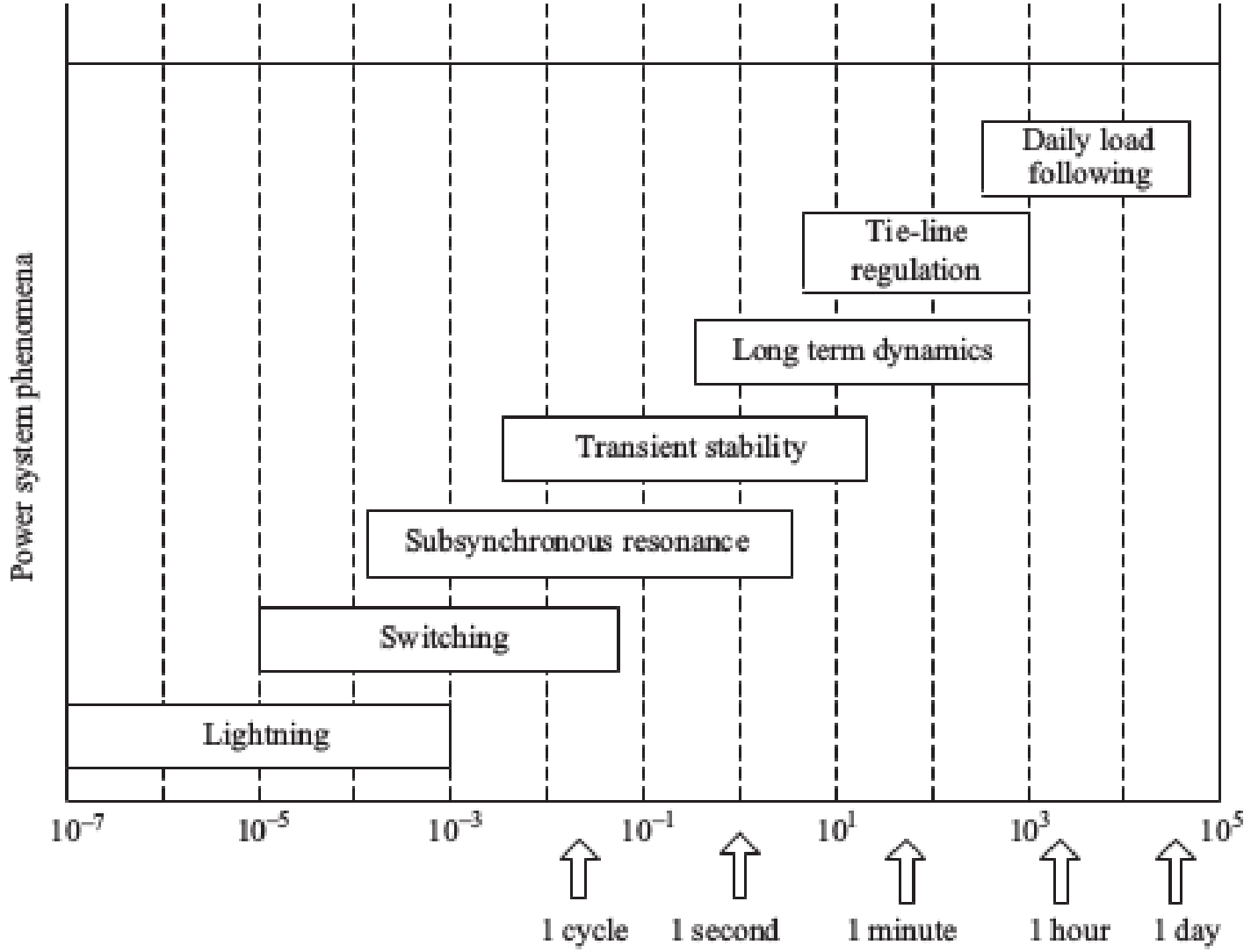
PEA5009 **Aula 2**

Modelagem e simulação numérica de componentes de sistemas elétricos de potência

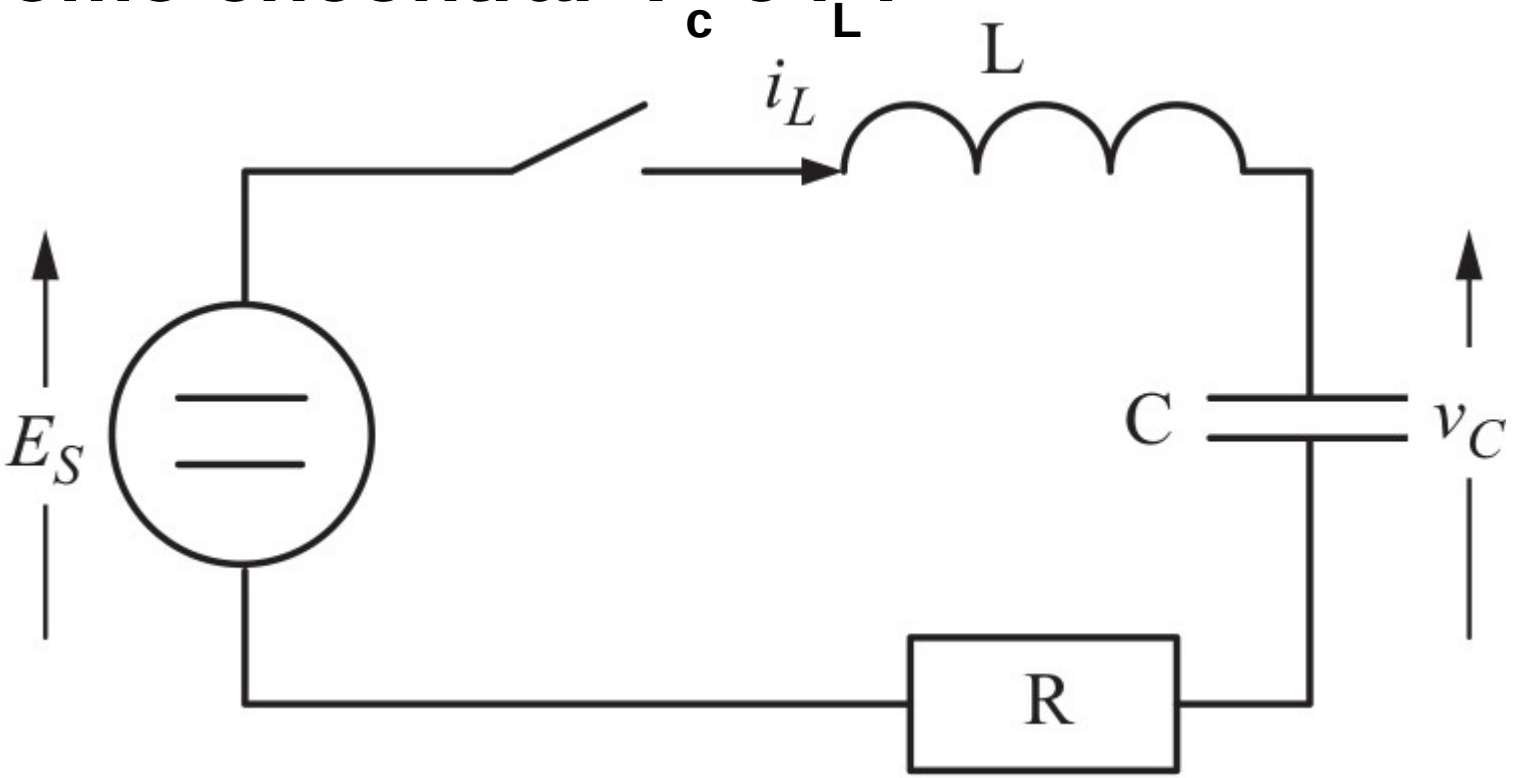
Introdução aos métodos de simulação numérica

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


Power system phenomena
Daily load following
Tie-line regulation
Long term dynamics
Transient stability
Subsynchronous resonance
Switching
Lightning
10^{-7}
10^{-5}
10^{-3}
10^{-1}
10^{1}
10^{3}
10^{5}
1 cycle
1 second
1 minute
1 hour
1 day

Fonte: [1]

Como encontrar V_c e i_L?



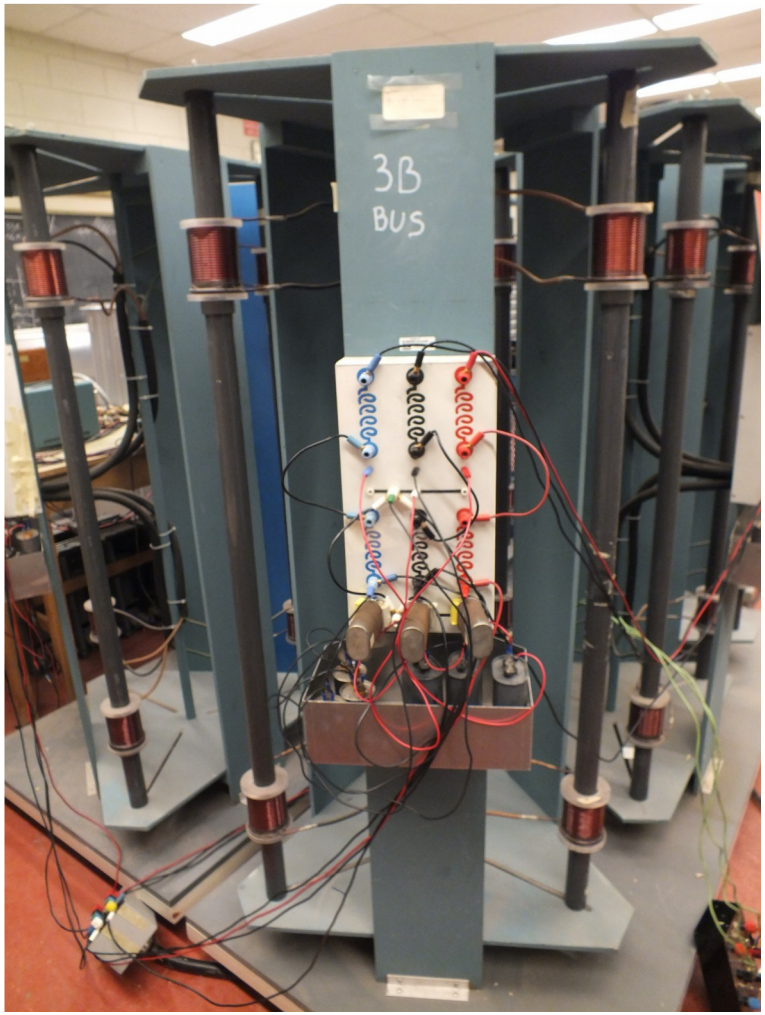
R=20Ω L=6,95mH C=1μF Es=1 V

Chave fecha em 0,1 ms

Fonte: [1]

Solução Analítica

Ensaios 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	EPRI	www.emtp96.com/
ATP program		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 Trios Rivieres	cpee.uqtr.uquebec.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 Blockset	MATHworks (MATLAB based)	www.mathworks.com/products/
	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

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

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

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

Fonte: [1]

Simulação por Espaço de Estados

Equação de Saída

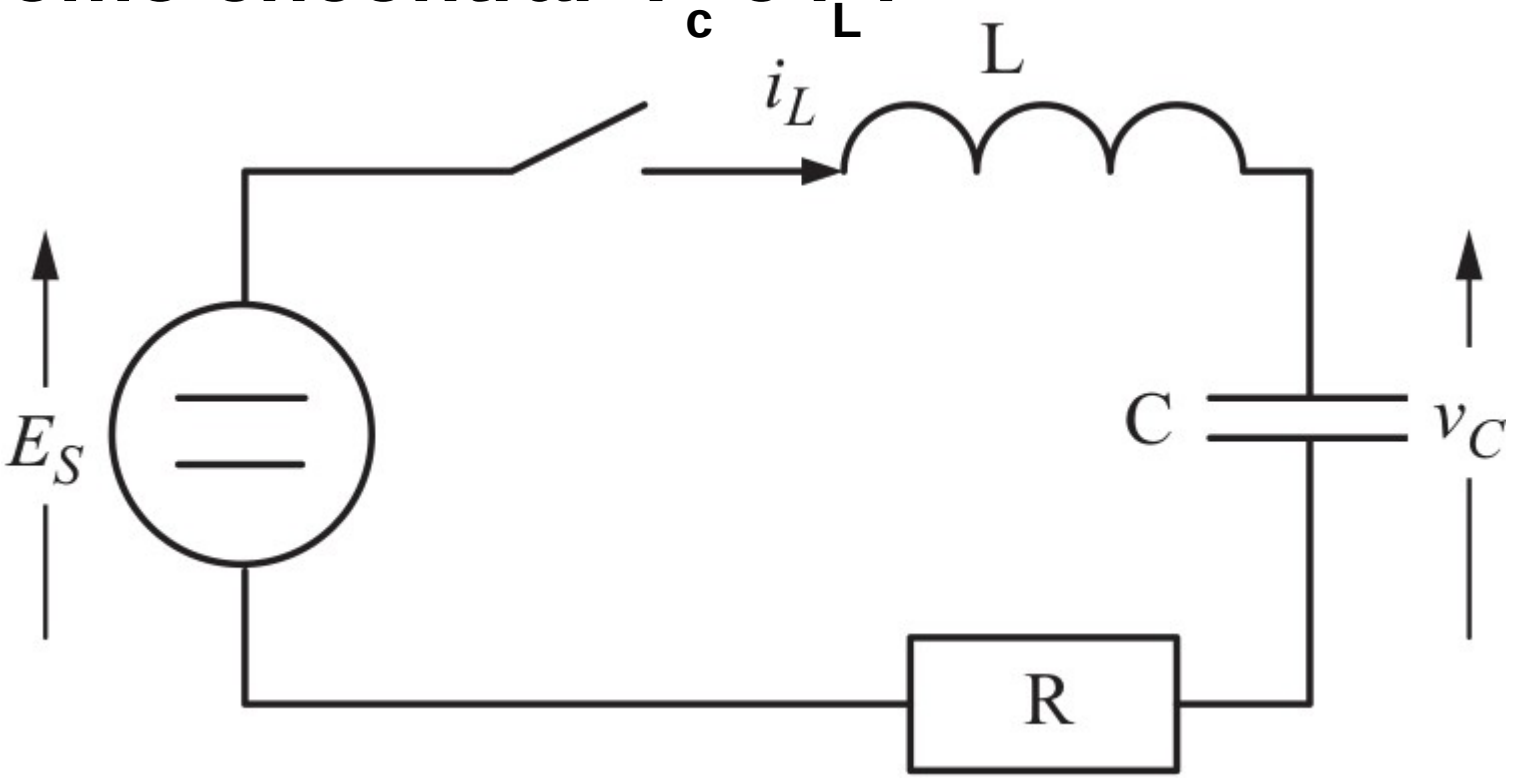
$$y_1(t) = c_{11}x_1(t) + c_{11}x_2(t) + \cdots + c_{1n}x_n(t) + d_{11}u_1(t) + d_{12}u_2(t) + \cdots + d_{1m}u_m(t)$$
$$y_2(t) = c_{21}x_1(t) + c_{22}x_2(t) + \cdots + c_{2n}x_n(t) + d_{21}u_1(t) + d_{22}u_2(t) + \cdots + d_{2m}u_m(t)$$
$$\vdots$$
$$y_0(t) = c_{01}x_1(t) + c_{02}x_2(t) + \cdots + c_{0n}x_n(t)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

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

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

Fonte: [1]

Como encontrar V_c e i_L?



R=20Ω L=6,95mH C=1μF Es=1 V

Chave fecha em 0,1 ms

Fonte: [1]

Espaço de Estado

Espaço de Estado

Como Resolver o EE?

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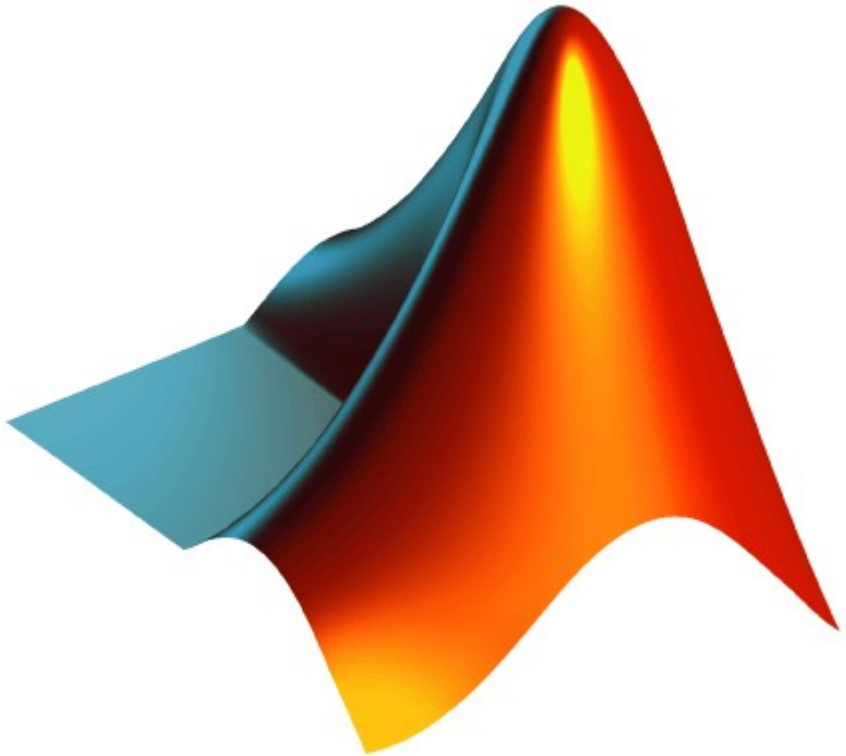
Introdução aos métodos de simulação numérica



Matlab[4]

Octave[5]

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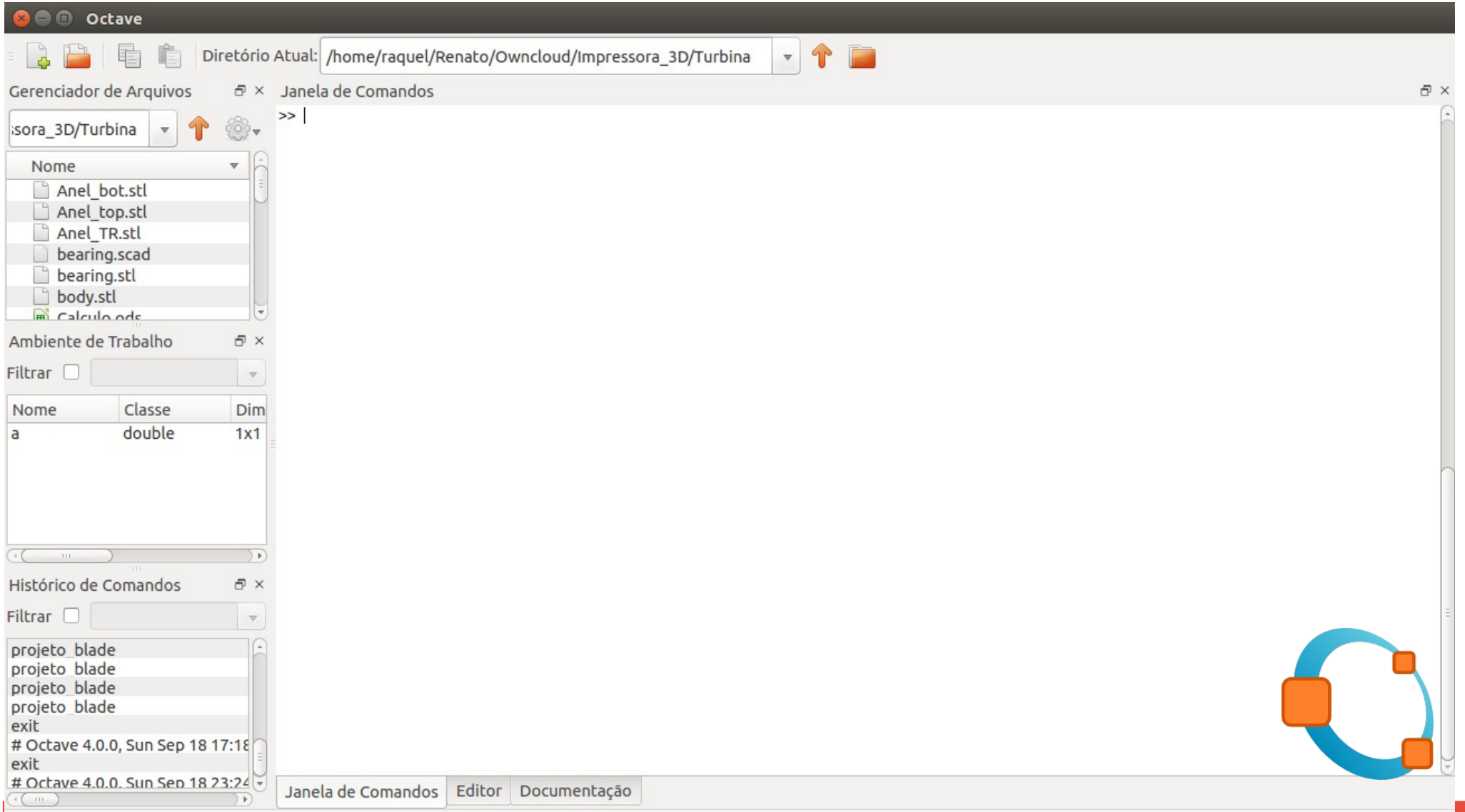
Introdução aos métodos de simulação numérica



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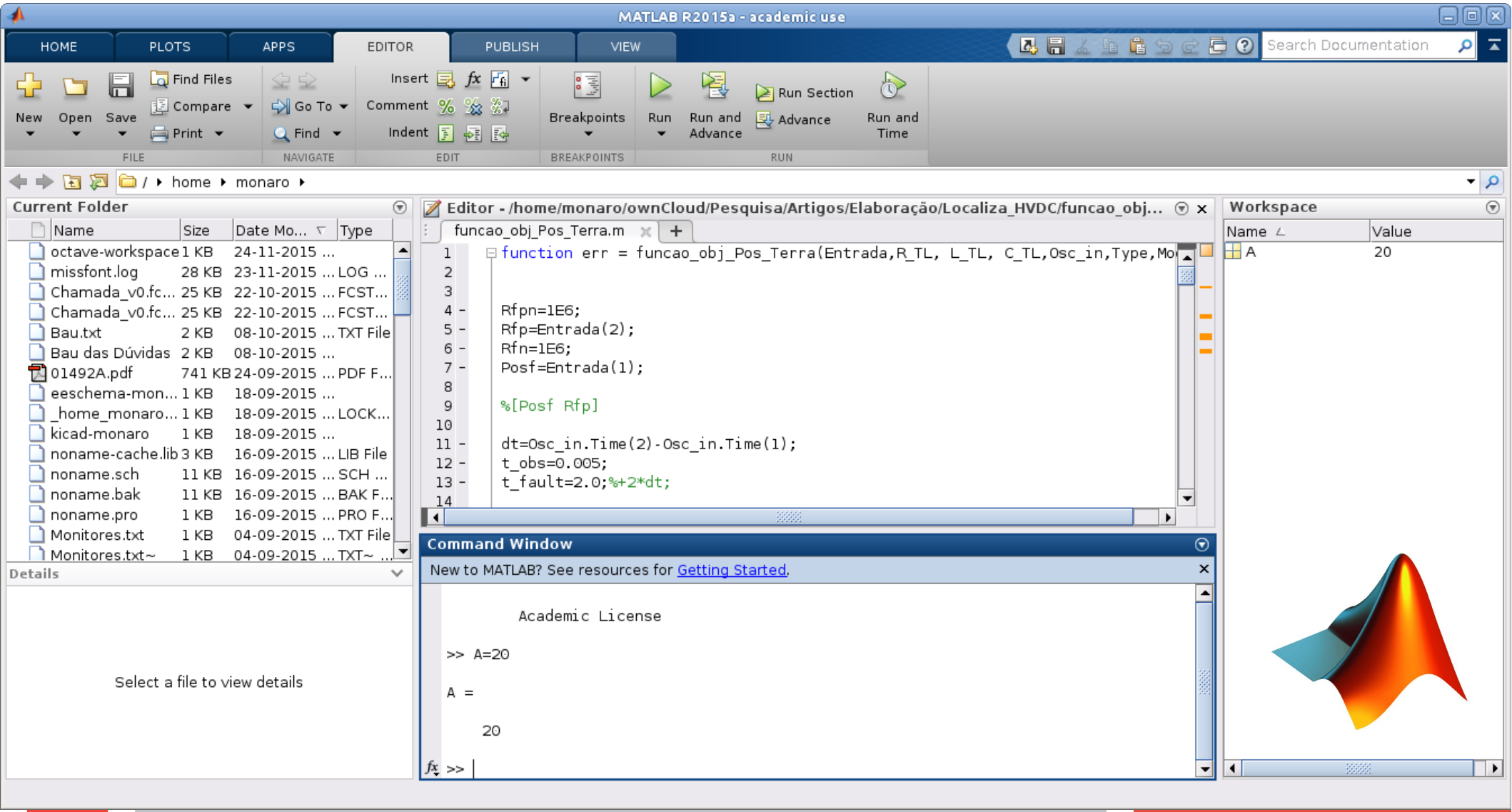

myode.m

```
##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/