Introduction to HVDC

VSC HVDC

Dr Radnya A Mukhedkar

Group Leader, Senior Principal Engineer

System Design

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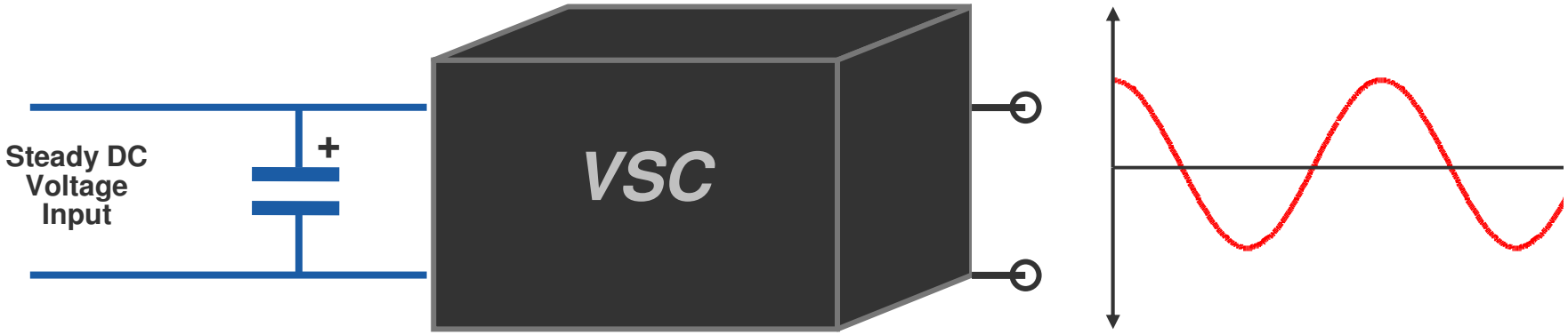
The Voltage Sourced Converter
Single Phase



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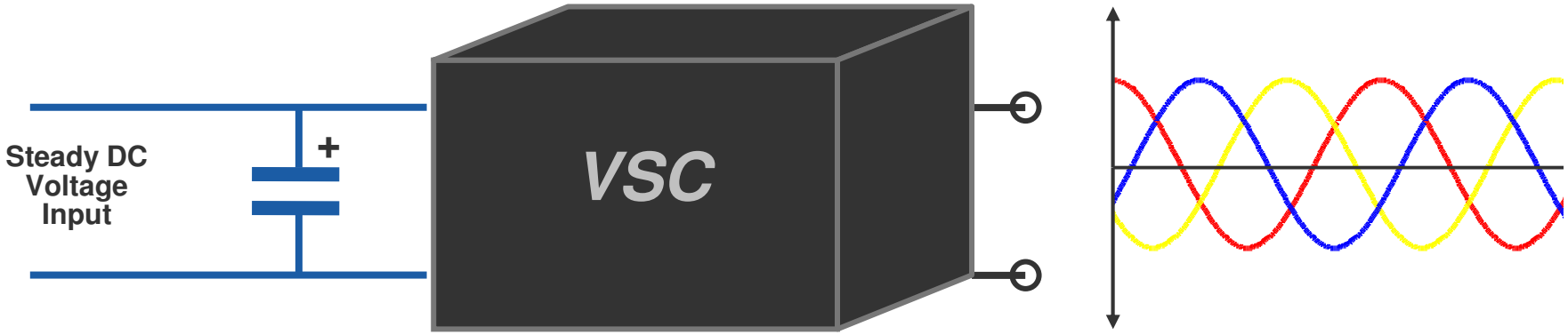
The Voltage Sourced Converter
Three Phase



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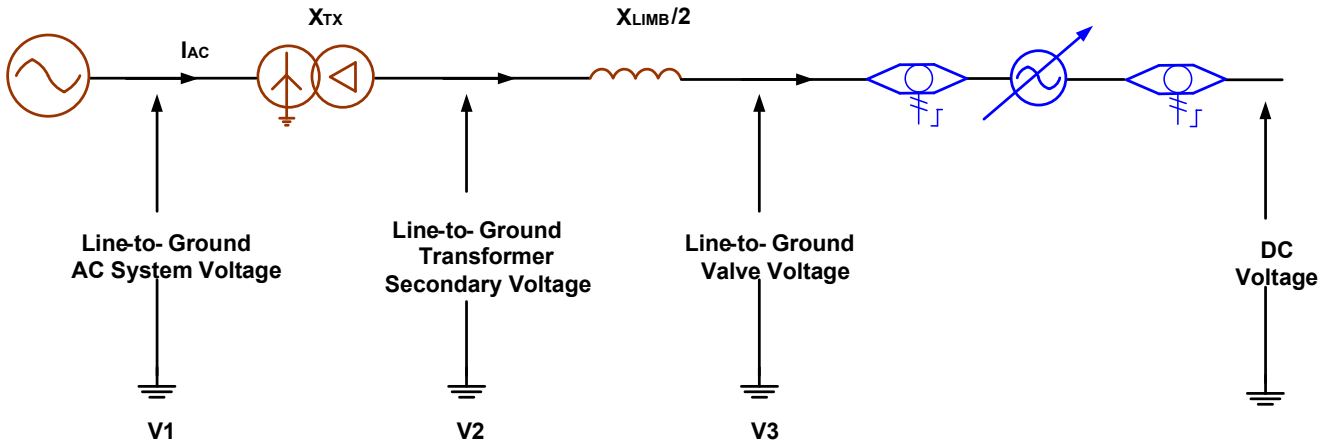
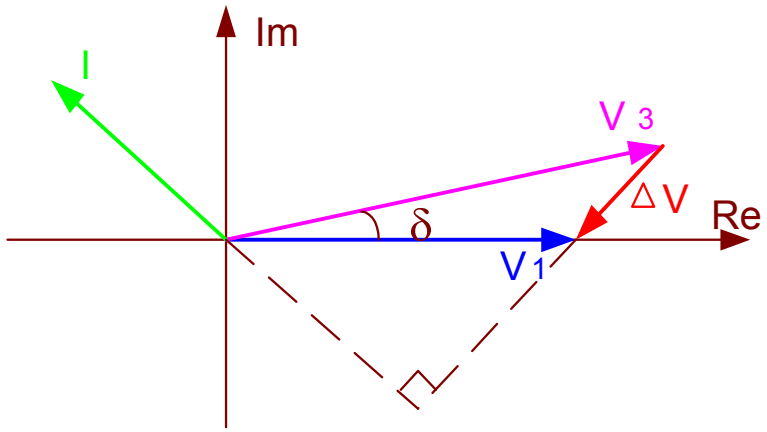
AC/DC System Schematic – Ideal Load Flow





$$P = \frac{V_3 \cdot \sin(\delta)}{X} \cdot V_1$$

$$Q = \frac{V_3 \cdot \cos(\delta) - V_1}{X} \cdot V_1$$

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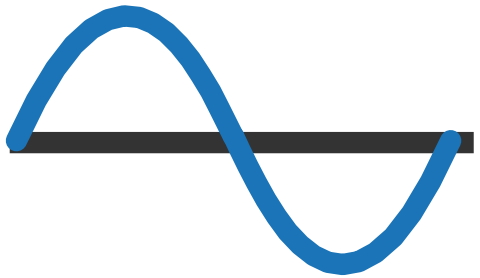
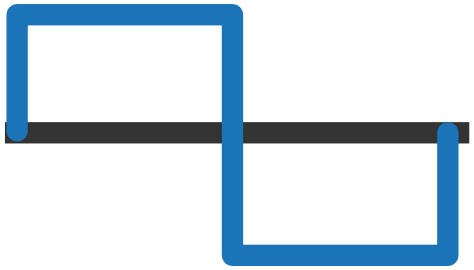
VSC
Synthesis of a Sine Wave

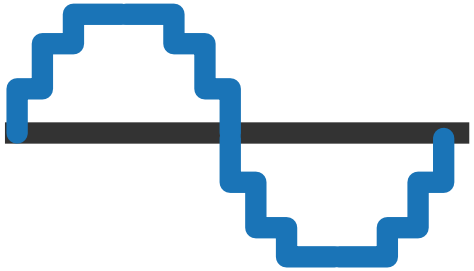
Voltage Waveforms



Ideal Waveform

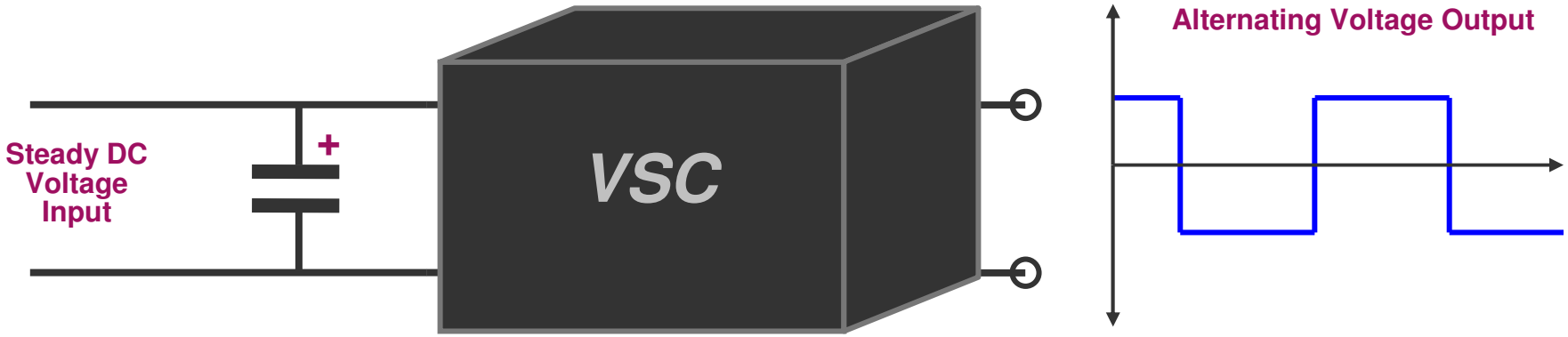


Simplest Possible Waveform



Acceptable Approximation if Sufficient Steps are Used

The Voltage Sourced Converter
Single Phase, 2-level



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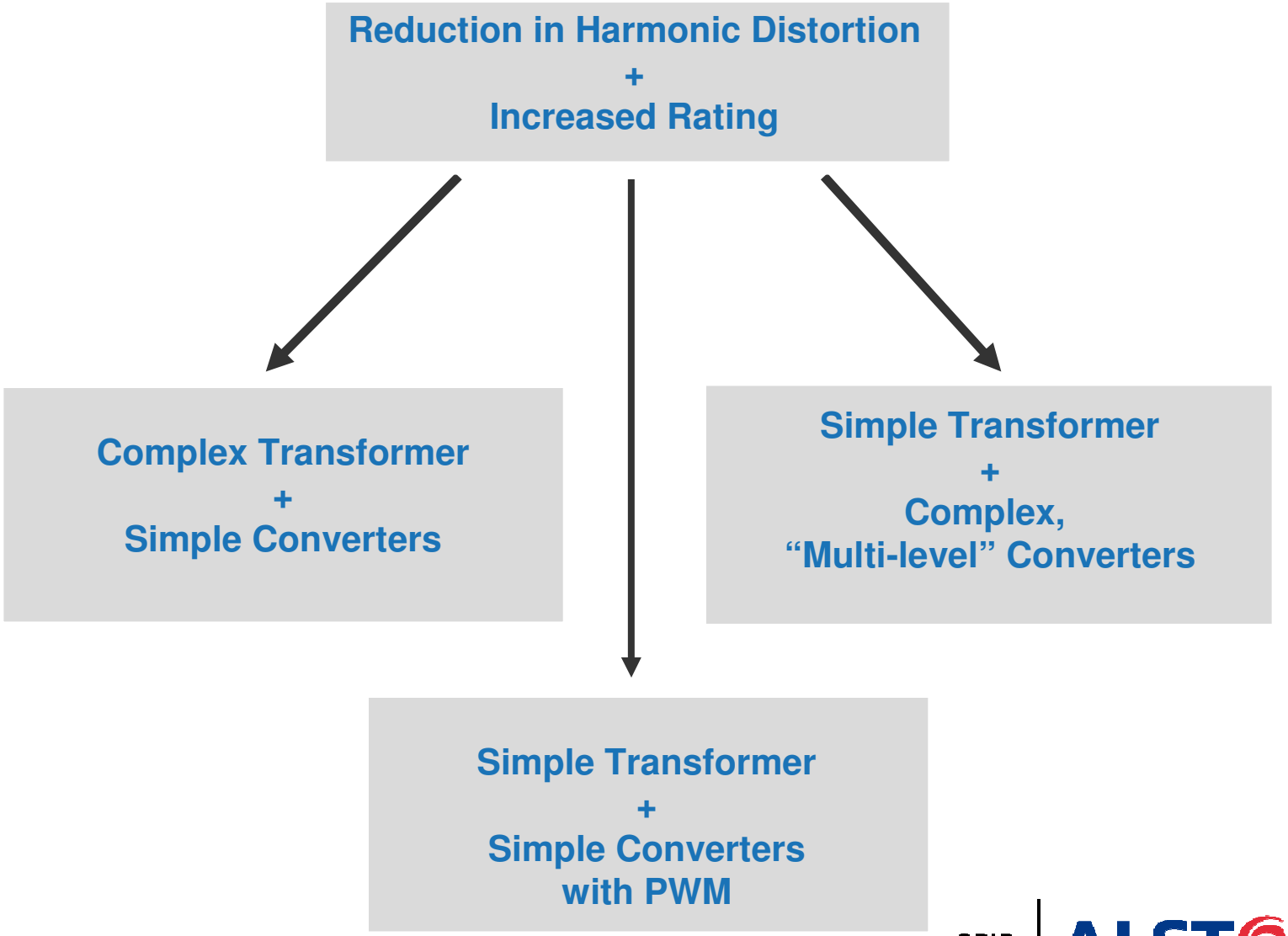
VSC: Three Main Classes



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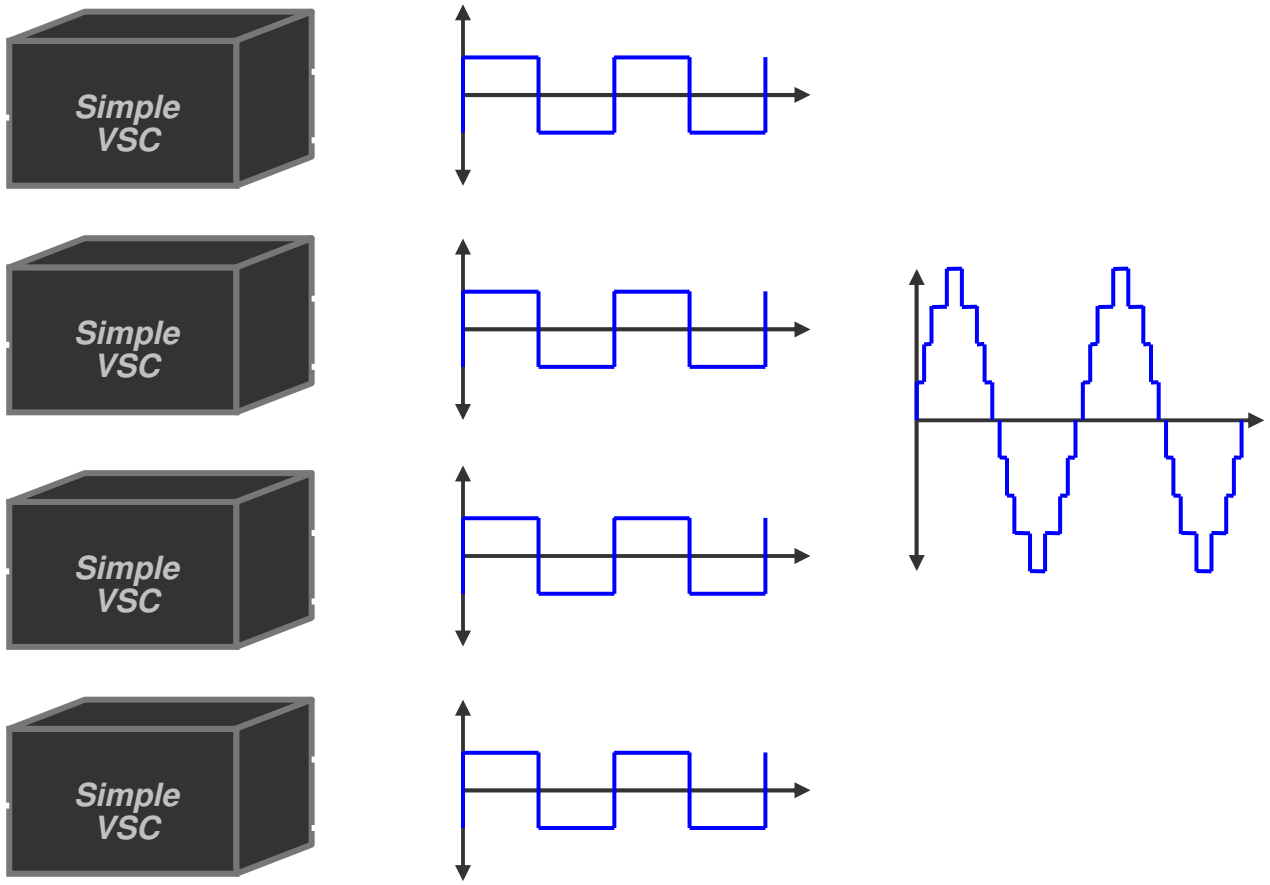
Complex Transformer + simple converters



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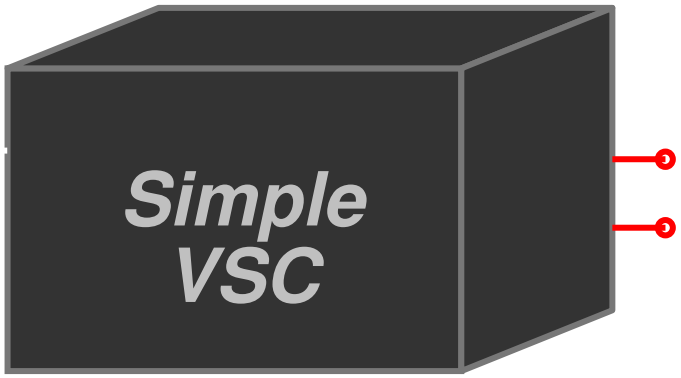
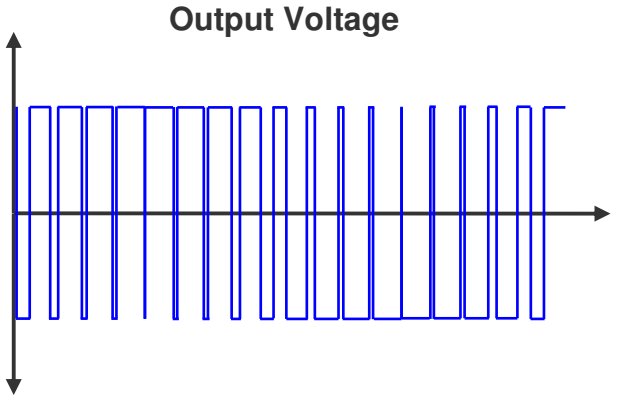
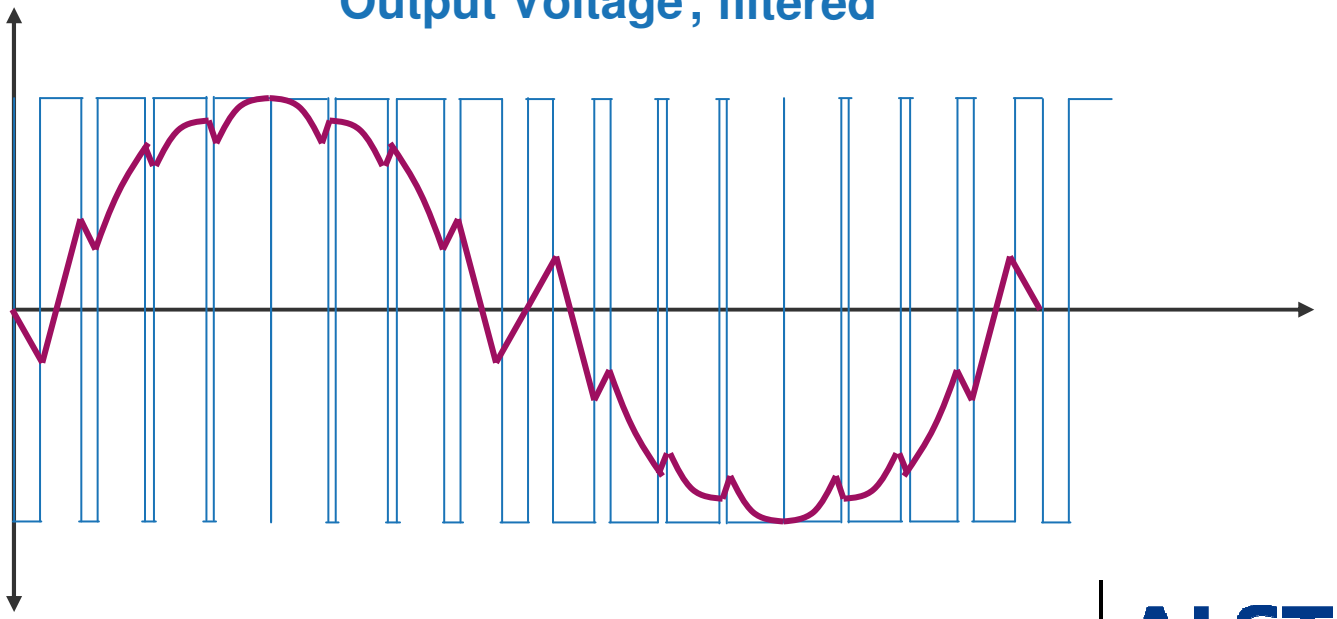
Simple Transformer, Simple Converter + PWM





Output Voltage, filtered



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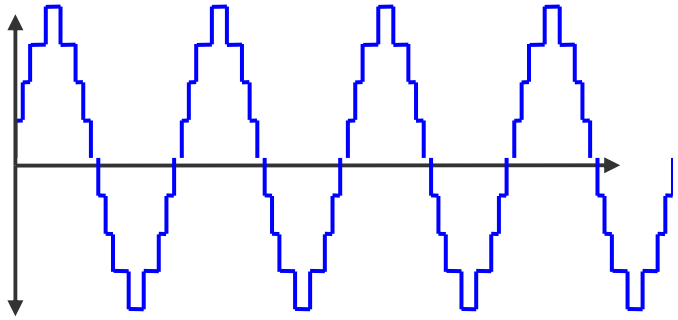
Multi-Level Converter



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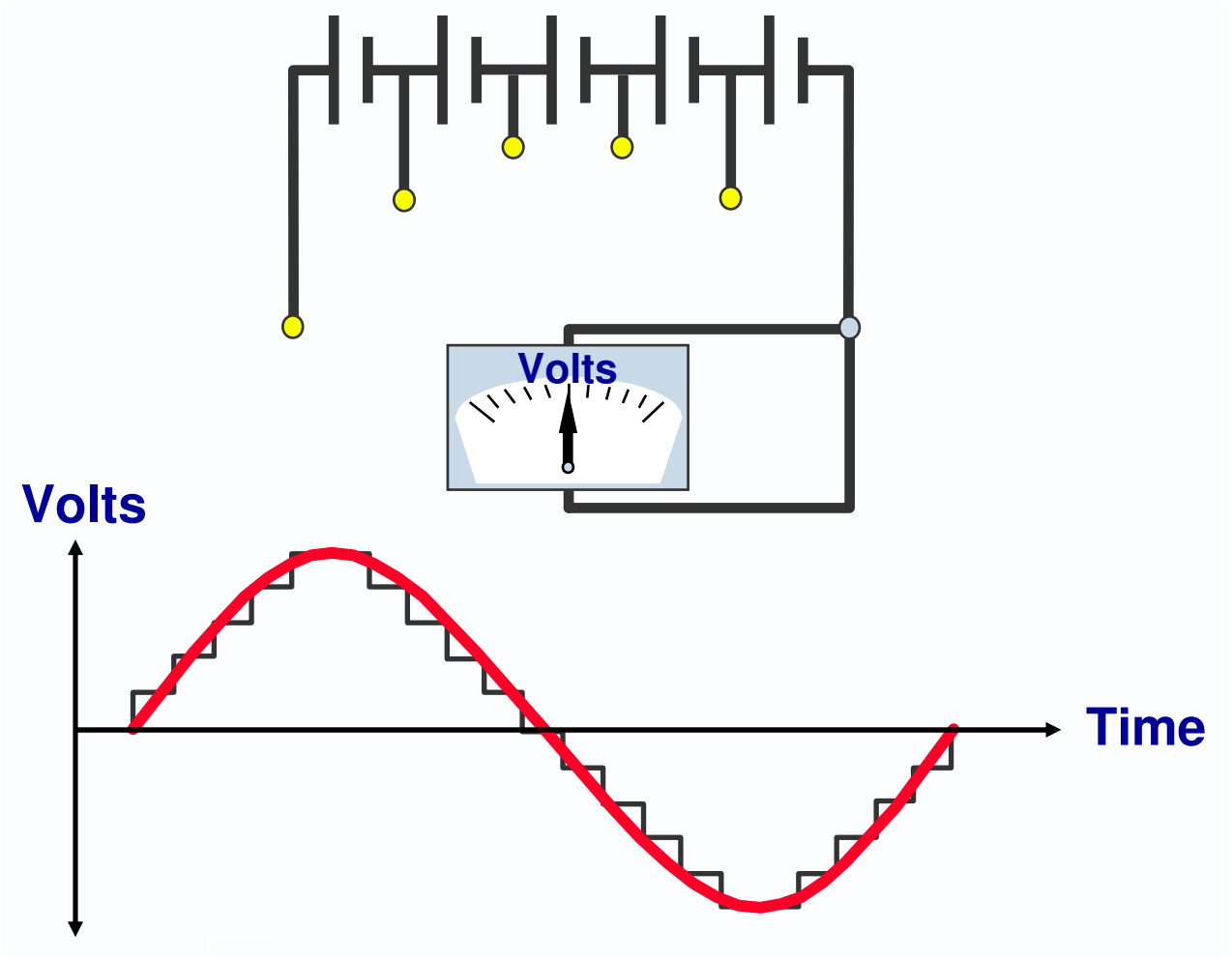
What is a multi-level converter?



Total Flexibility

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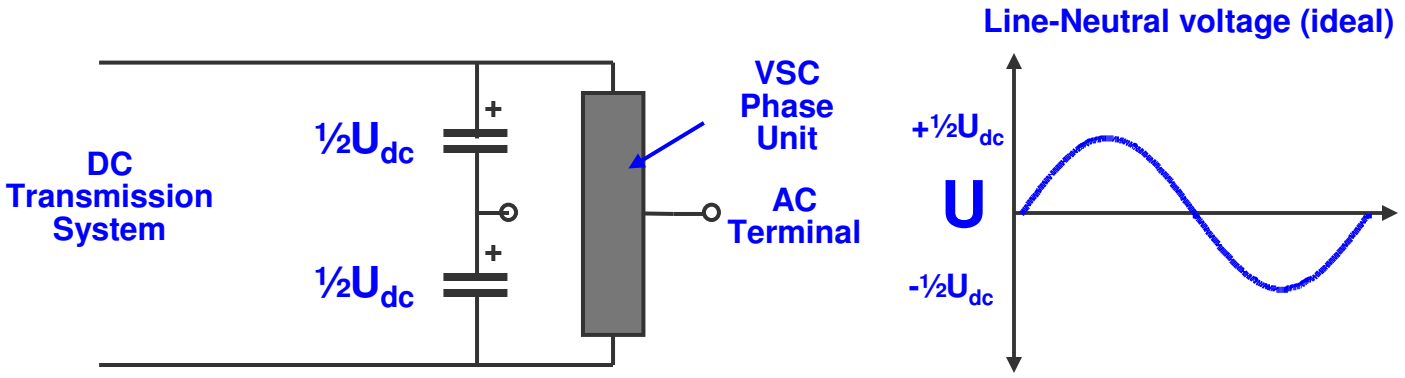
VSC Converter: phase arm



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Semiconductors for VSC

Voltage-Sourced Converters require semiconductors which can carry current in both directions and withstand voltage in the positive direction

The following types of device have the appropriate properties:

Thyristor derivatives:

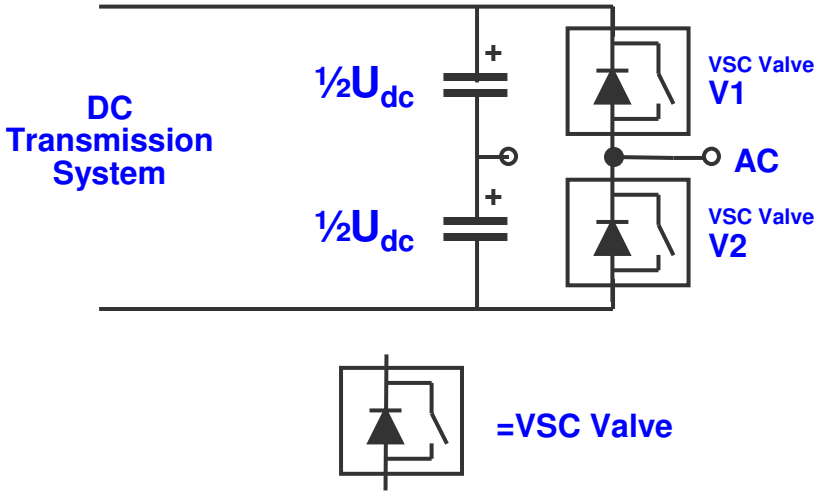
- GTO: Gate Turn-Off thyristor
- GCT: Gate Commutated Thyristor (= a GTO with a better gate drive)
- IGCT: Integrated Gate Commutated Thyristor (=a GCT with the gate drive "integrated" into the semiconductor package)

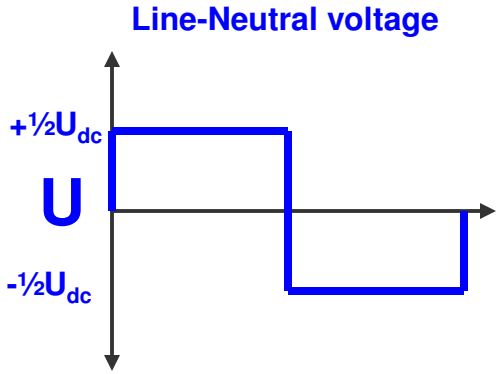
Transistor derivatives:

- BJT: Bipolar Junction Transistor (only for low power and low frequency)
- MOSFET: Metal-Oxide Semiconductor Field Effect Transistor (only for low power)
- IGBT: Insulated Gate Bipolar Transistor
- IEGT: Injection Enhanced Gate Transistor – similar to an IGBT

Do not confuse IGBT and IGCT!!

Basic 2-level inverter
One phase arm





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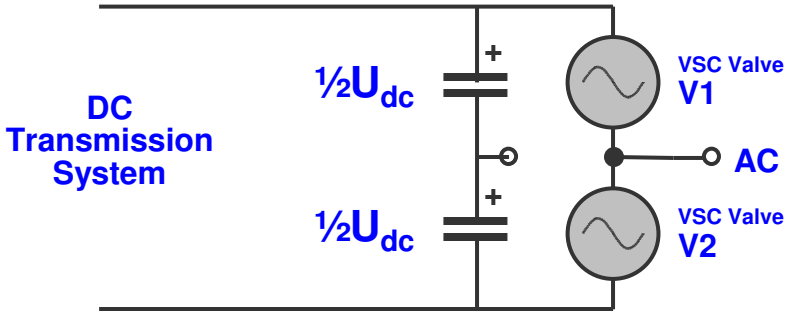
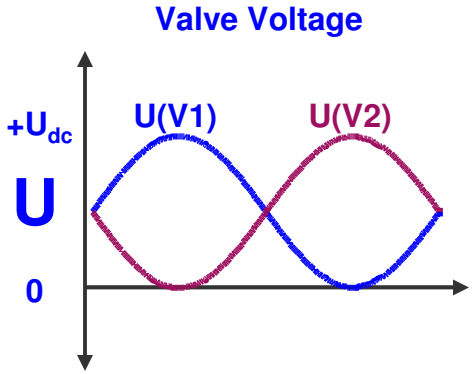
VSC Valves of the 'Controllable Voltage Source' type





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Circuit Types

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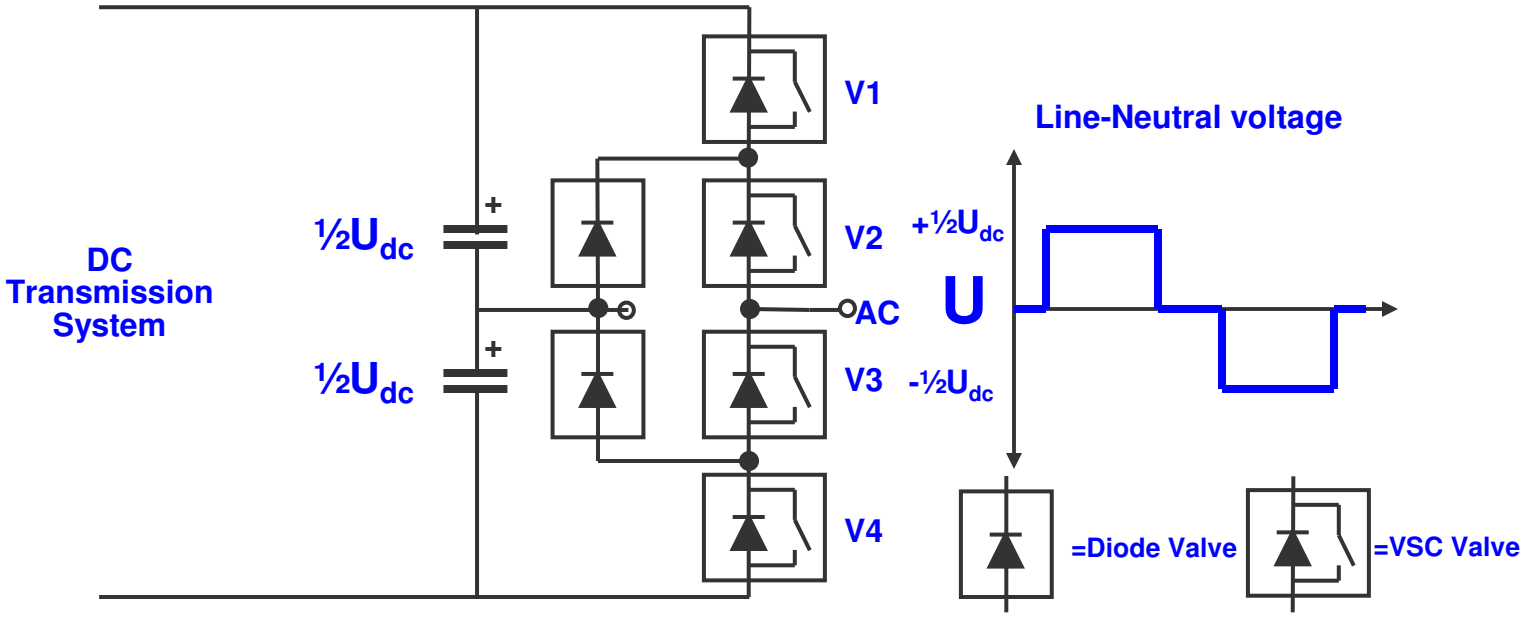
Neutral-point clamped inverter
One phase arm (3 level)



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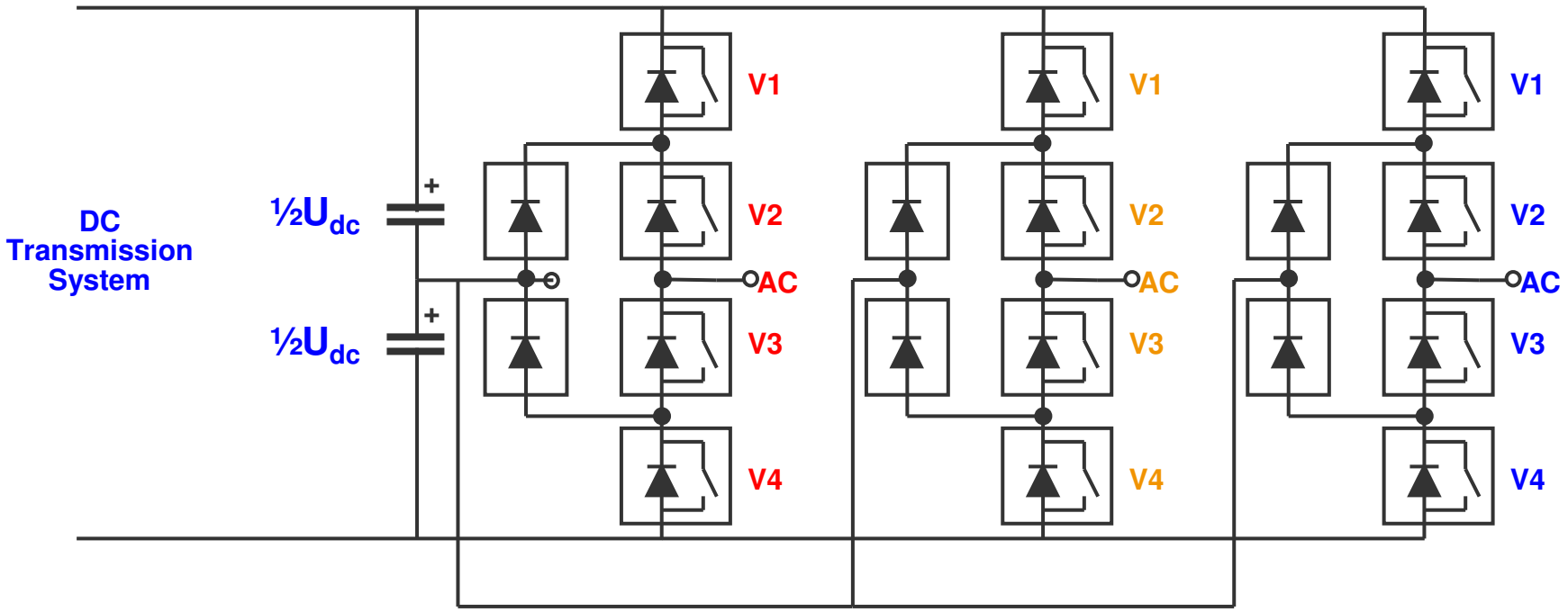
Neutral-point clamped inverter
Three-phase circuit (3 level)



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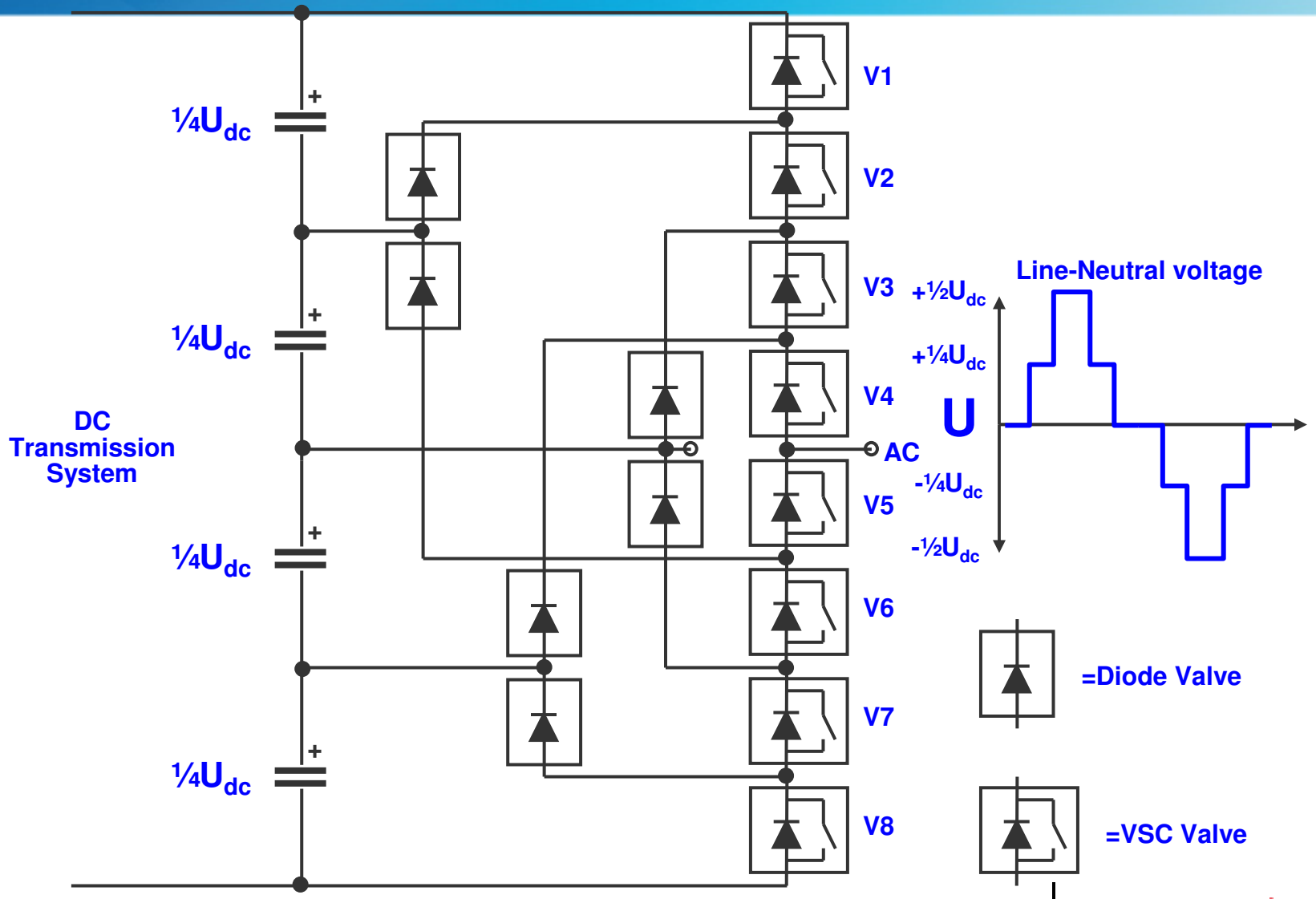
Neutral-point clamped inverter
One phase arm (5 level)



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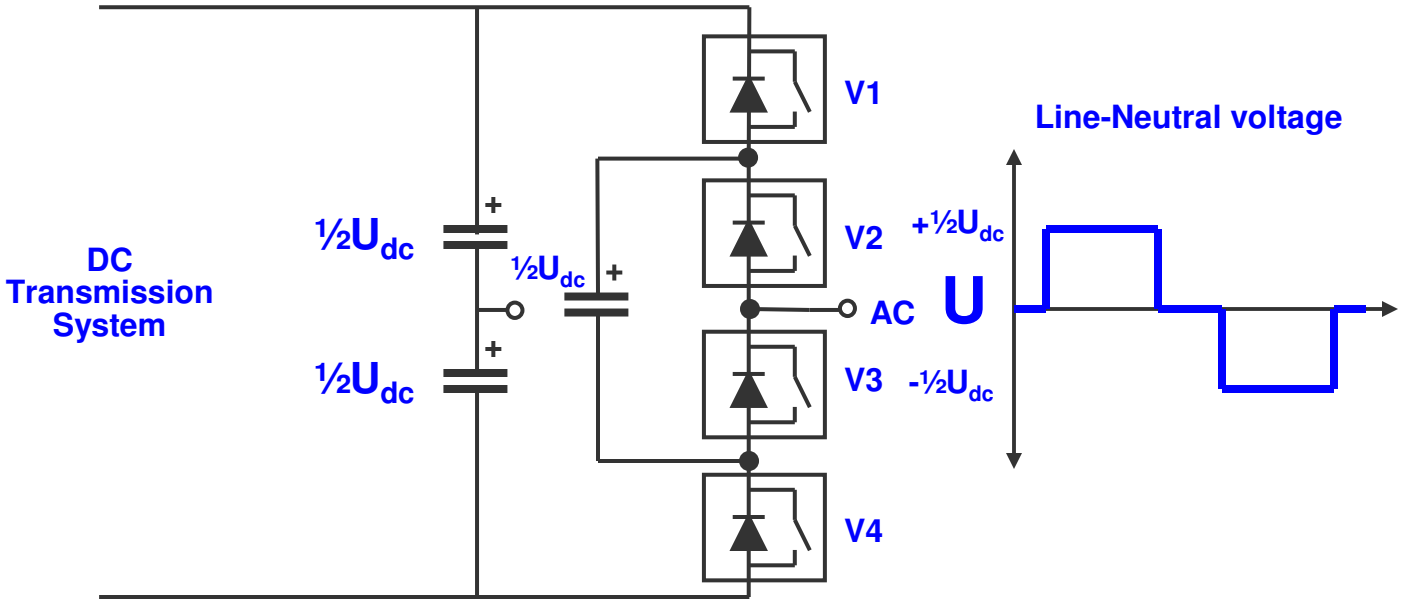
Flying Capacitor inverter
One phase arm (3 level)



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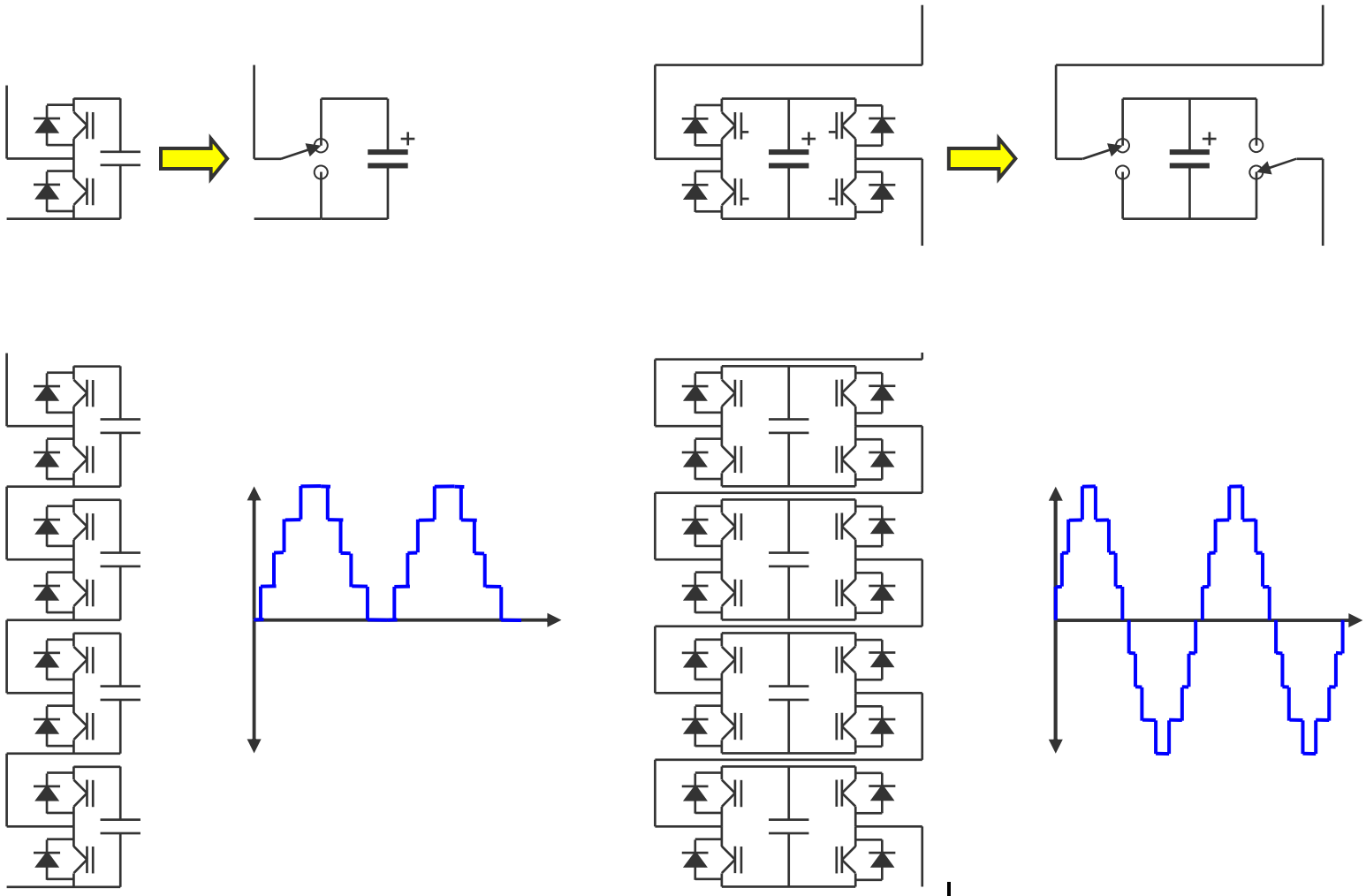
VSC with series-connected chain link modules

a.k.a. Modular MultiLevel Converter



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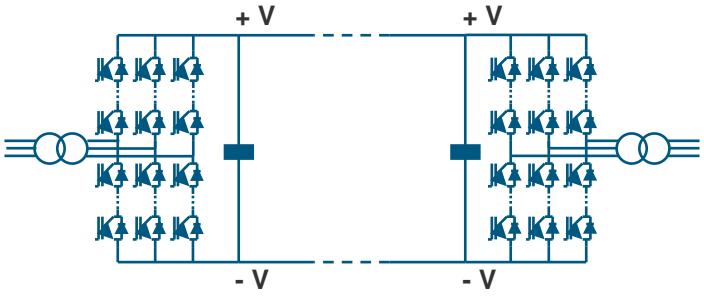
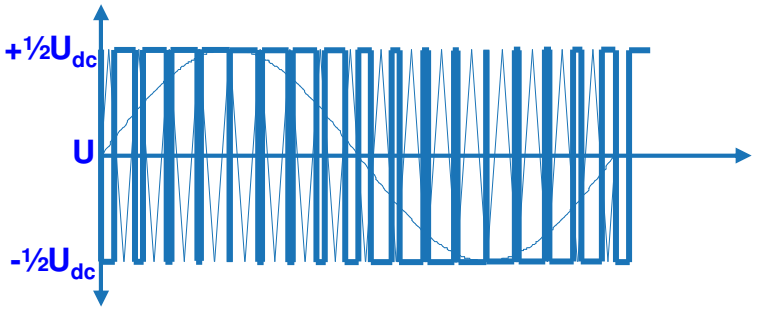
VSC-HVDC
2 Basic Approaches

Series-Connected IGBTs

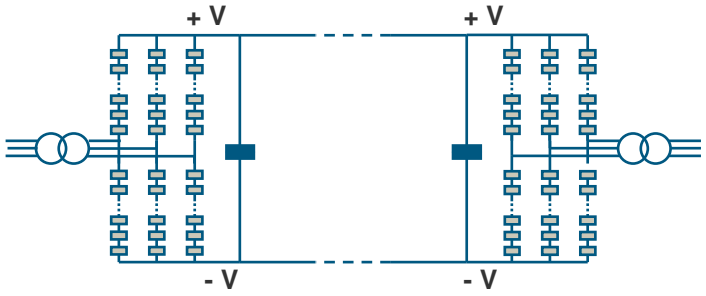
- ✓ Conceptually simple circuit
- ✘ Requires PWM
- ✘ High switching losses
- ✘ Harmonic and EMC problems from PWM



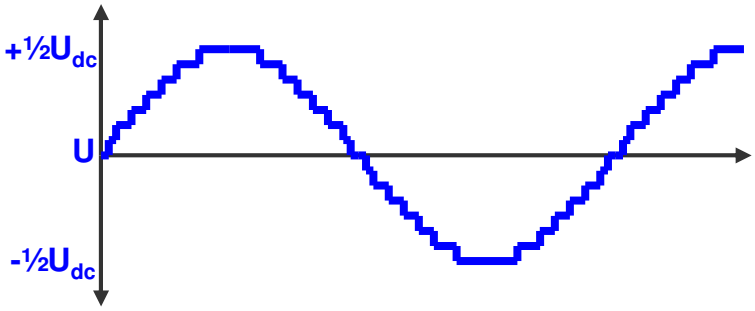


Multi-level circuit

- ✓ Low switching losses
- ✓ Easily "scaleable"
- ✓ Virtually no harmonics
- ✘ More complex controls



= "Chain-Link" Module



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Valve Design

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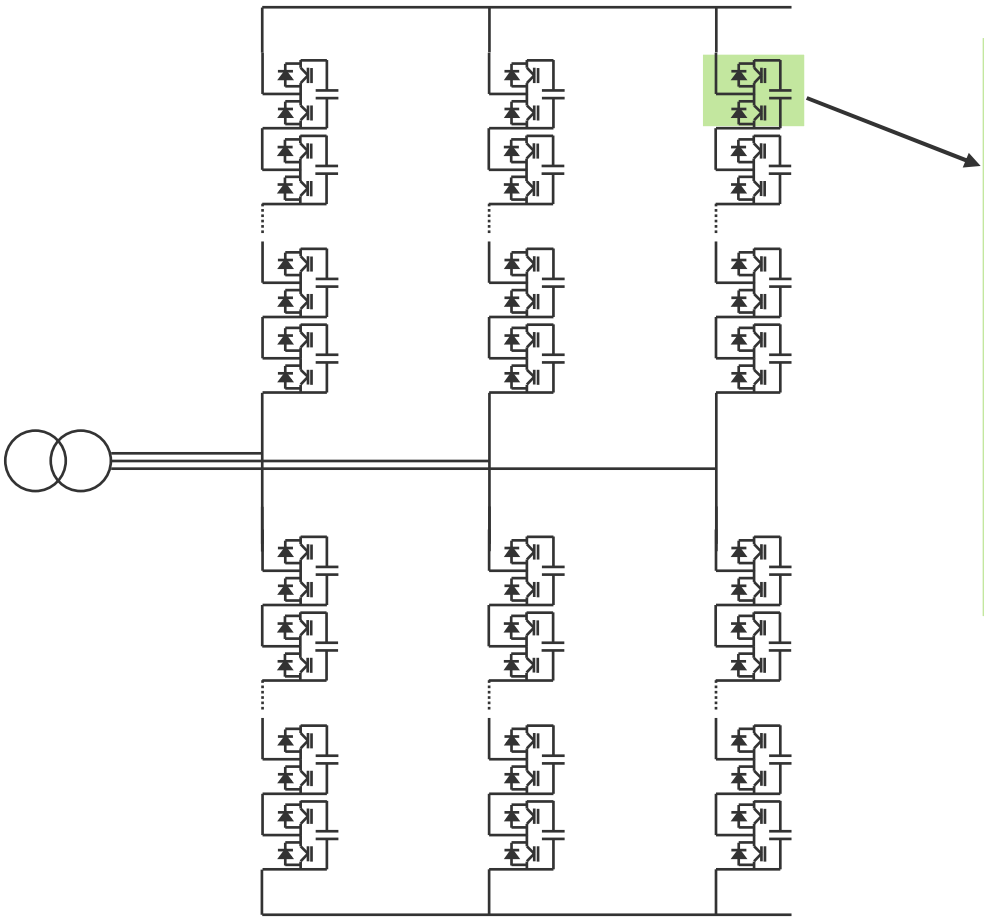
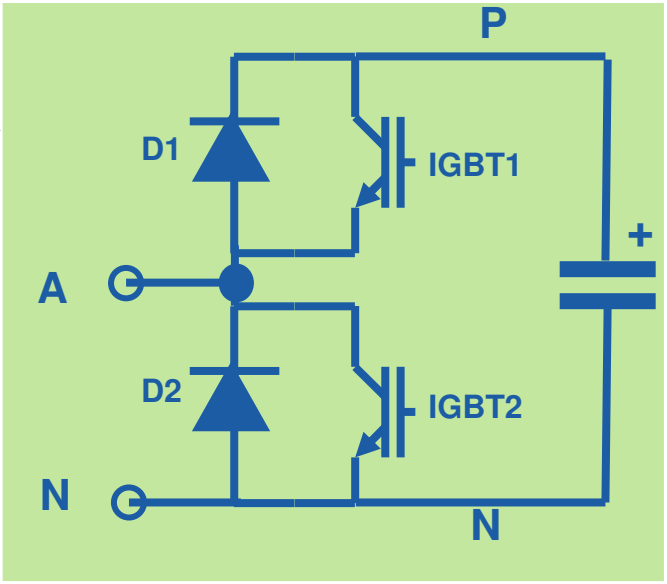
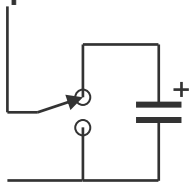
VSC with series-connected half-chain links

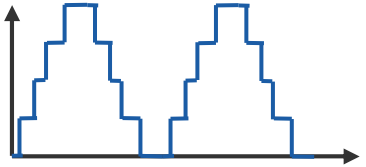




Equivalent to:



Valve Output Voltage



Cannot electronically suppress faults on the DC side. Need to open the AC circuit breaker instead.

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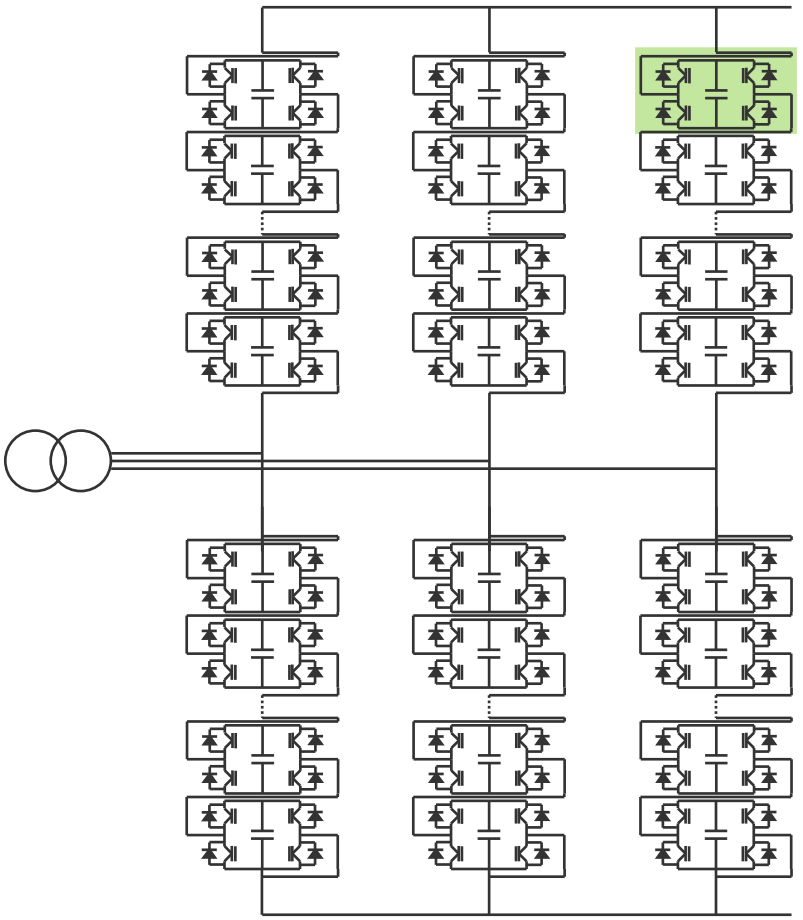
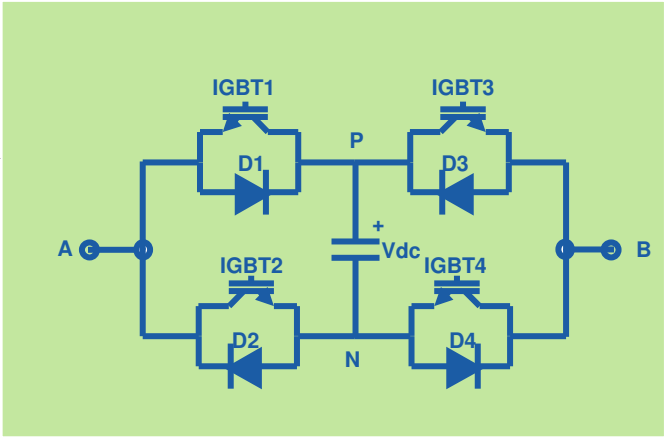
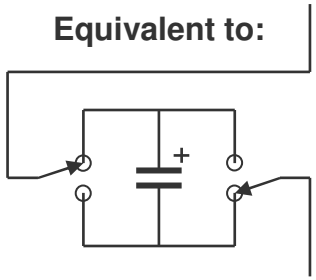
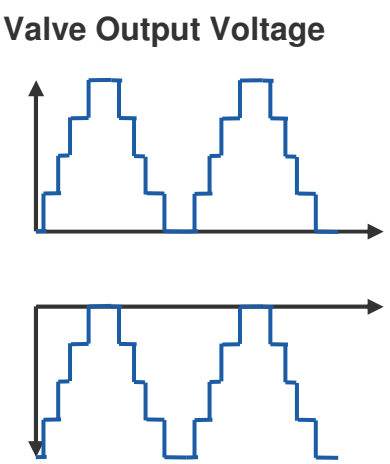
VSC with series-connected full-chain links









Can suppress faults on the DC side by blocking the chain links
(or putting them "in reverse")

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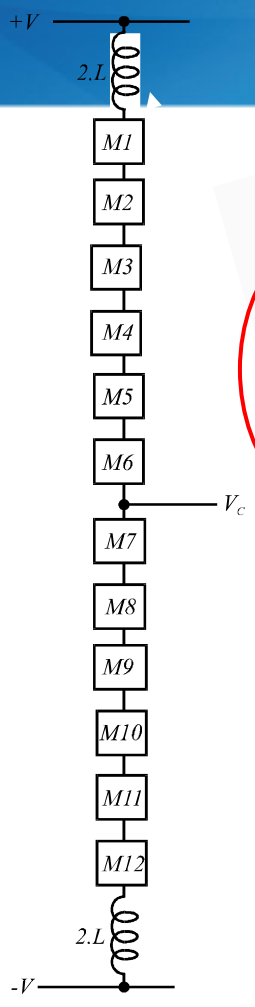
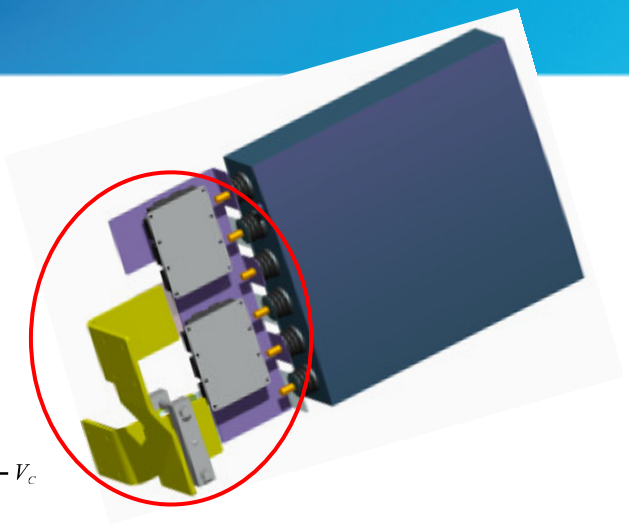
Circuit Topology



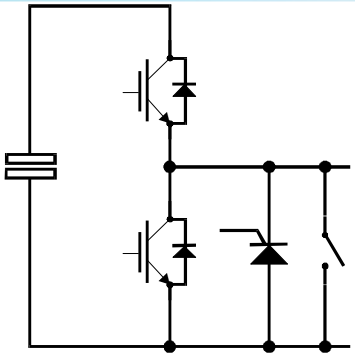
Seven Level

Overall Topology



Power Module

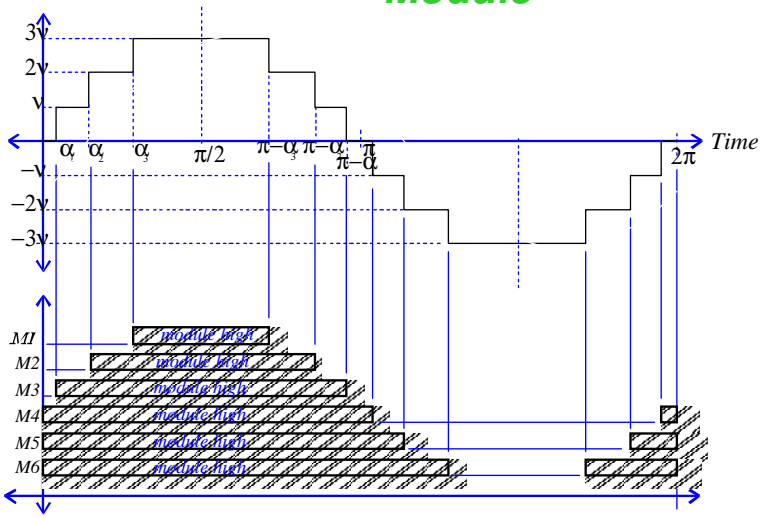
Capacitor



Module

Line reactance (L) split

Becomes a means of protection



Stepped Waveform

- The number of modules = the number of devices in a conventional circuit
  - Requires twice the number of devices

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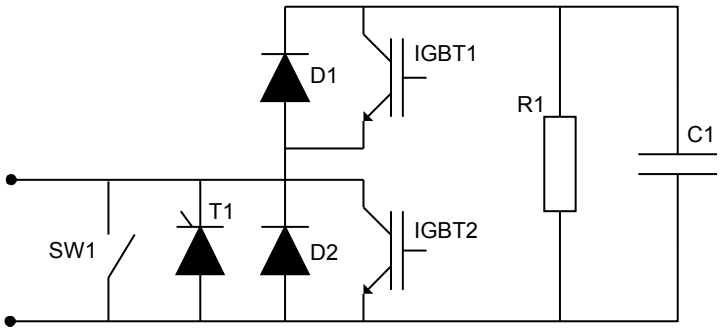
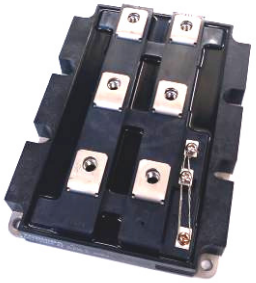
VSC Valves - Sub-module Components

VSC Sub-Module



Inter Sub-module Connector



IGBT

Bypass Switch

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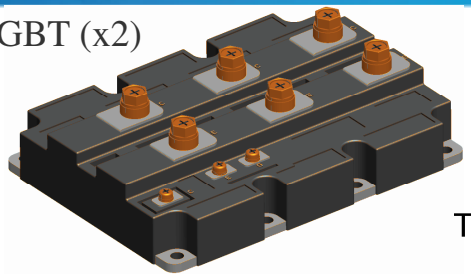
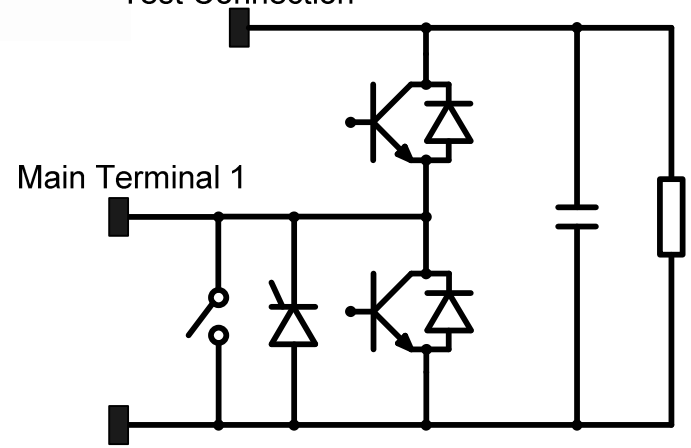
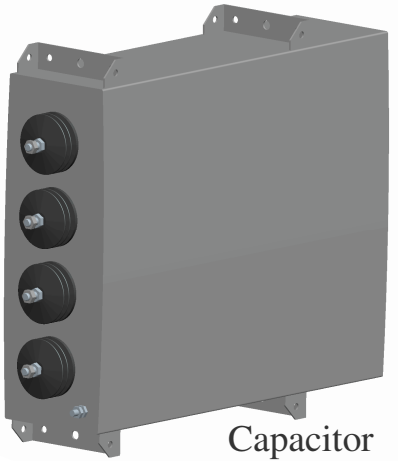
Main Components in 'Half Bridge'

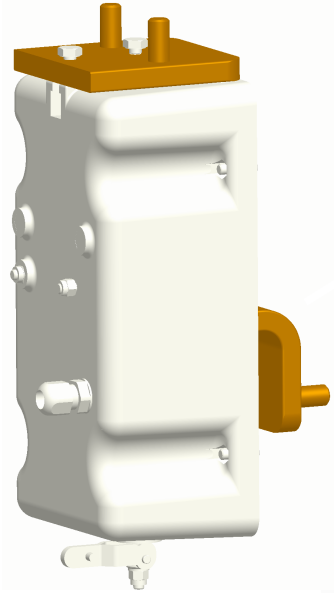
IGBT (x2)



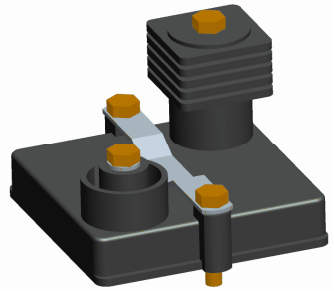




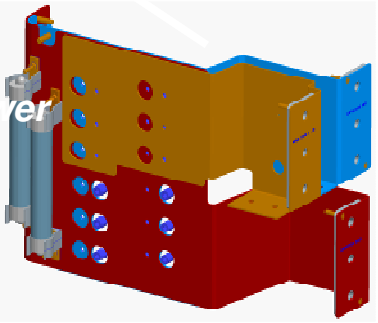
Capacitor



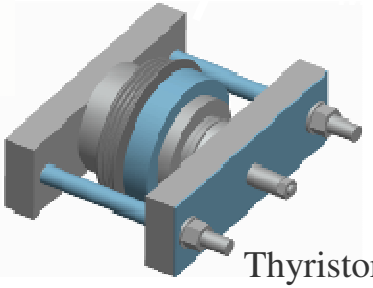
By-pass Switch



Bleed Resistor (x2)



Laminated Bus-Bar



Thyristor and Clamp

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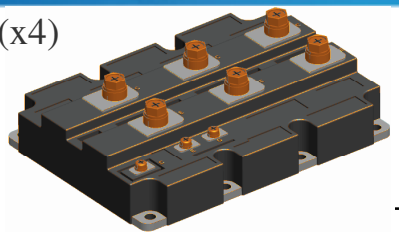
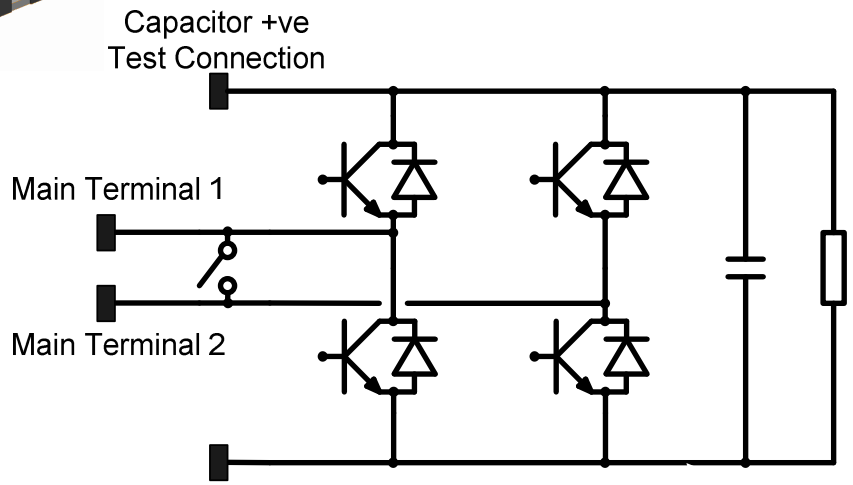
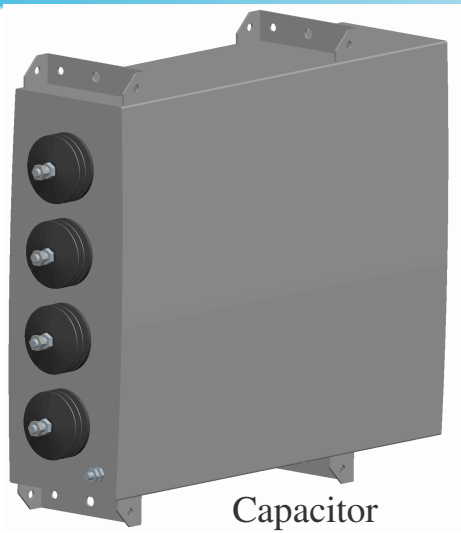
Main Components in 'Full Bridge'

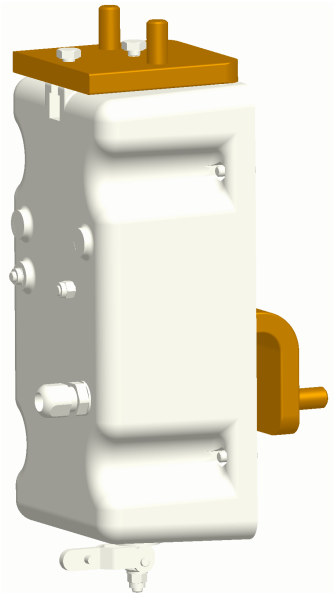
IGBT (x4)



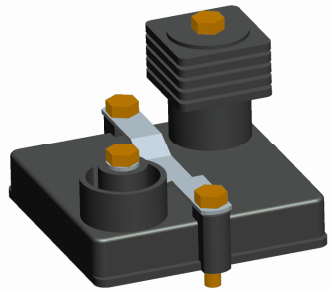




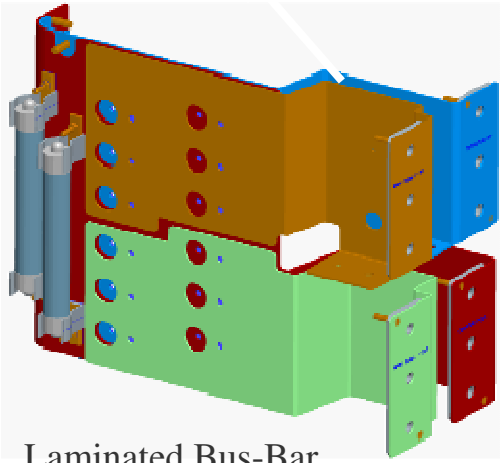
Capacitor



By-pass Switch



Bleed Resistor (x2)



Laminated Bus-Bar

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