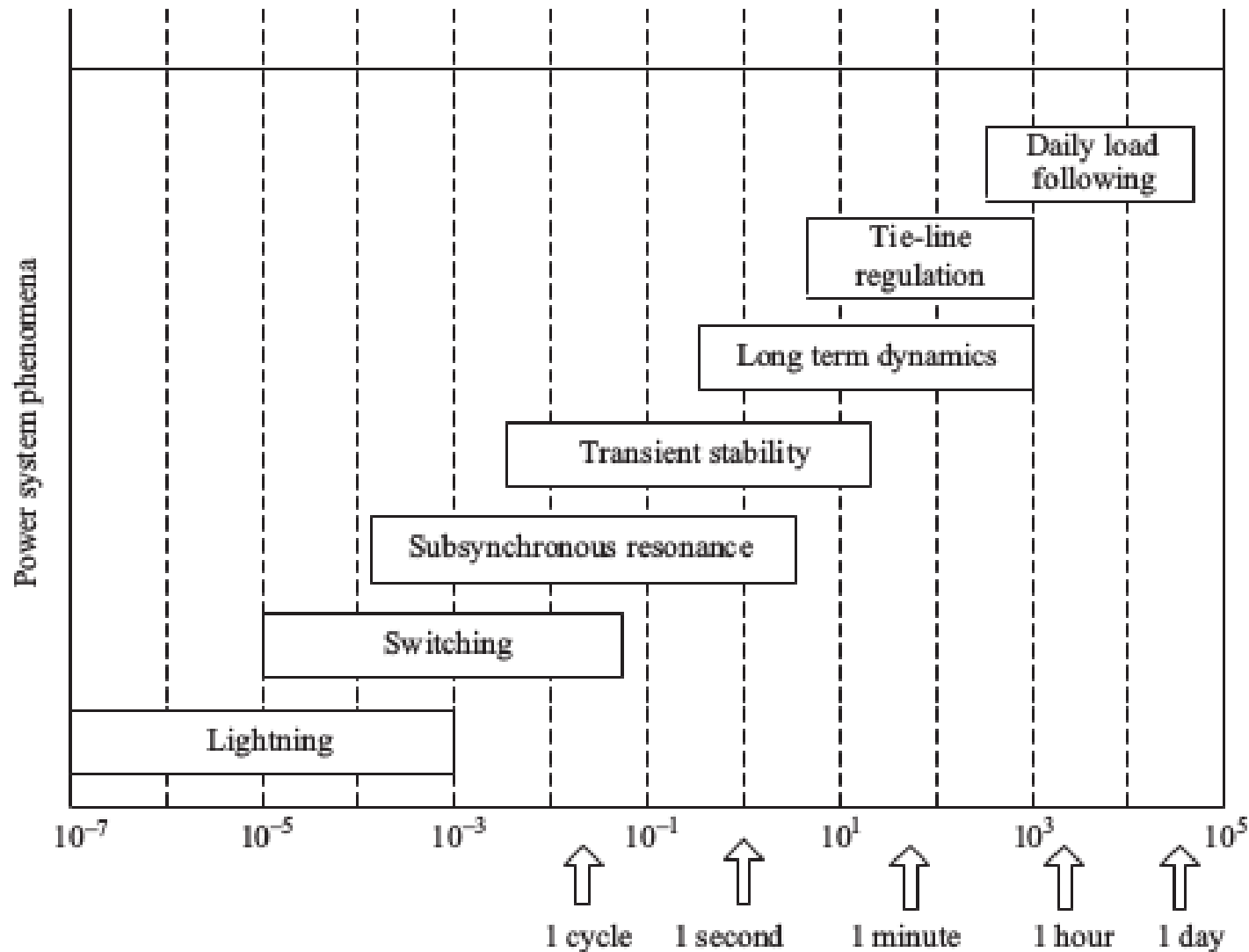


Introdução aos métodos de simulação numérica

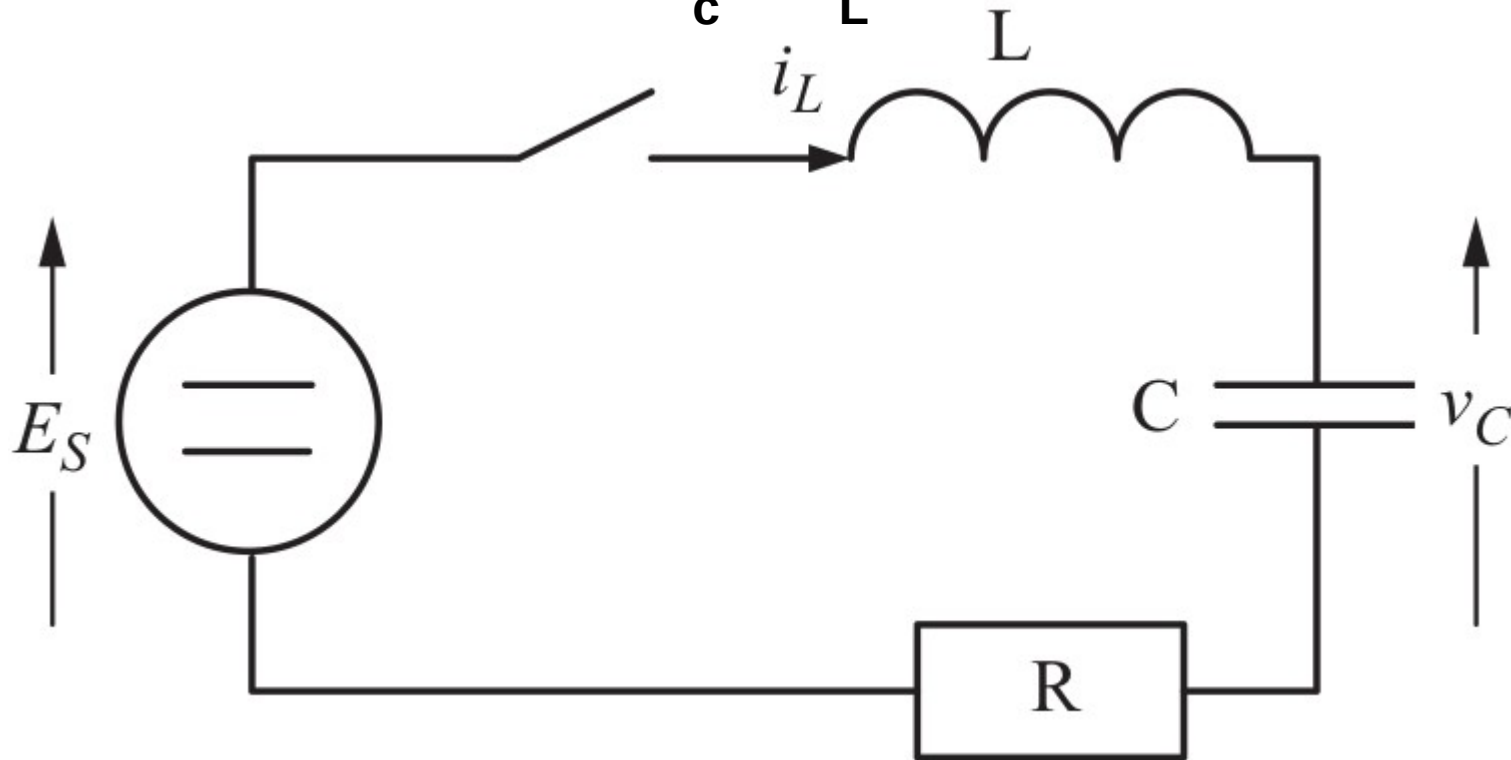
Prof. Dr. Eduardo Coelho Marques da Costa
Prof. Dr. Renato Machado Monaro

Introdução aos métodos de simulação numérica



Fonte: [1]

Como encontrar V_c e i_L ?



$R=20\ \Omega$ $L=6,95\text{mH}$ $C=1\ \mu\text{F}$ $E_S=1\ \text{V}$

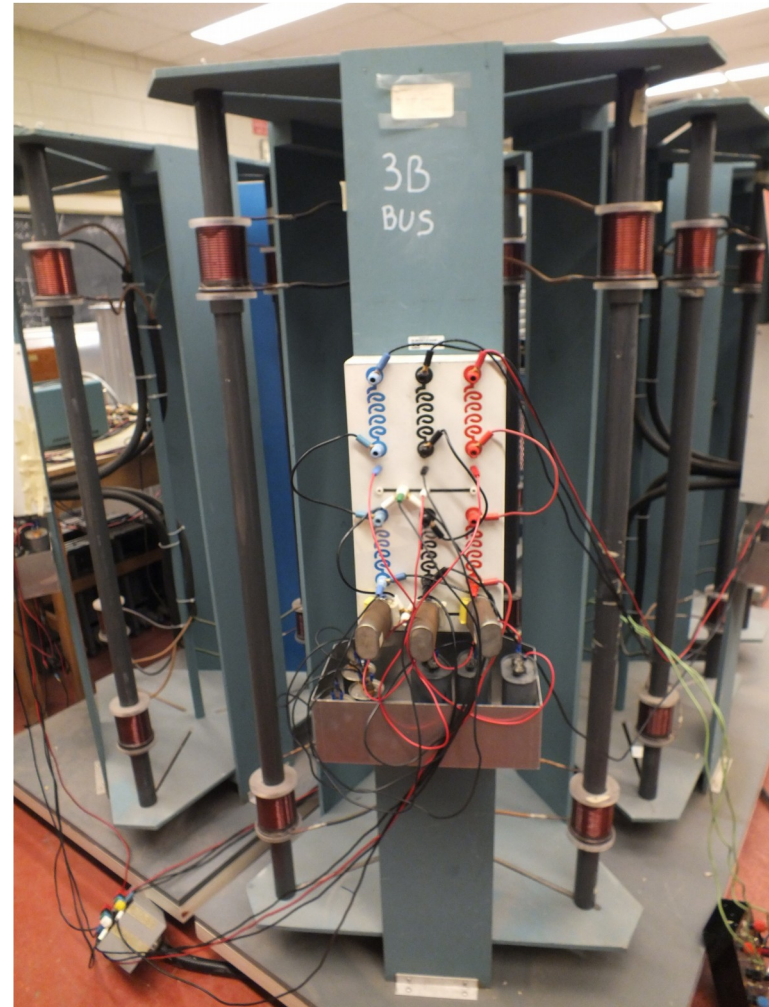
Chave fecha em $0,1\ \text{ms}$

Fonte: [1]

Solução Analítica



Ensaio Práticos



Simuladores Analógicos



TNA- Transient network analyser

Fonte:[2]

Simuladores Analógicos



TNA- Transient network analyser

Fonte:[2]

Simuladores Digitais

Program	Organisation	Website address
EPRI/DCG EMTP ATP program	EPRI	www.emtp96.com/ www.emtp.org/
MicroTran	Microtran Power Systems Analysis Corporation	www.microtran.com/
PSCAD/EMTDC	Manitoba HVDC Research Centre	www.hvdc.ca/
NETOMAC	Siemens	www.ev.siemens.de/en/pages/
NPLAN	BCP Busarello + Cott + Partner Inc.	
EMTAP	EDSA	www.edsa.com/
PowerFactory	DIgSILENT	www.digsilent.de/
Arene	Anhelco	www.anhelco.com/
Hypersim	IREQ (Real-time simulator)	www.ireq.ca/
RTDS	RTDS Technologies	rtds.ca
Transient Performance Advisor (TPA)	MPR (MATLAB based)	www.mpr.com
Power System Toolbox	Cherry Tree (MATLAB based)	www.eagle.ca/cherry/

Fonte: [1]

Simuladores Digitais

Program	Organisation	Website address
ATOSEC5	University of Quebec at Trio Rivieres	cpee.uqtr.quebec.ca/dctodc/ato5_1htm
Xtrans	Delft University of Technology	eps.et.tudelft.nl
KREAN	The Norwegian University of Science and Technology	www.elkraft.ntnu.no/sie10aj/Krean1990.pdf
Power Systems	MATHworks (MATLAB based)	www.mathworks.com/products/
Blockset	TransEnergie Technologies	www.transenergie-tech.com/en/
SABER	Avant (formerly Analogy Inc.)	www.analogy.com/
SIMSEN	Swiss Federal Institute of Technology	simsen.epfl.ch/

Fonte: [1]

Simuladores Digitais

OEMTP-Open ElectroMagnetic Transient Program

Monaro e Di Santo

Open ElectroMagnetic Transient Program

7 commits

1 branch

Branch: master

New pull request

renato-monaro Initial condition added.

doc	Initial Upload
src	Initial condition added.
AUTHORS	Initial Upload
COPYING	Initial Upload
ChangeLog	Initial Upload



Fonte: [3]

Simulação por Espaço de Estados

Equação de Estado

$$\begin{aligned}\dot{x}_1(t) &= a_{11}x_1(t) + a_{12}x_2(t) + \cdots + a_{1n}x_n(t) + b_{11}u_1(t) + b_{12}u_2(t) + \cdots + b_{1m}u_m(t) \\ \dot{x}_2(t) &= a_{21}x_1(t) + a_{22}x_2(t) + \cdots + a_{2n}x_n(t) + b_{21}u_1(t) + b_{22}u_2(t) + \cdots + b_{2m}u_m(t) \\ &\vdots \\ \dot{x}_n(t) &= a_{n1}x_1(t) + a_{n2}x_2(t) + \cdots + a_{nn}x_n(t) + b_{n1}u_1(t) + b_{n2}u_2(t) + \cdots + b_{nm}u_m(t)\end{aligned}$$

$$\begin{pmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \vdots \\ \dot{x}_n \end{pmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} + \begin{bmatrix} b_{11} & b_{12} & \cdots & b_{1m} \\ b_{21} & b_{22} & \cdots & b_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ b_{n1} & b_{n2} & \cdots & b_{nm} \end{bmatrix} \begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_m \end{pmatrix}$$

$$\dot{\mathbf{x}} = [A]\mathbf{x} + [B]\mathbf{u}$$

Simulação por Espaço de Estados

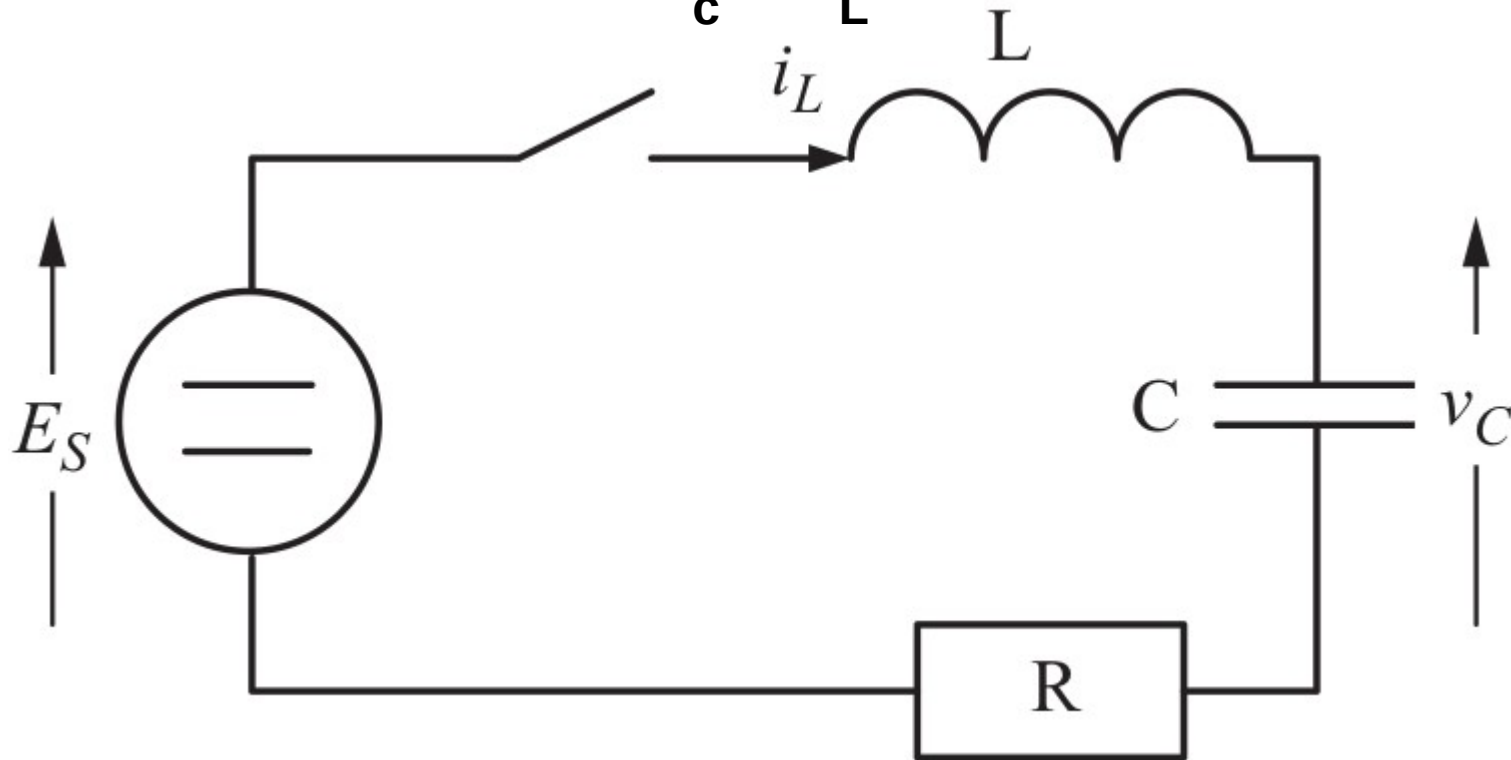
Equação de Saída

$$\begin{aligned}
 y_1(t) &= c_{11}x_1(t) + c_{12}x_2(t) + \cdots + c_{1n}x_n(t) + d_{11}u_1(t) + d_{12}u_2(t) + \cdots + d_{1m}u_m(t) \\
 y_2(t) &= c_{21}x_1(t) + c_{22}x_2(t) + \cdots + c_{2n}x_n(t) + d_{21}u_1(t) + d_{22}u_2(t) + \cdots + d_{2m}u_m(t) \\
 &\vdots \\
 y_0(t) &= c_{01}x_1(t) + c_{02}x_2(t) + \cdots + c_{0n}x_n(t) + d_{01}u_1(t) + d_{02}u_2(t) + \cdots + d_{0m}u_m(t)
 \end{aligned}$$

$$\begin{pmatrix} y_1 \\ y_2 \\ \vdots \\ y_0 \end{pmatrix} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1n} \\ c_{21} & c_{22} & \cdots & c_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ c_{01} & c_{02} & \cdots & c_{0n} \end{bmatrix} \begin{pmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{pmatrix} + \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1m} \\ d_{21} & d_{22} & \cdots & d_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ d_{01} & d_{02} & \cdots & d_{0m} \end{bmatrix} \begin{pmatrix} u_1 \\ u_2 \\ \vdots \\ u_m \end{pmatrix}$$

$$\mathbf{y} = [\mathbf{C}]\mathbf{x} + [\mathbf{D}]\mathbf{u}$$

Como encontrar V_c e i_L ?



$R=20\ \Omega$ $L=6,95\text{mH}$ $C=1\ \mu\text{F}$ $E_S=1\ \text{V}$

Chave fecha em $0,1\ \text{ms}$

Fonte: [1]

Espaço de Estado

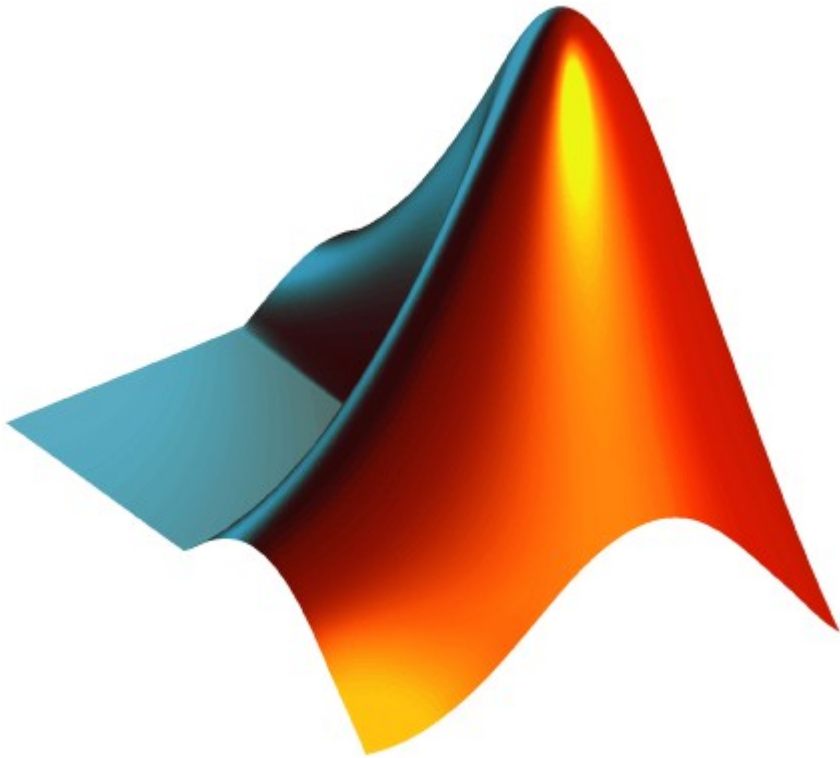


Espaço de Estado

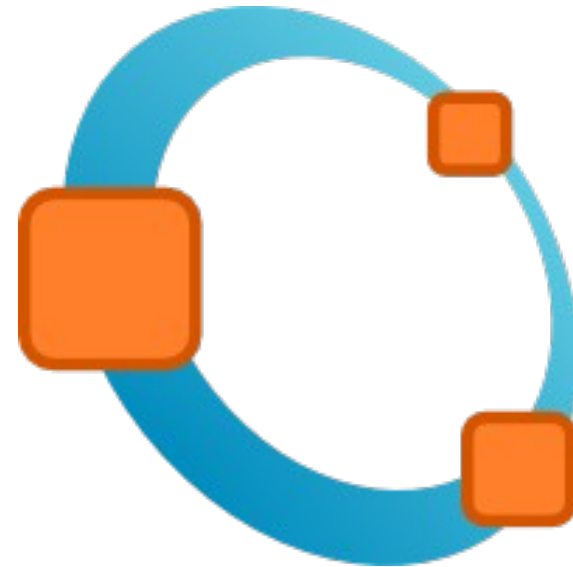


Como Resolver o EE?





Matlab[4]



Octave[5]



The screenshot displays the Octave software interface. The window title is "Octave". The current directory is "/home/raquel/Renato/Owncloud/Impressora_3D/Turbina". The interface is divided into several panels:

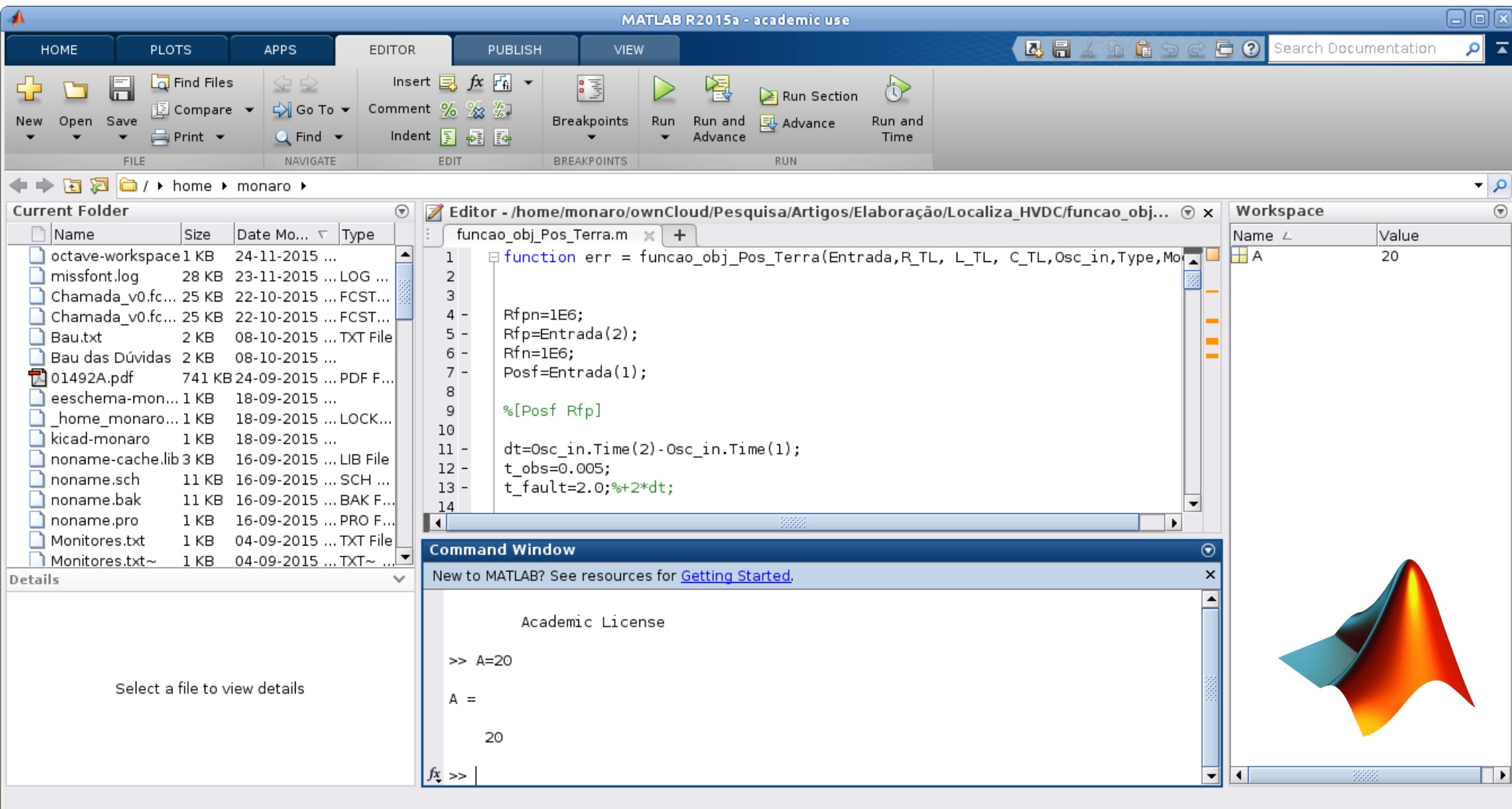
- Gerenciador de Arquivos:** Shows a list of files in the current directory:

Nome
Anel_bot.stl
Anel_top.stl
Anel_TR.stl
bearing.scad
bearing.stl
body.stl
Calculo.ods
- Janela de Comandos:** Shows the command prompt with the prompt ">> |".
- Ambiente de Trabalho:** Shows a table with the following data:

Nome	Classe	Dim
a	double	1x1
- Histórico de Comandos:** Shows a list of commands:

```
projeto blade
projeto blade
projeto blade
projeto blade
exit
# Octave 4.0.0, Sun Sep 18 17:18
exit
# Octave 4.0.0, Sun Sep 18 23:24
```

The bottom of the window shows tabs for "Janela de Comandos", "Editor", and "Documentação". A blue circular logo with orange squares is visible in the bottom right corner of the interface.



The screenshot displays the MATLAB R2015a - academic use interface. The top menu bar includes HOME, PLOTS, APPS, EDITOR, PUBLISH, and VIEW. The toolbar contains icons for file operations (New, Open, Save, Find Files, Compare, Print), navigation (Go To, Find), editing (Insert, Comment, Indent), breakpoints, and execution (Run, Run and Advance, Run Section, Advance, Run and Time). The current folder is /home/monaro. The editor window shows a script named funcao_obj_Pos_Terra.m with the following code:

```
1 function err = funcao_obj_Pos_Terra(Entrada,R_TL, L_TL, C_TL,Osc_in,Type,Mo...
2
3
4 Rfpn=1E6;
5 Rfp=Entrada(2);
6 Rfn=1E6;
7 Posf=Entrada(1);
8
9 %[Posf Rfp]
10
11 dt=Osc_in.Time(2)-Osc_in.Time(1);
12 t_obs=0.005;
13 t_fault=2.0;%+2*dt;
14
```

The Command Window shows the execution of the script:

```
New to MATLAB? See resources for Getting Started.

Academic License

>> A=20

A =

    20

fx >>
```

The Workspace window shows a variable A with a value of 20. A 3D surface plot is visible in the bottom right corner of the interface.

myode.m



```
##differential equation
function myode = f (x, t)
    xdot = zeros (3,1);
    xdot(1) = 77.27 * (x(2) + x(1) );
    xdot(2) = (x(3) - x(1)*x(2) - x(2))
    xdot(3) = 0.161*(x(1) - x(3));
endfunction
```

```
>> x0 = [ 4; 1.1; 4 ];
>> t = linspace (0, 500, 1000);
>> y = ode45 (@f, t,x0);
```

```
>> x0 = [ 4; 1.1; 4 ];
>> t = linspace (0, 500, 1000);
>> y = lsode ("f", x0, t);
```

Verificar Estabilidade

Autovalores de A devem ter parte real negativa

```
>> A=[-1 0; -1 -3];
```

```
>> eig(A)
```

```
ans =
```

```
-3
```

```
-1
```

Referências

[1] WATSON, Neville; ARRILLAGA, Jos. Power systems electromagnetic transients simulation. Iet, 2003.

[2] <http://www.ece.ncsu.edu/power/factstna.html>

[3] Monaro e Di Santo <https://github.com/renato-monaro/OEMTP>

[4] <http://www.mathworks.com/products/matlab/>

[5] <https://www.gnu.org/software/octave/>