AMBIENTE PARA SIMULAÇÃO HÍBRIDA EM MÚLTIPLAS ESCALAS DE TEMPO

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Antonio Carlos S. Lima

TÉCNICAS DE SIMULAÇÃO

Transitórios Eletromagnéticos
(valor instantâneo)

Transitórios Eletromecânicos
(fasor)

Transitórios Eletromagnéticos + Eletromecânicos

SIMULAÇÃO MULTIESCALA

Standard

EMTP
Electromagnetic
Transients Program

Propostas

MTS
Multiple Time-Step

FAST
Frequency Adaptative
Simulation of Transients

1. Método das Características

   Não adequado para $\Delta t > \tau$

2. Admitância Nodal ($\mathbf{Y}_n$)

$$\mathbf{Y}_n = \begin{bmatrix} \mathbf{Y}_s & \mathbf{Y}_m \\ \mathbf{Y}_m & \mathbf{Y}_s \end{bmatrix}$$

Vector Fitting

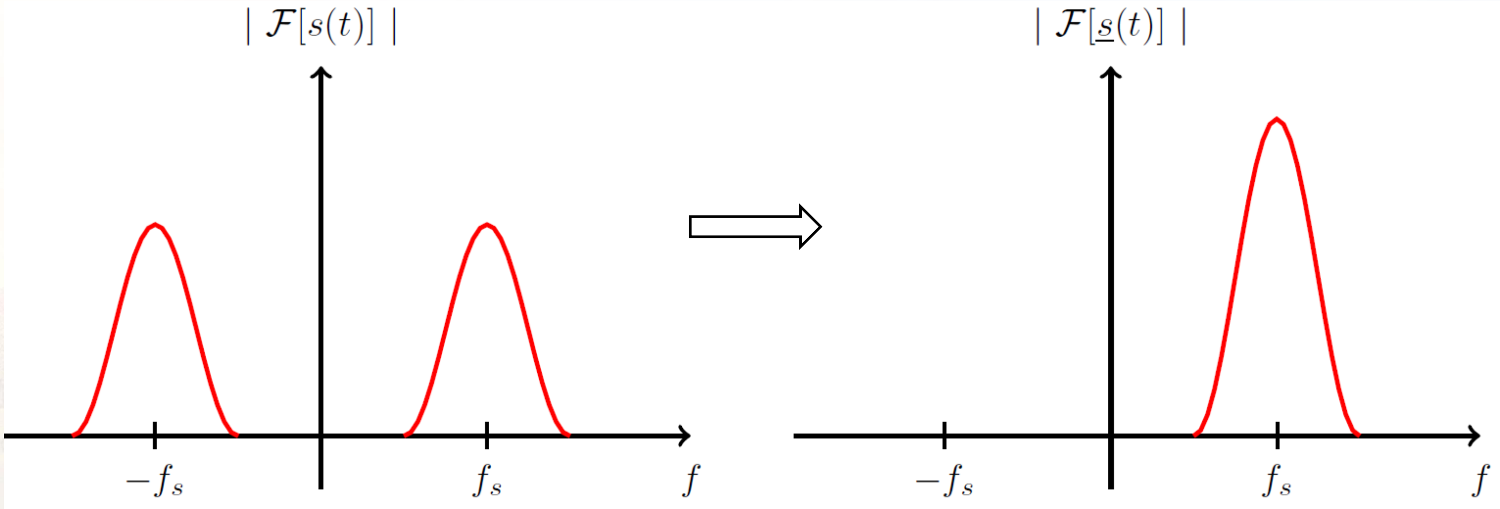
$$\mathbf{Y}_n = \sum_{i=1}^{n} \frac{\mathbf{R}_i}{s - p_i} + \mathbf{D}$$

$$\begin{cases} \mathbf{Y}_s = \mathbf{Y}_c\,(\mathbf{I} + \mathbf{H}^2)(\mathbf{I} - \mathbf{H}^2)^{-1} \\ \mathbf{Y}_m = -2\,\mathbf{Y}_c\,\mathbf{H}\,(\mathbf{I} - \mathbf{H}^2)^{-1} \end{cases}$$

SINAL ANALÍTICO

$\mathcal{A}[s(t)] \Rightarrow$ Descreve um sinal real $s(t)$ na forma complexa

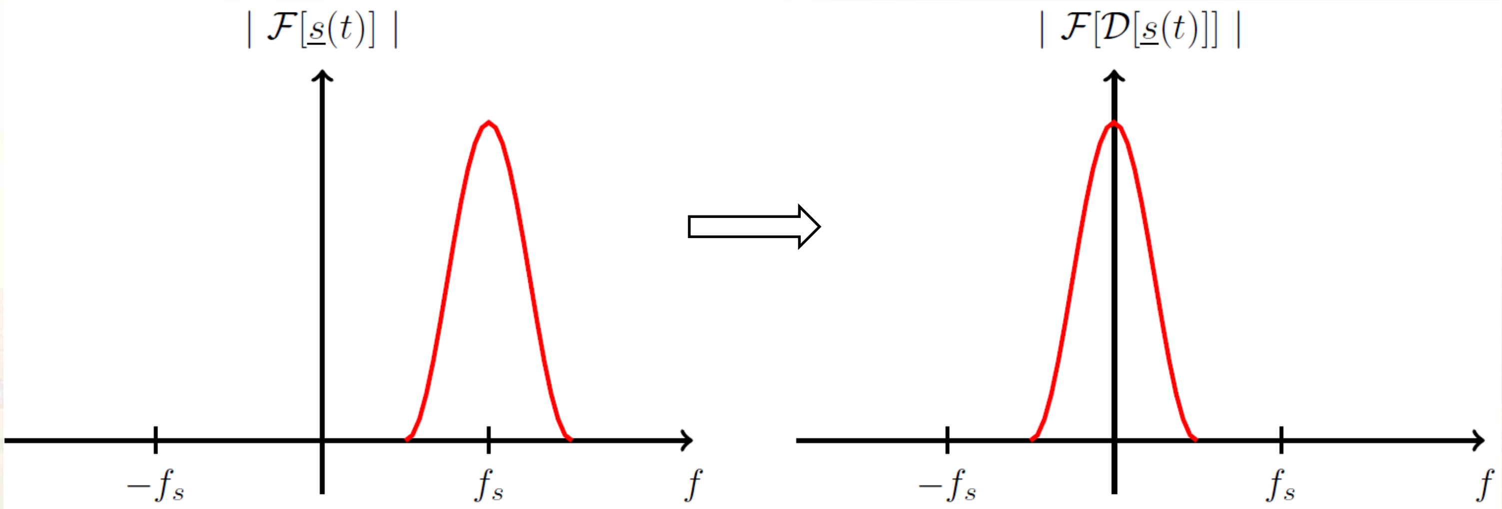
$$\mathcal{A}[s(t)] = \underline{s}(t) = s(t) + j\,\mathcal{H}[s(t)]$$



FASOR DINÂMICO

$\mathcal{D}[s(t)]$ ⇒ Fasor variante no tempo

$$\mathcal{D}[s(t)] = \mathcal{A}[s(t)].e^{-j\omega_s t} = \underline{s}(t).e^{-j\omega_s t}$$



EXEMPLO

Seja a equação diferencial que descreve L:

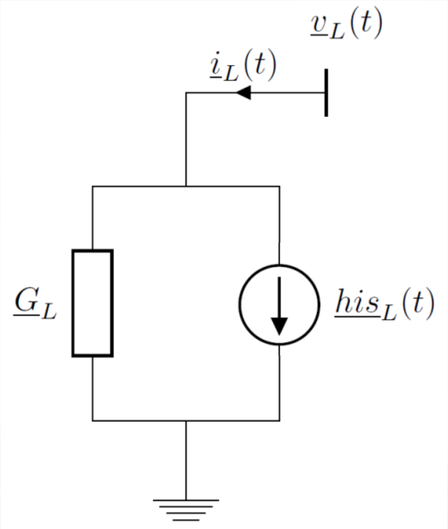
$$\frac{d\underline{i_L}(t)}{dt} = \frac{\underline{v_L}(t)}{L}$$

Inserindo a definição de $\mathcal{D}[\cdot]$:

$$\frac{d(\mathcal{D}[\underline{i_L}(t)].\, e^{j\omega_s t})}{dt} = \frac{\underline{v_L}(t)}{L}$$

Resolvendo para $\underline{i_L}(t)$, chega – se a:

$$\boxed{\underline{i_L}(t) = \underline{G_L}\, \underline{v_L}(t) + \underline{his_L}(t)}$$



Sendo :

$$\underline{G_L} = \left(\frac{1}{1 + j\omega_s \Delta t/2L}\right)\frac{\Delta t}{2L}$$

$$\underline{his_L}(t) = e^{j\omega_s \Delta t}\left[\left(\frac{1 - j\omega_s \Delta t/2L}{1 + j\omega_s \Delta t/2L}\right) i(t-\Delta t) + G\, v(t-\Delta t)\right]$$

MODELO RACIONAL

<u>Pólo−resíduo:</u>

$$I(s) = \left(\frac{r}{s+p} + d\right) V(s)$$

<u>Espaço de estados:</u>

$$\begin{cases} \underline{x}(n) = \underline{\alpha}\, \underline{x}(n-1) + \underline{v}(n-1) \\ \underline{i}(n) = r\,(\underline{\alpha}\, \underline{\lambda} + \underline{\mu})\, \underline{x}(n) + r\, \underline{\lambda}\, \underline{v}(n) \end{cases}$$

<u>Integração trapezoidal:</u>

$$\underline{p} = p - j\omega_s$$

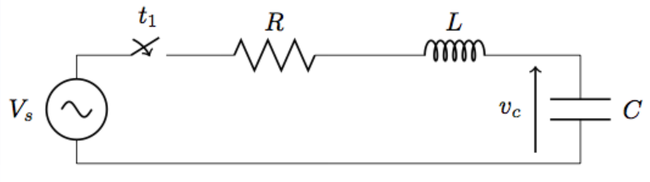
$$\underline{\alpha} = e^{j\omega_s \Delta t}\left(\frac{2 + \underline{p}\,\Delta t}{2 - \underline{p}\,\Delta t}\right) \qquad \underline{\lambda} = \frac{\Delta t}{2 - \underline{p}\,\Delta t} \qquad \underline{\mu} = e^{j\omega_s \Delta t}\left(\frac{\Delta t}{2 - \underline{p}\,\Delta t}\right)$$

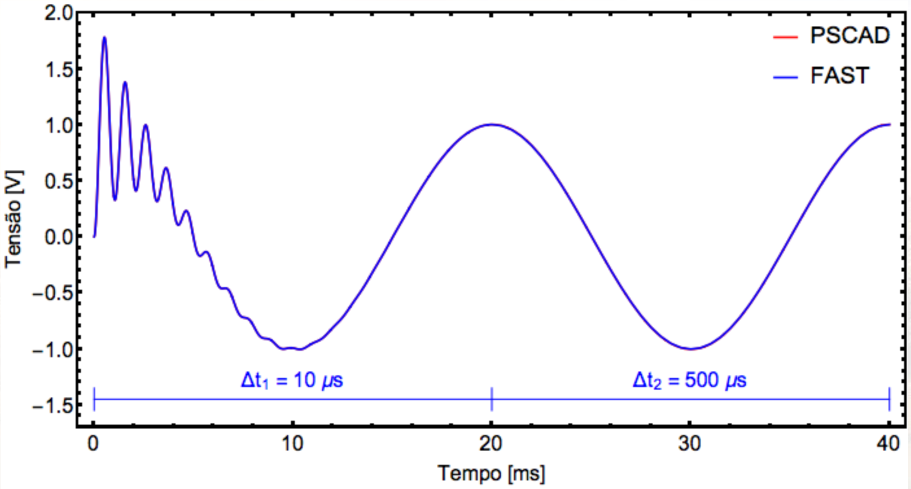
<u>Convolução recursiva:</u>

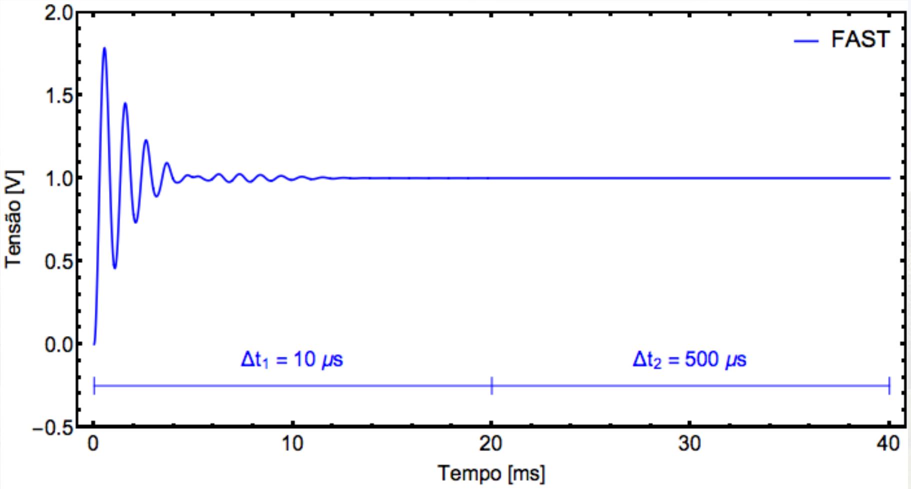
$$\underline{p} = p - j\omega_s$$

$$\underline{\alpha} = e^{\underline{p}\,\Delta t} \qquad \underline{\lambda} = -\frac{1}{\underline{p}}\left(1 + \frac{1 - e^{\underline{p}\,\Delta t}}{\underline{p}\,\Delta t}\right) \qquad \underline{\mu} = -\frac{1}{\underline{p}}\left(\underline{\alpha} - \frac{1 - e^{\underline{p}\,\Delta t}}{\underline{p}\,\Delta t}\right)$$

CASO #1: CIRCUITO RLC







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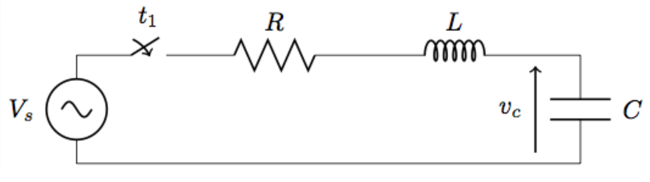
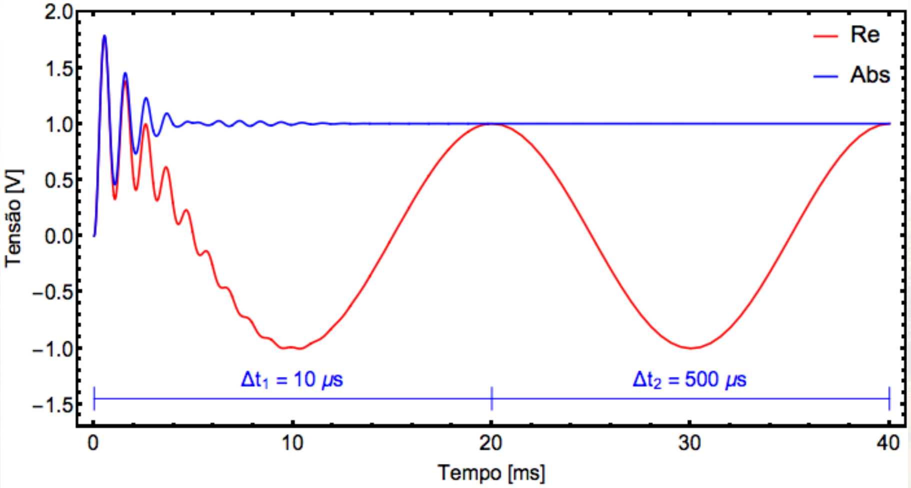
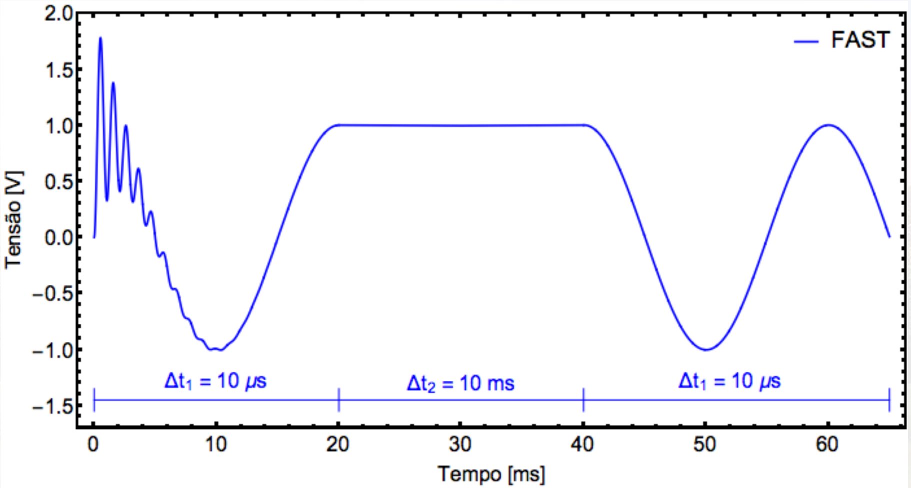
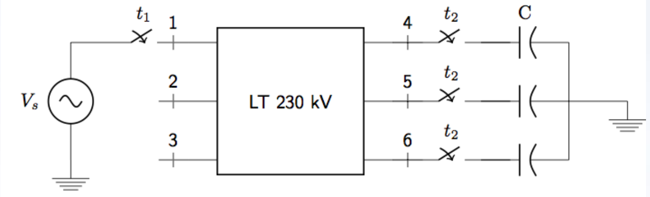
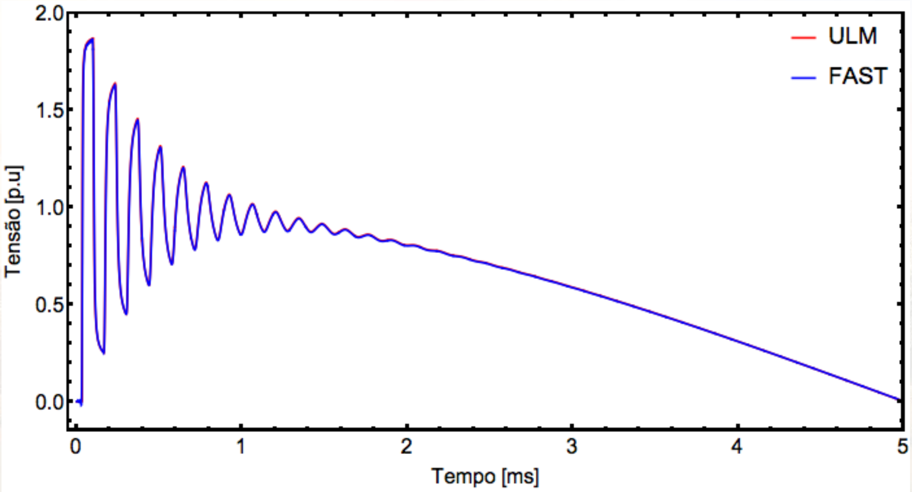


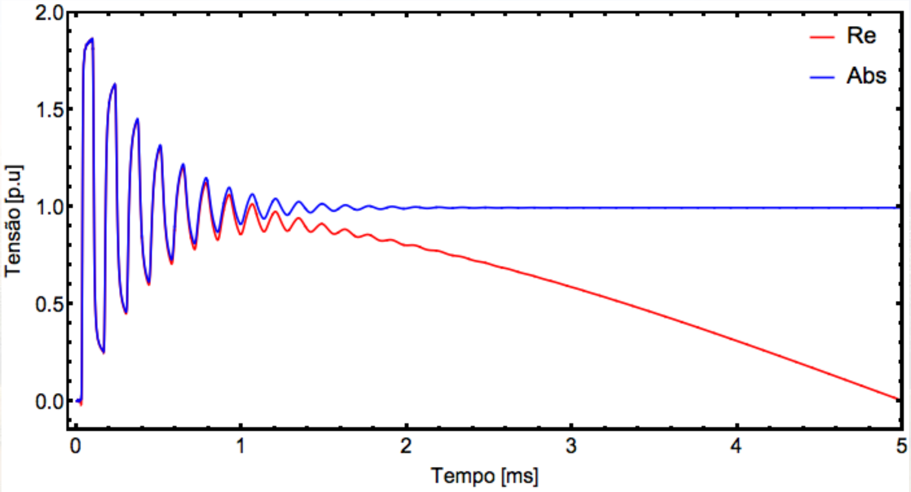




CASO #2: LT 230kV 10km







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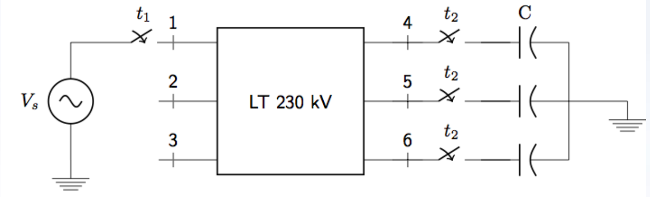

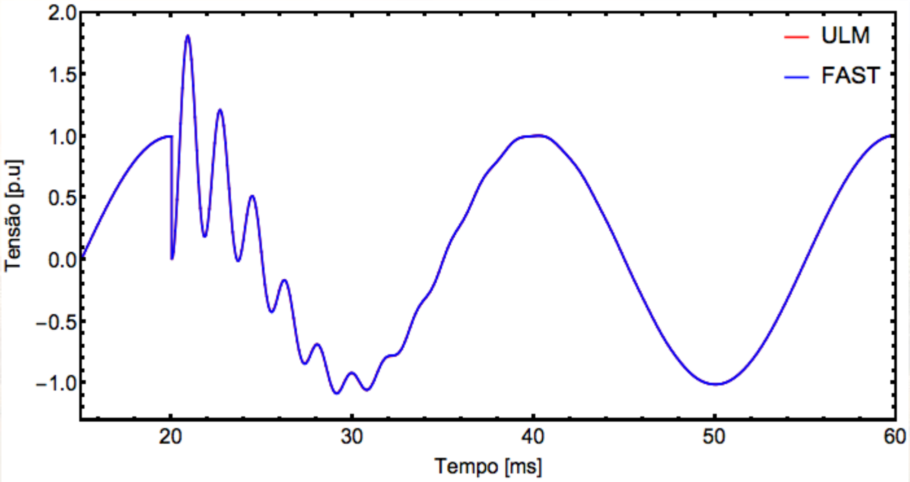

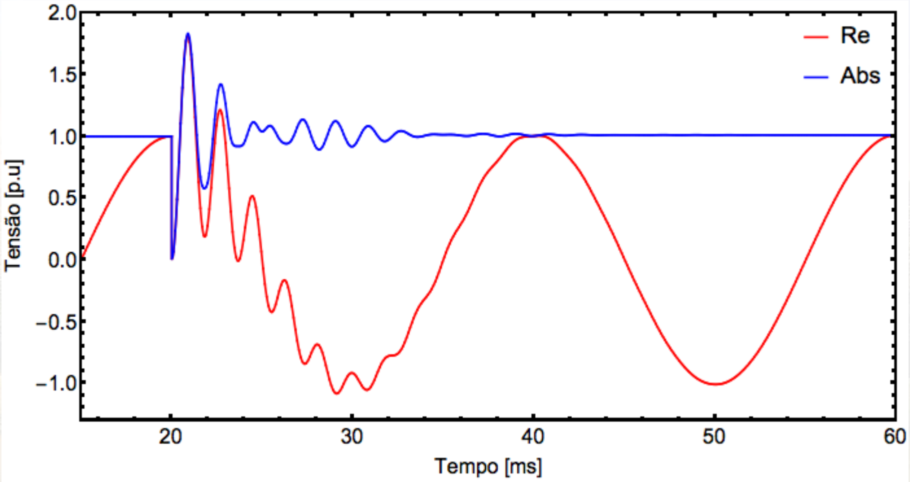

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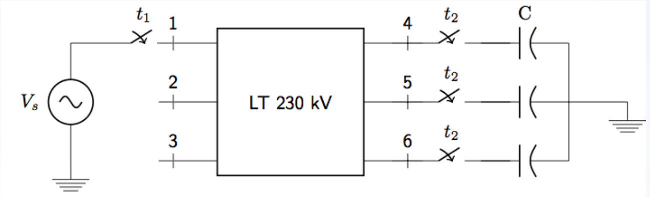

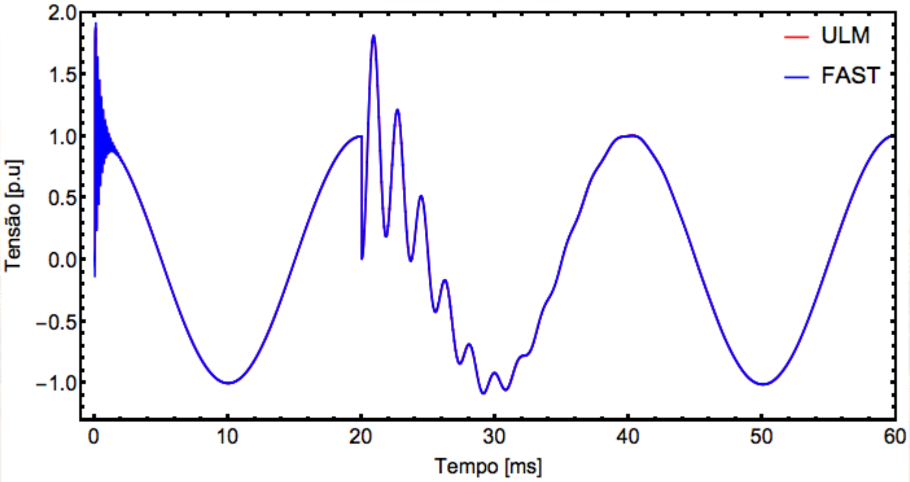

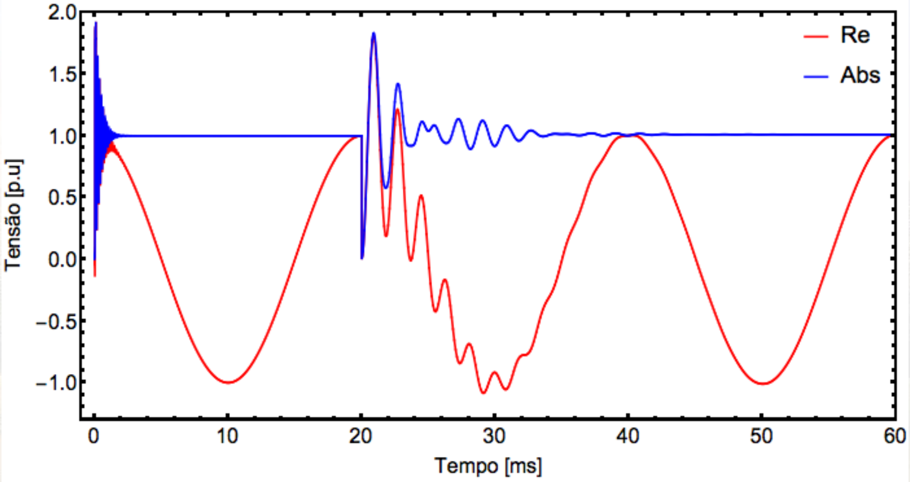

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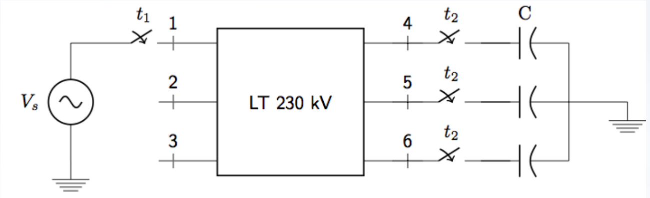

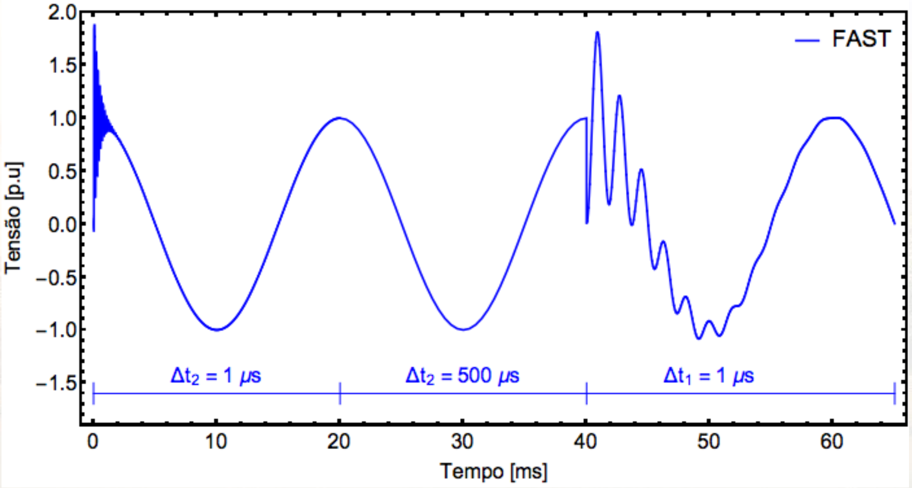

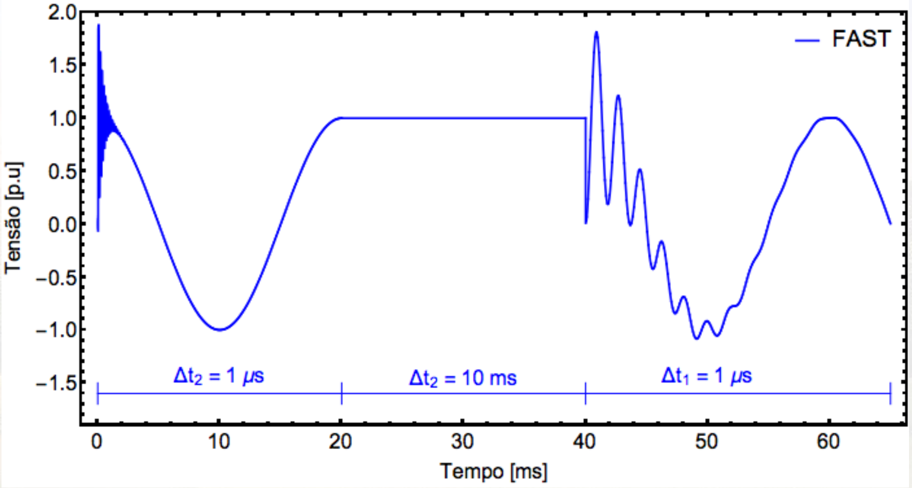

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