UNLOCK HIGH-PERFORMANCE GRID ANALYSIS FOR GRIDS WITH HIGH PENETRATION OF INVERTER-BASED RESOURCES

Large-scale EMT Model Management for the Transmission Grid

At a glance

Electrical grids are undergoing a massive shift towards a decentralized control structure dominated by inverter-based resources. This energy transition is fueled by the pressing need to combat climate change and achieve net-zero emissions. While the rapid integration of renewable energy sources like solar PV and wind power contributes to a greener future, it also brings significant challenges in managing the evolving electrical grid. In this respect, flexible and reliable grid operation are key targets.

To support the stability of the evolving electrical network and to enable a smooth transition to the future grid with numerous software-driven controllers, it is imperative to develop and maintain accurate large-scale electro-magnetic transient (EMT) models of electrical grids. These models should produce trustworthy results that can be relied upon for operating the grid and planning future expansions mainly with Inverter-based resources (IBRs).

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PTI Consulting offers a comprehensive solution for developing and maintaining large-scale EMT models of electrical grids. Our services include:

- Data collection and creation of large-scale EMT models,
- Model development and maintenance,
- Integration of diverse inverter-based resources from multiple manufacturers in a large-scale network model,
- Dedicated training program for competence development in EMT modeling and studies,
- Extensive studies to analyze the grid performance and ensure a secure and stable grid operation.

The challenge

For several decades, power system studies, primarily related to dynamic assessments, have heavily utilized root-mean-square (RMS) models to analyze large electrical networks. These simplified yet efficient models have consistently provided reliable results for networks characterized by limited installed base of renewable generation, relatively higher fault levels, and substantial system inertia. However, as the power system network moves toward increased integration of renewables, accompanied by a decrease in conventional generation, it is vital to capture the complex dynamic behavior of modern power system with EMT simulations.

Recent real-world incidents

Latest critical incidents in power grids[1] depict the urgent need for more detailed modeling and analysis of evolving electrical grids with a high penetration of inverter-based resources:

- 2017: Three separate sub-synchronous oscillation (SSO) events transpired in the South Texas region, exhibiting instantaneous current frequencies in a range of 22 and 26 Hertz. These SSO events were eventually resolved by the wind-power-plant (WPP) vendors through updates to the WPP converter control software.
- 2018-2019: Post a planned 230-kV bus outage, two type-4 wind power plants connected to a 230 kV transmission grid in Canada showed oscillations at 3.5 Hz in actual power and reactive power measurements. System strength observed from the WPPs was considerably reduced due to the outage. Additionally, another nearby photovoltaic plant reported sustained reactive power oscillations.
- 2019: In August 2019, a power system disruption in Great Britain (GB) was preceded by the observation of 9-Hz oscillations 10 minutes earlier. These weak grid oscillations led to the de-loading of an 800-MW offshore wind power plant. Consequently, the WPP vendor upgraded its control software to prevent such incidents in the future.
- 2021: An energy company in the eastern United States, reported that a solar PV farm under their jurisdiction displayed voltage oscillations at a frequency of 22 Hz. Also, measurements of instantaneous currents and voltages revealed 38 Hz and 82 Hz components within these oscillations.
- 2021: Scotland experienced two instances of 8-Hz fluctuations in RMS voltage. Each disturbance lasted approximately 20-25 seconds, with a gap of roughly 30 minutes between them. These oscillations were reduced upon reintroducing certain conventional power plants into the system. It is noteworthy that Scotland has a considerable proportion of wind farms integrated into its energy grid.

Key benefits of EMT simulations

While RMS models offer computational efficiency for grid analysis, modeling the inverter control loops, sequence-based controls, and potential frequency dependencies in EMT models is vital for accurately evaluating both small-signal and large-signal stability, including interactions among controllers. This approach provides a more robust assessment of power grid stability in modern electrical networks with high IBR penetration.

[1] Source: *IEEE transactions on power systems, vol. 38, no. 1, January 2023 - Real-World Sub-synchronous Oscillation Events in Power Grids with High Penetrations of Inverter-Based Resources*

Let us delve into the key benefits of EMT simulations:

- Instantaneous values: EMT simulations operate on instantaneous values of voltages and currents, allowing for precise analysis of system behavior during dynamic events.
- System asymmetry: EMT simulations consider the system asymmetry of the power network, including DC offsets, harmonics, and negative & zero sequence phasors.
- Representation of non-linear effects: EMT simulations can readily incorporate nonlinear effects of power system equipment, such as transformer saturation, when these phenomena significantly impact inverter response during dynamic events. This capability is essential for modeling the behavior of complex power systems accurately.
- Frequency dependency: EMT models can simulate system components across a range of frequencies, enabling accurate representation of transient damping at various frequencies, resulting in a realistic system response model.
- Accurate representation of control systems: EMT simulation tools can accurately model key components of IBR control systems. This enables comprehensive analysis for control interactions and dynamic stability of overall network.

Challenges with large-scale EMT model development

While EMT simulations offer several benefits, the initial step often involves creating a precise EMT model of the electrical network. Developing such a model from scratch for a complex grid with diverse components and numerous controllers can be a time-consuming process, potentially taking several months of engineering effort. The model development timeline can significantly affect the delivery of study results, thereby impacting subsequent assessments, planning, and decision-making processes. To ensure preparedness for timely decision-making and planning, it is beneficial to proactively develop and maintain an EMT model of the large electrical grid over time. This preemptive approach eliminates the need for urgent model development during critical situations, saving valuable time and expediting response efforts.

Despite their high accuracy, EMT models of the electrical grid come with certain drawbacks. They require small-time steps (in the range of few microseconds) during simulations, resulting in extremely slow simulation speeds. Large EMT network models with multiple controllers can make simulations painstakingly slow, especially when several scenarios and variants need to be investigated. Based on our experience, it typically takes several months to complete model development and studies for large electrical networks. One effective way to mitigate this issue is to exploit hardware capabilities by using highly parallelized or distributed computation. Furthermore, developing and maintaining EMT models often requires highly specialized skills and extensive experience.

Our solution

PTI Consulting provides a complete solution for developing and maintaining extensive EMT models of electrical grids. Our offering includes the following crucial aspects:

- Data collection, validation, and enhancement in case of missing values according to our experience, best practices, and international standards, in the extent defined together with the customer.
- Representation of all network elements in EMT domain with frequency dependency
- Setup of highly parallelized or distributed EMT models using several CPU cores or computer clusters such that several simulations can be completed within few minutes.
- Integration of manufacturer's black-box model for inverter-based resources in the electrical network model. In case manufacturer model is not readily available, PTI could provide generic models for the components in agreement with customer's requirements.
- Initialization of the network model for various operating contingencies
- As part of a maintenance process, the network model is updated regularly, incorporating changes in the network. The frequency of these updates is agreed with the customer.
- Demonstration of the developed EMT model for certain number of simulation cases.
- Training of customer personnel in questions about the network model and simulation.

Additional studies such as controller interaction in time domain, dynamic stability etc. can be offered as optional service.

Your value

Given the crucial role of simulation models in grid planning and operation, a large-scale EMT model of the electrical grid has become a necessity as more and more inverter-based resources are integrated to the network. Key benefits of developing and maintaining EMT models for the transmission grid:

- Empowers you to create and manage large-scale EMT models for comprehensive grid analysis.
- Addresses the complexities associated with integration of diverse inverter-based resources from different manufacturers in large-scale network models.
- Up to date and readily available EMT models eliminate the need for time-consuming model development process prior to conducting crucial system assessment studies, allowing for rapid evaluation of critical planning and operational decisions.
- Enables the analysis of the small and large signal dynamic stability of the transmission grid and control interactions, aiding to ensure a stable and secure grid operation.
- Continuous model maintenance facilitates regular intermittent updates to the model, ensuring the latest and most accurate representation of the grid.
- Get familiar with model operation and analysis techniques with our dedicated training program.

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Are you interested in learning more about our services? We are happy to answer your questions. Please get in touch via our web contact form.

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