delt (delt is the time−step size). Therefore, the RC branch is basically capacitive up to several kiloHertz. It is not often that the User will need to change these default parameters. However, if several banks are located on the same SVC−side transformer bus, then the damper values of second and subsequent banks can be made very large. Only one set of damper branches is required on the SVC−side of the transformer.

13.6 INPUT SIGNAL NAMES: SVC VALVE FIRING

The next menu is the INPUT SIGNAL NAMES: SVC VALVE FIRING menu, as shown below. This menu enables the User to specify the source of firing pulse information as three words passed on the backplane in the RTDS rack.



The TCR−type bank requires all three input words. The TSC−type bank requires only the firing pulse word (item “n1fp”). This is because the TCR−type bank implements improved firing accuracy techniques while this is not required for TSC−type bank. Words will be “greyed out” if they are not required for the type of bank which has been specified by the User.

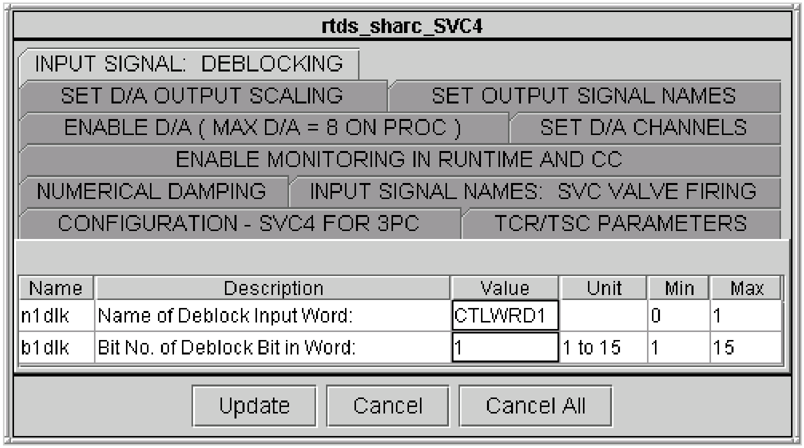
Firing information is passed at the end of the time−step (not the middle of the time−step) because this SVC4 model is embedded in the main network solution rather than being interfaced to the main network solution. Thus, in creating the firing pulse words the User should look at Chapters for other embedded−type models (TCSC or HVDC valve group) and NOT at Chapter 12 which describes the interfaced SVC3 model.

The three named words may be generated in the Controls Compiler blocks. The use of the rtds_ctl_DITS component is explained in Chapter 11 which describes the 3PC−based TCSC model. It is also useful to look at Chapter 8 on the 3PC Six−Pulse HVDC Valve Group which has similar requirements for firing pulse information.

The valve numbers are shown in the icon for the model illustrated above. The least−significant−bit (LSB) in the word is for valve number 1; the second LSB is for valve number 2; and so on to the 6^{th} LSB. A valve is fired by a bit value of 1 for the particular bit (as opposed to a 0).

13.7 INPUT SIGNAL: DEBLOCKING

The INPUT SIGNAL: DEBLOCKING menu is available if the User has selected the option in the CONFIGURATION menu of having a “Block/Deblock” signal. This DEBLOCKING menu is used to specify the source of the deblock bit for the SVC bank. The User does this by specifying the name of an integer control word and the bit number within the control word. The least significant bit (LSB) is referred to as bit 1.

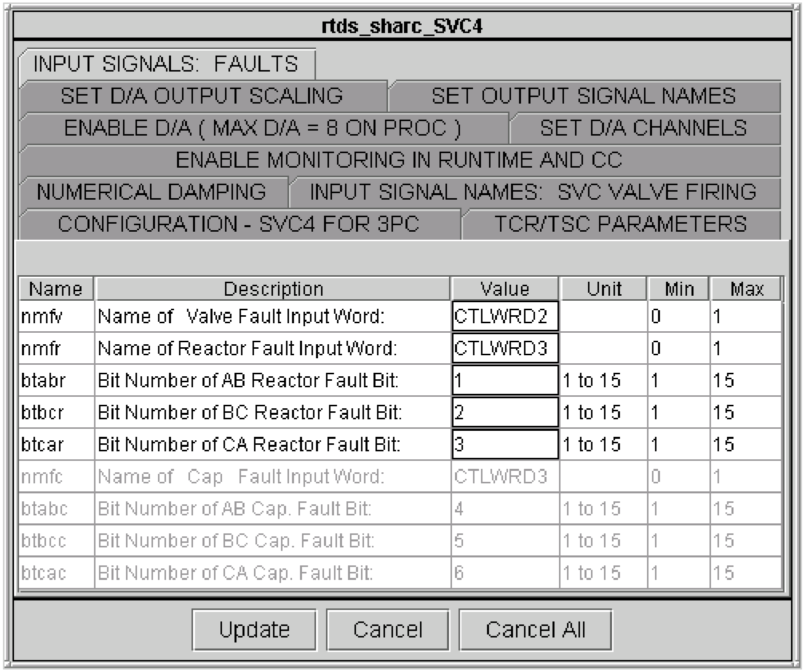


The optional integer control word may be created either in the Controls Compiler (CC) or in the Sequencer. Please see examples in Chapter 11 on the 3PC TCSC model and Chapter 8 on the HVDC valve group model.

13.8 INPUT SIGNALS: FAULTS

In the CONFIGURATION menu, the User has the option of enabling valve faults (item: "envf"); reactor faults (item: "enrf"); and/or capacitor faults (item: "encf"). Of course, the capacitor faults can only be enabled for TSC type banks. If the User has requested the use of the "Large Icon" in the CONFIGURATION menu, then the enabled faults will be shown in the icon for the model in DRAFT.

Once enabled the User must provide signals to apply or remove the faults at the required times. The INPUT SIGNALS: FAULTS menu prompts the User to identify the control words to the SVC4 model.



Name	Description	Value	Unit	Min	Max
nmfv	Name of Valve Fault Input Word:	CTLWRD2		0	1
nmfr	Name of Reactor Fault Input Word:	CTLWRD3		0	1
btabr	Bit Number of AB Reactor Fault Bit:	1	1 to 15	1	15
btbcr	Bit Number of BC Reactor Fault Bit:	2	1 to 15	1	15
btcar	Bit Number of CA Reactor Fault Bit:	3	1 to 15	1	15
nmfc	Name of Cap Fault Input Word:	CTLWRD3		0	1
btabc	Bit Number of AB Cap. Fault Bit:	4	1 to 15	1	15
btbcc	Bit Number of BC Cap. Fault Bit:	5	1 to 15	1	15
btcac	Bit Number of CA Cap. Fault Bit:	6	1 to 15	1	15

If the User has enabled valve faults in the CONFIGURATION menu, then the first entry in the above menu (“nmfv”) prompts the User for the name of a second firing pulse word. This second 6−bit firing pulse word (fault FP word) is put into a bitwise OR function with the normal firing pulse word. The output of this OR function is used by the valves. If the User wants the AB valves to continuously conduct in both directions during a fault, then the User could set the FP2 word to 9 to apply the valve fault and 0 to remove the valve fault. (Note: 9 equals 1 for valve 1 plus 8 for valve 4).

If the User has enabled reactor faults in the CONFIGURATION menu, then the next entry (“nmfr”) in the above menu prompts for the name of the integer word containing the reactor fault control bits. This word can be created either in the Controls Compiler or the Sequencer. The next three items (“btabr” , “btbcr” , and “btcar”) prompt the User to identify the bit numbers in the word that will control the reactor faults. If the User does not want to trigger a fault on a certain leg, then the User should make certain that the observed bit is always a 0 bit. In order to apply a reactor fault, the User should set the observed bit to 1 at the appropriate time using the Controls Compiler or the Sequencer. The ON and OFF resistance of an enabled reactor fault must be specified by the User in the TCR / TSC PARAMETERS menu. Each reactor fault branch actually has a very small reactor in series with the fault resistance. The RL time constant of the reactor fault branch is 2 time−steps. This is discussed above in the explanation of the TCR / TSC PARAMETERS menu.

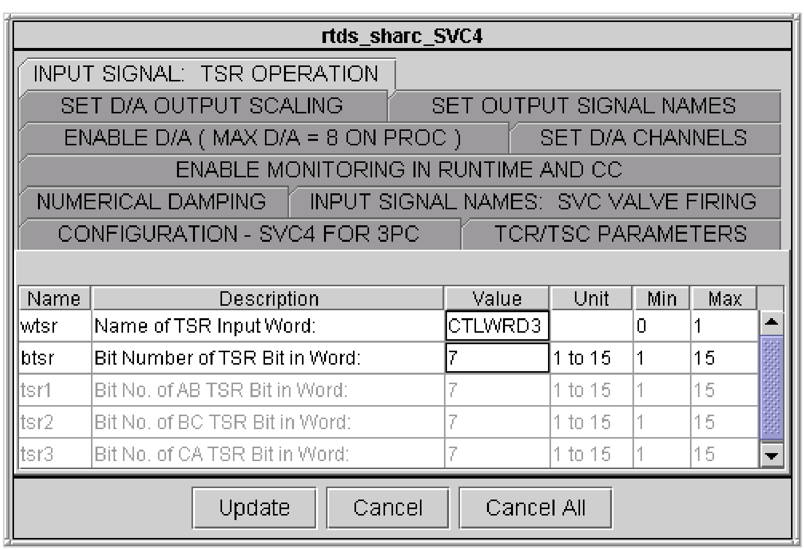
If the bank is a TSC type bank, then the User may also enable capacitor type faults in the CONFIGURATION menu. If the User has enabled capacitor faults in the CONFIGURATION menu, then the next entry (“nmfc”) in the above menu prompts the User for the name of the integer word containing the capacitor fault control bits.

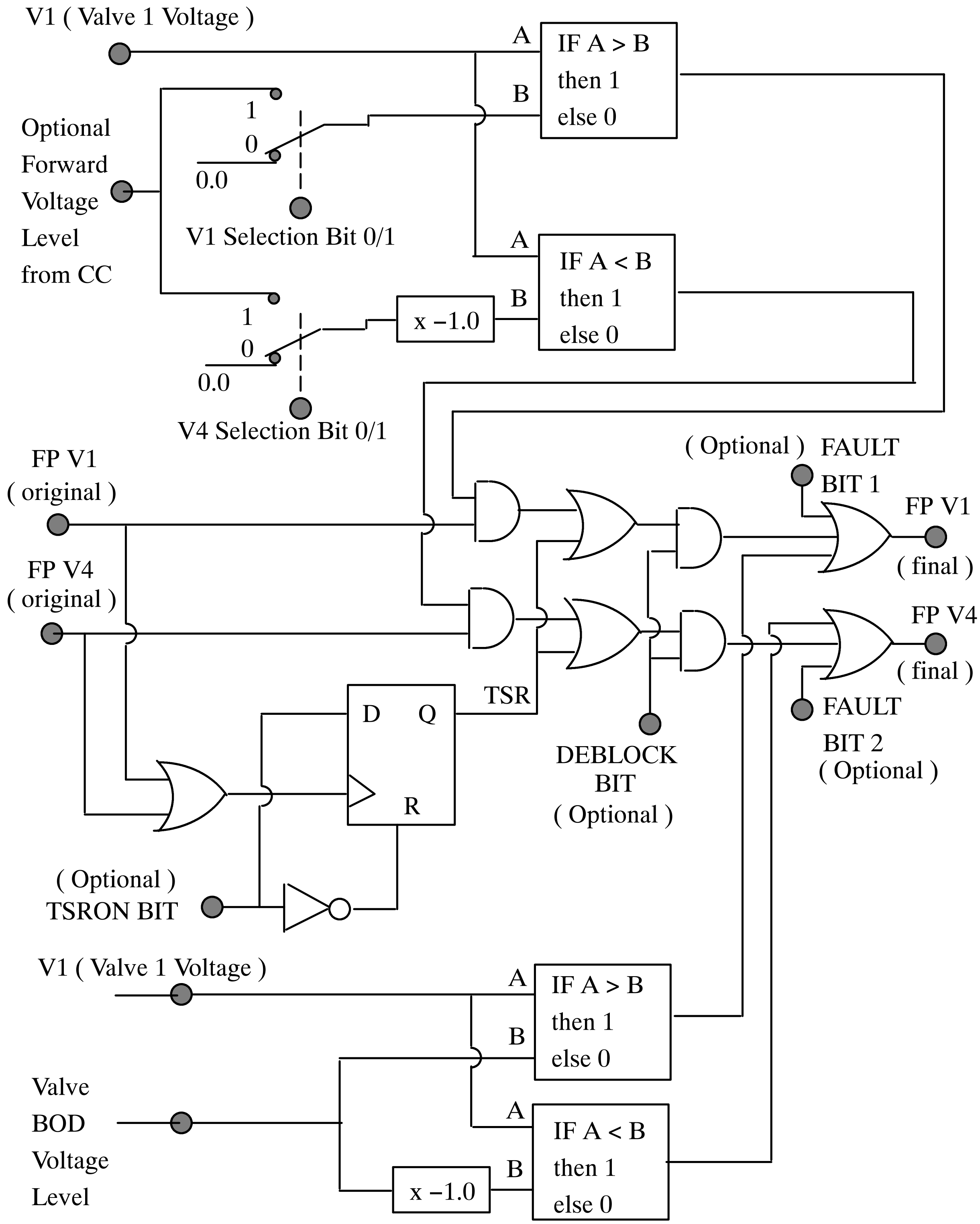
This word can be created either in the Controls Compiler or the Sequencer. The next three items (“btabc” , “btbcc” , and “btcac”) prompt the User to identify the bit numbers in the word that will control the capacitor faults. If the User does not want to trigger a fault on a certain leg, then the User should make certain that the observed bit is always a 0 bit. In order to apply a capacitor fault, the User should set the observed bit to 1 at the appropriate time using the Controls Compiler or the Sequencer. It is not necessary to specify the ON and OFF resistance of the capacitor fault branch. When the capacitor fault is OFF, then the resistance of the capacitor fault branch is infinite. When the capacitor fault is applied, then the capacitor fault branch resistance is equal to the Dommel resistance for the capacitor branch (0.5 * Delt / C) which is quite small. With this value of capacitor fault resistance, the RC time−constant of the capacitor and capacitor fault resistance would be 0.5 Delt (Delt = time−step size). Thus, the capacitor is essentially discharged in the first time−step after application of the capacitor fault.

13.9 INPUT SIGNAL: TSR OPERATION

In the CONFIGURATION menu, the User may request that a TSR trigger should be made available for TCR type banks. This option is not available for TSC type banks. In the case where a TSR trigger is requested , the CONFIGURATION menu also enables the User to request separate TSR activation bits for each of the three legs of the bank.

The INPUT SIGNAL: TSR OPERATION menu is available if the User has selected the option in the CONFIGURATION menu of having a “TSR trigger” available. This TSR OPERATION menu is used to specify the source of the TSR trigger bit for the TCR type bank or alternatively for each of the legs (AB, BC and CA). The User does this by specifying the name of an integer control word and the bit numbers within the control word. The least significant bit (LSB) is referred to as bit 1.





FIRING LOGIC FOR A LEG (AB) OF THE MODEL

The optional TSR integer control word may be created either in the Controls Compiler (CC) or in the Sequencer. Please see examples in Chapter 11 on the 3PC TCSC model and Chapter 8 on the HVDC valve group model.

Firing Pulses taken into the TCR bank model are processed within each leg of the TCR as illustrated for Leg AB in the above diagram. The signal TSRON is set to 1 to enable TSR firing mode. The “original” firing pulses are brought into the logic on the left in the diagram. V1 is the forward valve in leg AB. V4 is the reverse valve in Leg AB.

When TSRON is asserted (logic 1), the arrival of the next firing pulse in the Leg causes both final firing bits, FP V1 and FP V4 on the right, to be asserted (logic 1) until TSRON is reset back to 0. However, these firing pulses are qualified by the Deblock Bit as shown in the above diagram.

13.10 INPUT SIGNAL: VALVE BOD AND FWD V LEVEL

The INPUT SIGNAL: VALVE BOD AND FWD V LEVEL menu is available if the User has requested BOD Level Voltage Input or Valve Firing Voltage Input in the CONFIGURATION menu.

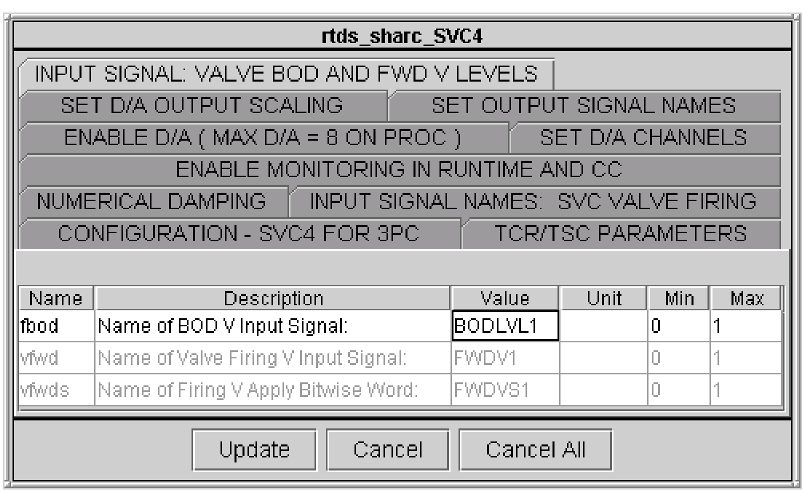
When the User has specified in the CONFIGURATION menu that a “BOD Level input” signal will NOT be required, then the valves will break over according to the default valve break−over voltage specified in the TCR / TSC PARAMETERS menu.

When a “BOD Level input” signal is used, then the valves will break−over according to that floating point input (in kV) as shown in the above diagram.

When the User has specified in the CONFIGURATION menu that “Valve Firing Voltage input” is NOT required, then a firing pulse can fire on the valve whenever the forward voltage is greater than 0.0.

When a “Valve Firing Voltage input” is used, then the selected valves will only turn on when the forward voltage is greater than the Valve Firing Voltage input.

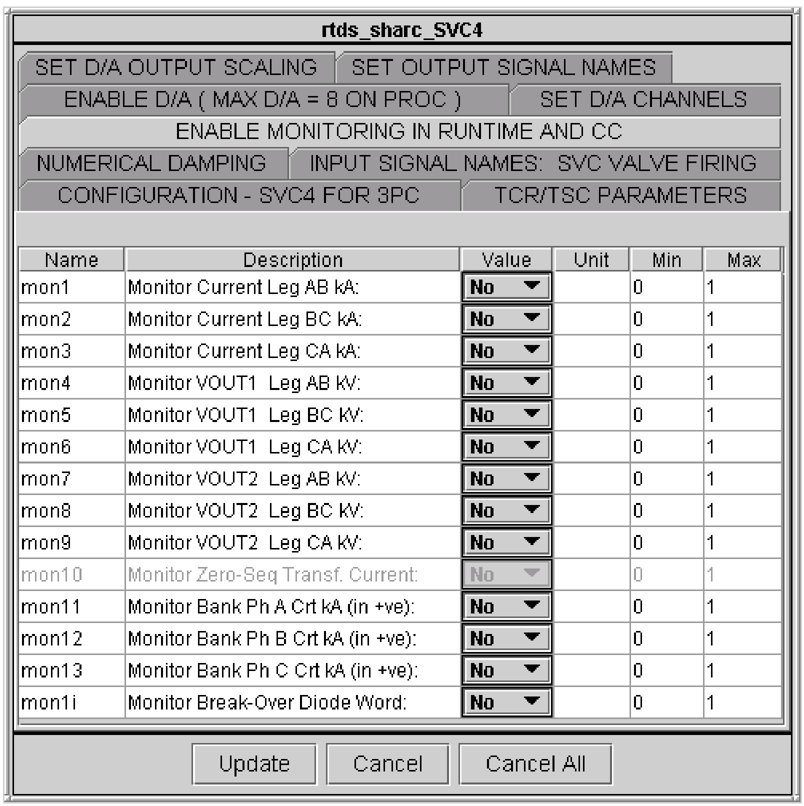
The INPUT SIGNAL: VALVE BOD AND FWD V LEVEL menu appears as follows:



There is a 6 bit integer word which can be monitored by the User in RunTime or passed to the Controls Compiler (see monitoring menu below). This 6 bit word will indicate when any of the 6 valves turns on according to BOD operation. The least–significant–bit (LSB) indicates valve number 1 BOD operation. The 2nd LSB indicates valve number 2 BOD operation and so on.

13.11 ENABLE MONITORING IN RUNTIME AND CONTROLS

The User is prompted in this menu to specify whether various possible output signals from the model will be transferred on the backplane. Signals passed on the backplane can be monitored in RunTime and used in the Controls Compiler. The first 13 signals are floating point signals which can be picked off of the backplane for analog output by 16 bit optically isolated D/A cards (ODAC). Signals do NOT need to be passed on the backplane in order to be passed out of the 12 bit D/A channels on the front of the model processor card as specified in the ENABLE D/A... menu described below.



Name	Description	Value	Unit	Min	Max
mon1	Monitor Current Leg AB kA:	No		0	1
mon2	Monitor Current Leg BC kA:	No		0	1
mon3	Monitor Current Leg CA kA:	No		0	1
mon4	Monitor VOUT1 Leg AB kV:	No		0	1
mon5	Monitor VOUT1 Leg BC kV:	No		0	1
mon6	Monitor VOUT1 Leg CA kV:	No		0	1
mon7	Monitor VOUT2 Leg AB kV:	No		0	1
mon8	Monitor VOUT2 Leg BC kV:	No		0	1
mon9	Monitor VOUT2 Leg CA kV:	No		0	1
mon10	Monitor Zero-Seq Transf. Current:	No		0	1
mon11	Monitor Bank Ph A Crt kA (in +ve):	No		0	1
mon12	Monitor Bank Ph B Crt kA (in +ve):	No		0	1
mon13	Monitor Bank Ph C Crt kA (in +ve):	No		0	1
mon1i	Monitor Break-Over Diode Word:	No		0	1

The menu allows the User to enable transfer of single–phase floating point signals in the following list:

1) The current in each Delta–connected leg (mon1 to mon3).

2) A voltage signal for each leg (mon4 to mon6) composed according to the COMPONENTS OF 3 PH OUTPUT SIGNALS: VOUT1 menu described below.

3) A voltage signal for each leg (mon7 to mon9) composed according to the COMPONENTS OF 3 PH OUTPUT SIGNALS: VOUT2 menu described below.

4) The zero−sequence current from the main bus into the grounding transformer (mon10). Of course, this output is only available if the grounding transformer has been enabled in the CONFIGURATION menu.

5) The 3 bus currents into the model excluding grounding transformer current (mon 11 to mon13).

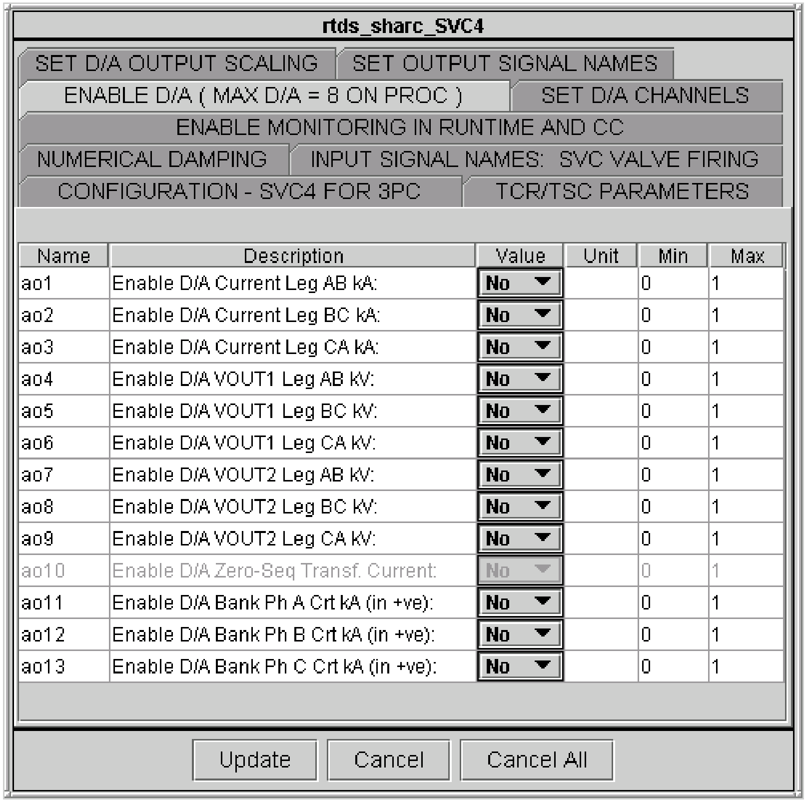
Signals which are selected for monitoring must be given names in the SET OUTPUT SIGNAL NAMES menu below.

The menu also allows the User to pass an integer word (mon1i) for BOD firing activity as explained in the section above describing the menu INPUT SIGNAL: VALVE BOD AND FWD V LEVEL.

13.12 ENABLE D/A OUTPUT

The User is prompted in the ENABLE D/A menu to specify which output signals from the model will be passed through D/A output channels on the front of the processor card. The menu allows the User to enable local D/A output of all single−phase signals listed in the previous section.

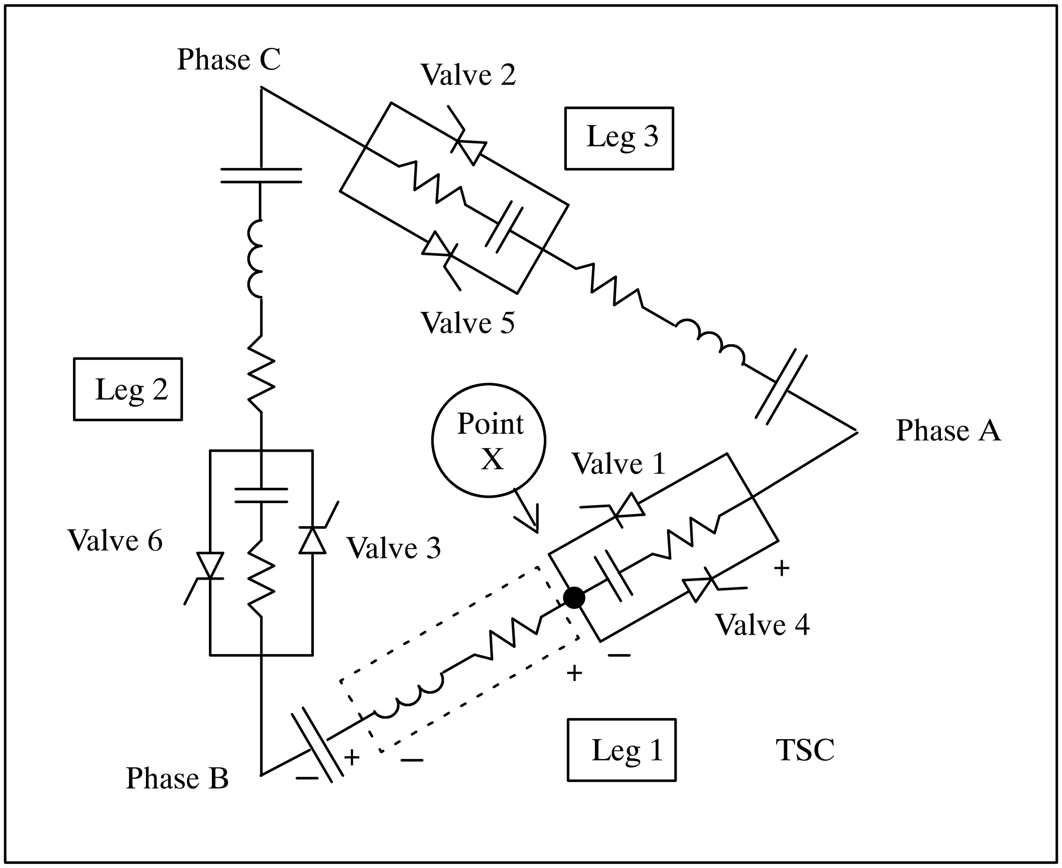
Each processor on a processor card has 8 dedicated D/A channels. If more than 8 D/A outputs per bank are required, then quantities must be passed on the backplane either to the Controls Compiler (CC) where they can be passed out of D/A channels on a CC processor or to an ODAC (optically isolated D/A converter) card through an oversampling component (rtds_sharc_DAOVR2).



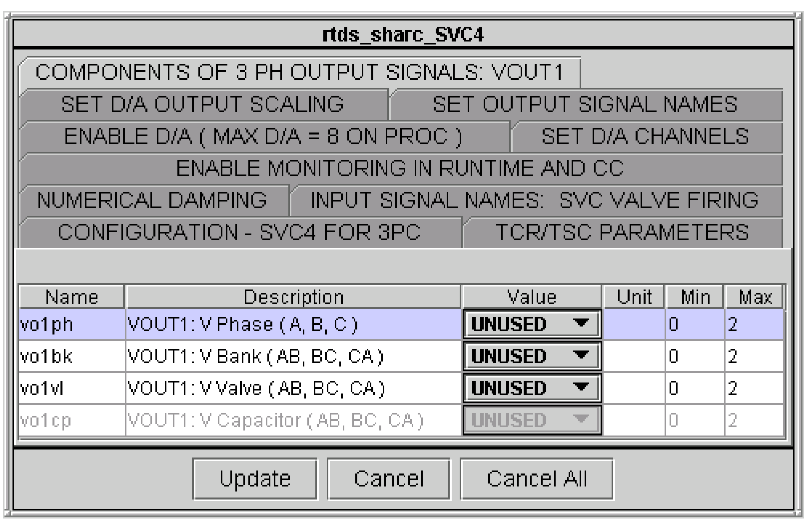
Signals which are selected for D/A output must be given names in the SET OUTPUT SIGNAL NAMES menu below. For each D/A output quantity, the User must select a channel (1 to 8) using the SET D/A CHANNELS menu described below. The User must also set an output scaling factor using the SET D/A OUTPUT SCALING menu described below.

13.13 COMPONENTS OF 3 PHASE OUTPUT SIGNALS: VOUT1

As mentioned in the ENABLE MONITORING... (mon4 to mon6) and ENABLE D/A... (ao4 to ao6) menus described above, the User may create a three−phase set of voltage signals for each leg composed of components of the leg voltage. The available components for the AB leg are the Phase A bus voltage; the AB leg voltage; the AB valve voltage; and the AB capacitor voltage. The reference directions of the components of voltage are as shown in the following figure. The components for the BC and CA legs are selected to be similar to the AB leg.



The three−phase set of output voltages VOUT1 can be defined by selecting components of the output voltage according to COMPONENTS OF 3 PH OUTPUT SIGNALS: VOUT1 as shown below. For example, if the User's SVC bank is configured as shown for the TSC bank illustrated above, and if the User wishes to monitor the voltage at point X, then the User would subtract the AB valve voltage from the Phase A voltage by selecting the appropriate toggle box positions as shown below.



rtds_sharc_SVC4

COMPONENTS OF 3 PH OUTPUT SIGNALS: VOUT1
SET D/A OUTPUT SCALING | SET OUTPUT SIGNAL NAMES
ENABLE D/A (MAX D/A = 8 ON PROC) | SET D/A CHANNELS
ENABLE MONITORING IN RUNTIME AND CC
NUMERICAL DAMPING | INPUT SIGNAL NAMES: SVC VALVE FIRING
CONFIGURATION - SVC4 FOR 3PC | TCR/TSC PARAMETERS

Name	Description	Value	Unit	Min	Max
vo1ph	VOUT1: V Phase (A, B, C)	UNUSED		0	2
vo1bk	VOUT1: V Bank (AB, BC, CA)	UNUSED		0	2
vo1vl	VOUT1: V Valve (AB, BC, CA)	UNUSED		0	2
vo1cp	VOUT1: V Capacitor (AB, BC, CA)	UNUSED		0	2

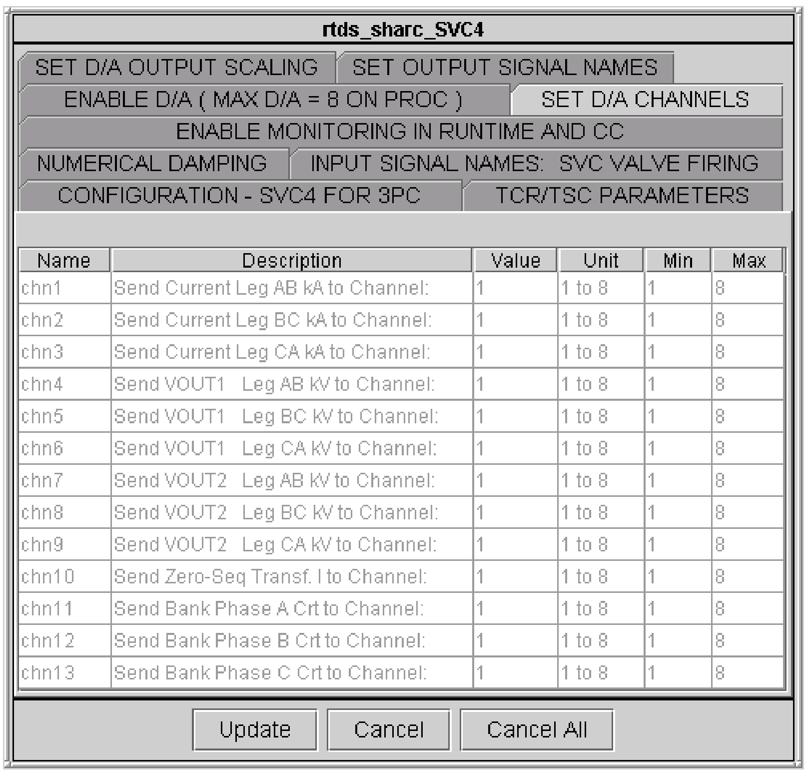
Update | Cancel | Cancel All

13.14 COMPONENTS OF 3 PHASE OUTPUT SIGNALS: VOUT2

This menu is used to define the second set of three−phase voltages for the SVC Bank in the same way that the first set of three−phase voltages was defined by the COMPONENTS OF 3 PH OUTPUT SIGNALS: VOUT1 menu described above.

13.15 SPECIFYING D/A CHANNELS

This menu is used for specifying the D to A output channels to be used for the D to A signals enabled in a previous menu.



Name	Description	Value	Unit	Min	Max
chn1	Send Current Leg AB kA to Channel:	1	1 to 8	1	8
chn2	Send Current Leg BC kA to Channel:	1	1 to 8	1	8
chn3	Send Current Leg CA kA to Channel:	1	1 to 8	1	8
chn4	Send VOUT1 Leg AB kV to Channel:	1	1 to 8	1	8
chn5	Send VOUT1 Leg BC kV to Channel:	1	1 to 8	1	8
chn6	Send VOUT1 Leg CA kV to Channel:	1	1 to 8	1	8
chn7	Send VOUT2 Leg AB kV to Channel:	1	1 to 8	1	8
chn8	Send VOUT2 Leg BC kV to Channel:	1	1 to 8	1	8
chn9	Send VOUT2 Leg CA kV to Channel:	1	1 to 8	1	8
chn10	Send Zero-Seq Transf. I to Channel:	1	1 to 8	1	8
chn11	Send Bank Phase A Crt to Channel:	1	1 to 8	1	8
chn12	Send Bank Phase B Crt to Channel:	1	1 to 8	1	8
chn13	Send Bank Phase C Crt to Channel:	1	1 to 8	1	8

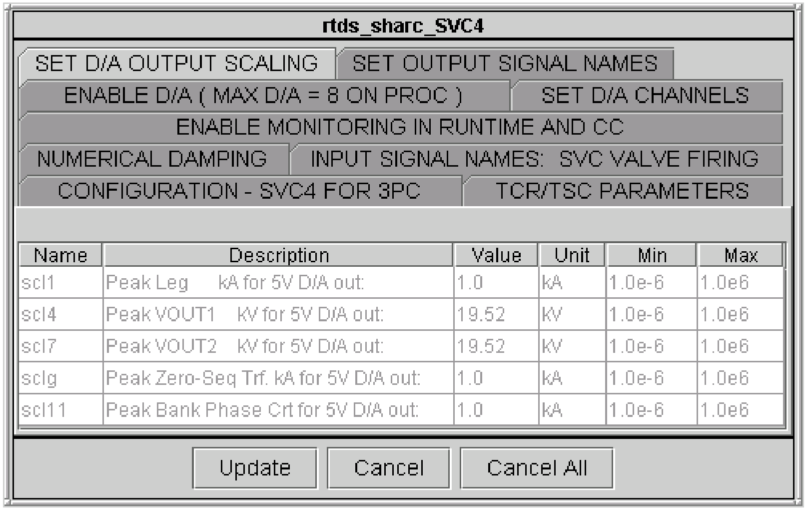
The menu described in section 13.12 allows the User to request that certain signals produced in the model be passed to D/A channels on the front of the processor card. If the User has not requested a signal in the ENABLE D/A... menu, then the corresponding line in this menu will be greyed out. The menu in this section allows the User to specify which of 8 D/A channels on the model processor should be used for a given enabled D/A signal. If the User attempts to assign more than one D/A signal to a given channel on the model processor, then an ERROR message will be given at COMPILE time in DRAFT.

Of course, the User cannot pass more than 8 signals through the D/A channels on the front of a 3PC Sharc processor. If the User needs more than 8 D/A channels from a bank in the SVC4 model then the additional signals can either be passed to a Controls Compiler processor for D/A output or to an optical D/A convertor card

(ODAC) by way of an oversampling output component (rtds_sharc_DAOVR2).

13.16 SPECIFYING D/A OUTPUT SCALING

The following menu enables the User to specify scaling factors for D/A output signals which were enabled in the ENABLE D/A... menu.



rtds_sharc_SVC4

SET D/A OUTPUT SCALING | SET OUTPUT SIGNAL NAMES

ENABLE D/A (MAX D/A = 8 ON PROC) | SET D/A CHANNELS

ENABLE MONITORING IN RUNTIME AND CC

NUMERICAL DAMPING | INPUT SIGNAL NAMES: SVC VALVE FIRING

CONFIGURATION - SVC4 FOR 3PC | TCR/TSC PARAMETERS

Name	Description	Value	Unit	Min	Max
scl1	Peak Leg kA for 5V D/A out:	1.0	kA	1.0e-6	1.0e6
scl4	Peak VOUT1 kV for 5V D/A out:	19.52	kV	1.0e-6	1.0e6
scl7	Peak VOUT2 kV for 5V D/A out:	19.52	kV	1.0e-6	1.0e6
sclg	Peak Zero-Seq Trf. kA for 5V D/A out:	1.0	kA	1.0e-6	1.0e6
scl11	Peak Bank Phase Crt for 5V D/A out:	1.0	kA	1.0e-6	1.0e6

Update | Cancel | Cancel All

The first entry in this menu enables the User to specify the scaling factor for the current in the Delta−connected legs (mon1 to mon3, the first three entries in the ENABLE D/A... menu). The User specifies the peak current which should correspond to 5 Volts out of the D/A channel for the signal.

The next two entries allow the User to specify scaling factors for the two three−phase voltage sets, VOUT1 and VOUT2.

The next entry allows the User to specify the scaling factor for the zero−sequence current into the grounding transformer from the main bus.

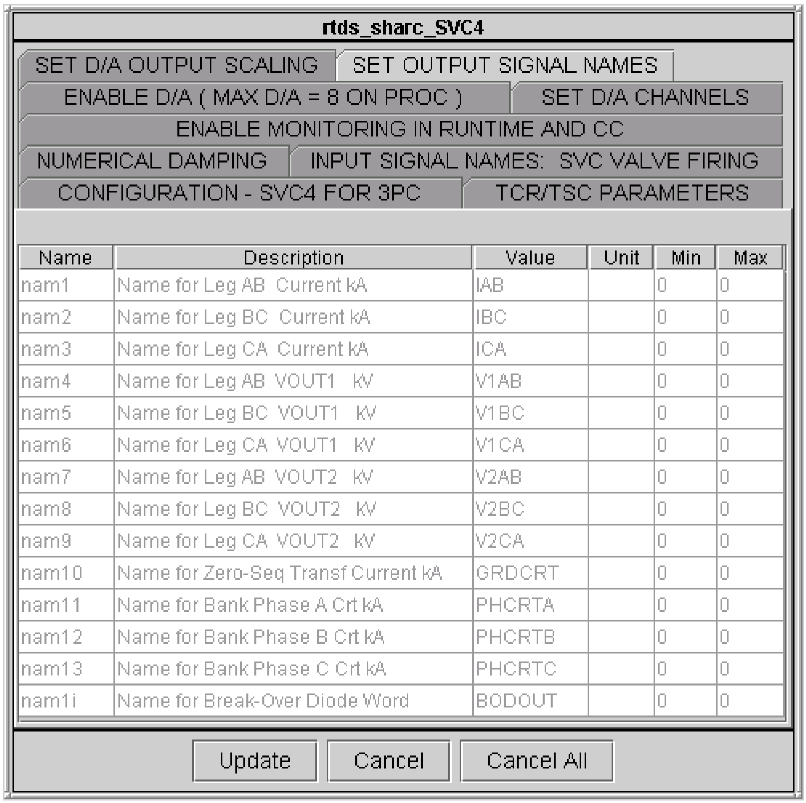
The final entry allows the User to specify the scaling factor for the current into the model from the main bus (excluding grounding transformer current).

Unity sliders are provided in RunTime for circumstances in which it is necessary to provide different scaling for individual signals in a three−phase group. Switches are also provided in RunTime to allow the User to light an LED over the output channel on the front of 3PC card according to signal name (see section 13.17 below). Signal Offset adjustment sliders are also available in RunTime.

13.17 Menu: SET OUTPUT SIGNAL NAMES

If the User requests output signals either in the ENABLE MONITORING... menu or in the ENABLE D/A... menu, then the User will be prompted to specify a unique signal name for each requested output signal. The specified name for a signal will be used if the signal is passed on the backplane. The specified name will also be used to identify the D/A scaling and offset adjustment sliders in RunTime and also the LED On/Off switch in RunTime.

The SET OUTPUT SIGNAL NAMES menu appears as follows:

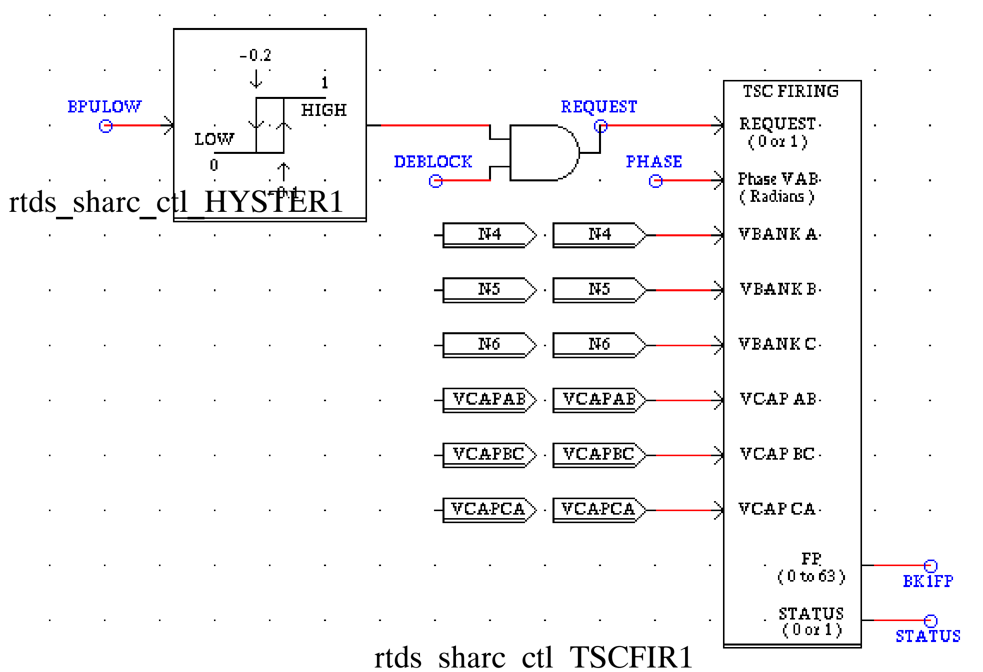


Name	Description	Value	Unit	Min	Max
nam1	Name for Leg AB Current kA	IAB		0	0
nam2	Name for Leg BC Current kA	IBC		0	0
nam3	Name for Leg CA Current kA	ICA		0	0
nam4	Name for Leg AB VOUT1 kV	V1AB		0	0
nam5	Name for Leg BC VOUT1 kV	V1BC		0	0
nam6	Name for Leg CA VOUT1 kV	V1CA		0	0
nam7	Name for Leg AB VOUT2 kV	V2AB		0	0
nam8	Name for Leg BC VOUT2 kV	V2BC		0	0
nam9	Name for Leg CA VOUT2 kV	V2CA		0	0
nam10	Name for Zero-Seq Transf Current kA	GRDCRT		0	0
nam11	Name for Bank Phase A Crt kA	PHCRTA		0	0
nam12	Name for Bank Phase B Crt kA	PHCRTB		0	0
nam13	Name for Bank Phase C Crt kA	PHCRTC		0	0
nam1i	Name for Break-Over Diode Word	BODOUT		0	0

Signals which are not requested in the ENABLE MONITORING menu or in the ENABLE D/A menu will be greyed out.

13.18 AVAILABLE CONTROLS COMPONENTS

It is normal that the firing of each leg in the TSC bank begins at a point in time when the voltage on the delta−connected capacitor is as close to the line−to−line voltage on the leg as is possible. Some controls component blocks useful for this purpose are shown in the following figure.



The control component rtds_sharc_ctl_HYSTER1 is a hysteresis function which responds to an input shown above as per unit low side susceptance (BPULOW). The state of the output is also affected by the state of the output in the previous time–step. This is clear when considering the input value of –0.15 in the above figure. The PARAMETERS menu for the component prompts the User to specify whether the input and output are real or integers; the two input levels; the two output levels; and the initial state in case it is not clear from the initial input value. The User may optionally specify a minimum time to be in each state so as to create a time hysteresis.

The control component rtds_sharc_ctl_TSCFIR1 is used to bring about the firing of the TSC banks according to the desired point in time as discussed above. The TSCFIR1 block receives a request for a TSC bank to be switched in (0=no, 1=yes). The block must also be provided with the phase of the Phase A to Phase B voltage on the low side of the TSC transformer in radians (shown as PHASE). This would typically come from a phase locked loop component. The TSCFIR1 block also receives the voltages on the low side of the TSC transformer (shown as N4, N5, and N6) and the TSC capacitor voltages (shown as VCAPAB, VCAPBC, and VCAPCA). The firing pulses of the three legs are combined into the TSC firing pulse word (shown as BK1FP). When all three legs are receiving firing pulses in BK1FP, then the bank STATUS will switch from 0 to 1. As soon as the REQUEST is removed, all firing pulses are removed and the STATUS and FP output are set to integer 0.

The User can improve of the function of the TSCFIR1 block be assembling control blocks which create status bits and associated alpha orders for each leg independently of the other legs.

13.19 SUMMARY

The Embedded SVC Bank Model (SVC4) for 3PC provides improved performance features as compared to the SVC3 model described in Chapter 12. The model has improved turn−off performance so that BOD firing can be more properly simulated. The model also allows for valve, reactor, capacitor and low−side bus faults. The increased capability and performance of the SVC4 model comes at the cost of generally using more hardware for the SVC4 solution as compared to the SVC3 model.

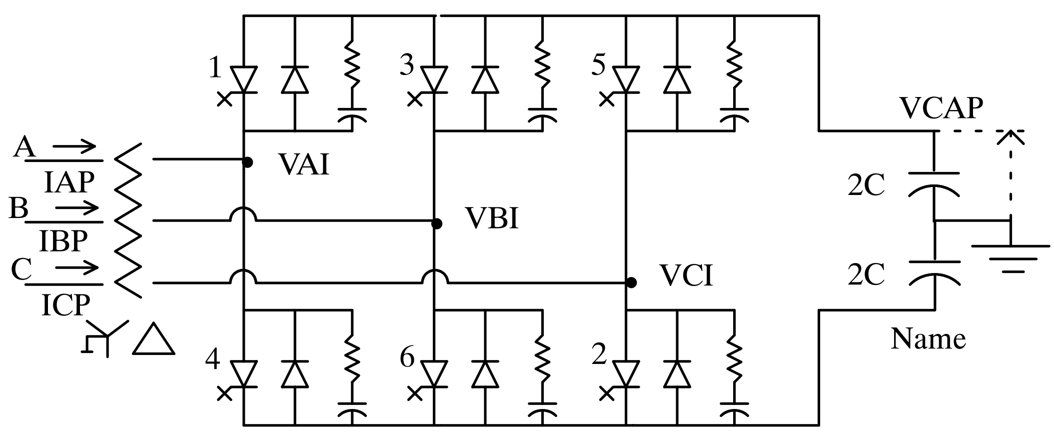
The SVC4 model can only be used in conjunction with the Real Time Network Solution for 3PC. The SVC4 model must be connected to “Connector” type nodes. At present, the SVC4 model can only accommodate Delta−connected SVC banks.

14 VOLTAGE TYPE CONVERTOR BRIDGE

(rtds_sharc_GTOB4)

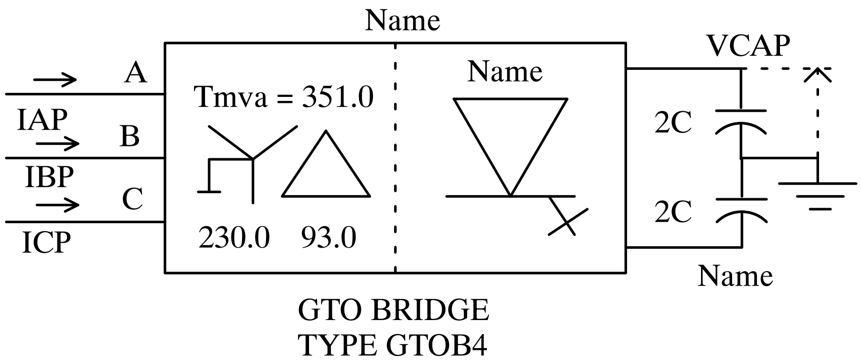
14.1 INTRODUCTION

The Voltage Type Bridge model interfaces to the main network solution and can be connected to either “Connector” type nodes or “Embedded” type nodes. The icon changes according to options selected. However, the most common appearance of the model is as shown below. Note the “TYPE GTOB4” in the lower left hand corner of the icon which distinguishes the model from earlier versions. Each bridge requires one processor out of the three on a 3PC card.



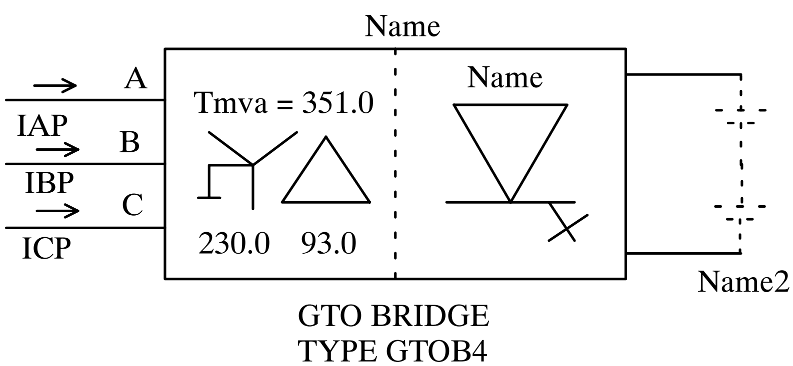
The numbering of valves in the six−pulse valve group is shown in the above icon. Firing pulse information required by the group can be given in two forms, either for the bridge as a whole, (Six Pulse Group mode), or for each of the three legs (1−4, 3−6, 5−2) separately (Three Leg mode). The requirements for firing pulse input are explained in more detail below.

There are several options which modify the appearance of the icon. The CONFIGURATION menu allows either a “Large” icon (shown above) or a “Small” icon, shown below. In the “Large” version, signals requested and named in menus are always shown in the icon according to the given names such as IAP, IBP, ICP, VAI, VBI, VCI, and VCAP. Only primary currents and capacitor voltage names are shown in the “Small” version.



The voltage type bridge model may share a capacitor located in another voltage type bridge, in order to form a back−to−back connection. If a bridge is using a capacitor located in another bridge, then the capacitor appearance will be modified as illustrated below with the name of the other bridge (“Name2”) shown below the modified capacitor.

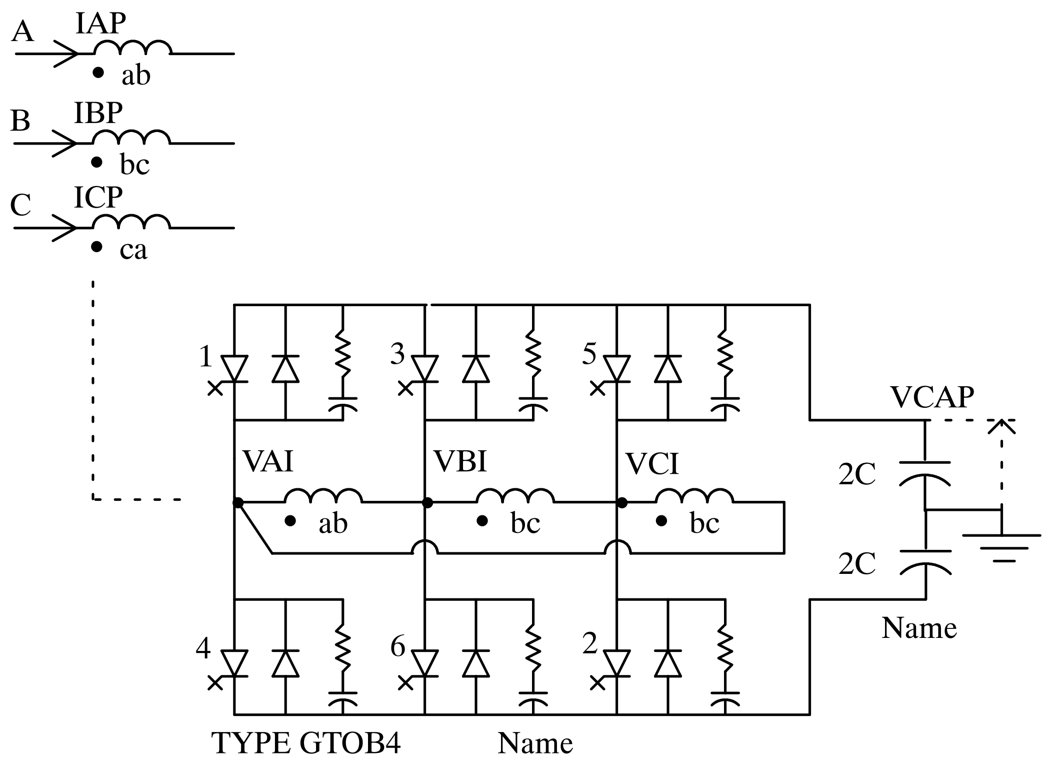
No other connection may be made to the capacitor in the model.



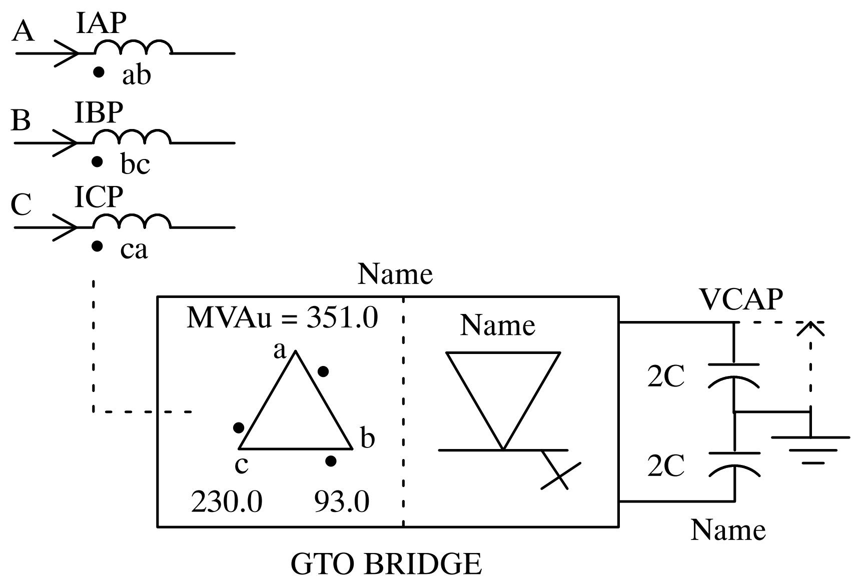
Circuit connections in DRAFT are not allowed between external nodes and the embedded bridge capacitor. Sharing a capacitor between bridges is the only connection allowed. However, the capacitor voltage can be specified during a simulation by creating a “Mode” switch and a “V Cap Set” slider. The capacitor voltage will follow the “V Cap Set” slider when the “Mode” switch is in the “SET” position. The default position is “FREE”, and the slider is ignored in that position.

Bridges sharing a capacitor must be calculated on the same 3PC card. When GTOB4 models are in “Automatic” placement mode in the CONFIGURATION menu, bridges which share a capacitor and which are arranged to be calculated on the same rack will in fact be calculated on the same 3PC card, as required.

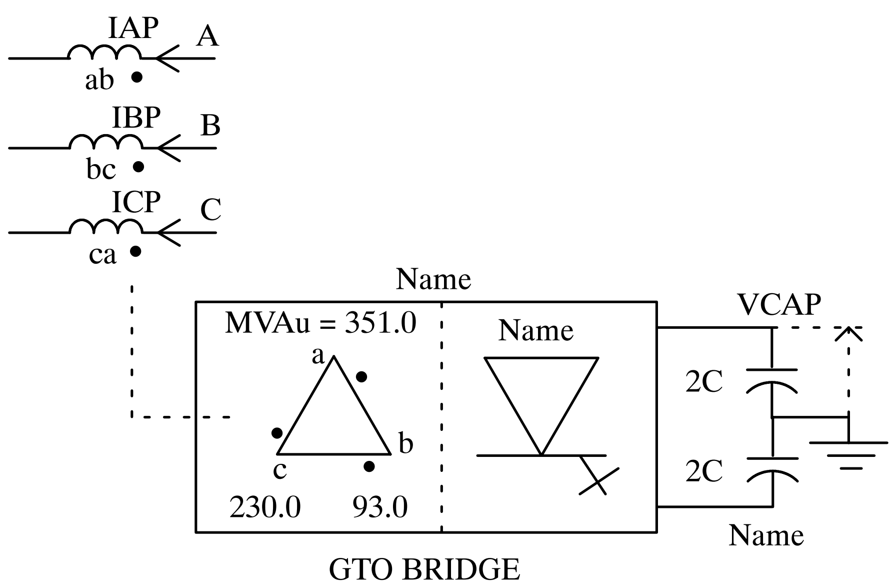
The transformer appearance will also change according to menu selections. This includes the appearance of a series transformer connection suitable for use in a Unified Power Flow Controller (UPFC). A UPFC can be made from two voltage−type bridge models connected back–to–back, with one bridge selected to have a “UPFC” type transformer connection. The “Large” icon for the voltage bridge model with a UPFC transformer connection is as shown below.



The “Small” icon with a “UPFC” type transformer connection appears as shown below:

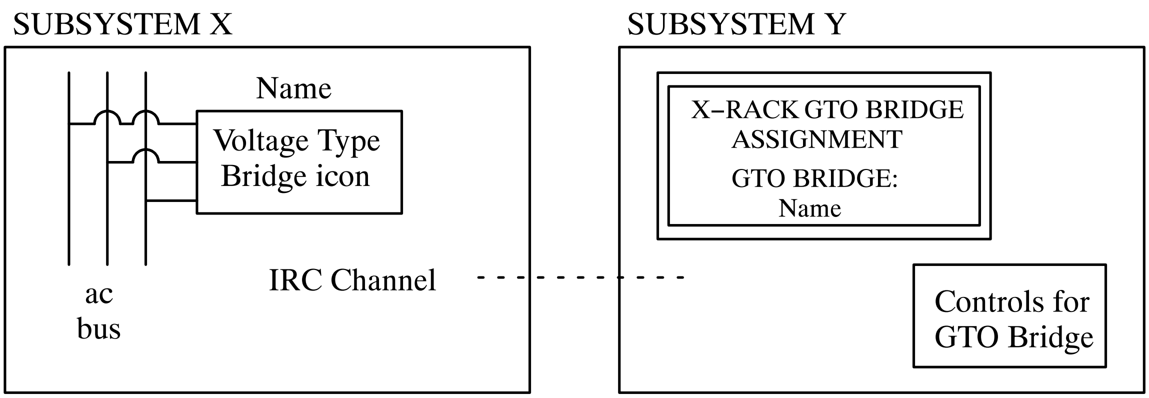


In the UPFC TRANSFORMER PARAMETERS menu, there is an option to "mirror" the series winding in the UPFC transformer icon. If that option is selected "Yes", then the series winding will be "mirrored" to appear as follows:



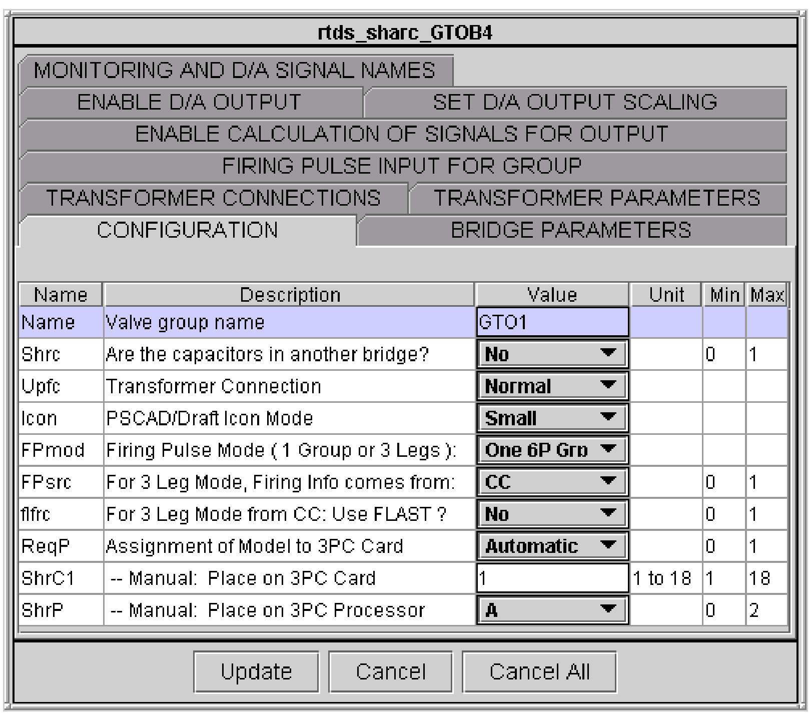
The "mirror" option for the UPFC transformer is to provide flexibility in connecting the model into the circuit. There is no functional difference in the model due to the "mirror" option.

The voltage−type bridge model requires a 3PC processor for calculation. If there is no 3PC processor available in the subsystem (rack) where the bridge is to be connected to an ac bus, the bridge calculation may be conducted in another rack connected by an inter−rack communication channel. In order to shift the location of the calculation, a cross−rack icon (rtds_sharc_xrack_gto) should be placed into the subsystem where the calculation is to occur. The controls for the bridge must also be located in the subsystem where the bridge calculation occurs. Therefore, the cross−rack arrangement of two subsystems would appear as follows:



14.2 CONFIGURATION MENU

The CONFIGURATION menu, as well as the menu tabs that are available by default appears as follows:



Name	Description	Value	Unit	Min	Max
Name	Valve group name	GTO1			
Shrc	Are the capacitors in another bridge?	No		0	1
Upfc	Transformer Connection	Normal			
Icon	PSCAD/Draft Icon Mode	Small			
FPmod	Firing Pulse Mode (1 Group or 3 Legs):	One 6P Grp			
FPsrc	For 3 Leg Mode, Firing Info comes from:	CC		0	1
flfrc	For 3 Leg Mode from CC: Use FLAST ?	No		0	1
ReqP	Assignment of Model to 3PC Card	Automatic		0	1
ShrC1	-- Manual: Place on 3PC Card	1	1 to 18	1	18
ShrP	-- Manual: Place on 3PC Processor	A		0	2

The CONFIGURATION menu, as usual, first prompts for a unique name to be given to this instance of the voltage−type bridge.

The second through seventh entries in the CONFIGURATION menu will be discussed in relation to other menus discussed below.

The last three entries (ReqP, ShrC1, ShrP) allow for automatic or manual model assignment to the subsystem (rack) where the calculation is to take place. The model is calculated in the subsystem where the bridge icon is located unless a cross rack icon has been placed, as previously explained.

If "Automatic" is selected in response to the "ReqP" menu item, the next two items ("ShrC1" and "ShrP") will be ignored. If "Manual" is selected, a specific processor can be specified by card number and processor A, B or C. A 3PC card number of 1 means the first 3PC card in the rack. If two models request the same processor, an ERROR message will be given. Manual assignment is useful where external equipment is connected through I/O to a given processor. In that case, Manual assignment assures that the model will continue to be calculated on that processor as the case is modified.

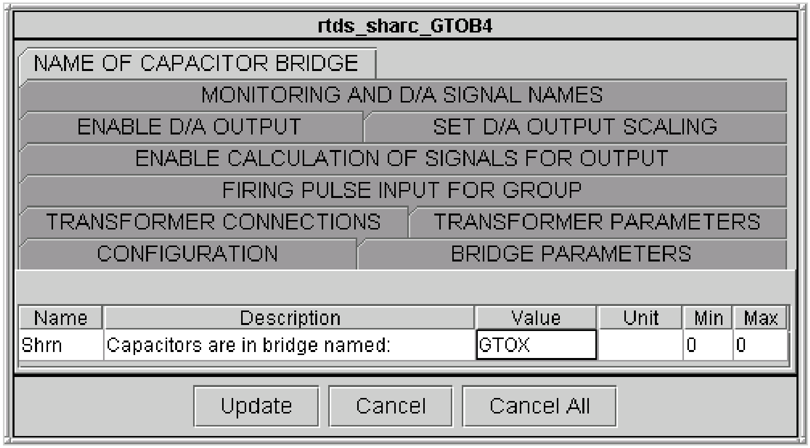
14.3 NAME OF CAPACITOR BRIDGE

As mentioned in the introduction, a voltage–type bridge can be configured to use the capacitor in another voltage type bridge. To support this interaction, the two models must be calculated in two processors on the same 3PC card.

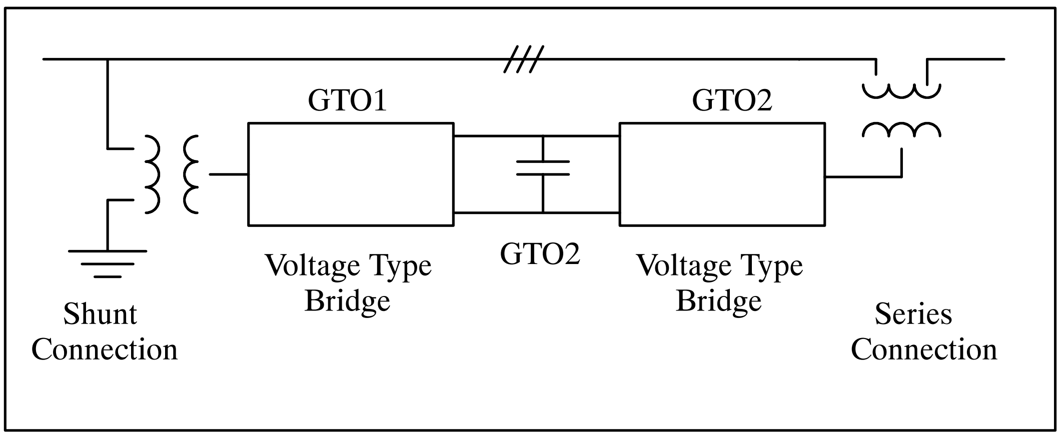
If "Automatic" assignment was selected in the CONFIGURATION menu of both models, the two–bridge models must be calculated in the same rack (possibly using cross rack icons). In that case, the two bridges will automatically be assigned to two processors on the same 3PC card.

If "Manual" is selected in the CONFIGURATION menu of both models, then calculation of the models to two processors must be manually assigned to the same card in a rack.

In order to connect to the capacitor in another bridge, the option must be selected in the CONFIGURATION menu (" Shrc " equals " Yes "). If this selection is made, an additional menu tab (NAME OF CAPACITOR BRIDGE) will appear. This menu appears as follows:



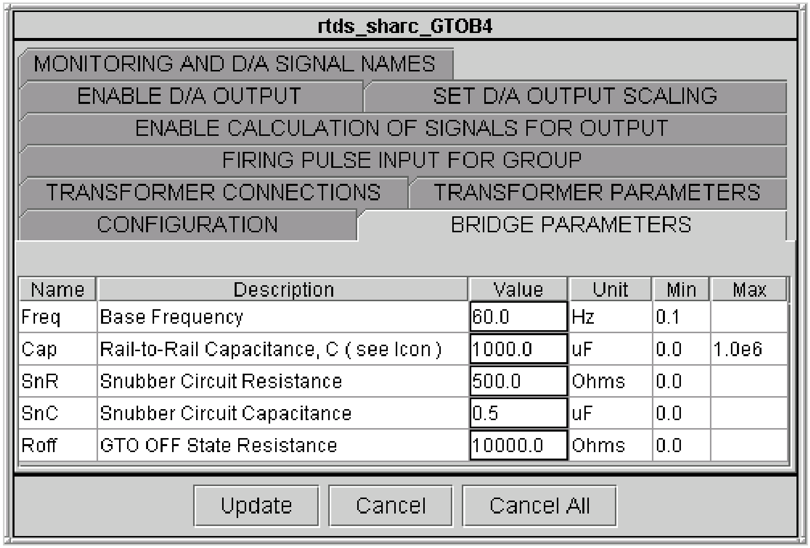
The sharing of a dc capacitor by two bridges can be used to provide either a voltage−type back−to−back dc link or a unified power flow controller (UPFC). The basic configuration of a UPFC is as shown in the following figure:



The GTOB4 model icons have been prepared so that the capacitor of one icon can be laid over the capacitor of the other icon to give the correct visual appearance. In the above illustration, bridge GTO1 uses the capacitor in bridge GTO2. Bridge GTO2 continues to use it’s local capacitor. Therefore, the name GTO2 is shown under the capacitor in both icons. There appears to be only one name because the two identical names overlap.

14.4 BRIDGE PARAMETERS

The BRIDGE PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
Freq	Base Frequency	60.0	Hz	0.1	
Cap	Rail-to-Rail Capacitance, C (see Icon)	1000.0	uF	0.0	1.0e6
SnR	Snubber Circuit Resistance	500.0	Ohms	0.0	
SnC	Snubber Circuit Capacitance	0.5	uF	0.0	
Roff	GTO OFF State Resistance	10000.0	Ohms	0.0	

The Rail−to−Rail Capacitance to be specified in the above menu is the total capacitance of the two series capacitors shown in the icon. Each series capacitor in the icon is labelled “2C” to indicate that the Rail to Rail Capacitance is “C”.

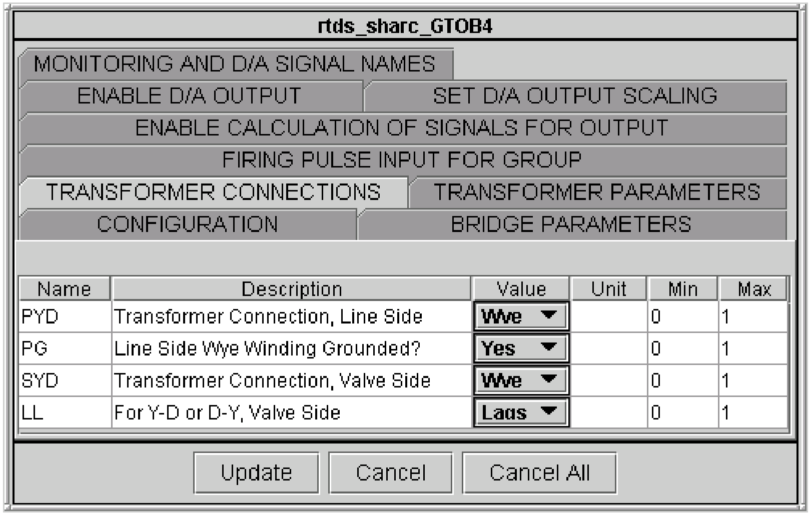
The snubber RC time constant should be maintained to be more than two time−steps in duration. Some effective conductance in the valves in the OFF state should be maintained for numerical reasons.

14.5 TRANSFORMER CONNECTIONS AND TRANSFORMER PARAMETERS

The CONFIGURATION menu allows the choice of using a “Normal” or a “UPFC” transformer connection. The “Normal” selection provides a transformer in “Shunt”, while “UPFC” provides a transformer in “Series”. The “Shunt” and “Series” connections are illustrated in the Introduction and in section 14.3 above.

If “Normal” transformer connection is selected, the TRANSFORMER CONNECTIONS and TRANSFORMER PARAMETERS menu tabs will be available. Alternatively, if a “UPFC” is selected, the UPFC TRANSFORMER PARAMETERS menu tab will be available.

The TRANSFORMER CONNECTIONS menu appears as follows:

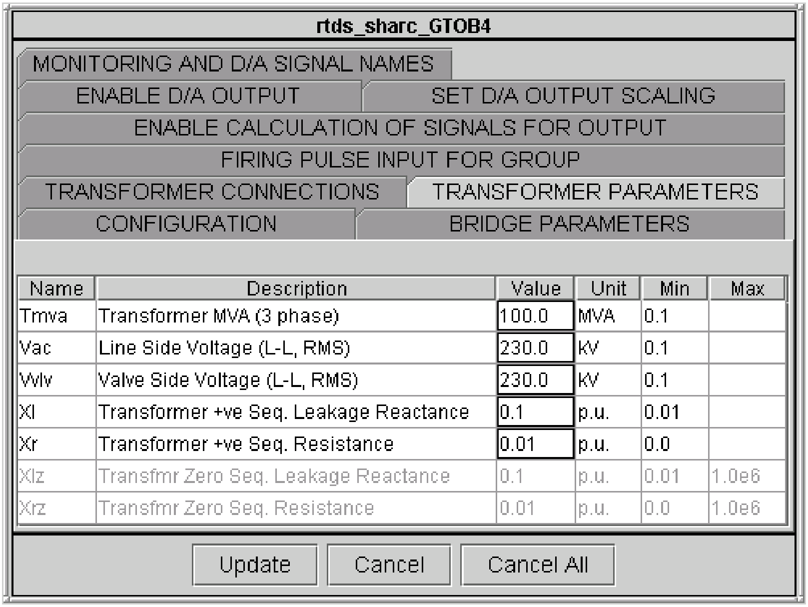


The TRANSFORMER CONNECTIONS menu affects only shunt “Normal” connected transformers. The usual Y (Wye) or Δ (Delta) connection of the primary and valve−side windings is selected using items “PYD” and “SYD”.

If the Primary Winding is Y connected then the the second item “PG” may be used to ground the neutral point on the primary. If the Primary Winding is Δ connected, then the item “PG” is ignored.

If one side of the transformer is connected in Y and the other side is connected in Δ , then the fourth item “LL” is used to specify whether the Valve−Side node voltages “Lag” or “Lead” the Primary−Side voltages by 30 degrees. If both sides of the transformer are connected in Y or in Δ, then the item “LL” is ignored.

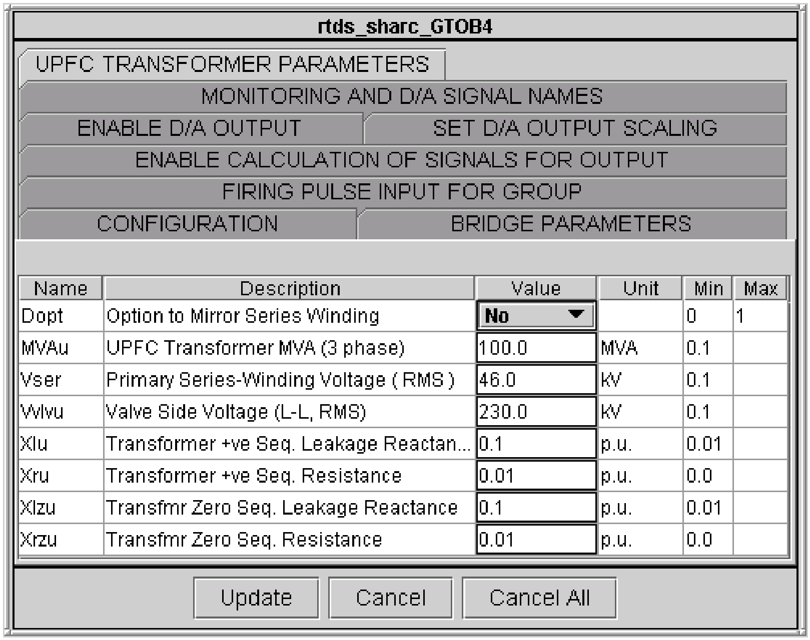
The TRANSFORMER PARAMETERS menu appears as follows:



The contents of the TRANSFORMER PARAMETERS menu applies only to "Normal" connected transformers. "UPFC" connected transformers are discussed in the next section.

14.6 UPFC TRANSFORMER PARAMETERS

The UPFC TRANSFORMER PARAMETERS menu appears as follows:



Name	Description	Value	Unit	Min	Max
Dopt	Option to Mirror Series Winding	No		0	1
MVAu	UPFC Transformer MVA (3 phase)	100.0	MVA	0.1	
Vser	Primary Series-Winding Voltage (RMS)	46.0	kV	0.1	
Vvlvu	Valve Side Voltage (L-L, RMS)	230.0	kV	0.1	
Xlu	Transformer +ve Seq. Leakage Reactan...	0.1	p.u.	0.01	
Xru	Transformer +ve Seq. Resistance	0.01	p.u.	0.0	
Xlzu	Transfmr Zero Seq. Leakage Reactance	0.1	p.u.	0.01	
Xrzu	Transfmr Zero Seq. Resistance	0.01	p.u.	0.0	

Contents of the TRANSFORMER PARAMETERS menu apply only to “UPFC” connected transformers. “Normal” transformers are discussed in the preceding section.

The “Dopt” item in this menu allows the reference direction of the series winding as drawn in DRAFT to be selected. The effect of using this option is illustrated in the Introduction section.

The base voltage for the per−unit system on the primary side of the transformer is the “Primary Series Winding Voltage” prompted by the item “Vser”.

14.7 FIRING PULSE INPUT FOR GROUP

The choice in the CONFIGURATION menu is made (item “FPmod”) between firing the group as one six pulse bridge (“One 6P Grp”) or as three separate legs (“Three Legs”). This option is actually between improved firing accuracy algorithms.

In the “One 6P Grp” mode, there is only one 6−bit firing pulse integer word (FP), one active bit integer word (FLAST), and one fraction floating−point word (FRAC) for the entire six−pulse valve group. The result is that there can be an improvement in the firing accuracy of only one valve out of six in each time−step. Refer to Chapter 13 on the Interfaced SVC model for an explanation of the three components of firing pulse information (FP, FLAST, and FRAC) .

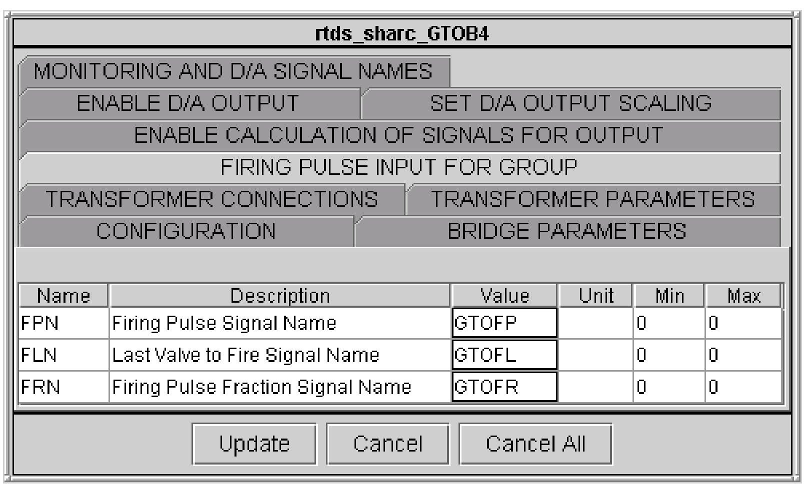
Alternatively, in the "Three Legs" mode, there is one 2−bit firing pulse word, one active bit word, and one fraction word for each separate leg in the valve group. Leg 1 contains valves 1 and 4 and reverse diodes. Leg 2 contains valves 3 and 6 and reverse diodes. Leg 3 contains valves 5 and 2 and reverse diodes. Consequently, in the "Three Legs" mode, firing of all three legs can be improved in a given time−step. This is important for pulse width modulation (PWM) where one leg may switch in the same time−step as some other leg in the group.

In normal voltage−type bridge firing, when one valve in a leg is receiving a firing pulse, the other is not. If both valves in a leg receive a firing pulse at the same time, the leg will short the capacitor.

It is a limitation of the model that it will ignore a firing pulse to the bottom valve when the top valve is receiving a firing pulse. Accordingly, a leg in the model can never short the capacitor.

A monitoring facility can be created in the Controls Compiler to warn of overlaps in firing pulses applied to a Leg. Of course, all firing pulses to a leg may be blocked to cause the leg to operate in diode mode.

The FIRING PULSE INPUT FOR GROUP menu appears as follows:



The first word, ("FPN") the Firing Pulse Input, is an integer having a permitted range of values from binary 000000 to binary 111111. Each bit represents a firing pulse bit, with the least significant bit (LSB) corresponding to the firing pulse for valve number 1. A one bit asserts firing of a valve. The valve numbers are shown in the "Large" icon illustrated in the Introduction section.

The second word (“FLN”) is an integer identifying the last bit in the firing pulse word to transition ON, in the last time−step (the active bit). If no bit transitioned ON, the word “FLN” should contain 0. If a bit did transition ON, that bit number should be contained within “FLN”. For example, if firing pulse bit 4 transitioned ON 2/3 of the way through the last time−step, the integer 4 would be passed to the model on the backplane in the “FLN” word.

In this latter case, the third named word (“FRN”) should contain a floating point number, between 0.0 and 1.0, which describes the fractional position in the time−step when the ON transition occurred (Example: 0.66667).

It must be noted that the GTOB4 voltage−type bridge model is an “Interfaced” model similar to the SVC3 model described in the Chapter 13. **Therefore, it is necessary to pass firing pulse signals to the model during the T0 transfer period (in the middle of the time−step) using the rtds_sharc_ctl _SENDT0 icon or the rtds_sharc_ctl_SETFLAG icon.**

For the controls compiler operating in the “Automatic” mode of ordering calculations, a T0 transfer can be produced as described in Chapter 12, INTERFACED SVC MODEL FOR 3PC. For the controls compiler operated in “Priority” mode, an example can be found for a T0 transfer in Chapter 2, Appendix A, USER−DEFINED BRANCHES USING THE CONTROLS COMPILER.

The component “rtds_ctl_sharc_FPGEN” can be used to generate normal six−pulse firing for the voltage−type bridge exactly as described in Chapter 12.

14.8 FIRING PULSE INPUT FOR 3 LEGS

In the CONFIGURATION menu, the choice is made (item “FPmod”) between firing the group as one six pulse bridge (“One 6P Grp”) or as three separate legs of the bridge (“Three Legs”). As explained in the preceding section, this is a choice between improved firing accuracy algorithms.

In the “Three Legs” mode, the model will require one 2−bit firing pulse word, one active bit word (optional with CC input), and one fraction word for each separate leg in the valve group. Leg 1 contains valves 1 and 4 and reverse diodes. Leg 2 contains valves 3 and 6 and reverse diodes. Leg 3 contains valves 5 and 2 and reverse diodes. Consequently, in the “Three Legs” firing mode, the firing of all three legs can be improved in a given time−step. This is important for pulse width modulation firing where one leg may switch in the same time−step as some other leg in the group.

In normal voltage–type bridge firing, when one valve in a leg is receiving a firing pulse, the other is not. If both valves in a leg receive a firing pulse at the same time, the leg will short the capacitor.

It is a limitation of the model that it will ignore a firing pulse to the bottom valve when the top valve is receiving a firing pulse. Accordingly, a leg in the model can never short the capacitor.

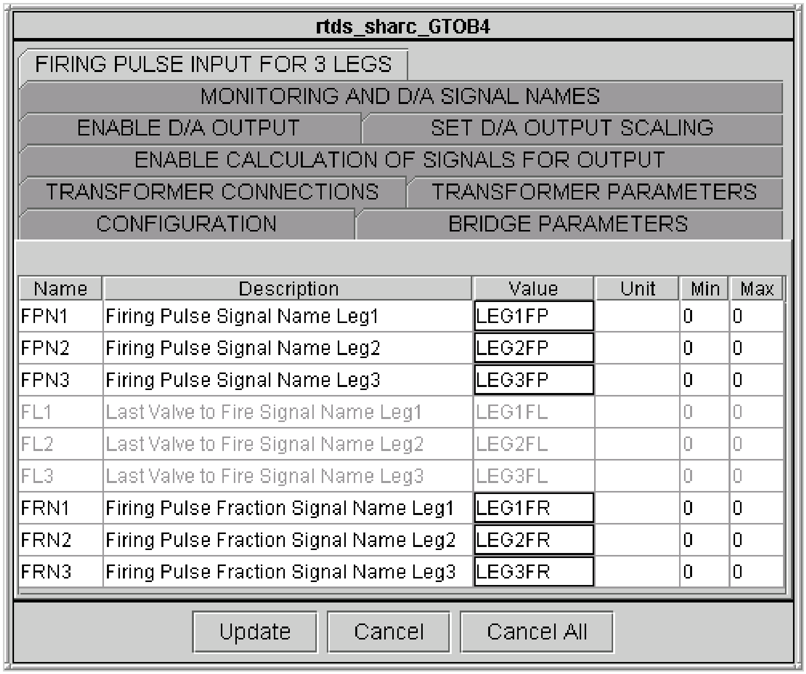
A monitoring facility can be created in the Controls Compiler to warn of overlaps in firing pulses applied to a Leg. All firing pulses to a leg may be blocked to cause the leg to operate in diode mode.

With PWM firing based on a saw–tooth waveform, the "ON" period of a given valve in a leg may be very short in duration. The GTOB4 voltage–type bridge model has a limitation concerning processing two firing pulse changes in consecutive time–steps.

In particular, if the bridge receives firing pulse transitions in two consecutive time–steps to fire the top and then the bottom valves in a leg, or the reverse, the second transition will not be processed until a third time–step.

This limitation makes the model generally not suitable for PWM above about 1000 Hz, depending on how close the modulation index is to 1. If the controls place a lower limit on the "ON" time of a firing pulse, the limitation may be less critical. Consequently, the performance of the model should be monitored if high rate switching simulations are to be attempted.

The FIRING PULSE INPUT FOR 3 LEGS menu appears as follows:



Similar to the FIRING PULSE INPUT FOR GROUP, this menu prompts for the name of three firing pulse information signals per leg in each time−step. The signals are transferred on the backplane during the T0 (middle of time−step) transfer period are discussed above.

The first word (“FPN#”) is the Firing Pulse Input word for a Leg. This is an integer word having permitted binary values of 00, 01 and 10. An integer word of 11 is not allowed and will be interpreted as 01. Each bit represents a firing pulse bit, the least significant bit (LSB) corresponds to the firing pulse bit for the top valve in the leg. The second bit corresponds to the bottom valve in a leg. A one (1) bit asserts firing of a valve. For the purposes of Three Leg firing pulses, the top valve in a Leg is number 1 and the bottom valve is number 2.

The second word (“FL#”) is an integer identifying the last bit in the firing pulse word for the leg to transition “ON” in the last time−step (the active bit). If no bit transitioned “ON”, the word “FL#” should contain the integer 0. However, if one of the two bits did transition “ON”, then that bit number should be contained within “FL#”. For example, if firing pulse bit 2 (bottom valve) transitions “ON” 2/3 of the way through the last time−step, then the integer 2 would be passed to the model on the backplane in the FL#” word.

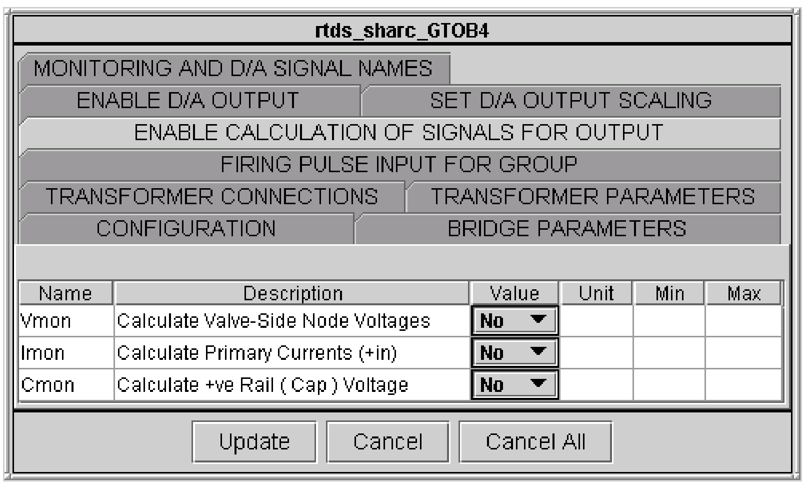
In this latter case, the third named word (“FRN#”) for a leg should contain a floating point number, between 0.0 and 1.0, which describes the fractional position in the time−step when the “ON” transition occurred (Example: 0.66667).

In “Three Legs” mode, the CONFIGURATION menu must specify whether the firing pulse signals will come from the Controls Compiler (CC) or from three separate digital input time stamp (DITS) cards.

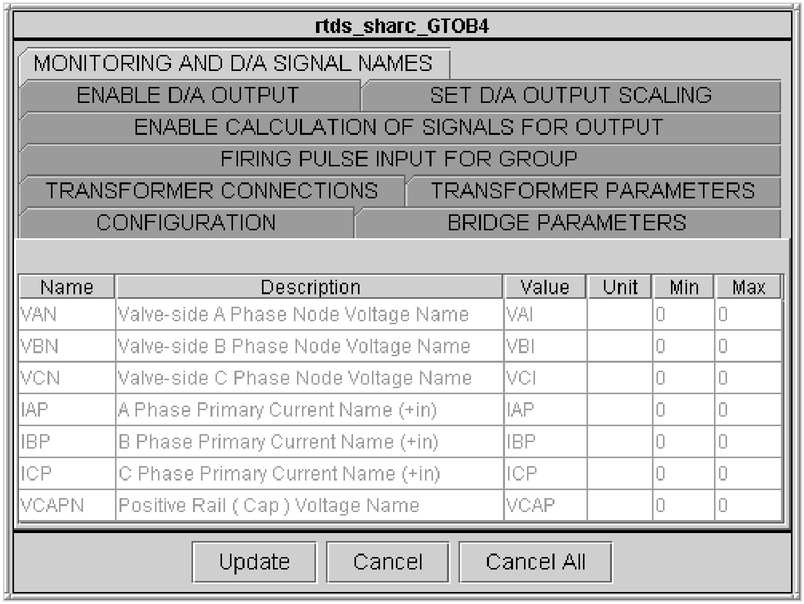
Also, in “Three Legs” mode, with firing pulse information from the CC, the CONFIGURATION menu can select that FLAST information (last bit to fire in the last time−step) is not required. The model can recover the FLAST by observing the two firing pulse bits in the 2−bit firing word (FPN#).

14.9 OUTPUT SIGNALS FROM THE MODEL

The model can be requested to calculate three groups of signals for output as listed in the ENABLE CALCULATION OF SIGNALS FOR OUTPUT menu:



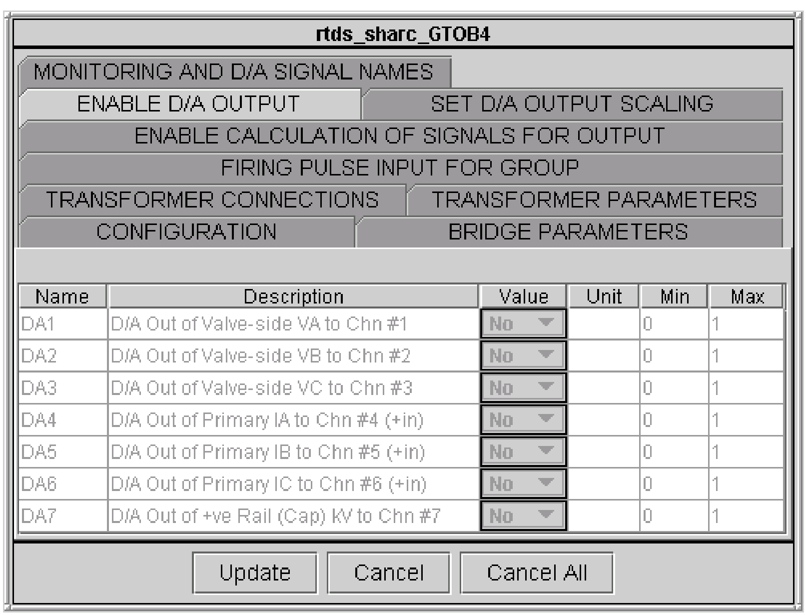
A “Yes” selection must be made before a signal can be sent to a D/A channel or monitored in RunTime (or the CC). When a “Yes” selection is made, names must be given for the requested signals in the MONITORING AND D/A SIGNALS NAMES menu:



Name	Description	Value	Unit	Min	Max
VAN	Valve-side A Phase Node Voltage Name	VAI		0	0
VBN	Valve-side B Phase Node Voltage Name	VBI		0	0
VCN	Valve-side C Phase Node Voltage Name	VCI		0	0
IAP	A Phase Primary Current Name (+in)	IAP		0	0
IBP	B Phase Primary Current Name (+in)	IBP		0	0
ICP	C Phase Primary Current Name (+in)	ICP		0	0
VCAPN	Positive Rail (Cap) Voltage Name	VCAP		0	0

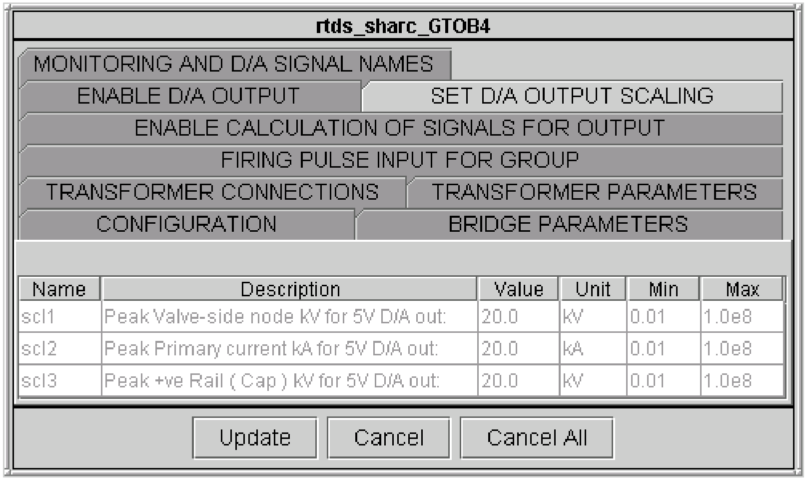
The requested names appear in the “Large” size icon (see CONFIGURATION menu) with reference directions.

If analog output is desired through the front of a 3PC card, it must be requested in the ENABLE D/A OUTPUT menu. There are only seven signals available. Therefore the channel selections are fixed as illustrated in the ENABLE D/A OUTPUT menu below:



Name	Description	Value	Unit	Min	Max
DA1	D/A Out of Valve-side VA to Chn #1	No		0	1
DA2	D/A Out of Valve-side VB to Chn #2	No		0	1
DA3	D/A Out of Valve-side VC to Chn #3	No		0	1
DA4	D/A Out of Primary IA to Chn #4 (+in)	No		0	1
DA5	D/A Out of Primary IB to Chn #5 (+in)	No		0	1
DA6	D/A Out of Primary IC to Chn #6 (+in)	No		0	1
DA7	D/A Out of +ve Rail (Cap) kV to Chn #7	No		0	1

Once D/A output has been requested, a basic scaling factor must be provided for each of the three groups of output as illustrated in the SET D/A OUTPUT SCALING menu illustrated below:



Once the D/A output has been enabled, a switch may be created in RunTime as follows;

Create –> SWITCH –> Subsystem # –> GTO BRIDGE –> Name of Bridge –> LED: Name of signal

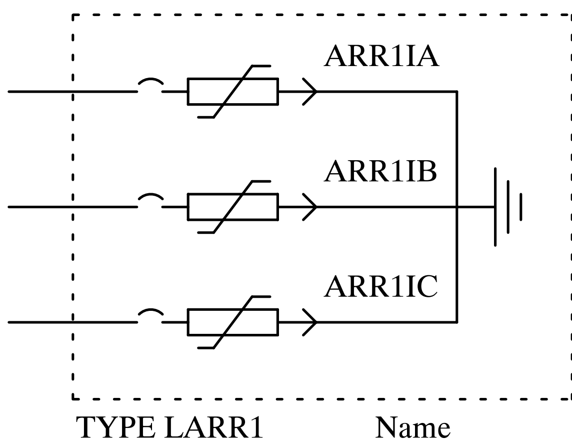
to turn on an LED on the front of the processor card immediately above the analog output channel. Similarly, Offset and Unity Gain sliders can be created for adjusting the analog output signals.

15 LINE ARRESTOR MODEL

(rtds_sharc_LARR1)

15.1 INTRODUCTION

The line arrestor model was developed to permit the simulation of a three−phase arrestor on a transmission line bus. The model requires the use of one Sharc processor on a 3PC card. The icon for the model is as illustrated below:



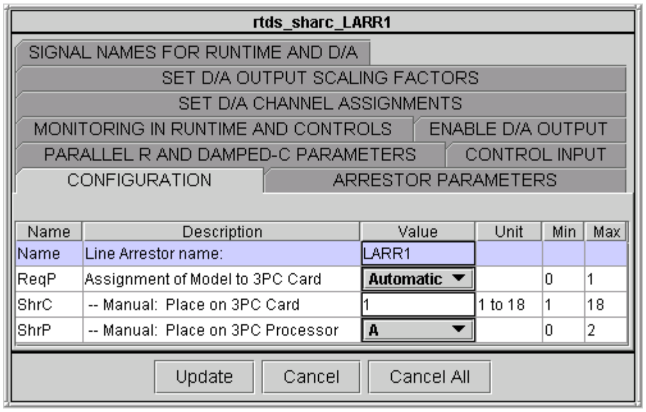
The model can be used with a 3PC−based Real Time Network Solution, and only connected to “Connector” nodes as described in Chapter 2. The model can also be used with an RPC/GPC network solution as all nodes are “Connector” type nodes. An Error message will be issued otherwise.

Internally, the model consists of voltage sources in series with conductances that are modified in each time−step, in each phase, to match the arrestor characteristic at the operating point. Two instances of the arrestor model should not be placed electrically close to each other as they might interact adversely.

In general, the arrestor model should be used with caution, as numerical instability may result.

15.2 CONFIGURATION MENU

The CONFIGURATION menu appears as follows:



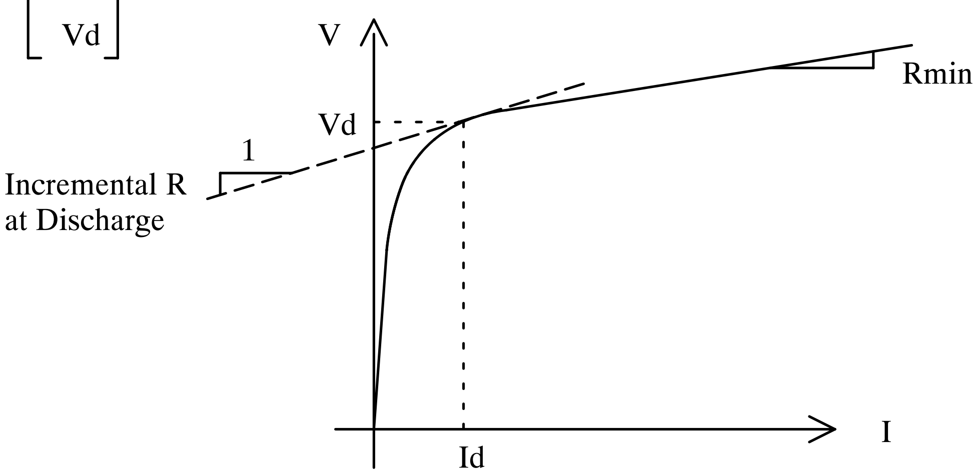
The first entry in the CONFIGURATION menu prompts for a unique name for the arrestor model.

The last 3 entries in the CONFIGURATION menu allow the model to be Automatically or Manually assigned to a specified processor. If automatic assignment is specified, the subsequent two entries in the menu are ignored. If manual assignment is specified, a specific processor can be requested by indicating 3PC card number and processor A, B, or C. A 3PC card number of 1 means the first 3PC card in a rack.

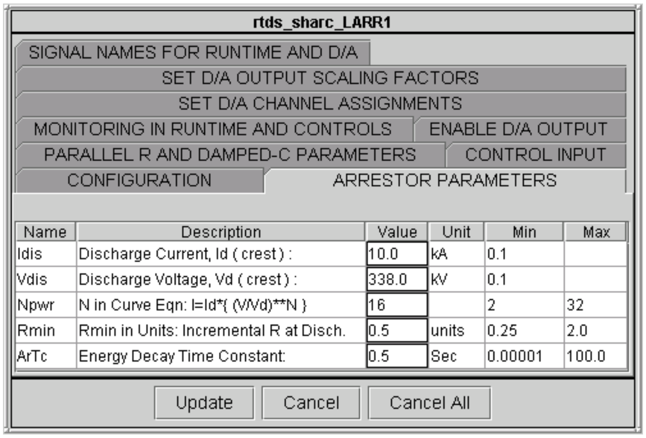
15.3 ARRESTOR PARAMETERS MENU

The Arrestor model operates according to the following V−I characteristic equation (in Quadrant I) where Id and Vd are the crest discharge current and voltage.

$$I = Id \left[\frac{V}{Vd} \right]^{N}$$



The arrestor characteristic is specified using the ARRESTOR PARAMETERS menu shown below:



Name	Description	Value	Unit	Min	Max
Idis	Discharge Current, Id (crest) :	10.0	kA	0.1	
Vdis	Discharge Voltage, Vd (crest) :	338.0	kV	0.1	
Npwr	N in Curve Eqn: I=Id*{ (V/Vd)**N }	16		2	32
Rmin	Rmin in Units: Incremental R at Disch.	0.5	units	0.25	2.0
ArTc	Energy Decay Time Constant:	0.5	Sec	0.00001	100.0

N in the arrestor curve equation can be any integer between 2 and 32. However, a high value of N means that the curvature is very high at the knee point. This can lead to numerical difficulties if the bus consists of inductive nodes (i.e. nodes connected to ground only through inductive branches or high resistance branches). Therefore, it is important to experiment with the circuit being simulated in order to select a suitable value for N.

The resistance at the discharge point of the characteristic is Vd / (N * Id). The incremental resistance of the curve drops rapidly as voltage rises above Vd. The Rmin item in the above menu allows specification of a lower limit on resistance. Rmin is specified as a fraction of the incremental resistance at the discharge point.

The Energy Decay Time Constant item “ArTc” generates a factor used in each time−step and in each phase, to multiply the accumulated energy of the arrestor. This determines the cooling factor for the model. The cooling factor is generated according to the following equation:

$$\text{Factor} = e^{-\,\text{delt}\,/\,\text{ArTc}}$$

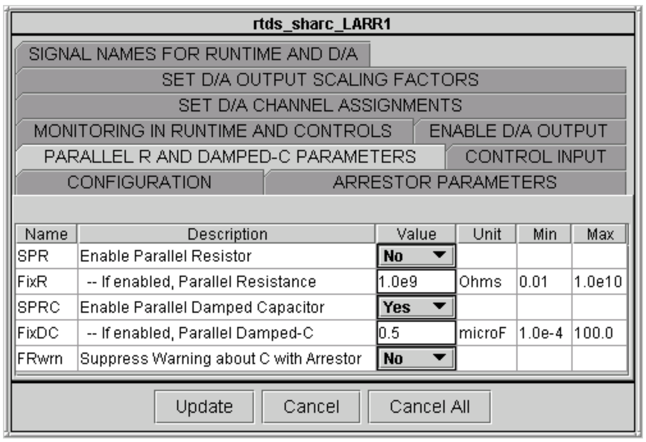
where delt is the time−step size and
ArTc is the cooling time constant

The cooling factor is not allowed to be larger than 0.9999995. For a 50 microsecond time−step, this corresponds to a cooling time constant of about 100 seconds.

As noted above, the arrestor model should be used with caution, as numerical instability may result.

15.4 PARALLEL R AND DAMPED−C PARAMETERS MENU

At low levels of voltage, the incremental resistance of the arrestor characteristic can be quite high. Thus, when the arrestor comes out of conduction it can be numerically similar to opening a breaker. For inductive nodes, this can lead to a numerical oscillation which can cause the arrestor model to malfunction. A parallel resistance branch and/or a parallel damped capacitance branch can be requested using the items labelled SPR and SPRC in the PARALLEL R AND DAMPED−C PARAMETERS menu. The Damped−C branch acts to damp numerical oscillations and is recommended unless a significant pure capacitance is already present on the arrestor bus. If a significant damped−C branch is not specified, a Warning message will be given in Draft during compilation. If a capacitor bank exists on the bus already, the Warning message may be suppressed using the “FRwrn” item.



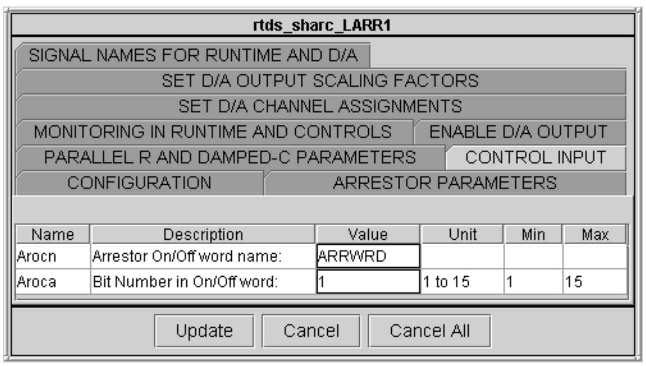
The Damped−C branch is simply a capacitor in series with a small resistance. The size of the series resistance R in the Damped−C branch is chosen to be equal to the Dommel resistance of the capacitor C, namely: delt / (2 C). The variable “delt” is the time−step size used in the simulation. This Damped−C branch is equivalent to a compensated resistive branch with resistance of 2R in which the current through the resistance is compensated in every time−step according to the current through the resistance in the previous time−step[Ref. 1].

The impedance of the Damped−C branch is determined by the capacitance C for the first few kiloHertz because of the relatively small value of the series resistance. Therefore, for estimating current flow through the Damped−C branch, it is possible to ignore the series resistance. In order to confirm the level of current through the parallel resistance and damped−C branches, the currents may be monitored in each phase in RunTime.

As noted above, it may be possible to omit the Damped−C branch when using an arrestor branch where capacitive filters are connected on the bus. In that case, the resulting Warning message may be suppressed with the “FRwrn” item. It is desirable to avoid using the Damped−C branch when possible, because it will have some effect on harmonic impedances, as would any capacitance. A Damped−C value of 0.5 microFarads used in conjunction with the parameters in the above menu provided a stable arrestor model on a purely inductive 230 kV bus with a 2000 MVA fault level. The capacitance provided approximately 10 MVAR of capacitive support to the bus.

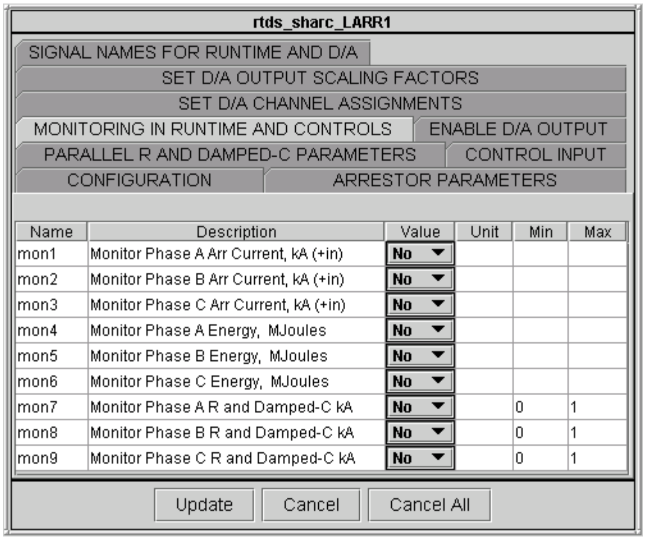
15.5 CONTROL INPUT MENU

The Line Arrestor model must be switched ON and OFF by a bit in an integer word passed on the backplane. This word can be provided by the Controls Compiler. The CONTROL INPUTS menu prompts for the word name and bit number. When the arrestor is switched OFF, the arrestor energy is reset to zero. The switch is physically in the closed position when the bit is set to 1. The model will only switch when the arrestor branch voltage passes through zero.



15.6 MONITORING IN RUNTIME AND CONTROLS MENU

Appropriate selections must be made in the MONITORING IN RUNTIME AND CONTROLS menu in order to monitor the Arrestor current and energy by phase. The net current per phase may also be monitored in the parallel R and Damped−C branches.



rtds_sharc_LARR1

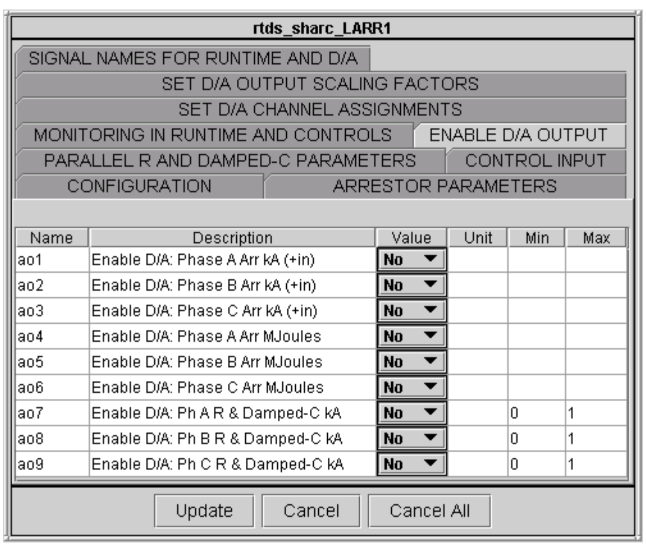
SIGNAL NAMES FOR RUNTIME AND D/A | SET D/A OUTPUT SCALING FACTORS | SET D/A CHANNEL ASSIGNMENTS | MONITORING IN RUNTIME AND CONTROLS | ENABLE D/A OUTPUT | PARALLEL R AND DAMPED-C PARAMETERS | CONTROL INPUT | CONFIGURATION | ARRESTOR PARAMETERS

Name	Description	Value	Unit	Min	Max
mon1	Monitor Phase A Arr Current, kA (+in)	No			
mon2	Monitor Phase B Arr Current, kA (+in)	No			
mon3	Monitor Phase C Arr Current, kA (+in)	No			
mon4	Monitor Phase A Energy, MJoules	No			
mon5	Monitor Phase B Energy, MJoules	No			
mon6	Monitor Phase C Energy, MJoules	No			
mon7	Monitor Phase A R and Damped-C kA	No		0	1
mon8	Monitor Phase B R and Damped-C kA	No		0	1
mon9	Monitor Phase C R and Damped-C kA	No		0	1

Update | Cancel | Cancel All

15.7 ENABLE D/A OUTPUT MENU

Appropriate selections must be made in the ENABLE D/A OUTPUT menu in order to pass the Arrestor current and energy by phase, to D/A output channels on the front of the 3PC card. The net current per phase in the parallel R and Damped−C branches can also be passed to analog output channels.



rtds_sharc_LARR1

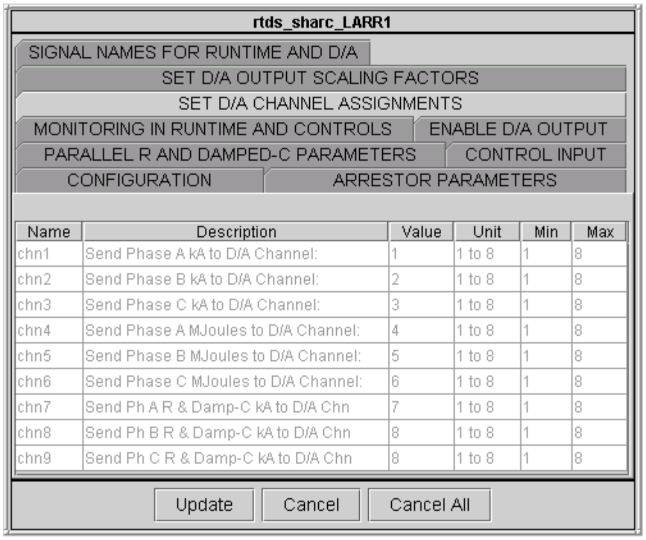
SIGNAL NAMES FOR RUNTIME AND D/A | SET D/A OUTPUT SCALING FACTORS | SET D/A CHANNEL ASSIGNMENTS | MONITORING IN RUNTIME AND CONTROLS | ENABLE D/A OUTPUT | PARALLEL R AND DAMPED-C PARAMETERS | CONTROL INPUT | CONFIGURATION | ARRESTOR PARAMETERS

Name	Description	Value	Unit	Min	Max
ao1	Enable D/A: Phase A Arr kA (+in)	No			
ao2	Enable D/A: Phase B Arr kA (+in)	No			
ao3	Enable D/A: Phase C Arr kA (+in)	No			
ao4	Enable D/A: Phase A Arr MJoules	No			
ao5	Enable D/A: Phase B Arr MJoules	No			
ao6	Enable D/A: Phase C Arr MJoules	No			
ao7	Enable D/A: Ph A R & Damped-C kA	No		0	1
ao8	Enable D/A: Ph B R & Damped-C kA	No		0	1
ao9	Enable D/A: Ph C R & Damped-C kA	No		0	1

Update | Cancel | Cancel All

15.8 SET D/A CHANNEL ASSIGNMENTS MENU

This menu is used for specifying the D to A output channels for the signals enabled in a previous menu.

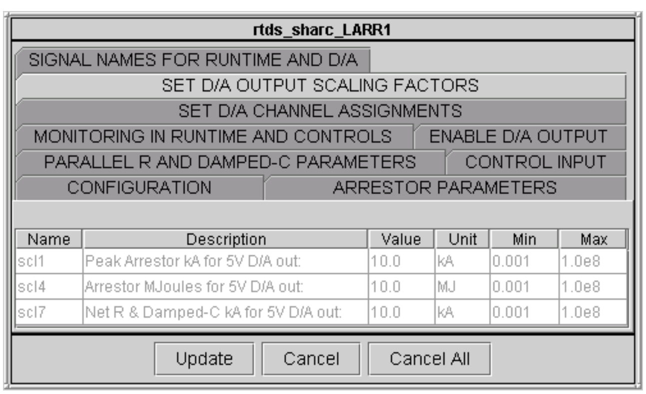


The menu described in section 15.7 allows certain signals produced in the model to be passed out of D/A channels on the front of the 3PC card. If the signal has not been requested in the ENABLE D/A OUTPUT menu, the corresponding line in this menu will be greyed out. The menu in this section allows specification of D/A channels for a given enabled D/A signal. If more than one D/A signal is assigned to a given channel, an Error message will be given at COMPILE time in DRAFT.

More than 8 signals cannot be passed through the D/A channels on the front of a 3PC card.

15.9 SET D/A OUTPUT SCALING FACTORS MENU

The following menu allows scaling factors to be specified for D/A outputs enabled in the ENABLE D/A OUTPUT menu.



The first entry specifies the scaling factor for the currents in the three phases of the arrestor bank. The current corresponding to 5 Volts out of the D/A channel for the signal should be specified.

The next entry allows the scaling factor to be specified for the energy in each phase of the arrestor.

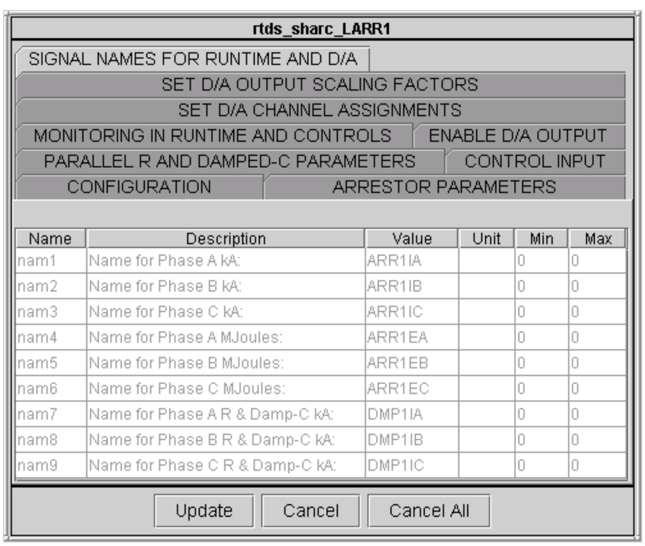
The final entry allows the scaling factor for the net current into each phase of the optional parallel R and Damped−C branches to be specified.

Unity sliders are provided in RunTime for circumstances in which it is necessary to provide different scaling for individual signals in a three−phase group. Switches are also provided in RunTime to illuminate an LED over the output channel on the front of 3PC card according to signal name (see section 15.10 below). Signal Offset adjustment sliders are also available in RunTime.

15.10 SIGNAL NAMES FOR RUNTIME AND D/A MENU

If output signals are requested either in the MONITORING IN RUNTIME AND CONTROLS menu or in the ENABLE D/A OUTPUT menu, a unique signal name must be provided for each signal. The specified name will be used if the signal is passed on the backplane. The specified name will also be used to identify the D/A scaling and offset adjustment sliders in RunTime and also the LED On/Off switch in RunTime.

The SIGNAL NAMES FOR RUNTIME AND D/A menu appears as follows:



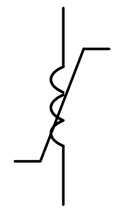
Signals which are not requested in the MONITORING IN RUNTIME AND CONTROLS menu or in the ENABLE D/A OUTPUT menu will be greyed out.

15.11 REFERENCES

1) “Improved Interfacing of Electrical Machine Models in Electromagnetic Transients Programs”, A.M. Gole, R.W. Menzies, D.A. Woodford, and H. Turanli, I.E.E.E. Trans. on Power Apparatus and Systems, Vol. PAS−103, No. 9, June 1984, pp. 2446−2451.

16 NON−LINEAR INDUCTOR

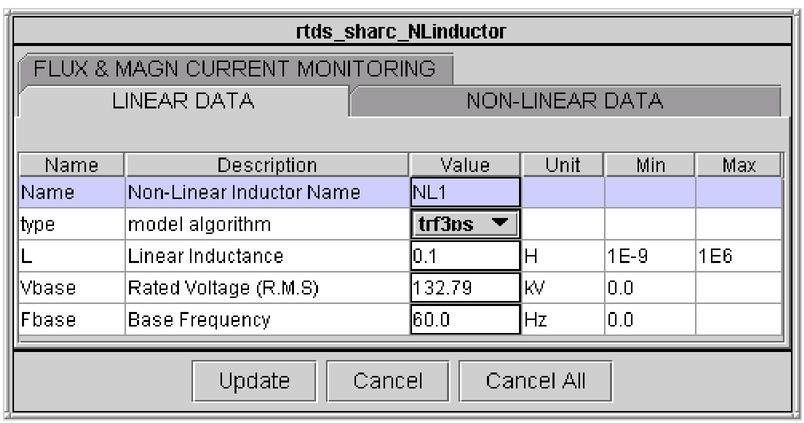
(rtds_sharc_NLinductor)



A single phase non−linear inductor can be modelled using the RTDS. The model uses the same saturation and hysteresis routine included as part of the transformer models to represent the non−linear characteristics. The non−linear reactor model can be used to represent a saturable reactor.

16.1 NON−LINEAR INDUCTOR MODEL INPUT DATA

Data entry menus for the non−linear inductor model are shown below. As in the case of transformer saturation and hysteresis (see Chapter 4), input data representing both the linear and non−linear operating regions is required.



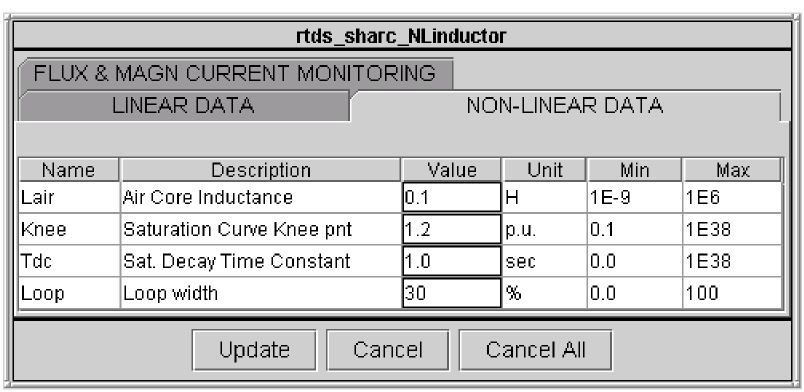
rtds_sharc_NLinductor

FLUX & MAGN CURRENT MONITORING

LINEAR DATA | NON-LINEAR DATA

Name	Description	Value	Unit	Min	Max
Name	Non-Linear Inductor Name	NL1			
type	model algorithm	trf3ps			
L	Linear Inductance	0.1	H	1E-9	1E6
Vbase	Rated Voltage (R.M.S)	132.79	kV	0.0	
Fbase	Base Frequency	60.0	Hz	0.0	

Update | Cancel | Cancel All



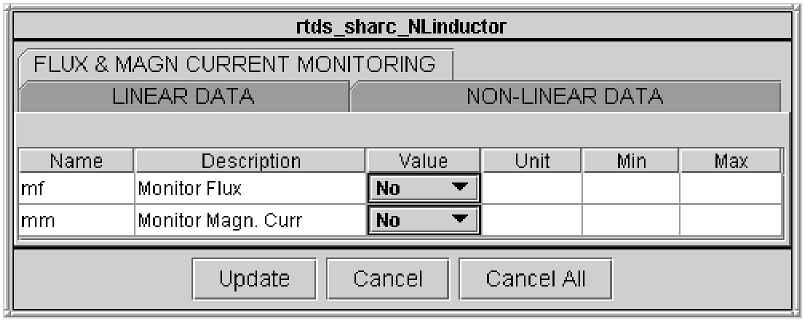
rtds_sharc_NLinductor

FLUX & MAGN CURRENT MONITORING

LINEAR DATA | NON-LINEAR DATA

Name	Description	Value	Unit	Min	Max
Lair	Air Core Inductance	0.1	H	1E-9	1E6
Knee	Saturation Curve Knee pnt	1.2	p.u.	0.1	1E38
Tdc	Sat. Decay Time Constant	1.0	sec	0.0	1E38
Loop	Loop width	30	%	0.0	100

Update | Cancel | Cancel All



rtds_sharc_NLinductor

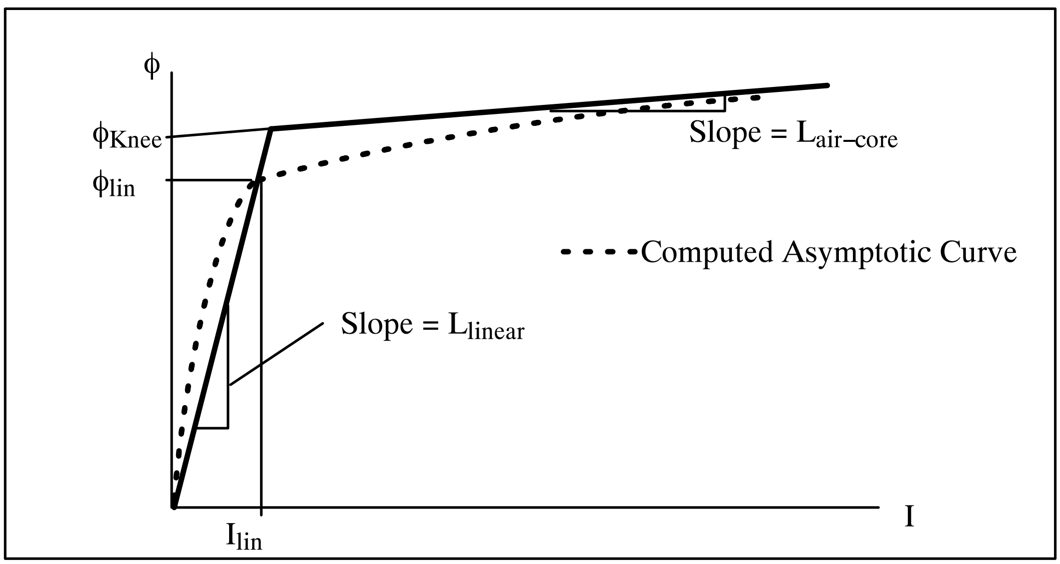
FLUX & MAGN CURRENT MONITORING | LINEAR DATA | NON-LINEAR DATA

Name	Description	Value	Unit	Min	Max
mf	Monitor Flux	No			
mm	Monitor Magn. Curr	No			

Update | Cancel | Cancel All

16.2 SATURATION AND HYSTERESIS MODEL

Saturation and hysteresis for the non−linear inductor is modelled using the same basic method as used with the RTDS transformer model and described in Chapter 4 of this manual. Although the characteristic of the the non−linear inductor model is a smooth curve, it is formulated using two straight line segments in the ϕ—i plane.



Flux − Current Characteristic

The linear inductance value is entered as 'L' in the component data menu. The air−core inductance value is entered as 'Lair'. Both inductance values are entered in Henries (H). As illustrated above, the slope of each of the two straight line segments is defined by the entered inductance values.

Within the RTDS compiler, a smooth curve is computed to approximately fit the two slope characteristic illustrated above. The smooth curve is asymptotic to Lair−core segment in the region beyond the knee point and asymptotic to the ϕ axis as current approaches zero. In addition to the two asymptotes, the smooth curve also passes through the point ϕlin−Ilin. The ϕlin value is computed based on input parameters using;

$$\phi lin = 0.8 * \phi knee$$

where $\phi knee = Knee * \phi rated$

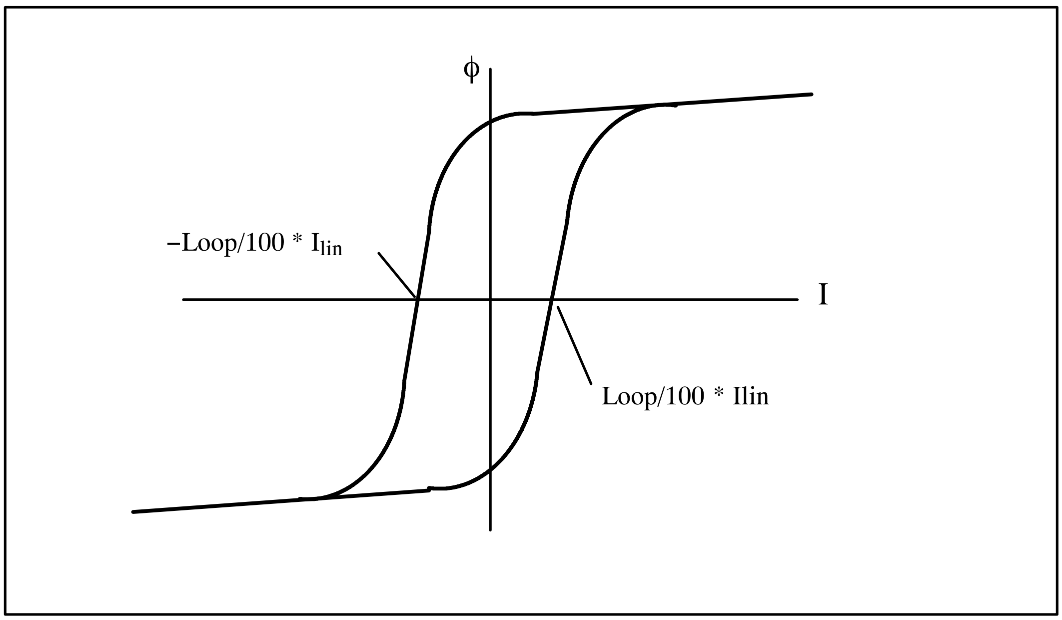
and $\phi rated = (\sqrt{2} * Vbase) / (2\pi * Fbase)$

The corresponding current (Ilin) is then found using ϕlin and the linear inductance value using;

$$Ilin = \phi lin / Llinear$$

As in the case of the transformer, hysteresis is modelled by shifting the computed single valued asymptotic curve by a specified amount (defined as 'loop width' in the data menu). The 'loop width' variable is entered in percent of Ilin, where Ilin is defined by the previously shown equation.

For example, if the variable 'loop width' is set to 30% then the asymptotic curve is shifted to the right and left by 30% of Ilin.



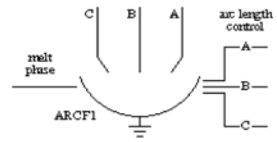
Hysteresis Curve (Outer most Loop)

Minor loops within the outer most hysteresis loop may be attained depending on the flux turn around points (ie. the operating point).

Selecting 'Yes' to monitor flux and magnetizing current items of the FLUX & MAG CURRENT MONITORING menu, instantaneous flux and magnetizing current can be captured during a simulation using RunTime Operator's Console plots.

17 ARC– FURNACE

(sharc_arc_furn)



A three phase electric arc–furnace can be modelled in the RTDS, based on an equation of an electric arc[1][2]. Arc length is dynamically altered for each electrode in every half cycle, using statistical techniques. Arc conductance is calculated in every time step and used in the network solution.

Loss of power quality associated with arc–furnaces can be investigated using a UIE type flicker meter. The last section in this chapter illustrates a controls compiler implementation of a flicker meter.

17.1 DYNAMIC CHARACTERISTICS OF HIGH CURRENT FAULT ARCS

High current fault arcs exhibit a hysteresis effect. The arc conductance initially rises in a steep linear fashion for increasing voltage and then saturates and clamps the voltage at an approximately fixed value. On the falling edge of the voltage, the conductance traverses a parallel but slightly reduced path. (See Figure 1.)

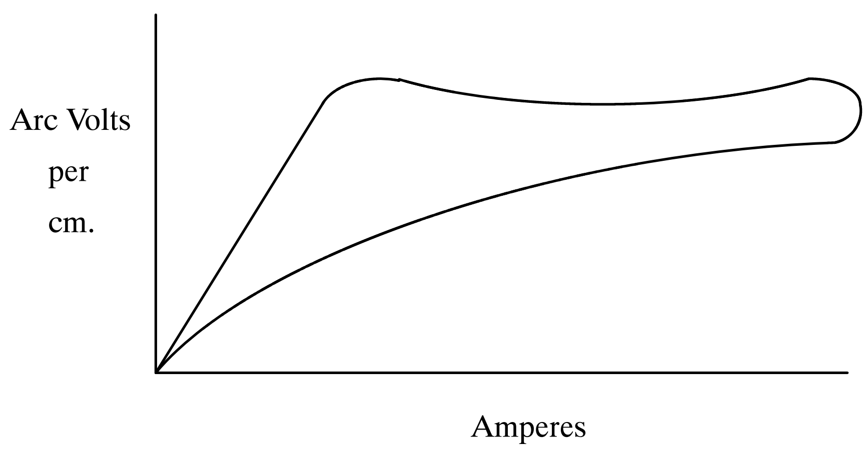


Figure 1

The arc characteristics are modelled with the following equation;

$$\frac{dg}{dt} = \frac{1}{T}(G - g) \qquad (1)$$

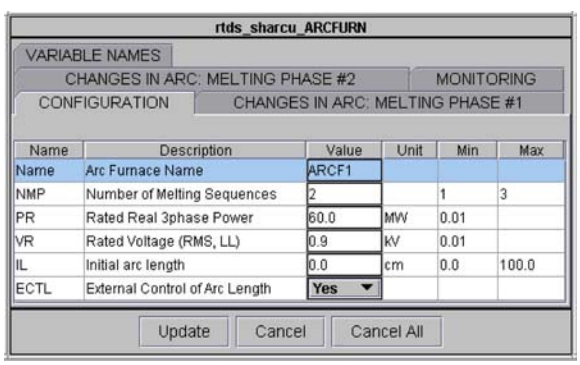
where g is the time varying arc conductance, G is the stationary arc conductance and T is a time constant, inversely proportional to the rate of rise of voltage. T is calculated in each half cycle as it depends on the peak value of current in the previous half cycle and the arc length. Although G is called stationary, it is based on the instantaneous absolute value of current, the peak voltage gradient of the arc and the arc length. It is calculated in every time step. Arc length is altered in a more or less random way and is calculated in each half cycle, as explained in the following section. In summary, equation (1) is solved in each time step with trapezoidal integration, for each of the 3 furnace electrodes.

Arc furnace behavior varies over time as the charge in the furnace is reduced from large pieces of solid metal to molten metal. The random nature of the arc length is very pronounced in the first phase and much more stable at the end. This effect is modelled by choosing 2 or 3 distinct phases through which the model can be switched, each with its own set of statistical and deterministic variables.

A typical arc furnace includes 1 or 2 step down transformers, with the high side of the high voltage transfomer referred to as the point of common connection(PCC). Noise measurements are made at the PCC. One or both of the transformers is connected in delta in at least one winding to block zero sequence components. Lead inductance and resistance are usually modelled between the low voltage output of the low voltage transformer and the arc−furnace itself, as the base impedance of this part of the circuit is very low. Furnace voltage is usually less than 1 kV.

17.2 THE ARC FURNACE MODEL

17.2.1 THE CONFIGURATION MENU


rtds_sharcu_ARCFURN

VARIABLE NAMES | CHANGES IN ARC: MELTING PHASE #2 | MONITORING | CONFIGURATION | CHANGES IN ARC: MELTING PHASE #1

Name	Description	Value	Unit	Min	Max
Name	Arc Furnace Name	ARCF1			
NMP	Number of Melting Sequences	2		1	3
PR	Rated Real 3phase Power	60.0	MW	0.01	
VR	Rated Voltage (RMS, LL)	0.9	kV	0.01	
IL	Initial arc length	0.0	cm	0.0	100.0
ECTL	External Control of Arc Length	Yes			

Update | Cancel | Cancel All

The configuration menu is shown on the above.

The first field requests a name for the model and must be supplied.

The number of melting sequences is selectable in the range from 1 to 3. The active sequence is controllable in RunTime by creating a selector switch. If the melt phase is set to zero, the conductance of the arc for each phase is set to a low value, i.e. the furnace is off.

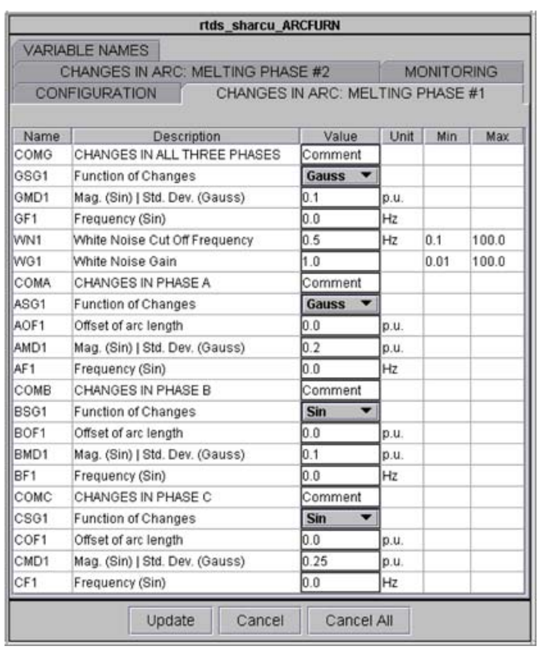
Rated Real 3 phase Power is only used for estimating the peak current for the first cycle of operation as this value is recomputed in subsequent cycles. The real power consumed in the furnace is a function of applied voltage, source impedance and average arc length. The longer the arc, the mode power the furnace will consume. However, if the arc is forced to be too long, it will not strike and the power will drop to zero.

Rated voltage is used to estimate initial arc length where this is supplied as 0.0. In this case, arc length is calculated as the voltage divided by the voltage gradient.

Initial arc length is used as the mean value around which the statistical variations are applied. It is not used if the arc is externally controlled. Some experimentation is required to obtain a satisfactory value, but typical values range from 20 to 30 cm. External control of the arc length is recommended at least until the perormance of the model is satisfactory.

The arc length can be controlled by controls created in the controls compiler or by a slider.

17.2.2 CALCULATION OF ARC LENGTH IN EACH MELT PHASE


rtds_sharcu_ARCFURN

VARIABLE NAMES | CHANGES IN ARC: MELTING PHASE #2 | MONITORING | CONFIGURATION | CHANGES IN ARC: MELTING PHASE #1

Name	Description	Value	Unit	Min	Max
COMG	CHANGES IN ALL THREE PHASES	Comment			
GSG1	Function of Changes	Gauss			
GMD1	Mag. (Sin) | Std. Dev. (Gauss)	0.1	p.u.		
GF1	Frequency (Sin)	0.0	Hz		
WN1	White Noise Cut Off Frequency	0.5	Hz	0.1	100.0
WG1	White Noise Gain	1.0		0.01	100.0
COMA	CHANGES IN PHASE A	Comment			
ASG1	Function of Changes	Gauss			
AOF1	Offset of arc length	0.0	p.u.		
AMD1	Mag. (Sin) | Std. Dev. (Gauss)	0.2	p.u.		
AF1	Frequency (Sin)	0.0	Hz		
COMB	CHANGES IN PHASE B	Comment			
BSG1	Function of Changes	Sin			
BOF1	Offset of arc length	0.0	p.u.		
BMD1	Mag. (Sin) | Std. Dev. (Gauss)	0.1	p.u.		
BF1	Frequency (Sin)	0.0	Hz		
COMC	CHANGES IN PHASE C	Comment			
CSG1	Function of Changes	Sin			
COF1	Offset of arc length	0.0	p.u.		
CMD1	Mag. (Sin) | Std. Dev. (Gauss)	0.25	p.u.		
CF1	Frequency (Sin)	0.0	Hz		

Update | Cancel | Cancel All

This menu controls arc length changes. It is broken into changes which affect all 3 phases and changes which affect phase a, b and c individually. The first part, relating to changes affecting all 3 phases, requires that sinusoidal or Gaussian noise modulating signals be selected.

If the selection is sin, the next line Mag.(sin) controls the magnitude of the sin wave. It is applied to all 3 phase in the same manner, i.e. it generates zero sequence signals. Gaussian noise is centered on zero, generates negative or a positive values, and is applied to all phases at the same time.

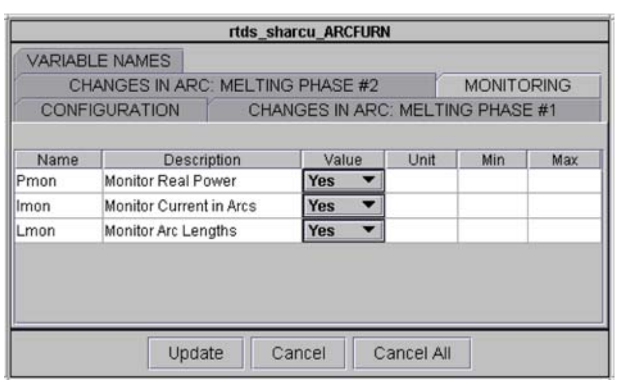
The next 2 lines ask for the cut off frequency and gain of white noise generators. These lines refer to white noise which may be requested for the individual phases. The same forth order low pass filter characteristics are used for each phase, but individual white noise generators and filters are used. If white noise is not selected in the subsequent sections, these entries are ignored. White noise is defined over a range of zero to one. It is offset by 0.5 and multiplied by a gain.

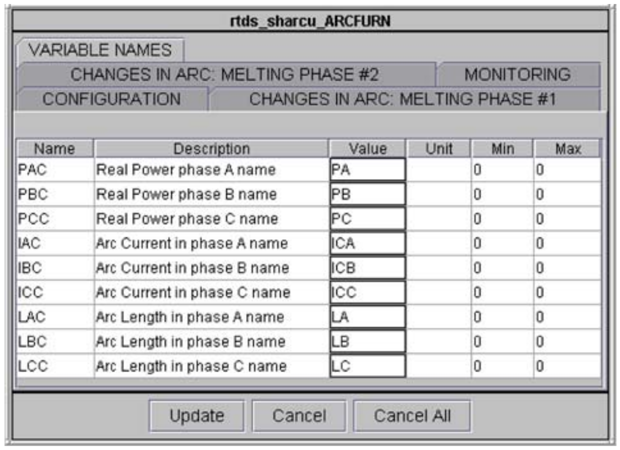
The next three sections for the individual phases are all the same. The first entry is a selection of modulation type, either white noise, Gaussian noise or sinusoidal noise.

An offset may be added to the arc lengths of the individual phases. This is applied to the initial arc length if external modulation is not used, or to the external modulation directly.

If the modulation is sin, then the frequency may be selected in the last line and the magnitude selected in the line above. If the modulation is Gaussian, the standard deviation may selected in the second to last line.

17.2.3 MONITORING AND VARIABLE NAMES





These menus are self explanatory.

17.3 REFERENCES

1.0 “Improved Techniques for Modelling Fault Arcs on Faulted EHV Transmission Systems”, A.T. Johns, R.K. Aggarwal and Y.H. Song, IEE. Proc.−Gen. Transm. Distrib., Vol.141, No.2,March 1994

2.0 “Digital Simulation of Fault Arcs in Power Systems”, M. Kizilcay, T. Pniok, ETEP Vol.1, No.1, Jan./Feb. 1991

3.0 “Flicker Measurement and Evaluation”, Second Revised Edition, International Union for Electroheat, 1991.

APPENDIX 17A) THE UIE FLICKER METER

The impact of electrical noise from an arc furnace can be estimated by creating and calibrating the UIE flicker meter. The RTDS implementation of the meter is described here, but its calibration is left for the user.

17A.1 METER THEORY

The UIE (International Union for Electroheat) specification for a flicker meter[3] is shown in block form in Figure 2. The meter is intended to model a tungsten filament lamp and the response of the human eye to changes in the voltage applied to the lamp. Flicker is perceptible to the human eye with sensitivity being a function of the magnitude of the voltage changes and the frequency of the change. Maximum sensitivity occurs at about 9 Hz. with a sinusoidal modulation of the input of about 0.25%. Modulation must be greater than this at all other frequencies to be perceived. A typical response curve is shown in [3].

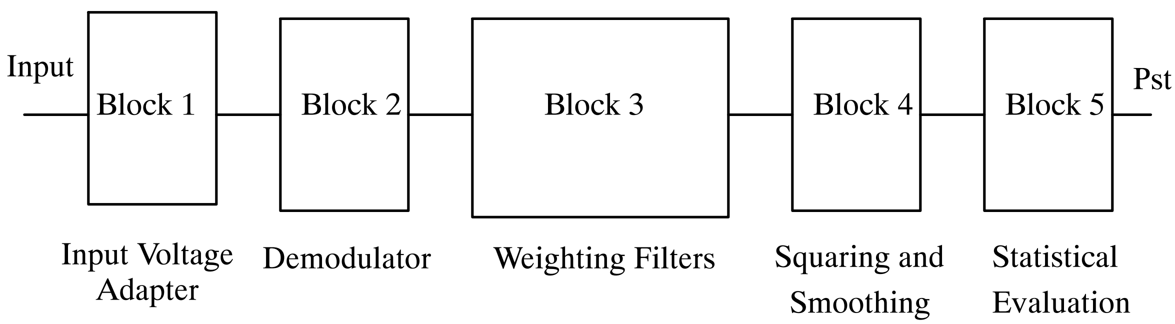


Figure 2

Outputs can be obtained from any block, but the output of block 4 is the instantaneous value of flicker. By providing a standard input to the meter, the output can be calibrated to give an output of 1. When the calibrated meter is then connected to a noise source, the duration of the instantaneous flicker at all levels is timed. The levels are counted over a 10 minute period and then normalized to give the Probability of flicker over a short time, Pst.

17A.2 METER IMPLEMENTATION

The first 4 of the above blocks can be implemented with standard controls compiler components. The Statistical Evaluation block however, requires a special component called rtds_sharc_ctl_PST. The Controls compiler implementation of Blocks 1 and 2 are shown in Figure 3. The implementation of Block3 is shown in Figure 4 and the final 2 blocks are shown in Figure 5.

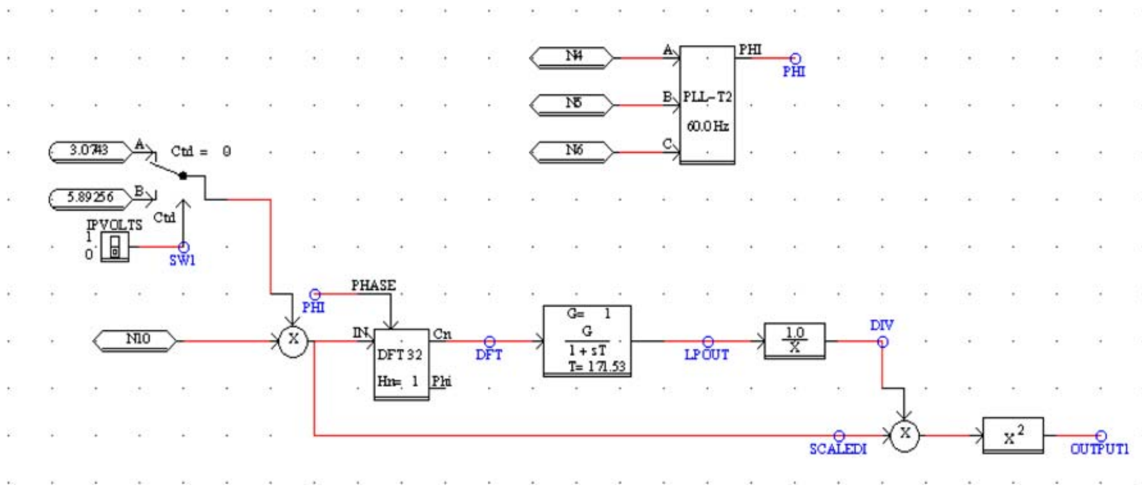


Figure 3

Note that the Import/Export icons attached to nodes N4, N5 and N6 in the figure are connected to the low voltage side of the first step down transformer in the arc furnace. N10 is at the PCC, i.e. the high voltage side of the first transformer. N10 is the actual flicker meter input.

The function of block 1 is to normalize the input voltage with a very long time constant. The Phase locked loop tracks the phase of the fundamental signal component and synchronizes samples taken in the Digital Fourier Transform block. This technique provides good rejection of harmonics. Scaling factors are switchable between 120 and 230 volts. The only parameter of importance in this section is the 171.53 sec time constant in the first order low pass filter.

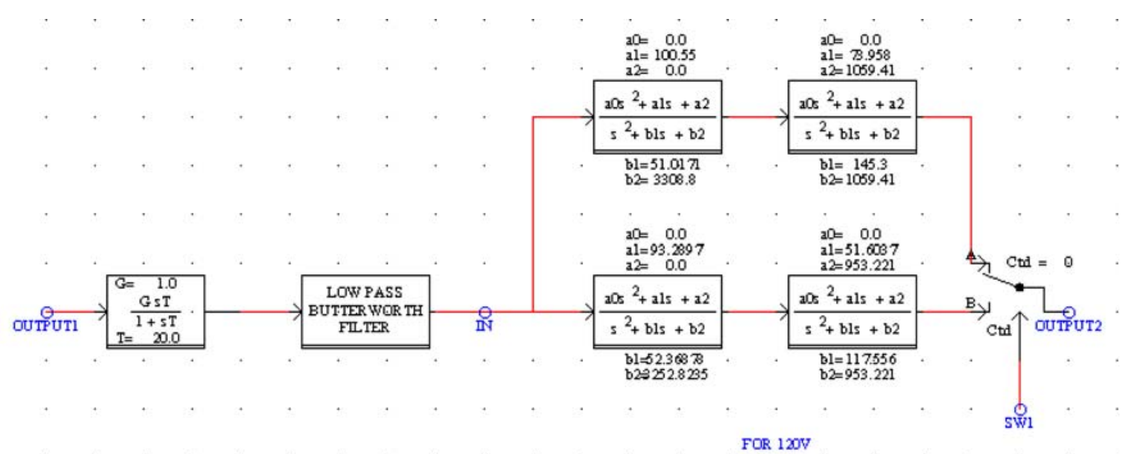


Figure 4

The leftmost block in Figure 4, and the block to its right, create the demodulator. This a bandpass filter with a first order highpass block giving a lower cutoff of 0.05 Hz and a sixth order Butterworth lowpass filter block giving an upper cutoff of 35 Hz. The set of 4 filter blocks on the right create the weighting filter, with parameters shown. The upper pair are for 230 Vrms input and the lower pair are for 120 Vrms input. All parameters of importance are shown except for the previously mentioned Butterworth filter.

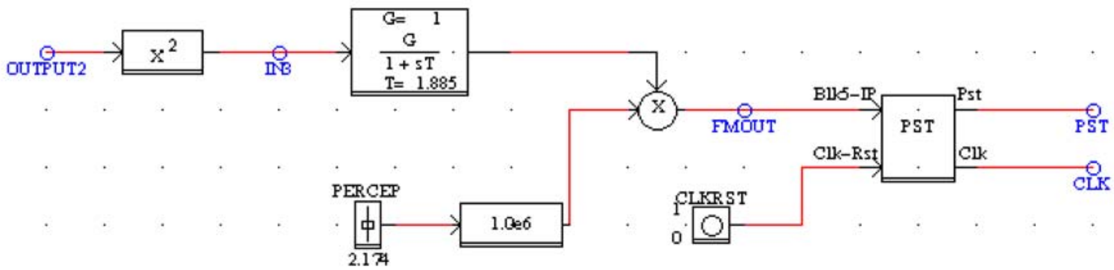
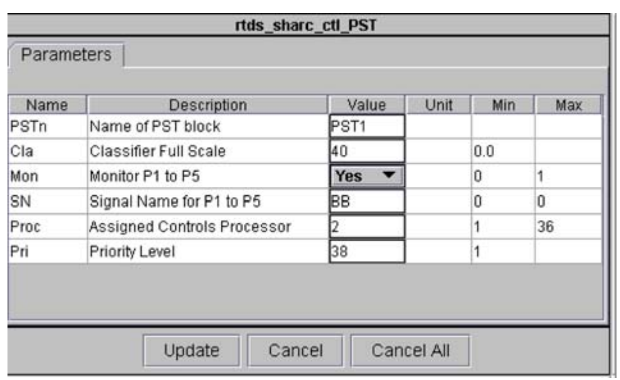


Figure 5

Figure 5 shows the squaring, smoothing, and statistical evaluation functions.

The gain function has been added to calibrate the output for a calibrated input. It is straight−forward to produce a standardized input from control blocks in the RTDS[3]. This signal can be written to a D/A and connected through amplifiers to a commercial flicker meter. The flicker meter implemented here can then be checked against the commercial unit.

The menu for the PST block is shown below.



rtds_sharc_ctl_PST

Parameters

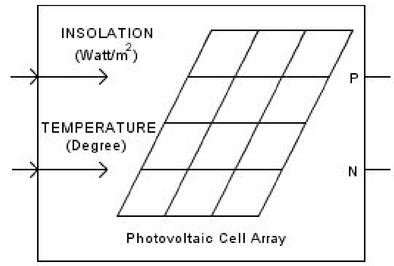
Name	Description	Value	Unit	Min	Max
PSTn	Name of PST block	PST1			
Cla	Classifier Full Scale	40		0.0	
Mon	Monitor P1 to P5	Yes		0	1
SN	Signal Name for P1 to P5	BB		0	0
Proc	Assigned Controls Processor	2		1	36
Pri	Priority Level	38		1	

Update Cancel Cancel All

The Classifier Full Scale should be chosen so that few if any, instantaneous flicker values exceed this number. On the other hand, if it chosen too large, the five guage points will not be calculated accurately. The five guage points refer to the level of flicker exceeded 50% of the time, 10% of the time, 3% of the time, 1% of the time and 0.1% of the time. These are referred to as P5 to P1 but can be named anything for plotting. The classifier is designed for the 10 minute test only.

18 PHOTO VOLTAIC (PV) ARRAY MODEL

(_rtds_PV.def)



18.1 INTRODUCTION

There are many different types of devices which are able to convert the energy found in solar rays into electrical power. The silicon based P−N junction type Photo−Voltaic(PV) cell is one of the most prevalent types of solar energy generating devices. This is mainly because a module is relatively cheap in comparison with other similar devices which use different technologies and because it can be manufactured in scale economically.

The basic element of a solar array is the solar cell. In most cases, however, the power from a single solar cell is very small and in order to produce enough power to supply a conventional load, the individual cells are connected in series to form a module. A solar array can then be constructed from modules to meet the design specification of the solar generation system. An array consists of modules which are connected in series and in parallel.

Figure 1 shows a diagram of how multiple PV cells can be connected in order to form a solar array. The number of cells in a module is denoted by *Nc*; the number of modules in parallel is denoted by *Np* and the number of series connected modules is denoted by *Ns*.

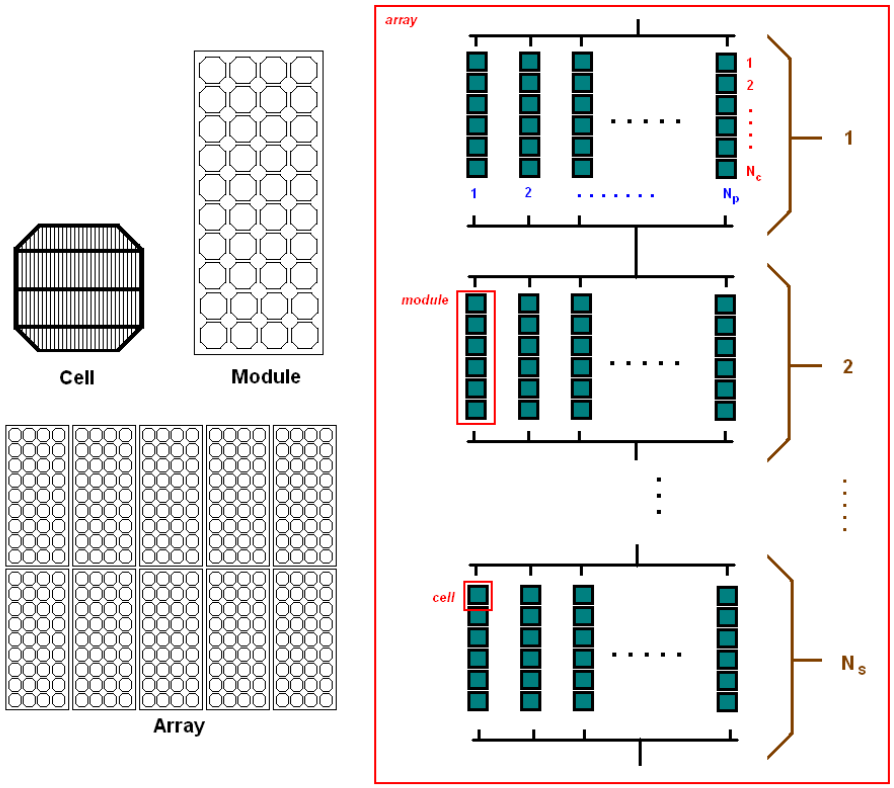


Figure 1: Elements of PV Array

PV Module Model

The following figure represents the conceptual model for a PV module. The current source represents the current generated by the energy contained in sun light. The diode models the characteristics of the junction between the P−type and N−type semiconductors.

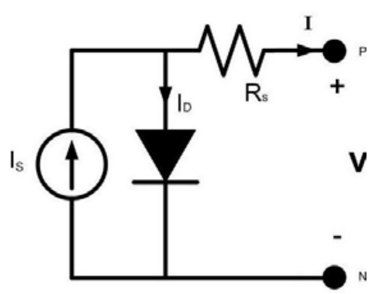


Figure 2: Conceptual Model of a PV module

The voltage, V, and current, I, output from the PV array are based on the calculated outputs for each individual module. In section 18.2 the equations used to calculate the currents and voltages of individual modules are provided; these are then scaled appropriately according to the topology of the array.

The total array current is the module current, given in equation 8, multiplied by the *Np* parameter. The total internal diode thermal voltage is the module thermal voltage, given in equation 2, multiplied by the *Ns* parameter.

Input and output of the model

The PV Array model has two power system nodes which allow it to be interfaced with the RTDS Network Solution; nodes P and N represent the positive and negative terminals respectively. The connections labeled ”INSOLATION” and ”TEMPERATURE” are the model’s control signal inputs. Together, along with the terminal conditions of the PV array, they are used to determine the quantities *Is* and *Id* of Figure 2’s conceptual model and consequently they dictate the output of the model.

Photo Voltaic Arrays are often characterized by plotting the array’s output current, I, versus its terminal voltage, V; these plots are known as an I−V characteristic. Both ambient temperature and insolation level impact such curves and Figure 3 shows how the I−V characteristics of an array change generally as a function of these two variables. Detailed mathematical relationships between these quantities are given in section 18.2.

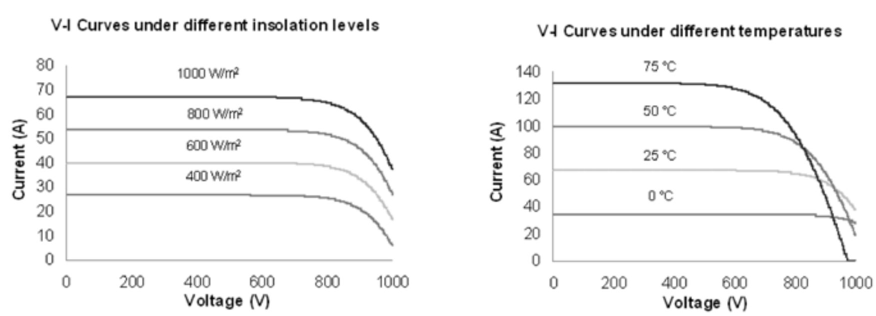


Figure 3: Illustration of how a PV array’s voltage and current are impacted by Insolation level and ambient temperature.

18.2 MATHEMATICAL DESCRIPTION OF MODEL

Internal Diode Representation

The current flowing through the internal diode representation is given by Equation 1. This equation is well know and is commonly refered to as the 'diode law'.

$$I_D = I_0\left(\exp\left(\frac{V + I \cdot R_S}{n \cdot V_T}\right) - 1\right) \qquad \text{Eq. 1}$$

I_o : *Diode saturation current* $\quad$ n : *Diode ideality factor*

V_T : *Thermal potential difference* $\quad$ $V + I \cdot R_S$: *Total diode bias voltage*

The calculation of Equation 1, requires that the thermal potential difference, V_T, and the diode saturation current, I_0, be defined. These two quanties are given in Equations 2 and 3 below

$$V_T = \left[(TEMP + 273) \cdot \frac{K}{q}\right] \cdot N_c \qquad \text{Eq. 2}$$

$TEMP$: *Temperature in centigrade*

K : *Boltzmann constant* $(1.3806503x10^{-23}\, m^2 \cdot kg \cdot s^{-2} \cdot K^{-1})$

q : *Elementary charge* $(1.602176x10^{-19}\, C)$

N_c : *Number of cells in a module*

$$I_0 = A \cdot (TEMP + 273)^{\gamma} \cdot \exp\left(\frac{E_g \cdot N_c}{nid \cdot V_T}\right) \qquad \text{Eq. 3}$$

A : *Temperature dependent coefficient of diode saturation current*

$TEMP$: *Temperature in centigrade*

γ : *Temperature dependency factor*

V_T : *Thermal potential difference*

E_g : *Band energy gap*

N_c : *Number of cells in a module*

nid : *Diode ideality factor*

Calculation of equations 2 and 3 require the intermediate calculation of other quantities. The *band energy gap* of the diode can be calculated using equation

4 and the *temperature dependent coefficient of the diode saturation current* is given by equation 5.

$$E_g = 1.16 - 0.000702 \cdot \frac{(TEMP + 273)^2}{(TEMP + 273 - 1108)} \qquad \text{Eq. 4}$$

$$A = \frac{I_{oref}}{(refTEMP + 273)^{\gamma} \cdot \exp\left(\frac{-E_{gref} \cdot N_c}{nid \cdot V_{Tref}}\right)} \qquad \text{Eq. 5}$$

I_{oref} : *Reference diode saturation current*

$refTEMP$: *Reference temperature in centigrade*

γ : *Temperature dependency factor*

V_{Tref} : $V_T \mid_{T = refTEMP}$

E_{gref} : $E_g \mid_{T = refTEMP}$

$N_{c:}$ *Number of cells in a module*

nid : *Diode ideality factor*

Finally, in order to calculate equation 5, we must define the *reference diode saturation current*. This quantity is given by equation 6.

$$I_{oref} = \frac{I_{scref}}{\exp\left(\frac{V_{ocref}}{nid \cdot V_{Tref}}\right) - 1} \qquad \text{Eq. 6}$$

I_{scref} : *Short circuit current*

V_{ocref} : *Open circuit voltage*

V_{Tref} : $V_T \mid_{T = refTEMP}$

nid : *Diode ideality factor*

Internal series resitance representation

The following equation is used to obtain the value of the internal series resistance shown in Figure 2.

$$R_S = \frac{nid \cdot V_{Tref} \cdot \ln\left(\frac{I_{scref} - I_{mpref}}{I_{oref}} + 1.0\right) - V_{mpref}}{I_{Impref}} \qquad \text{Eq. 7}$$

nid : *Diode ideality factor*

V_{Tref} : $V_T \mid_{T = refTEMP}$

I_{scref} : *Short circuit current*

$I_{oref:}$ *Reference diode saturation current*

I_{mpref} : *Output Current at maximum power*

V_{mpref} : *Output Voltage at maximum power*

Internal current source representation

The internal current source in the PV array model can be described using the following equation.

$$I_{sc} = I_{scref} \cdot \left(\frac{INS}{1000}\right) \cdot \left(1.0 + \frac{J_{TMP}}{100.0} \cdot (TEMP - refTEMP)\right) \qquad \text{Eq. 8}$$

INS : *Insolation input*

J_{tmp} : *Temperature Coefficient of* I_{SC}

$TEMP$: *Temperature in centigrade*

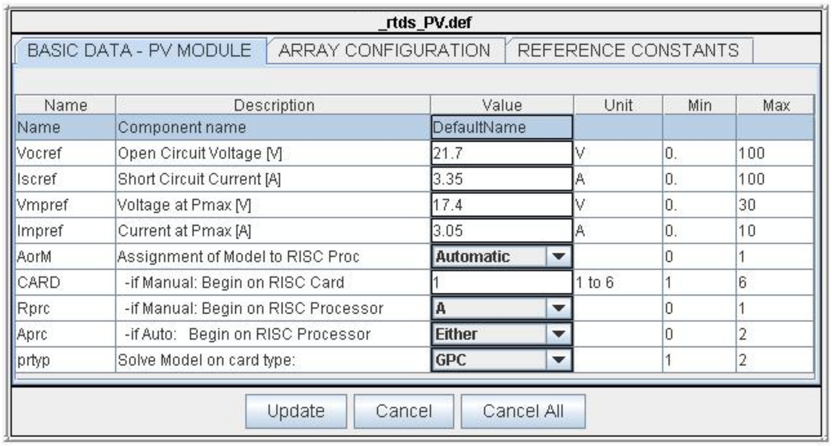
$refTEMP$: *Reference temperature in centigrade*

I_{scref} : *Short circuit current*

18.3 MODEL PARAMETERS

This section includes a description of the parameters for the PV array component.

BASIC DATA – PV MODULE MENU


_rtds_PV.def

BASIC DATA - PV MODULE | ARRAY CONFIGURATION | REFERENCE CONSTANTS

Name	Description	Value	Unit	Min	Max
Name	Component name	DefaultName			
Vocref	Open Circuit Voltage [V]	21.7	V	0.	100
Iscref	Short Circuit Current [A]	3.35	A	0.	100
Vmpref	Voltage at Pmax [V]	17.4	V	0.	30
Impref	Current at Pmax [A]	3.05	A	0.	10
AorM	Assignment of Model to RISC Proc	Automatic		0	1
CARD	-if Manual: Begin on RISC Card	1	1 to 6	1	6
Rprc	-if Manual: Begin on RISC Processor	A		0	1
Aprc	-if Auto: Begin on RISC Processor	Either		0	2
prtyp	Solve Model on card type:	GPC		1	2

Update | Cancel | Cancel All

Name A unique name for the PV array model should be assigned.

Vocref The open–circuit voltage is used in the calculation of the reference diode saturation current of equation 6.

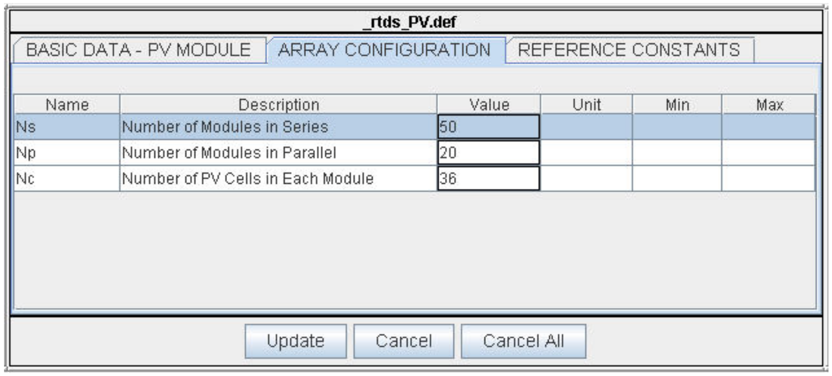
Iscref The short–circuit current is used in the calculation of equations 6 through 8.

Vmpref The voltage at maximum power which is used in the calculation of equation 7.

Impref The current at maximum power which is used in the calculation of equation 7.

The last 5 entries of the menu allow the model to be automatically or manually assigned to a specified processor. If automatic assignment is specified, the subsequent two entries in the menu are ignored. If manual assignment is specified, a specific processor can be requested using the *CARD* and *Rprc* parameters The *Aproc* parameter determines which of the RISC card's processors is used when automatic assignment is selected. The last parameter, *prtyp*, determines the type of card the model runs on.

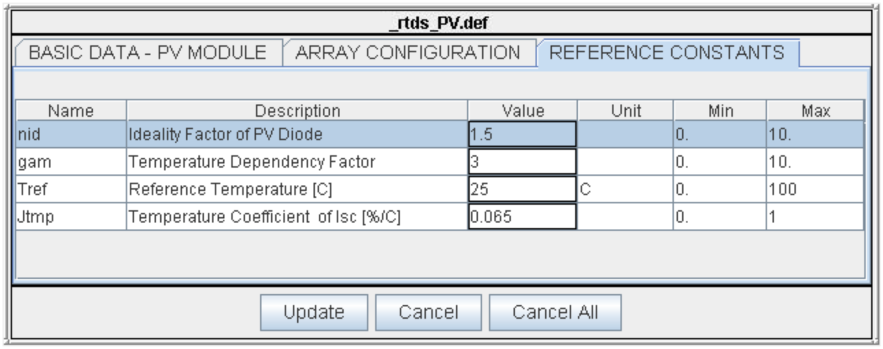
ARRAY CONFIGURATION MENU



As mentioned earlier, PV cells are generally connected in series to form what a called *modules* in order to generate practically useful amounts of electricity. Solar arrays are made up of parallel and series connected modules chosen in such a way to meet the design specifications of the solar generation system. Three parameters are needed to specify how the cells and modules are interconnected.

Nc	The number of cells in each module.
Ns	The number of series connected modules.
Np	The number of parallel connected modules.

REFERENCE CONSTANTS MENU



nid Represents the diode ideality factor and is used in equations 4, 5 and 6.

Gam The temperature dependency factor; it is used in the calculation of equations 5 and 6.

Tref The reference temperature used in equations 5, 6, 7 and 8.

Jtmp The temperature coefficient of Isc used in equation 8.

18.4 INTERFACE WITH SMALL TIME STEP SIMULATION

Usually interface transformer components are used to transfer power system signals between large and small time step simulations. These interface transformers, however, cannot be used for the PV array because the outputs of the PV array component are effectively DC signals which cannot flow through the transformer.

One solution which would bridge the large and small time step portions of the simulation is to construct the necessary interface by transferring voltage and current information between them. Voltage information from the large time step side of the simulation is transferred to the small time−step side of the simulation and current information from the small time step side is brought to the large time step side. Figure 4 illustrates the signals which must be interchanged between the large and small time step portions of the simulation.

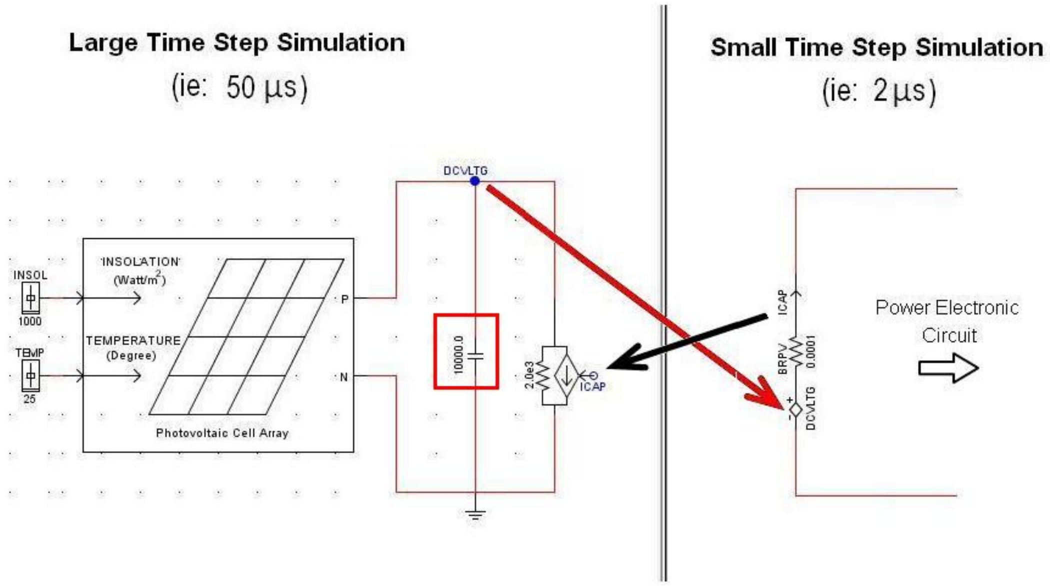


Figure 4: Interfacing the PV Array with a small time step simulation

The node voltage in the large time step side is transferred to the small time step side, driving a voltage source. The current in the small time step side is transferred back to the large time step side, driving a current source branch. In this configuration, an interface capacitor, marked with a red rectangle, contributes to the stability of the interface by smoothing the node voltage. A physical capacitor is commonly found in the power conversion system applications with PV arrays.

By using this interface technique, the necessary power electronics application device(s) can be accurately modeled and simulated with the PV array model.

18.5. ACKNOWLEDGEMENTS

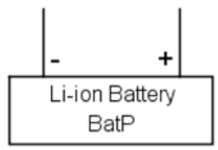
It is kindly acknowledged that the modeling work was greatly expedited by the help and advice of Dr. Min Won Park from Chang Won National University (Korea).

18.6 REFERENCES

[1] 'Development of a Dynamic Test Module for Testing Grid Interface of Renewable Energy Resource Generation', 2006, KERI (Korea)

19 LI–ION BATTERY MODEL

(_rtds_libat.def)



19.1 INTRODUCTION

This model in RTDS library represents a Li–ion battery. The mathematical description of the model is mainly based on the reference [1]. The model in the reference is extracted from a real commercial Li–ion polymer battery product, TCL–PL–383562 from TCL Hyperpower Batteries Inc (China)[2].

A curve fitting method was used in the reference in order to extract parameters. The focus of the modelling is on the electrical behavior of the battery, namely Voltage–current Characteristics. Hence, the battery lifetime modeling, which would describe long term battery behavior such as self–discharge is not considered in the model. The thermal aspect of the battery such as the thermal dependency of the circuit parameters are not considered in the model, either. The equivalent electrical circuit of the battery model is presented below.

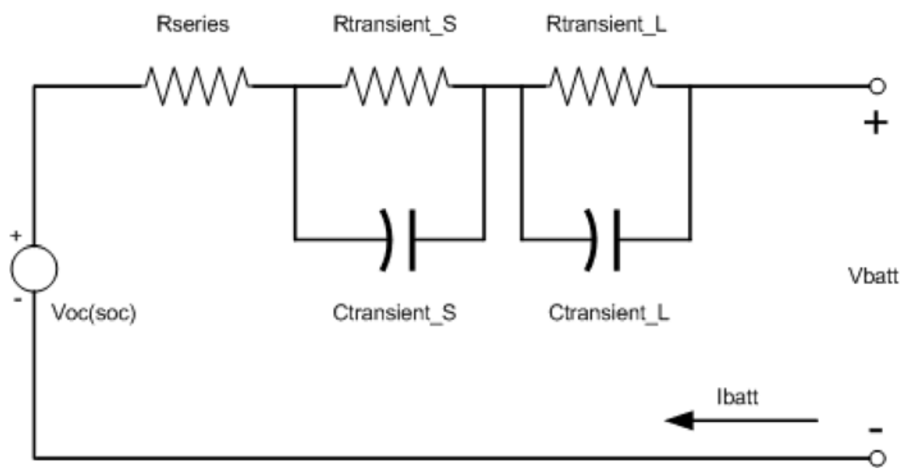


Figure 1. Electrical equivalent circuit of Li–ion battery

19.2 MATHEMATICAL DESCRIPTION OF MODEL

In above circuit, Rtransient_S and C_transient_S are responsible for the short−term transient of the battery, whereas Rtransient_L and C_transient_L are responsible for the long−term transient of the battery. It was noted in the reference paper [1] that two RC time constants as employed in the mode is the best tradeoff between accuracy and complexity of the model.

All the non−linear circuit parameters in above circuit are functions of state of charge (SOC). Single variable functions were used to describe the behavior of those parameters mathematically. The functions are as belows:

$$V_{OC}(SOC) = -1.031 \cdot e^{-35 \cdot SOC} + 3.685 + 0.2156 \cdot SOC - 0.1178 \cdot SOC^2 + 0.3201 \cdot SOC^3$$

$$R_{Series}(SOC) = 0.1562 \cdot 2^{-24.37 \cdot SOC} + 0.07446$$

$$R_{Transient\_S}(SOC) = 0.3208 \cdot e^{-29.14 \cdot SOC} + 0.04669$$

$$C_{Transient\_S}(SOC) = -752.9 \cdot e^{-13.51 \cdot SOC} + 703.6$$

$$R_{Transient\ L}(SOC) = 6.603 \cdot e^{-155.2 \cdot SOC} + 0.04984$$

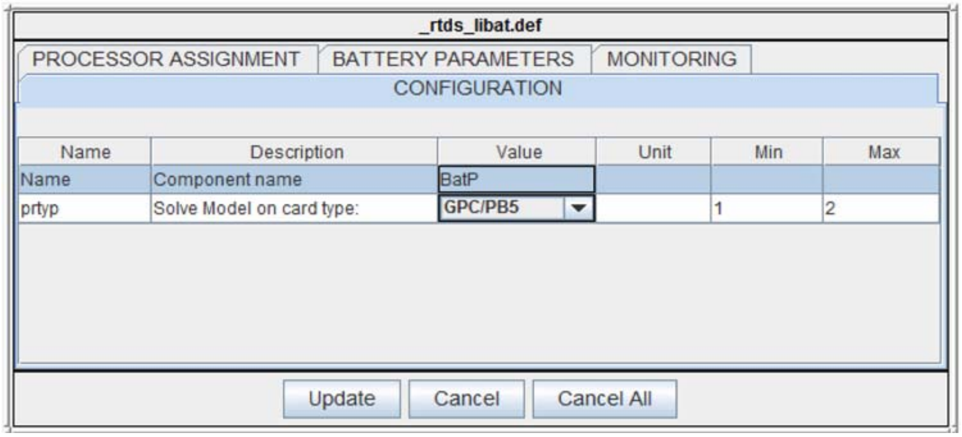
$$C_{Transient\ L}(SOC) = -6056 \cdot e^{-27.12 \cdot SOC} + 4475$$

19.3 INPUT AND OUTPUT OF MODEL

The Li−ion battery model has two power system nodes. One is designated as ’+’ node and the other is designated as ’−’ node. Because the lifetime and thermal aspect of the battery are not considered, no control input exists with the model.

19.4 MODEL PARAMETERS

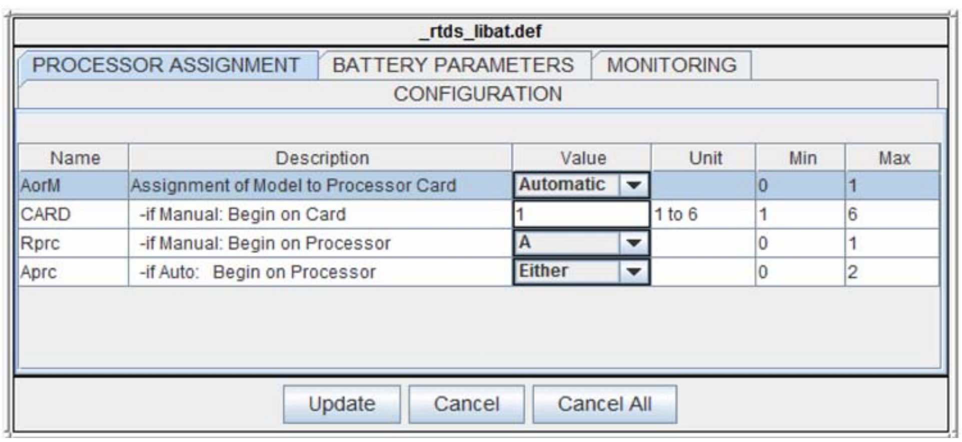
CONFIGURATION



Name A unique name for the battery model should be assigned.

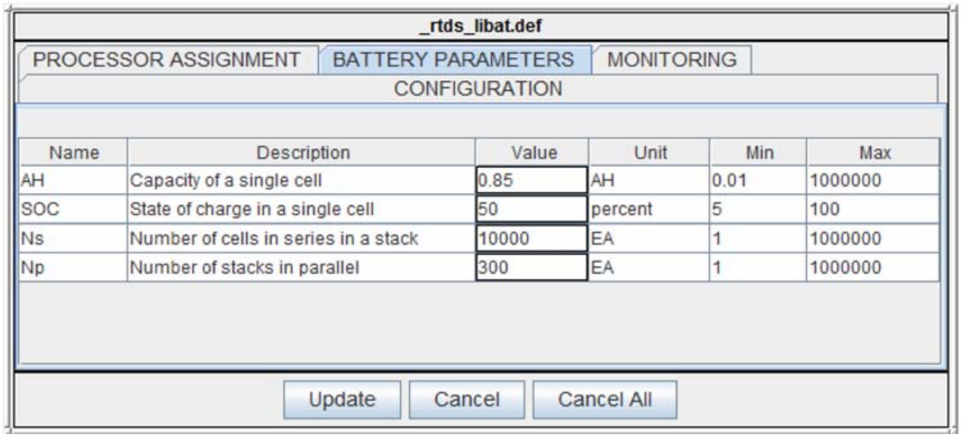
prtyp The type of processor where the model can run.

PROCESSOR ASSIGNMENT



The 4 entries of the menu allow the model to be automatically or manually assigned to a specified processor. If automatic assignment is specified, the subsequent two entries in the menu are ignored. If manual assignment is specified, a specific processor can be requested using the CARD and Rprc parameters. The Aproc parameter determines which of the RISC card¡¯s processor is used when automatic assignment is selected.

BATTERY PARAMETERS



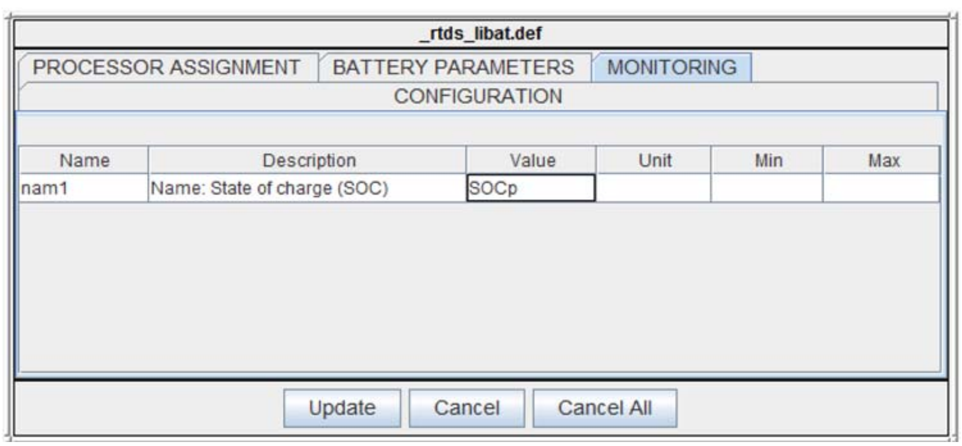
AH Capacity of a single Li−ion battery cell in AH (Ampere−Hour)

SOC Initial state of charge (SOC) in percent (%)

Ns Number of battery cells connected in series in a stack

Np Number of battery stacks in parallel

MONITORING



nam1 Name of variable for state of charge (SOC) of battery

19.5 REFERENCE

[1] C. Min and G. A. Rincon−Mora, "Accurate electrical battery model capable of predicting runtime and I−V performance," Energy Conversion, IEEE Transactions on, vol. 21, pp. 504−511, 2006.

[2] TCL Hyperpower Batteries Inc. (2009). Available: http://www.tclbattery.com/english/product01−1.asp