Power System Simulation Challenges

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Introduction

Power system simulations are routinely used to check the response of electric power systems to large disturbances. Operation of non-expandable grids closer to their stability limits and unplanned generation patterns stemming from renewable energy sources require dynamic studies. Furthermore, under the pressure of electricity markets and with the support of active demand response, it is likely that system security will be more and more guaranteed by emergency controls responding to the disturbance.

Power System Simulations

Static (computation of new system equilibrium)

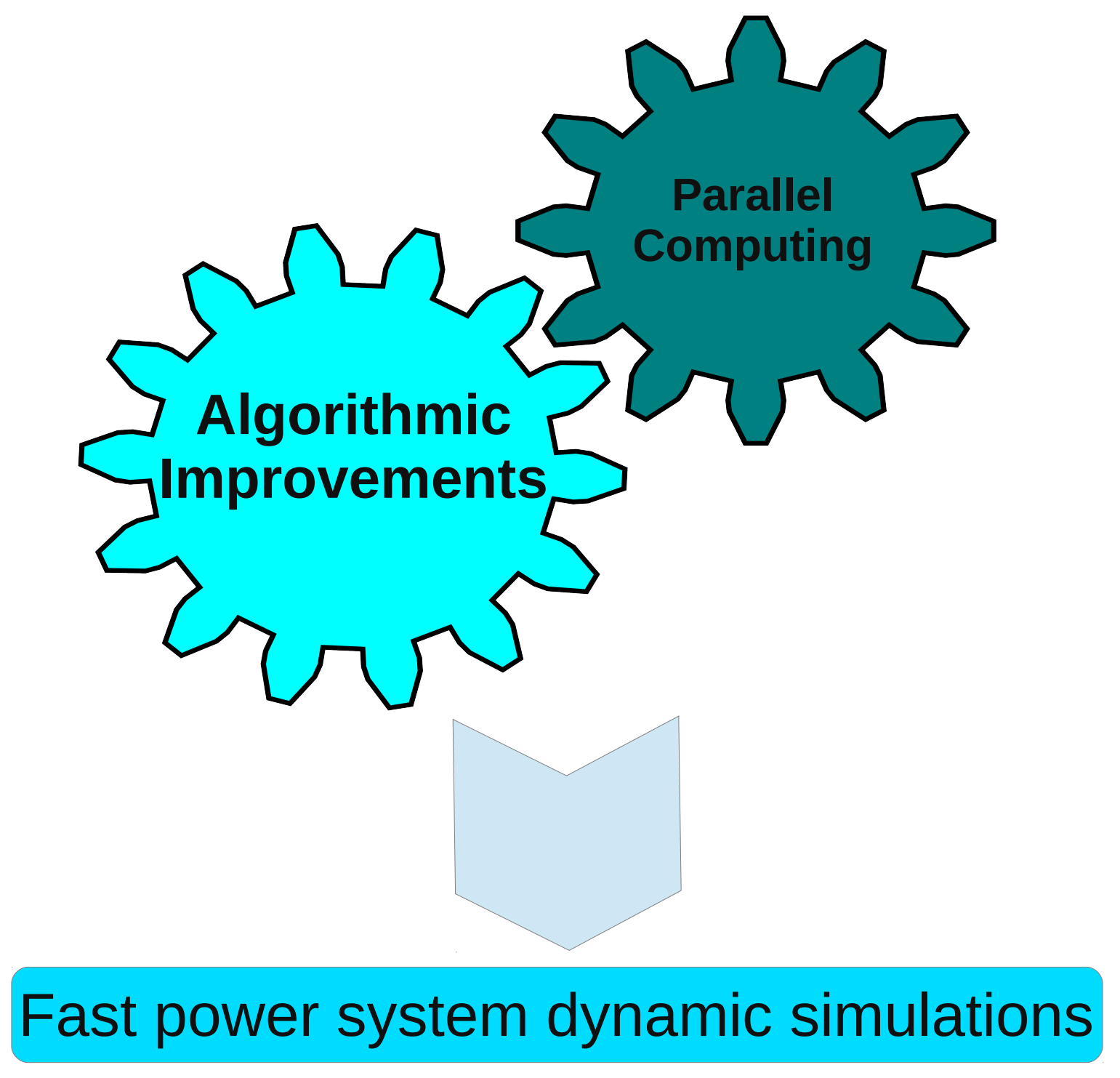
- \+ Fast
- \- Neglects the dynamic evolution and the effect of acting protections between the pre and post disturbance point

Dynamic (computation of system evolution through time)

- \- Time consuming
- \+ Considers the dynamic evolution and the effect of acting protections between the pre and post disturbance point

Dynamic simulations find application in:

- **Dynamic Security Assessment:** an evaluation of the ability of a certain power system to withstand a predefined set of contingencies and to survive the transition to an acceptable steady-state condition.
- **Hardware-in-the-loop:** the addition of a real component (electronic control unit, real engine, etc.) in the simulation
- **Operator training:** training control center operators through the simulation of possible contingency scenarios
- **Simulation assisted design for planning, control and security**
- and more.


Parallel Computing

Algorithmic Improvements

Fast power system dynamic simulations

Theoretic Background

In dynamic simulations, power system components are modeled by sets of *nonlinear stiff hybrid Differential-Algebraic Equations* (DAEs) based on their *physical properties* and *control schemes*. A large interconnected power system may involve hundreds of thousands of such equations spanning very different time scales and undergoing many discrete transitions.

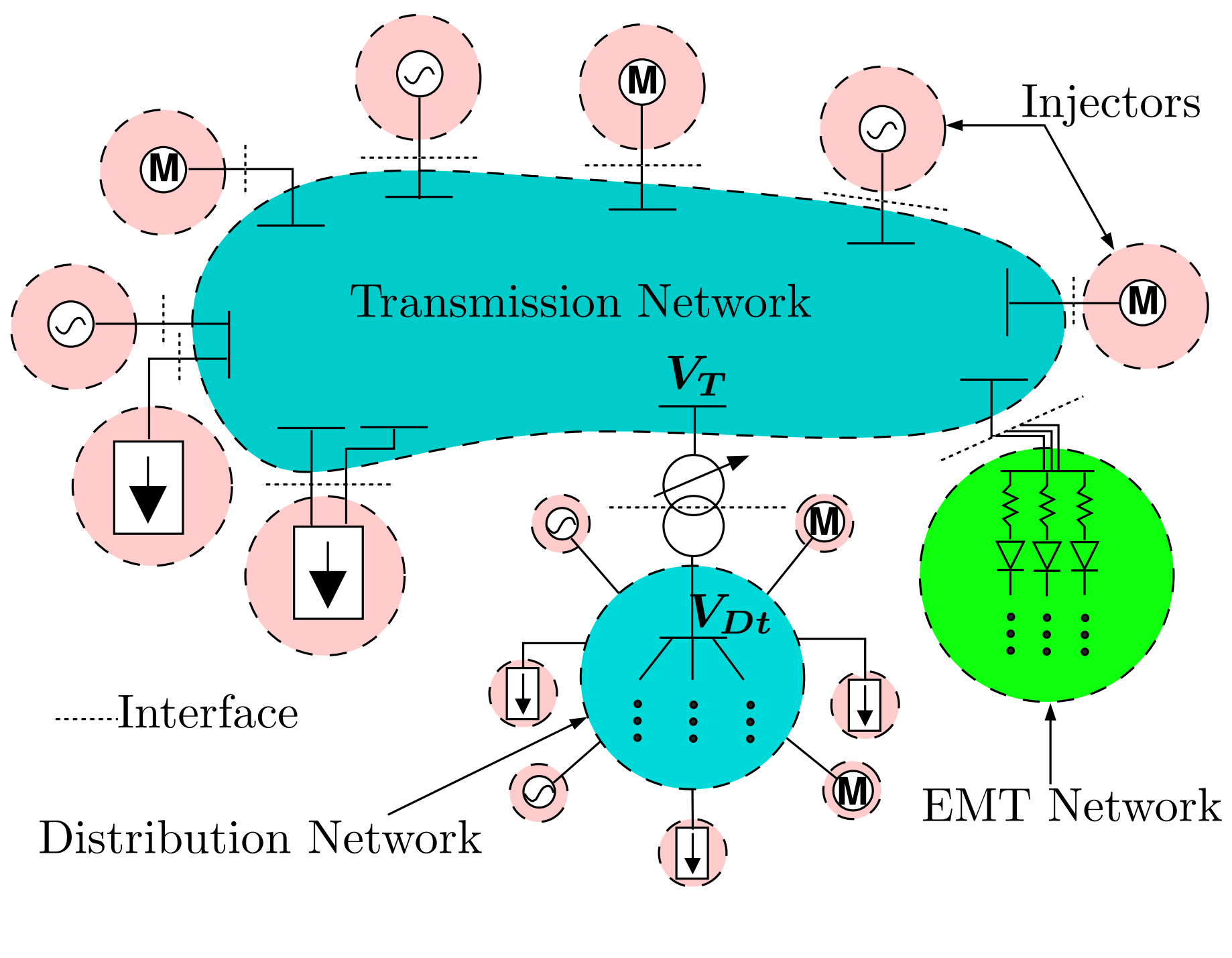


Figure 1: *Decomposed Power System*

The power system can be considered as a collection of components interfacing with each other through the Transmission Network (TN) as shown in the Figure. All the components connected to the TN that either produce or consume power in normal operating conditions (such as power plants, induction motors, other loads, etc.) are called *injectors*. Bigger components that include many components, like distribution networks, can be considered as *super-injectors*. This leads to a natural decomposition of the power system allowing us to apply Domain Decomposition Methods (DDMs) to increase simulation performance.

The i-th injector/super-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, $(\boldsymbol{\Gamma}_i)_{\ell\ell} = \begin{cases} 0 & \text{if the } \ell\text{-th equation is algebraic} \\ 1 & \text{if the } \ell\text{-th equation is differential} \end{cases}$ and $\boldsymbol{V}$ the vector of TN voltages.

At the same time, under the fundamental-frequency approximation, the TN can be described by the linear algebraic equations:

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

Domain Decomposition Methods

DDMs allow the solution of each injector/super-injector of the decomposed system in Fig. 1 separately and concurrently. Several schemes differ mainly by the method of exchanging interface variables, that is the variables shared between the TN and the injectors/super-injectors.

Basic classification of DDM based on the interface exchange scheme:

1. **Schwartz:** interface variables are updated after computing a converged solution of each decomposed sub-system
2. **Schur-complement:** a global reduced system is used to compute the interface variables before performing a Newton iteration on each decomposed sub-system

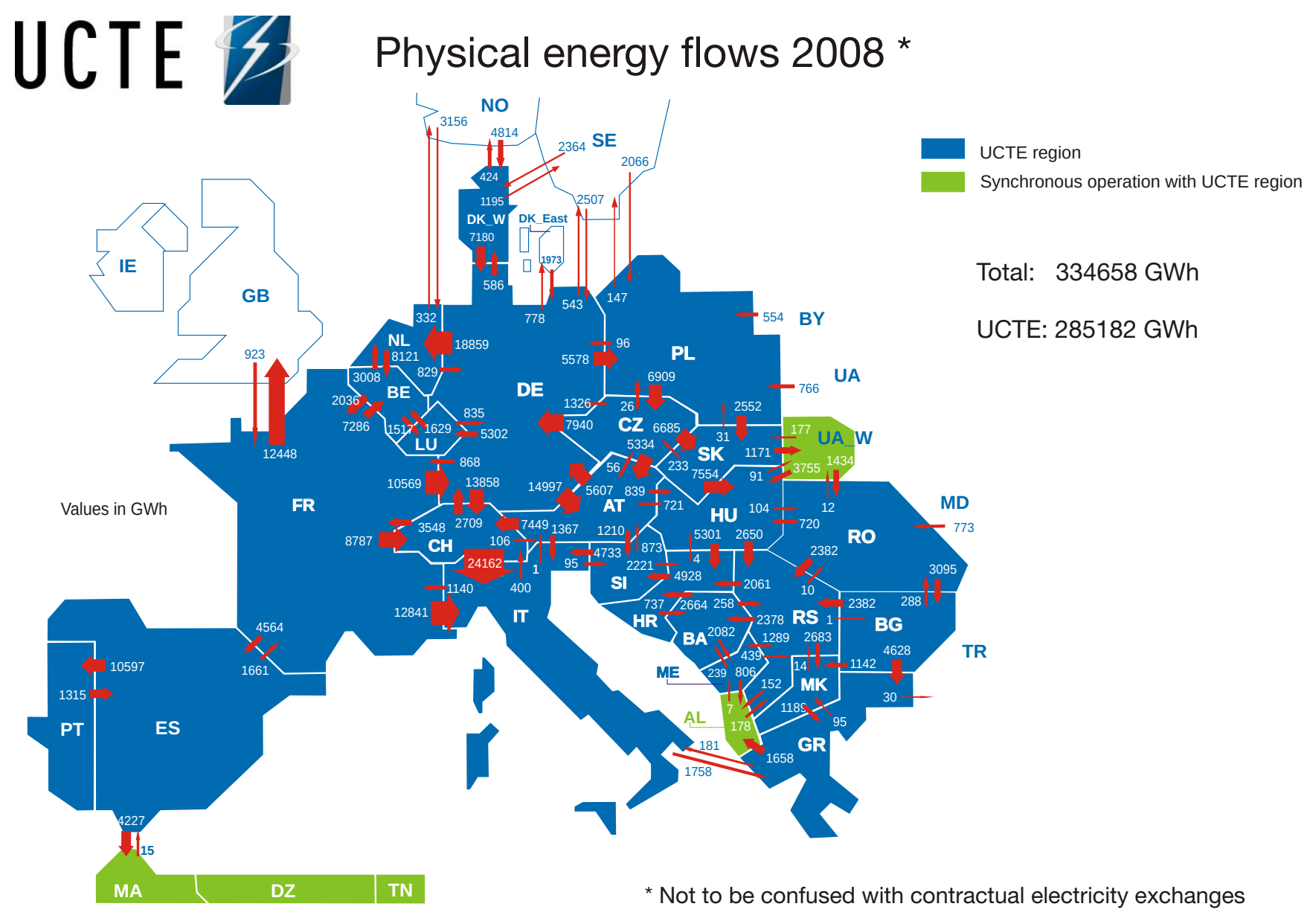
DDMs yield acceleration of the simulation procedure in two ways:

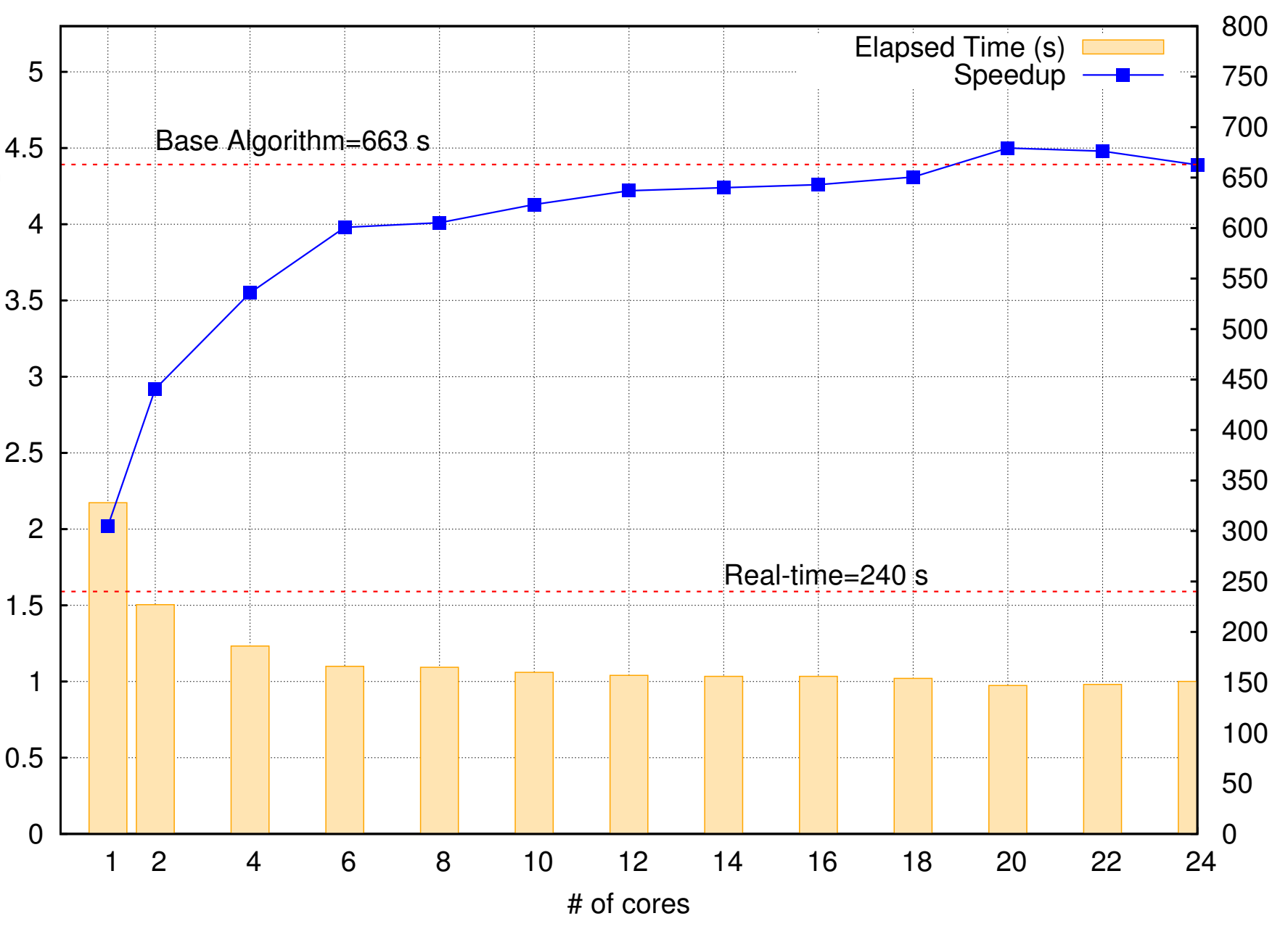
- **Numerically:** exploiting the localized nature of power systems to avoid many unnecessary computations (factorizations, evaluations, solutions)
- **Computationally:** exploiting the parallelization opportunities inherent to DDMs.

Large Interconnected Power System Example

Test-case based on a large-size power system representative of the Western European main transmission grid (UCTE area):

- 15226 buses and 21765 branches,
- 3483 synchronous machines represented in detail together with their excitation systems, voltage regulators, power system stabilizers, speed governors and turbines,
- 7211 other models (equivalents of distribution systems, induction motors, impedance and dynamically modeled loads, etc.).
- 146239 DAE states in total

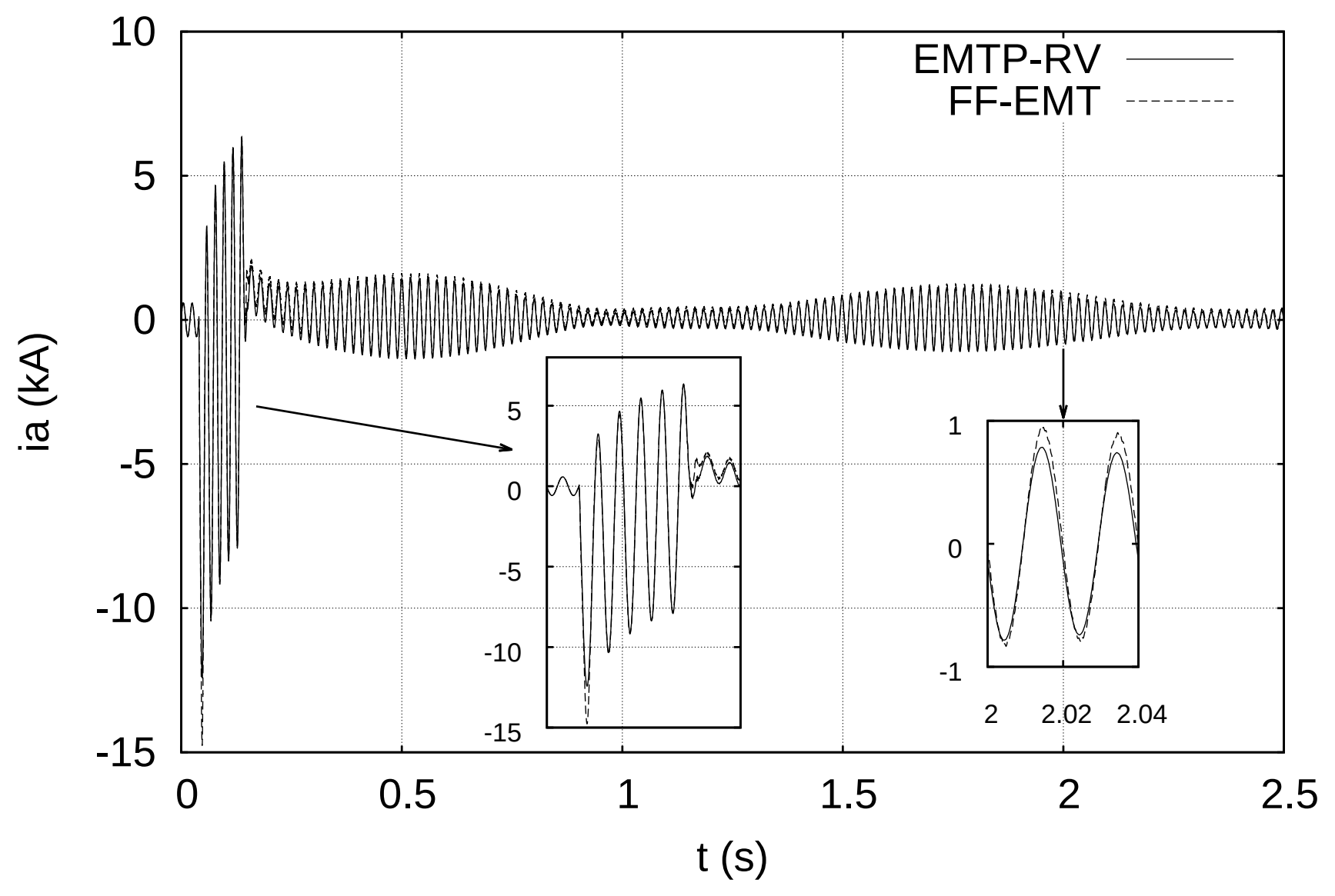


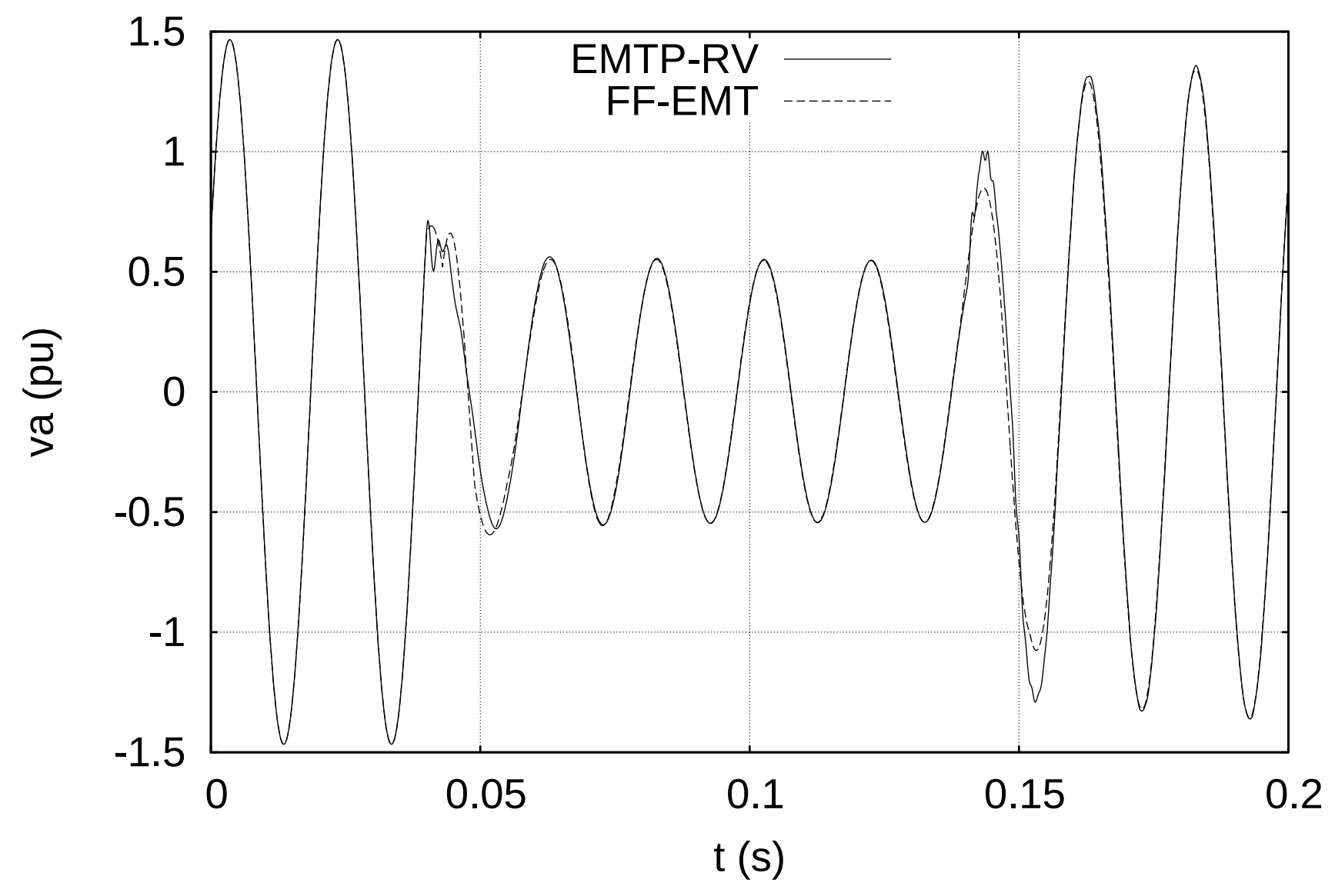


The disturbance simulated on this system consists of a short circuit near a bus lasting 5 cycles (100 ms at 50 Hz), that is cleared by opening a double-circuit line. The system is simulated over a period of 240 s with a time-step of 1 cycle (20 ms) using a *Schur-complement based DDM*.

Extension to Hybrid Simulations

More detailed dynamic simulations demand the representation of power system components by their ElectroMagnetic Transient (EMT) models. Although more accurate, EMT simulations are extremely time consuming. To accelerate the simulation, a multi-rate technique (using a *Schwartz based DDM*) is used to combine fundamental-frequency simulation with EMT simulation. The objective of this hybrid approach is to obtain more accurate simulations than with the fundamental-frequency approximation, while saving computing time by applying the detailed model to a subsystem only (see Fig. 1). It also allows to remove some limitations of fundamental-frequency simulations, such as the difficulty of simulating unbalanced faults. The test system is the 74-bus, 102-branch, 20-machine Nordic32 model. The Figures show the response of the system to a disturbance when modeled in EMT (EMTP-RV) and hybrid (FF-EMT).





Conclusions

In the future, the rising need for simulating larger power system models, including active distribution networks, will further increase the computational burden of dynamic simulations. Applying DDMs can improve the dynamic simulation performance and accuracy and allow the safe and economic operation of power systems closer to their stability limits.

Selected Publications

[1] Petros Aristidou, Davide Fabozzi, and Thierry Van Cutsem. Exploitation of localization for fast power system dynamic simulations. In *Paper submitted for presentation at Power Tech 2013 conference*.

[2] Petros Aristidou, Davide Fabozzi, and Thierry Van Cutsem. A Schur Complement Method for DAE Systems in Power System Dynamic Simulations. *Domain Decomposition Methods in Science and Engineering XXI*, 2013.

[3] Petros Aristidou and Thierry Van Cutsem. Dynamic simulations of combined transmission and distribution systems using decomposition and localization. In *Paper submitted for presentation at Power Tech 2013 conference*.

[4] Frédéric Plumier, Christophe Geuzaine, and Thierry Van Cutsem. A multirate approach to combine electromagnetic transients and fundamental-frequency simulations. In *Paper submitted for presentation at IPST 2013 conference*.

Second IntelliCIS Training School, 4-8 March 2013, Aachen, Germany