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Modelling approaches of power systems considering grid-connected converters and renewable generation dynamics

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Paper objectives

This paper presents a comparative analysis among several modelling approaches, considering different levels of detail of the main components of power systems with RES. It also considers the dynamics of PV power plants and mechanical dynamics of wind generators (WGs).

The models are compared in terms of: • Execution time • Precision • Simplicity

The tests were performed as follows. First, one model ofeach element (SG, transmission lines, converter, RES) was chosen to form a base group, which are indicated with underline. Afterwards, each test was performed varying one element per time in relation to the base group. This allowed to identify the influence of each model in the overall system behaviour.

Renewable generation

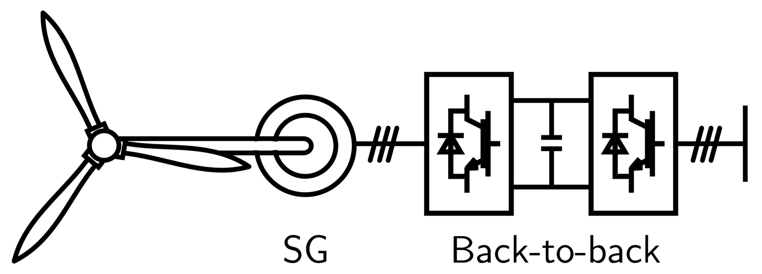
Ideal DC voltage source: The DC link is conected to an ideal DC voltage source.

Wind turbine

Static wind: This model comprises algebraic power relations that statically portray the produced power depending on the current wind speed as only input to the model.

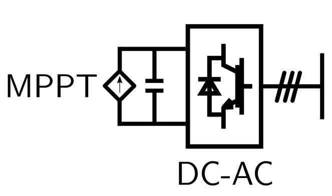
$$P_w = \frac{1}{2} c_P\left(\frac{\omega R}{v}, \beta\right) \rho \pi R^2 v^3$$

Dynamic wind: The dynamic model is capable of displaying the interaction of the mechanical turbine states and the control loops. It relies on the Takagi-Sugeno modeling framework that uses a convex description of linear models to describe nonlinear dynamics.

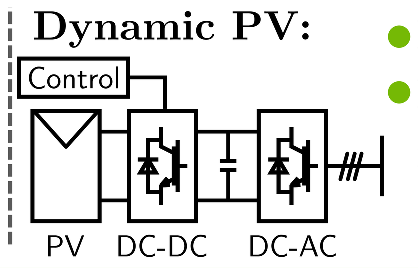


Photovoltaic power station

Static PV:
- It has no control dynamics
- Extracts the maximum power from a given irradiance and temperature



Dynamic PV:
- Includes the P&O control
- It can track the power including MPPT.



Synchronous machines

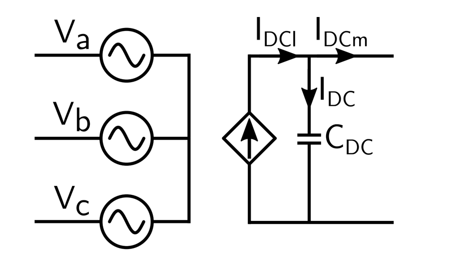
Simplified model: The simplified SG model consists of a voltage-behind-impedance model with variable frequency, governed by the swing equation.

IEEE Model 2.2: The IEEE Model 2.2 is a precise yet simple electrical model in the dq axis. This model takes into account the dynamics of the stator, field, and damper windings.

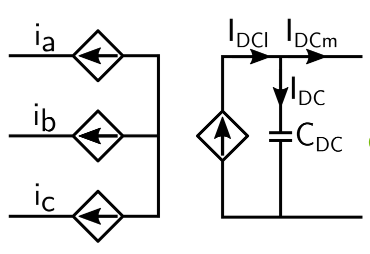
IEEE Model 2.2 with saturation: In this study, the saturation was modelled as factor k added to the excitation.

Converter

EMT average model:
- Neglects the converter's high-frequency switching



Phasor model:
- The grid differential equations are substituted by algebraic equations
- The phasors are assumed to be rotating at nominal angular speed

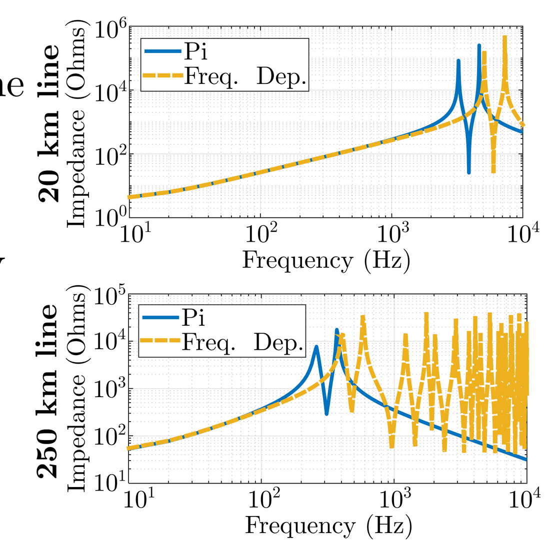


Transmission lines

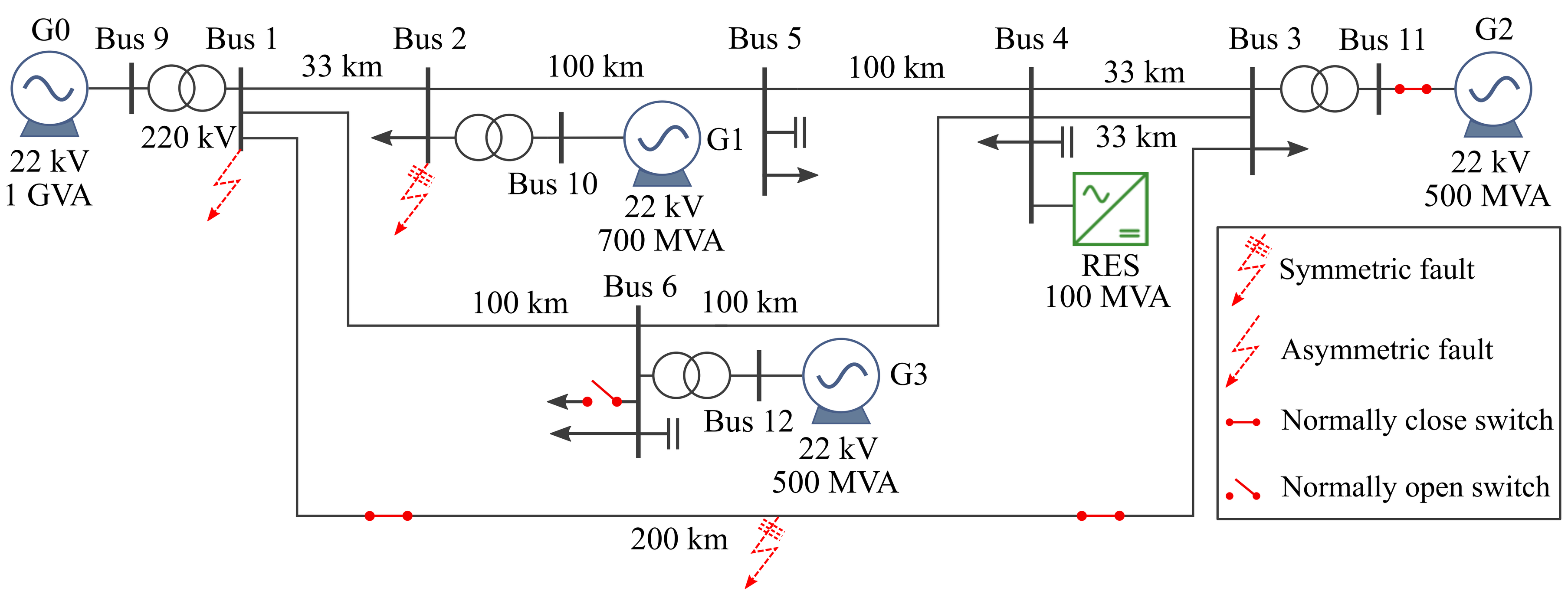
PI model: • It is simple

Bergeron model: • It has distributed parameters and considers the travelling waves

Frequency-dependent: (FD)
- The line electrical parameters are obtained from the physical line geometry and are frequency dependant
- The travelling waves are accurately represented and the travelling wave speed is also frequency-dependen



Methodology, Resuts and Discussion

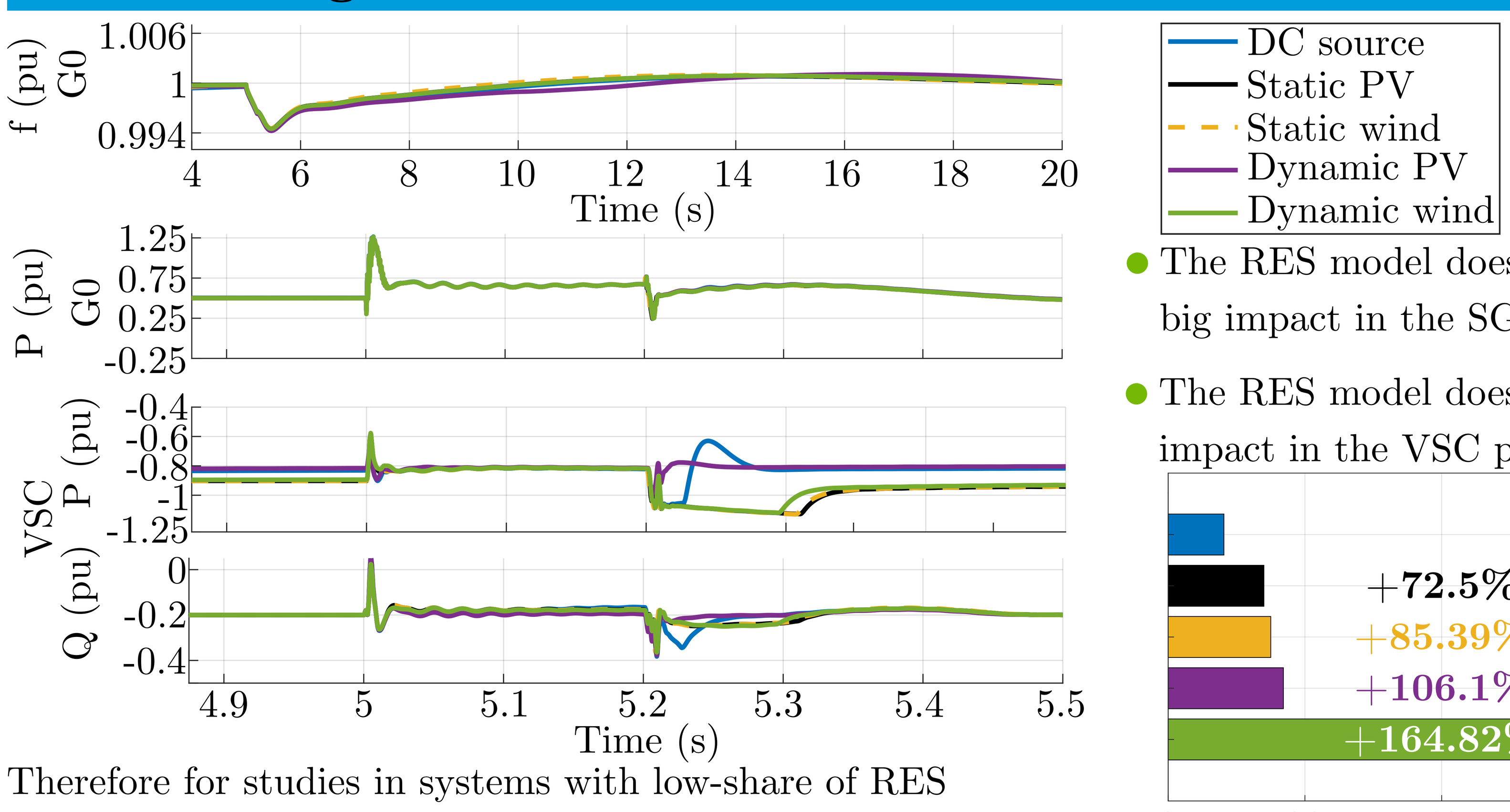


To assess the influence of the models, several studies were performed using an adapted Cigre European HV transmission network benchmark system, modelled in Simulink®. The system is composed of four synchronous generators, eight transmission lines and one VSC, and represents a generic equivalent transmission system.

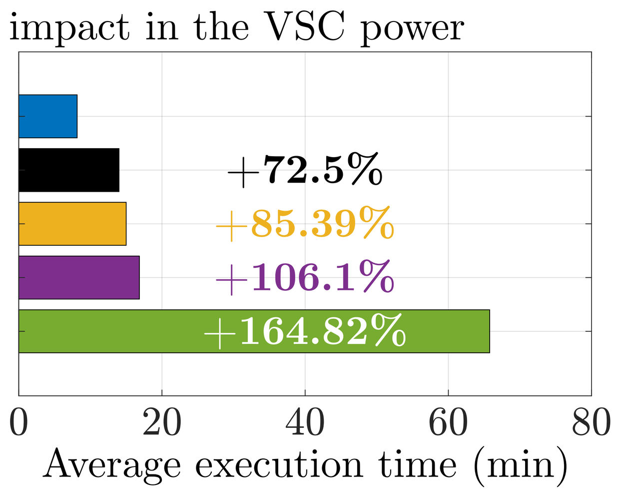
The test perform were:

1. Setpoint tracking: change of RES power reference
2. Load connection: in bus 6
3. Symmetrical fault: in bus 2
4. Asymmetrical fault: in bus 1
5. Loss of generation: disconnection of G2
6. Line outage: Symmetrical fault plus disconnection

Renewable generation

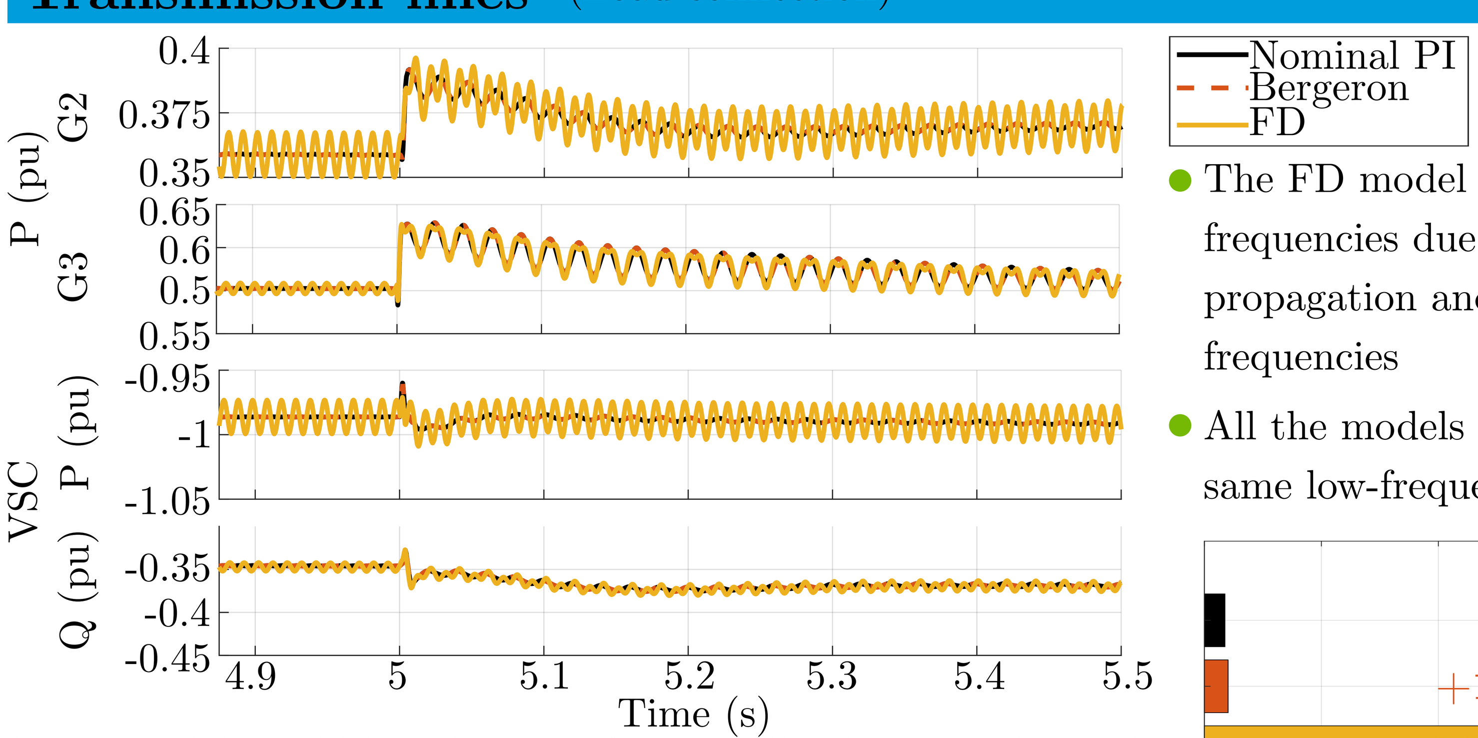


- The RES model does not have a big impact in the SG power
- The RES model does have an impact in the VSC power

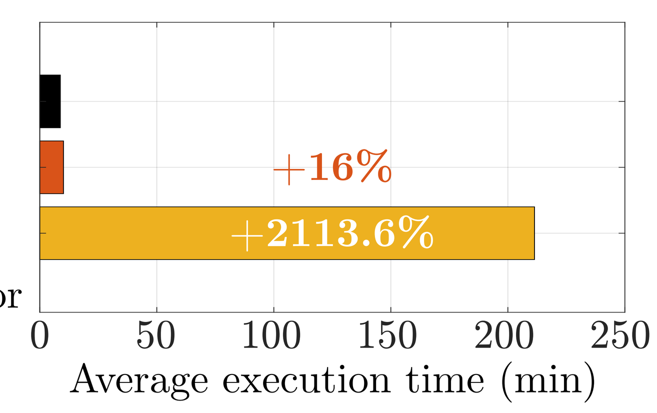


Therefore for studies in systems with low-share of RES and dominated by SGs, the ideal DC source would provide adequate accuracy. Conversely, for studies in systems with high-share of RES, static and dynamic models should be used.Static models are good options as they are faster to simulate than dynamic models and provide a similar response to those in several events.

Transmission lines (Load connection)

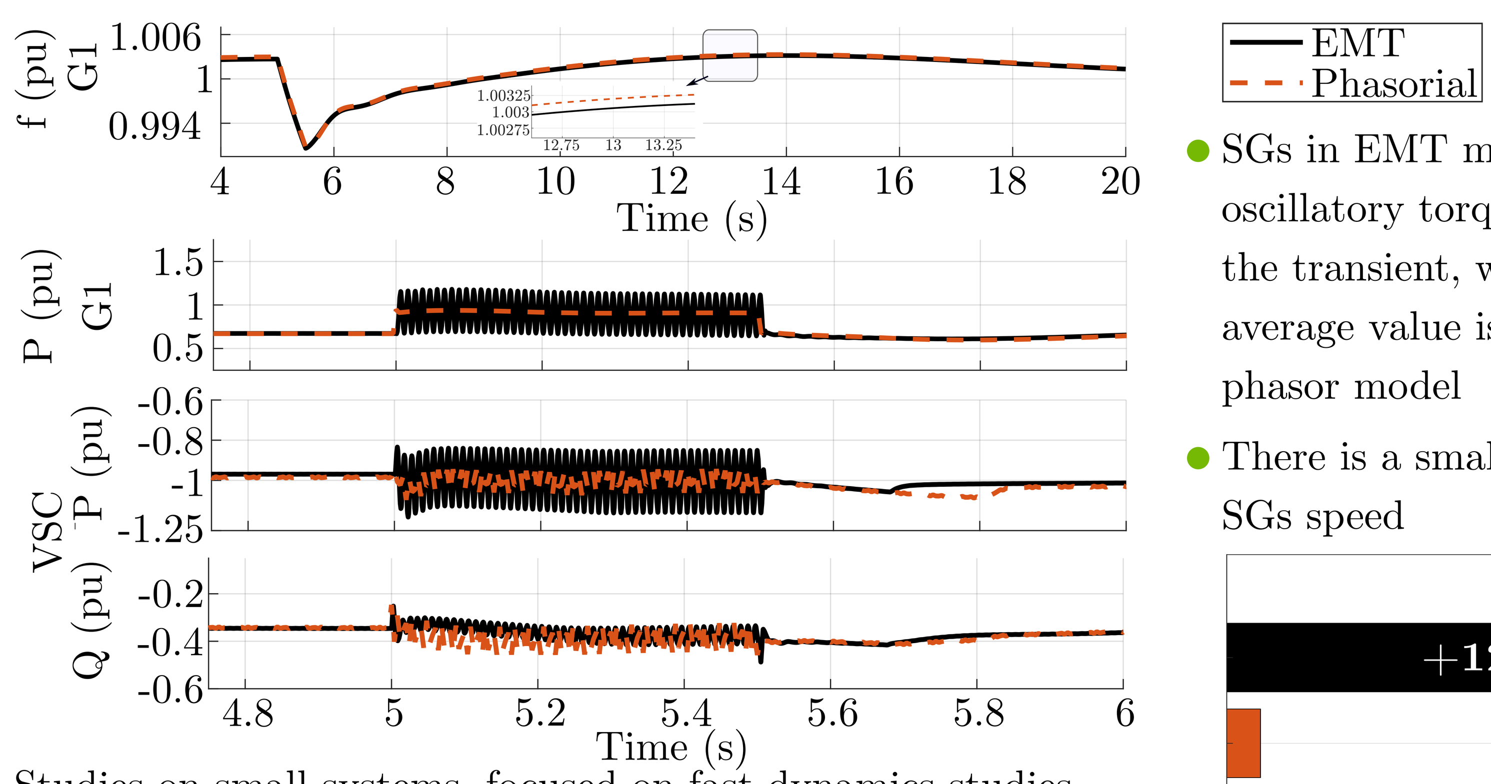


- The FD model represents higher frequencies due to wave propagation and resonance frequencies
- All the models represent the same low-frequency tendency

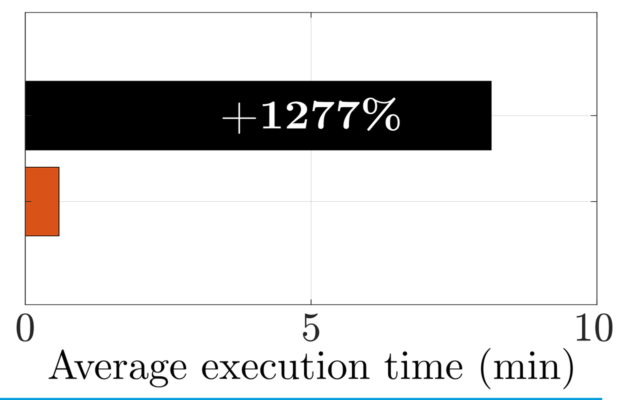


The PI model would be adequate if essentially electromechanical transients are simulated. Using high-order models would add minor precision at the cost of a larger simulation time. Nevertheless, if electromagnetic transients are simulated or if the converter switching or control dynamics are a concern, the FD might be better representing high-frequency components. The Bergeron model might be adequate between both extremes.

Converter

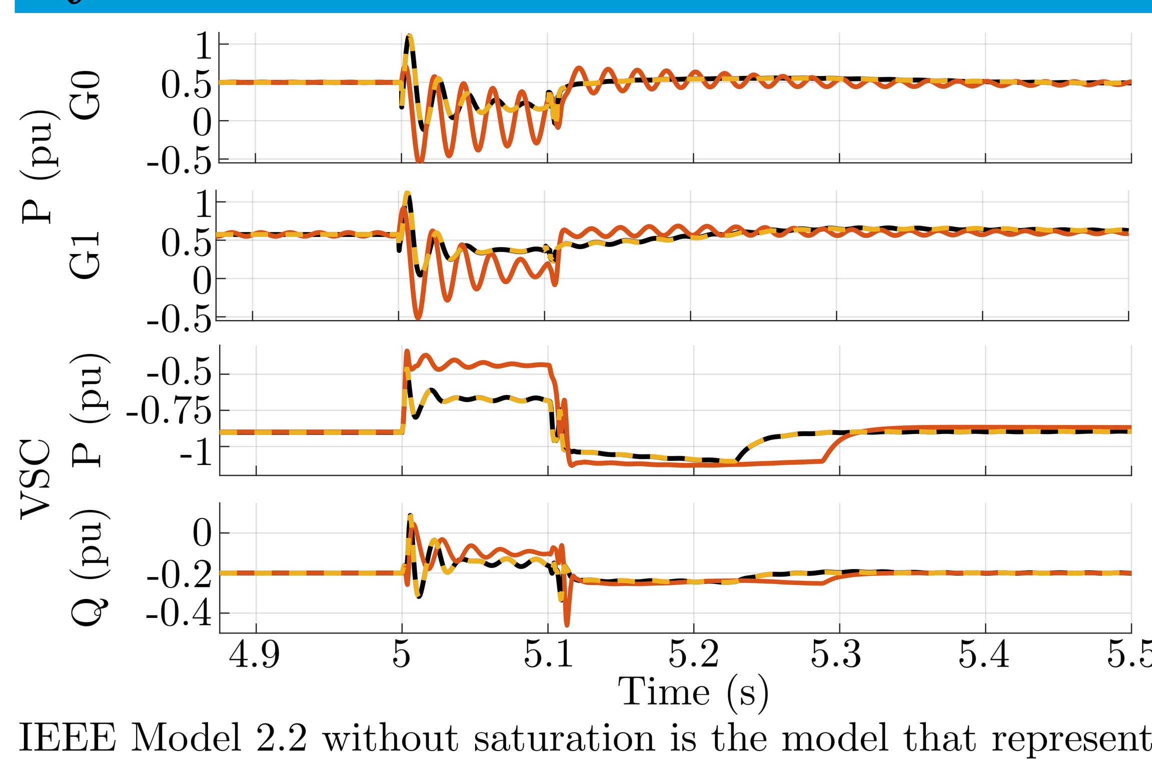


- SGs in EMT model show an oscillatory torque produced by the transient, where only the average value is captured by the phasor model
- There is a small offset in the SGs speed

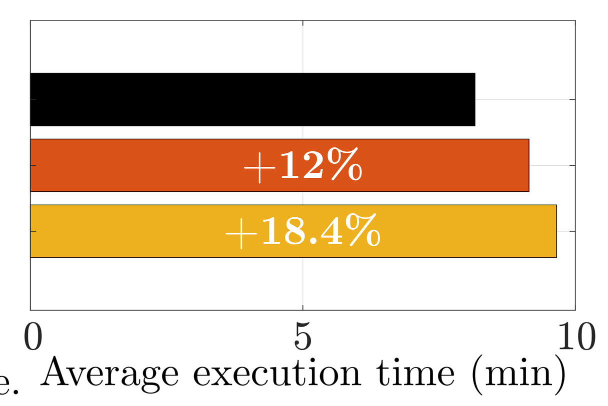


Studies on small systems, focused on fast dynamics studies might require EMT simulation. Electromechanical studies on large systems can be precisely simulated using phasor models.

Synchronous machines (Line outage)



- The models with and without saturation have similar response.
- The inertia only model, due to lack of damper windings has more oscilations.



IEEE Model 2.2 without saturation is the model that represents better the electromechanical events with less computational time.

Conclusions

From the tests performed, it could be observed that the most suitable models for the study of an electromechanical events in the system tested were: the Model 2.2 without saturation, nominal PI model, phasor model and ideal DC voltage source. These models were able to track the fundamental components of the variables been simulated and at the same time haveless computational burden.