

Power System Modelling Capability Review

Important notice

Purpose

This document has been prepared by ISON, an international network of system operators, based on information available as at the date of publication.

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Opportunity and impact

Modern power systems are becoming increasingly complex, requiring enhancement of modelling tools to represent new technologies and interactions with enough detail to support decision-making in planning and operational timeframes. The purpose of this review was to identify areas for potential uplift and any critical gaps in the current state of power system modelling of the International System Operator Network (ISON).

The roadmap developed in this project provides a high-level prioritisation action plan that identifies that the largest impact for change is in increased collaboration on technical and operational objectives between System Operators (SOs), vendors, Original Equipment Manufacturers (OEMs) and industry in the short, medium and long term. While the roadmap provides a common reference framework, implementation timelines and individual priorities may differ across SOs.

ISON would like to thank Electric Power Research Institute (EPRI) for coordinating the modelling capability review, and the software vendors that provided input and assistance.

System Operators engaged

The following System Operators were involved:

- AEMO – Australia
- CAISO – United States of America (California)
- EirGrid – Republic of Ireland
- Energinet – Denmark
- ERCOT – United States of America (Texas)
- NESO – Great Britain

Key gaps and uplift areas

Insight from Capability Review

The capability review provided a comparison of modelling approaches and practices across system operators and vendor tools, producing a cross-ISON view of how power system modelling is currently applied in practice.

In particular, the analysis indicated that:

- Different modelling domains (such as Root Mean Square (RMS) and Electromagnetic Transients (EMT)) are applied in parallel in some cases and in others as part of integrated sequential study workflows.
- Modelling approaches and data are typically distributed across multiple tools and environments, requiring coordination to ensure consistency.
- Detailed modelling approaches are increasingly required for specific system behaviours, requiring more targeted application to balance complexity and study efficiency.
- Strengthening alignment between planning and operational modelling environments is becoming increasingly important to enable planning for operability.
- Models increasingly need to be validated and refined using operational measurements and observed system events to ensure they accurately represent real-world performance. This is driven by the complexity of behaviour from power electronic device operation and how this creates interactions between generators, loads, distributed energy resources (DER), and other power electronic devices to impact system behaviour.

These observations highlight the need for improved coordination across modelling domains, stronger model management practices as a critical enabler across all modelling tools, and more targeted application of advanced modelling approaches, which are reflected in the capability uplift areas below.

Areas for capability uplift

The findings from the review highlight several areas where capability uplift is expected to support future system requirements, including:

- improving interoperability of models across tools and simulation environments,
- strengthening model validation processes and ensuring consistency across modelling domains,
- enhancing integration between operational data and modelling workflows,
- expanding modelling approaches to better represent emerging technologies, including inverter-based resources, large loads, and DER,
- increased use of advanced modelling and studies such as EMT, small signal analysis where appropriate (and where it is not already utilised), and
- developing improved processes (including screening tools) for identification and prioritisation of detailed studies.

These areas represent common focus points across system operators and are reflected in the roadmap themes and actions outlined below.

Key recommendations

A standardised roadmap was produced to categorise recommended uplifts as short, medium and long term, based on the impact and urgency of the recommendations.

While the roadmap provides a common reference framework, implementation timelines and individual priorities may differ across SOs and may not align directly with individual vendor development roadmaps. The roadmap is intended to be dynamic and adaptable, allowing recommendations to evolve alongside emerging technologies, changing system requirements, and new solution pathways for addressing capability gaps.

The themes in this roadmap are:

1. model development,
2. model management and validation,
3. real-time capability and monitoring, and
4. modelling techniques.

Selected roadmap actions are accompanied by short descriptions outlining their intent and application across system operator environments.

Across all roadmap areas, there is an increasing emphasis on ensuring that models used for planning and operations are transparent, explainable, and supported by clearly defined assumptions and data. This supports greater confidence in modelling outcomes and enables more effective communication of results to stakeholders.

Theme 1 – model development

The model development theme covers the following areas:

- increasing system complexity driving the need for improved representation of emerging technologies, including inverter-based resources, large loads, and DER – for example, investigating requirements to model the distribution network and modelling existing constant and time-varying loads to support DER visibility,
- greater consistency and interoperability of models across tools and environments required to support efficient study processes and cross-platform integration, and
- growing need to balance model granularity, computational efficiency, and user-friendliness, requires targeted application of detailed models while maintaining manageable study complexity.

Example implementation pathways:

- **Vendor-agnostic models (Short-term)** – define minimum model format and interface requirements to enable interoperability between modelling tools, and begin incorporating these into new connection processes and vendor engagements.
- **Regional EMT models (Short-term)** – develop pilot EMT models for selected high-priority regions or study types to reduce complexity and simulation time, particularly to support targeted analysis of emerging system behaviours.
- **Grid-forming models and performance requirements (Medium-term)** – establish consistent modelling assumptions and performance expectations for newer technologies such as grid-forming inverters and power electronic interfaced loads, and integrate these into connection and planning frameworks.

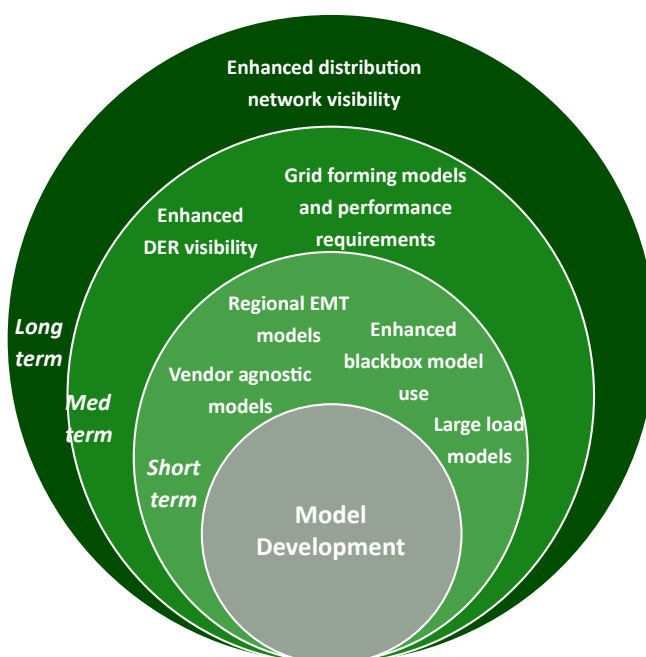


Figure 1: Roadmap actions related to model development activities

Theme 2 – model management and validation

The model management theme covers the below gaps and uplift opportunities. This is a critical enabler of modelling to ensure that accurate, fit-for purpose models and data are available irrespective of the tool or methodology used by engineers for planning, connections and operational studies. It covers these areas:

- models and supporting data often distributed across multiple tools and environments, creating challenges in maintaining consistency across studies and use cases,
- a need to strengthen model governance, including standardisation of submission, validation, and version control processes, and
- continued model validation through improved integration between operational data and modelling workflows increasingly important to ensure models remain aligned with real system conditions.

Example implementation pathways:

- **Standardised model submission and validation (Short-term)** – introduce common submission requirements and validation checks to ensure models are consistently reviewed before being accepted into operational use.
- **Updating EMT models using Energy Management System (EMS) data (Medium-term)** – develop workflows that use operational data to improve model initialisation and alignment with system conditions.
- **Scalable computing environment (Medium-term)** – expand computational capability to support increasingly complex studies, enabling larger and more detailed simulations to be undertaken efficiently (for example, distributed simulation techniques to improve scalability).

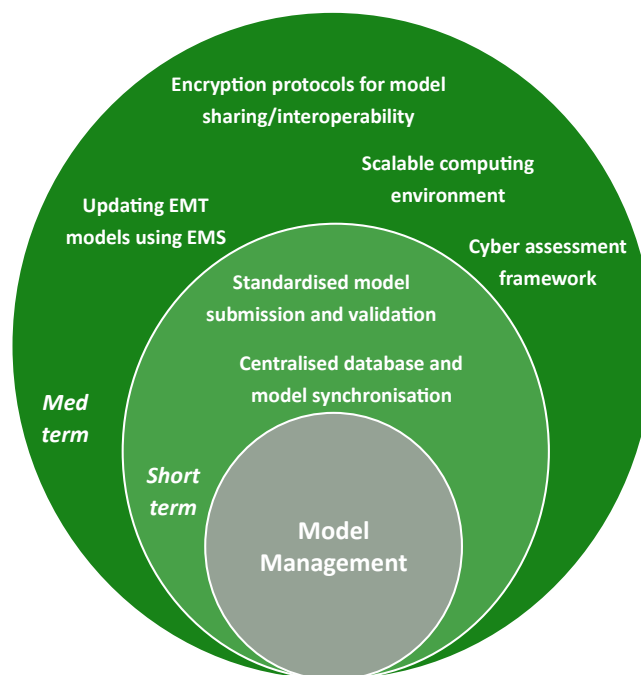


Figure 2: Roadmap actions related to model management

Theme 3 – real-time capability and monitoring

The real-time monitoring theme covers the following gaps and uplift opportunities:

- increasing availability and accuracy of high-resolution measurement data to improve model validation processes and real-time situational awareness as well as automated model validation and performance assessment,
- a need to better integrate measurement data into both planning and operational processes to support better informed decision-making, and
- enhanced integration of high quality measurement data that can support improved understanding of system behaviour and enable more proactive management of emerging risks. Although a range of relevant inputs (such as operational forecasting and uncertainty visibility) will impact modelling capabilities and accuracy, these are outside of the scope of this report.

Example implementation pathways:

- **Defined oscillation thresholds and mitigation (Short-term)** – establish thresholds for identifying unstable oscillatory behaviour and develop corresponding operational or planning responses, supported by Phasor Measurement Units (PMU) and oscillation detection capabilities.
- **Real-time fault level and inertia (Long-term)** – integrate measurement-based estimates of key system parameters into operational tools to support real-time decision-making.
- **Look-ahead simulation tools (Long-term)** – develop tools that use current system conditions to assess potential future system states and support planning for operability.

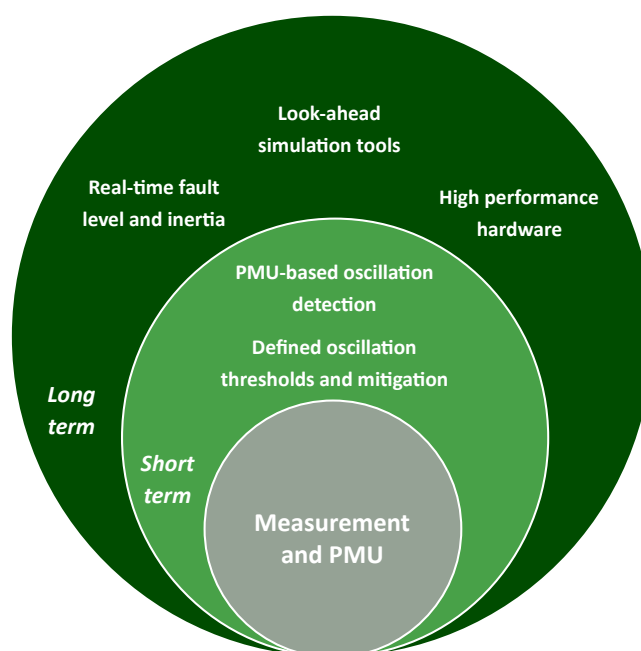


Figure 3: Roadmap actions related to real-time monitoring

Theme 4 – modelling techniques

The modelling techniques theme covers the following gaps and uplift opportunities:

- increasing system complexity driving need for more advanced and scalable modelling approaches to efficiently capture emerging system behaviours,
- a need for improvement in the application and coordination of different modelling techniques, enabling more targeted use of detailed simulations where most impactful, and
- emerging technologies and analytical approaches creating opportunities to improve study efficiency, automation, and integration across planning, operational, and validation processes. Example technologies include advancing artificial intelligence (AI), surrogate models, and digital twin representations.

Example implementation pathways:

- **Implement screening processes (Short-term)** – introduce structured approaches to identify which scenarios or parts of the system require more detailed modelling or greater analysis, particularly for emerging dynamic behaviour, improving the efficiency of study processes.
- **Investigate co-simulation (Short-medium term)** – explore how different simulation environments (for example, EMT and RMS) can be combined and integrate co-simulation workflows into study processes for more consistent application across planning and operational assessments.
- **Automated fault levels and impedance scans (Medium-term)** – implement automated processes to perform routine analytical tasks, improving consistency and reducing manual effort in study preparation.
- **Enhanced equivalencing of regional EMT (Long-term)** – develop improved methods for representing wider system behaviour in reduced and/or hybrid models, enabling more efficient large-scale studies while maintaining key dynamics for the areas of interest.
- **Frequency domain and small signal analysis tools (Long-term)** – integrate additional analytical tools into standard workflows to support assessment of emerging system dynamics and stability risks.

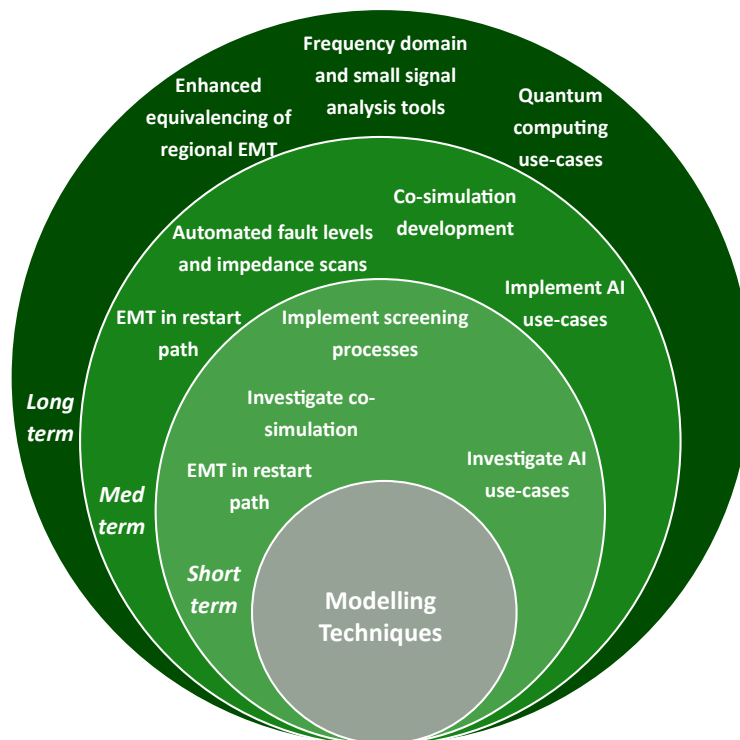


Figure 4: Roadmap actions related to modelling techniques

Key functional gaps

Models:

- demonstrated application of standard IEEE/CIGRE models to EMT and RMS tools, and
- models accurately representing newer developments in large loads, and grid-forming inverter behaviour

Software:

- ability to compile and convert models between formats and versions (user model portability),
- support for IEEE/CIGRE standard models,
- co-simulation capability,
- fast EMT analysis including enabling deployment of EMT simulations to Graphics Processing Units (GPUs),
- unbalanced dynamic studies in RMS tools,
- auto-layout, automated post-processing and plotting gaps,
- application of AI for screening analysis,
- fast and robust load flow solvers,
- improved debugging/error report capability of simulation software to help users identify the source of issues with the case or software, and
- improved integration of market modelling and engineering analysis tools.

Hardware:

- high-performance hardware including optimal clock speed and Remote Direct Memory Access (RDMA) server configurations to meet simulation time requirements, and
- future application of quantum computing for power system analysis applications.

Training:

- increased staff readiness and familiarity with EMT software tools and analysis methods.

Learnings from software vendor inputs

A questionnaire covering the different modelling capabilities and some of the ongoing improvements/plans to the software platforms was prepared and shared with multiple software vendors who develop software packages for RMS/EMT/Real Time simulation. The choice of vendors engaged provided a broad coverage of the software solutions available to SOs. ISON would like to thank the software vendors for their feedback and the responses to the questionnaire. A summary of some of the responses is provided below, specifically along certain features. Please note this information was provided directly by vendors and has not been independently verified.

- **Unbalance modelling** – the EMT and Real Time platforms fully support unbalance modelling. Most RMS platforms utilise positive sequence simulations and have limited support for unbalance through sequence-based analysis, though some RMS platforms with unbalance modelling support do exist.
- **User Defined Model (UDM)** – all platforms support UDMs in binary form, in most cases in the form of Dynamic Linked Library (DLL). Some of the platforms have platform-specific/native UDMs or require models to be written in particular languages. Some platforms have an additional graphical editor for creating native UDMs or support UDMs according to Functional Mock-up Interface (FMI)/Functional Mock-up Unit (FMU), and additional platform specific options may exist. Some of the standard DLL formats supported (support varies across platforms) include CIGRE/IEEE format DLLs, IEC 61400-27-1, and FMI.

- **EMS/SCADA** – some platforms have support for interfaces with real-time and forecast data via different standard communication protocols (one example is IEC 61850, some other commonly mentioned protocols include IEC 60870, DNP3, Modbus, IEEE C37.118; note, different protocols may be supported by different platforms). Some platforms achieve connection with EMS and SCADA systems through databases and Representational State Transfer (REST) Application Programming Interfaces (APIs), or through standard files such as sequence of events, comtrade, text files (csv, powerflow data, xml). In some other cases, such updates can be made using the application API.
- **Frequency/small signal** – some of the RMS tools have a dedicated frequency domain/eigenvalue analysis module. Most RMS and EMT tools have some form of impedance scan tool available, though features may differ. Additional modules in some of the tools include prony/matrix pencil, dissipating energy factor analysis and oscillation identification, harmonics, subsynchronous resonance stability analysis, Fast Fourier Transform (FFT), parameter identification, and impedance-based stability assessment.
- **Automation tools** – available automation tools differ by platform; some of the tools are for model quality testing, North America Electric Reliability Corporation (NERC) case quality assessment, contingency analysis, transfer analysis, grid code assessment, time series power flow, task automation and time/file watcher, parametric scenario creation/simulation, line/transformer/substation/motor design, tools for result analysis, and record/play-back functionality.
- **Automation APIs** – all platforms support Python (with certain limitations for few of the platforms), and some other supported languages are C, C++, MATLAB, and Javascript. Platform-specific programming languages also exist for some of the platforms, and some platforms also support REST and database APIs.
- **Data/model management** – model databases with version control are available in some of the platforms; this feature is more common for RMS tools. Some other tools rely on external version control using the input files or project/case data (this is more common for EMT and Real Time platforms). Some features available in a few of the tools include Common Information Model (CIM) support, conversion to other domains, and scenario/contingency data and model management.
- **Co-simulation** – dedicated support for co-simulation varies across the tools, ranging from co-simulation that can be achieved using the application API, to support for co-simulation with specific software platforms (this is the case for most tools, though specific platforms for co-simulation will differ). Tools supporting both RMS and EMT modelling can also perform hybrid simulations, with both RMS and EMT portions modelled in the same software. Some of the tools support FMI-based co-simulation, though there may also be some support in a few tools for other co-simulation frameworks.
- **Additional improvements** – some of the common additional improvements mentioned by vendors include improved support for CIGRE/IEEE DLLs, CIM support, improvements to small signal stability and frequency domain impedance based analysis, model quality testing/checks and validation, improvements to post-processing and plotting, more co-simulation options, and additional automation, which may be through tools for specific studies such as for grid code compliance or motor starting analysis, or enhancements to APIs.

Contact

For any specific feedback on this Knowledge Sharing Brief, please contact contact@isonetwork.org.