Power system dynamic simulation: an iterative multirate approach

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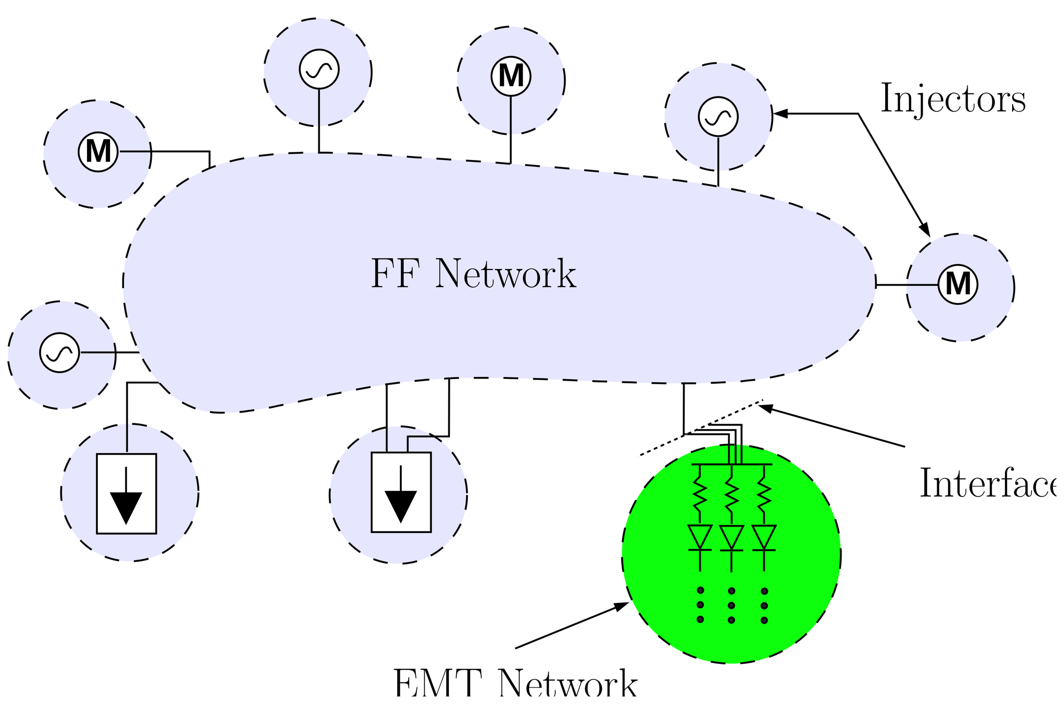
Objective: Combine accuracy of detailed EMT simulation with efficiency of simplified FF simulation.

1. Power System representation



In dynamic simulations, power system components are modeled by sets of *nonlinear stiff hybrid Differential-Algebraic Equations* (DAEs).

The i-th injector can be described by a DAE system of the form:

$$\boldsymbol{\Gamma}_i \dot{\boldsymbol{x}}_i = \boldsymbol{\Phi}_i(\boldsymbol{x}_i, \boldsymbol{V})$$

where $\boldsymbol{x}_i$ the model's internal states, $\bar{V}^{(j)}_{k+1}$

$$(\boldsymbol{\Gamma}_i)_{\ell\ell} = \begin{cases} 0 & \text{if the } \ell\text{-th equation is algebraic} \\ 1 & \text{if the } \ell\text{-th equation is differential} \end{cases}$$

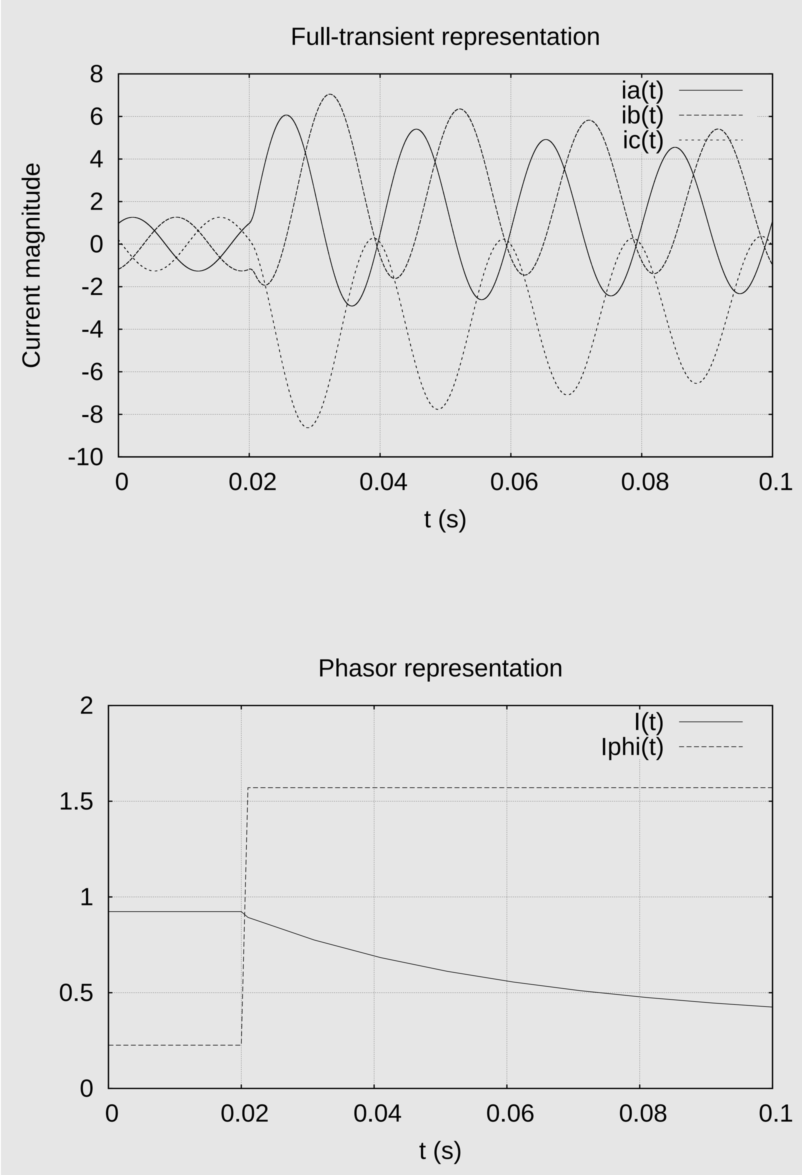
and $\boldsymbol{V}$ the vector of network voltages.

Two modeling families are traditionnally used in power system dynamic simulations:

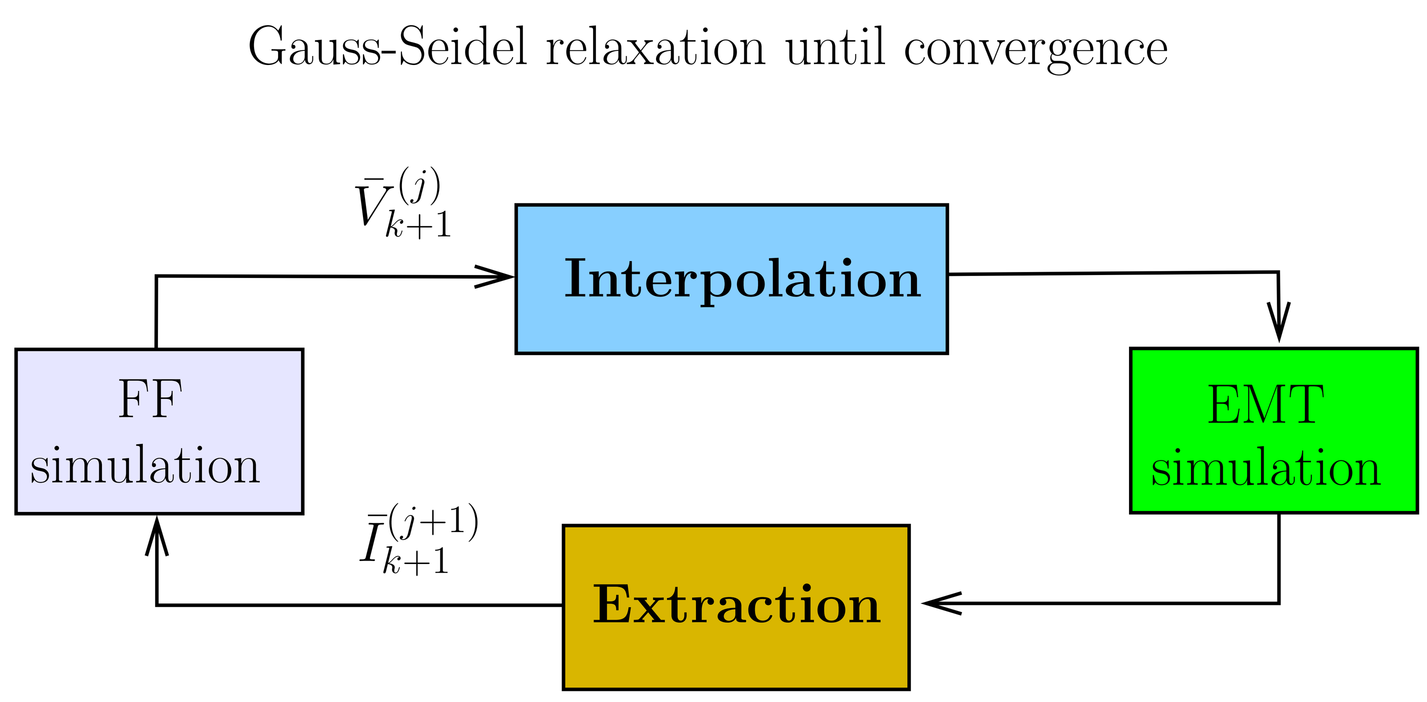
1. Full-Transient or ElectroMagnetic Transients (EMT) simulation
2. Fundamental-Frequency (FF) approximation for which the network can be described by the linear algebraic equations:

$$\boldsymbol{0} = \boldsymbol{D}\boldsymbol{V} - \boldsymbol{I} = \boldsymbol{g}(\boldsymbol{x}, \boldsymbol{V})$$

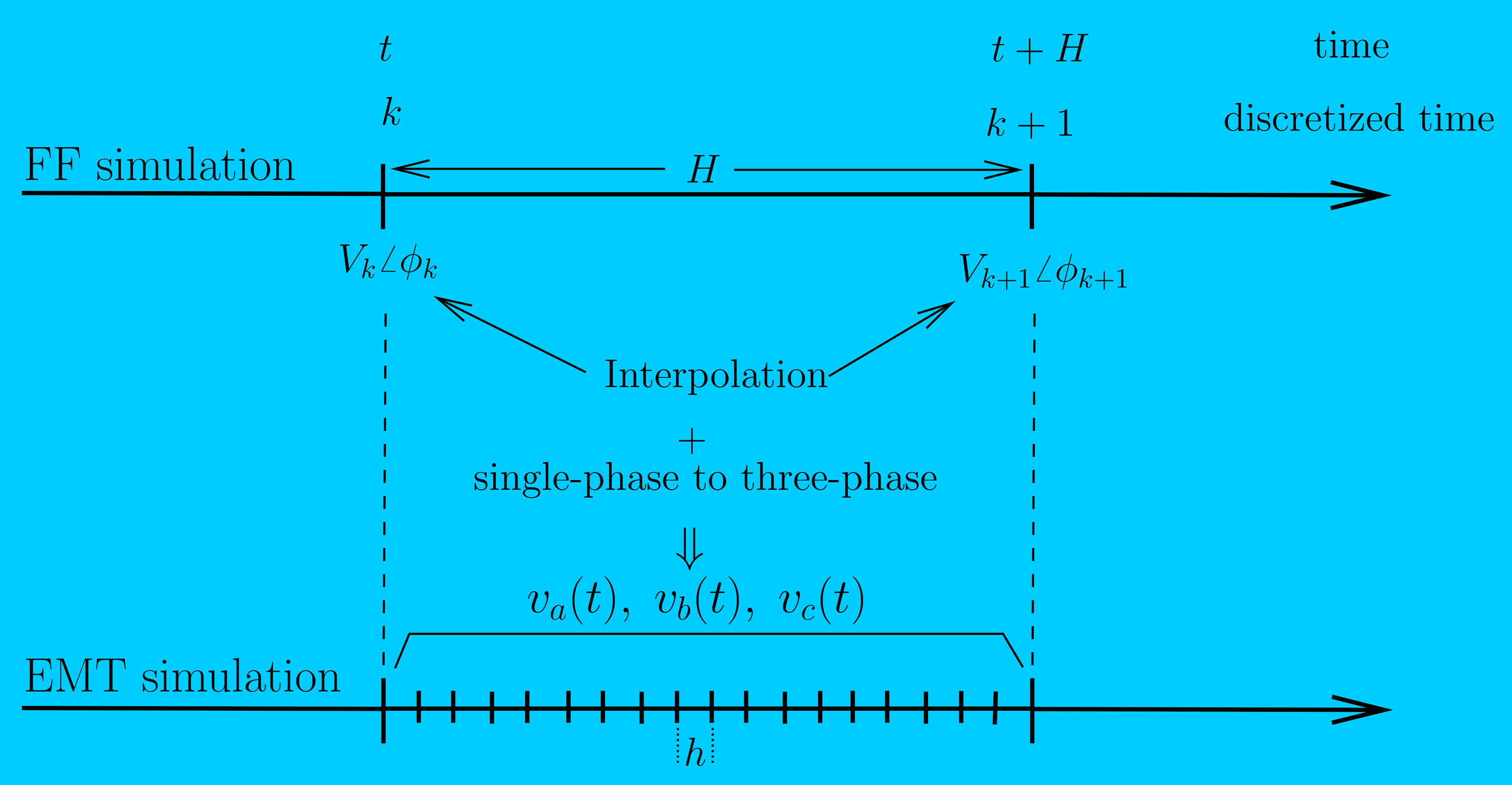
EMT vs FF: Three-phase fault



2. Iterative multirate approach



Interpolation



Considering phase a, for instance, the voltage evolution is taken as ($n = 0, 1, 2, \ldots$):

$$v_a(t+nh) = \sqrt{2}\, V_a(t+nh)\cos\left(\omega(t+nh) + \phi_a(t+nh)\right)$$

where $V_a(t+nh) = V_a(t) + (V_a(t+H) - V_a(t)) \cdot \dfrac{nh}{H}$

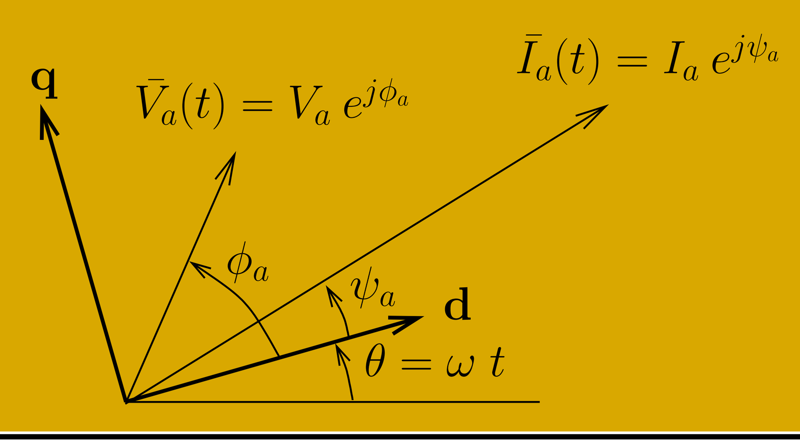
and $\phi_a(t+nh) = \phi_a(t) + (\phi_a(t+H) - \phi_a(t)) \cdot \dfrac{nh}{H}$

where ω is the nominal angular speed of the system.

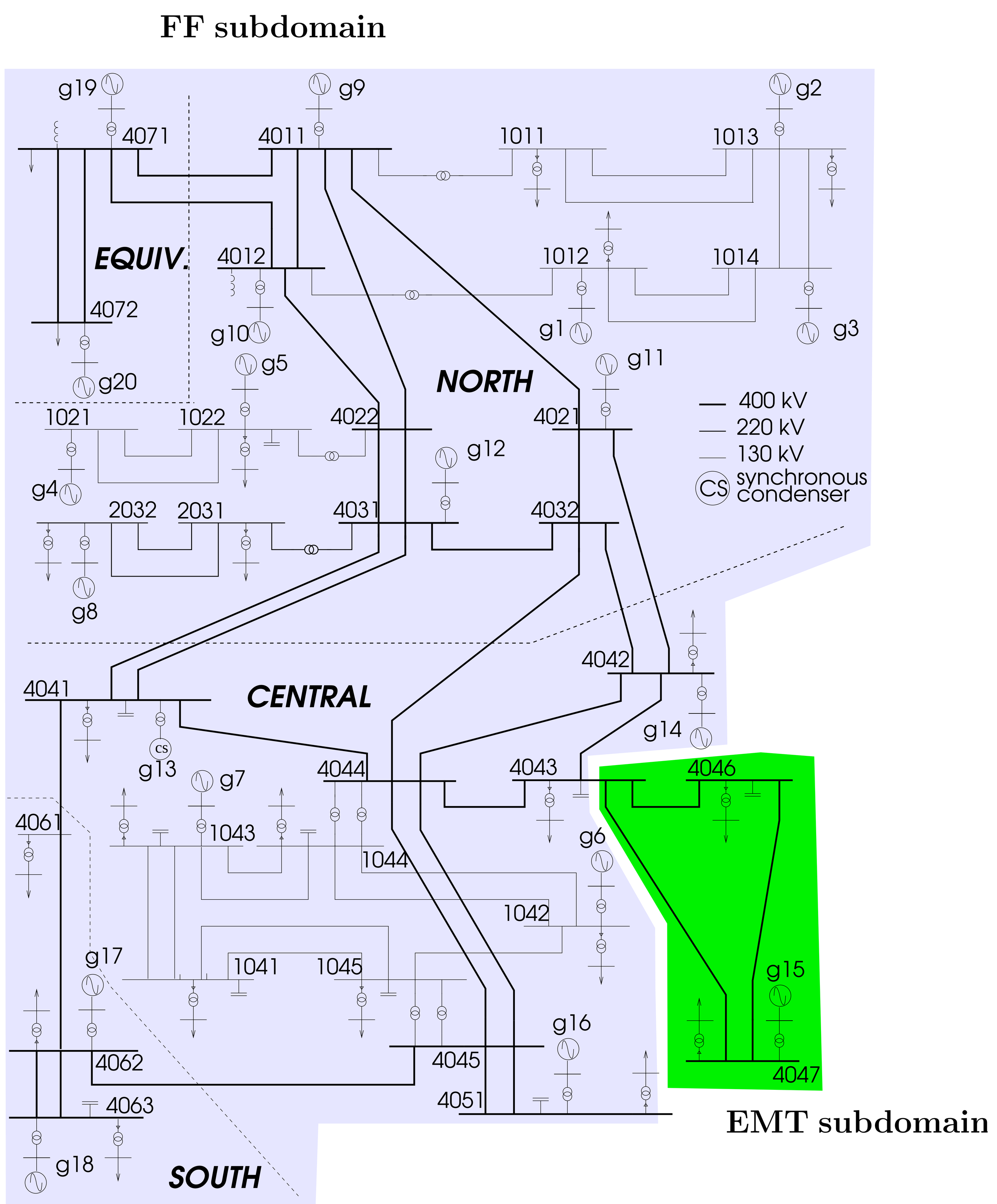
Extraction: projection on a rotating frame + filtering

$$\mathbf{I}_{0qd} = \mathbf{T}\,\mathbf{I}_{abc} = \frac{\sqrt{2}}{3}\begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \end{bmatrix}\begin{bmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{bmatrix} \approx \begin{bmatrix} 0 \\ I_a\cos\psi_a \\ I_a\sin\psi_a \end{bmatrix}$$

$$\Longrightarrow I_a = \sqrt{I_d^2 + I_q^2} \qquad \psi_a = \arctan\left(\frac{I_q}{I_d}\right)$$

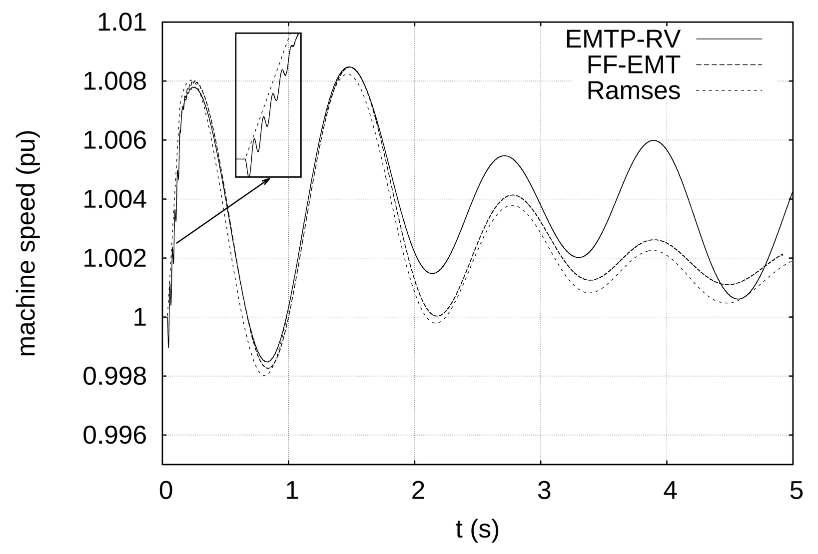


3. Test system: Nordic-32

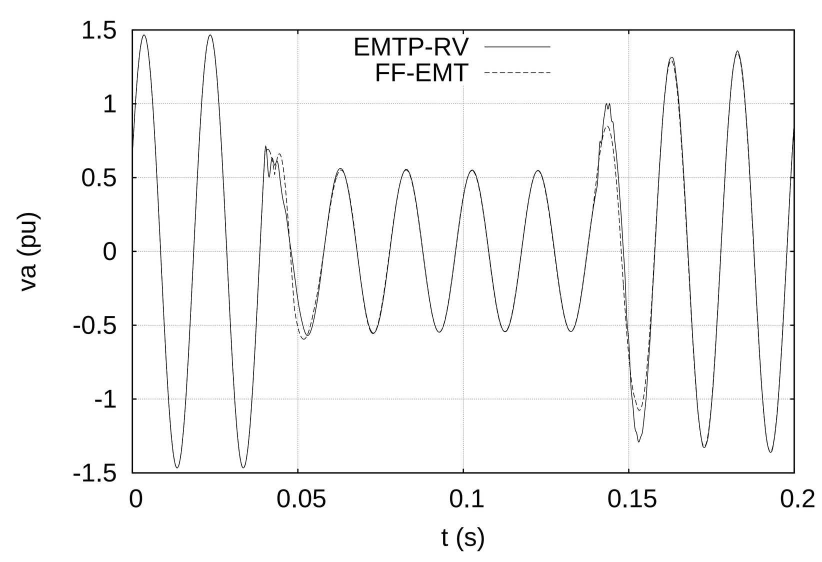


4. Preliminary results for a three-phase fault

Rotor speed of machine g15



Voltage at bus 4043



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