Public

Guidance Notes for Electro-Magnetic Transient (EMT) Models

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Foreword

These Guidance Notes have been prepared by the National Energy System Operator (NESO) to describe to Generators and other Users on the system the EMT modelling requirements, including guidelines for modelling efficiency, fidelity, usability, document, and maintenance.

These Guidance Notes are prepared, solely, for the assistance of prospective Users connecting directly to the National Electricity Transmission System. In the event of dispute, the Grid Code and Bilateral Agreement documents will take precedence over these notes.

The Operability Innovation Manager (see contact details below) will be happy to provide clarification and assistance required in relation to these notes.

NESO welcomes comments including ideas to reduce the modelling effort while maintaining the level of confidence. Feedback should be directed to the NESO Operability Innovation Team at:

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Disclaimer: This document has been prepared for guidance only and does not contain all the information needed to comply with the specific requirements of a Bilateral Agreement with NESO. Please note that whilst these guidance notes have been prepared with due care, NESO does not make any representation, warranty or undertaking, express or implied, in or in relation to the completeness and or accuracy of information contained in these guidance notes, and accordingly the contents should not be relied on as such.

Version	Date	Comment
Issue 1.0	Jan 2023	First Guidance for EMT modelling requirements for Users
Issue 2.0	Sep 2025	Revised Guidance Notes based on Industry feedback

Contents

Introduction

As Great Britian's Electricity System continues to decarbonise, we continue to see increasing penetration of Inverter Based Resources (IBR). These IBRs are connected to the grid through power electronic converters whose dynamic characteristics are different from the conventional synchronous generators. Critical control system elements such as phase-locked loop (PLL) within Inverter-based resources (IBR) would affect the interaction with network dynamics. In traditional Root Mean Square (RMS) models of IBRs, these critical control system elements are not included or not adequately represented; RMS models-based analysis might not identify potential system risks such as oscillations at sub synchronous frequencies. EMT models would be needed, for the system security, to identify the potential risk with high penetration of IBR such as system oscillations. The current Grid Code obligates the Users to provide the EMT models of their plant and apparatus to the NESO.

This document outlines the guidance notes for EMT models, which should be followed by the Users, who need to submit the EMT model as per Grid Code, when they develop and submit the EMT models of their plant and apparatus. EMT models compatible with these guidance notes would enable the NESO to effectively setup the study, merge the Users' models to the network model, and execute the simulation studies. In the event of dispute, the Grid Code and Bilateral Agreement documents will take precedence over these notes.

These guidance notes cover the requirements in:

- Efficiency: specify the software environment and model features which mitigate any compatibility issues.
- Usability: specify the model features that allow the model users effectively configure parameters, setup and execute the simulation, and analyse the results.
- Fidelity: specify the model contents and parameterization to ensure accurate representation of the plan and apparatus.
- Document: specify the user guidance and other items that should be documented.
- Maintenance: specify the requirements that ensure the maintenance for the model.

Guidance on model efficiency

The EMT model should:

1. Be compatible with PSCAD/EMTDC version 5.0 or above.
2. Be compatible with Intel Fortran Complier version 19.2 and higher, and Visual studio 2019 and newer. Users connecting from Jan 2026 should provide the EMT model compatible with both 32 –bit and 64- bit versions of Intel Fortran Complier.
3. Have time steps which must be appropriate for the accurate representation of the switching algorithms used in the Plant and Apparatus and compatible with study time steps in the range of 10µs to 20µs. The simulation time step should not be hard-coded but allow the user to have the flexibility to change the simulation time step. Any accuracy limitations at 20µs time steps must be clearly flagged to the NESO in the model documentation.
4. Allow it to be used as several "instances" or "definitions" in the same simulation case. The EMT model can be implemented functionally several times in the same PSCAD simulation file without requiring significant changes to be made.
5. Support the PSCAD "time snapshot" and "multiple run" features.
6. Not use global variables. Allow replication in different PSCAD cases or libraries through the "copy" or "copy transfer" features.
7. Not utilize multiple layers in the PSCAD environment, including 'disabled' layers.
8. Be capable of self-initialisation, with initialisation to user defined terminal conditions within 4 to 6 seconds of simulation time. Additionally, it should be capable of completing a simulation run of 20 seconds within a 15-minute timeframe.
9. Be based on plant design data and rigorously tested against factory acceptance tests for the corresponding version of plant.
10. Be delivered in a format that allows for maintenance for life of asset (e.g. .dll, support files).
11. Not have dependencies on additional external commercial software, however dependencies on free, commonly available redistributable libraries may be acceptable.
12. Have all plant and control system models contained within a single EMT case, rather than spanning across a simulation set. Methods used to split a single plant's model components across several files for (typically SMIB) processing speed improvements may not be compatible with the broader case into which it will be integrated.

13. Effectively manage computing resources; for example, this may involve memory allocation and deallocation, the use of debug versus release flags, and other related factors.
14. Be numerically stable and accurate for a minimum 100 seconds following any set point changes or system incidents/faults.

Guidance on model fidelity

The EMT model should:

1. Work for a range of dynamic simulation solution parameters rather than for specific settings only and be numerically stable and accurately reflect the plant behaviour for the full operating range including the designed MW and MVAr output, the designed range of short circuit ratio (SCR) at the grid entry point and grid fault X/R ratio in different operational modes; any model validity limitations due to system impedance or strength should be clearly defined.
2. Represent all electrical and mechanical configuration, such as machines/converters, SVC, STATCOM, cables, filters, transformers, and capacitors. Mechanical features, such as flywheel, clutch, gearbox, and pitch controllers, should be included in the model if they impact electrical performance.
3. Represent the sub-synchronous oscillation (SSO) mitigation and/or protection including the ability to enable and disable SSO mitigation/protection, if applicable.
4. Include the transformer magnetizing curves.
5. Include any control or dynamic feature of the actual equipment which may influence simulation behaviour, such as, all the operating modes of converters, control strategies of SVC and STATCOM, etc. If any relevant control or dynamic features are simplified or not represented, they should be documented.
6. Represent plant level control. Power Plant Control (PPC) must be represented in sufficient detail to accurately represent its performance, including specific measurement methods, detailed representation of hardware and software filters, communication time delays, transitions into and out of ride-through modes, settable control parameters or options, and any other specific implementation details which may impact plant behaviour. Generic PPC representations are not acceptable unless the final PPC controls are designed to exactly match the generic PPC model. If multiple plants are controlled by a common controller, or if the plant includes multiple types of IBRs (e.g., Hybrid BESS/PV) this functionality must be included in the plant control

model. If supplementary or multiple voltage control devices (e.g., STATCOM) are included in the plant, these should be coordinated with the PPC.

7. Include model parameters, configured to match expected site-specific equipment settings, not the manufacturer default setting. Any user-tuneable parameters or options should be set in the model to match the equipment at the specific site being evaluated, as far as they are known. Default parameters are not appropriate.
8. Represent the plant grounding system. The plant grounding will impact the generator fault contribution and represent the imbalance in the three-phase system.
9. Have no unexpected or uncharacteristic responses. The model must not show characteristics that are not present in the plant response, both in terms of the electrical response and modelling numerical artefacts. Numerical artefacts refer to errors that arise from the computational process rather than the actual physical behaviour of the plant. Examples of artefacts can include numerical instability, round-off errors, discretization errors, simulation software crashes, or other numerical inaccuracies that can lead to distorted simulation results (spikes) or unrealistic behaviour (active, reactive power spiking to 2 p.u or higher) in the model.

1. Synchronous and induction generators

Following the points 1-9 above, this part covers the additional guidance for synchronous machines and induction machines, for example combustion turbine generators, steam turbine generators, hydro generators, and Type 1 and Type 2 wind turbines.

10. The representation of mechanical rotating mass of a synchronous machine or induction machine as a single lumped inertia as used in transient stability is required. It is also necessary to provide the multi-mass torsional shaft data for a synchronous machine or induction machines as appropriate. The model data should include the inertia constants, shaft spring constants, torque share between the different masses, and damping.
11. Include representation of the machine saturation or magnetizing curve.
12. Represent the generator excitation system / governor model / power system stabilizer (PSS) as a user written PSCAD model or as standard PSCAD block models with the model type and data specified. If standard PSCAD block models are used, a statement from the manufacturer or plant operator confirming that the models can represent the accurate excitation system performance in transient simulations (10 -20 micro-second time step) must be included.

13. Represent all installed protection system in detail for both balanced and unbalanced fault conditions. This could include various over-voltage and under-voltage protection (individual phase and RMS), overcurrent protection, frequency protection, loss of field protection, under/over-excitation protection, reverse power protection, out of step protection, and any other pertinent types of protection. Represent any run back scheme or special protection scheme in which machine/plant participates in. The actual hardware code is recommended to be used for these protection features. Any protection which can influence dynamic behaviour or fault ride-through in the simulation period should be included and documented. The model should allow the user to enable and disable these protection systems.

2. Inverter-based resources - IBRs

Following the points 1-9 above, this part covers the additional guidance for IBRs.

14. The power electronic switches may be represented as switching type models, detailed equivalent model or through controlled voltage or current source (average type) representation. If the model is based on average type representation of the inverters, the vendor should verify that the control and protection functionalities are not simplified, benchmarked with the actual firmware, and the model is suitable for dynamic response analysis.
15. Represent the full detailed inner control loop for the power electronics. This representation should include all fast inner controls implemented in the physical equipment. Models which embed the actual hardware code into a PSCAD component is recommended. If the model is assembled using standard blocks available in the PSCAD master library, a validation against actual hardware performance is required.
16. Represent all control features as per the site settings and adopted control system strategy. This should include external voltage controllers, plant level controllers, customized phase locked loop (PLL) systems, ride-through controllers, sub-synchronous control interaction damping controllers, and others. Operating modes that require system specific adjustment should be user accessible.
17. Represent all installed protection system in detail for both balanced and unbalanced fault conditions. This could include various over-voltage and under-voltage protection (individual phase and RMS), frequency protection, DC bus voltage protection, overcurrent protection, and any other pertinent types of protection. The actual hardware code is recommended to be used for these protection features. Any

protection which can influence dynamic behaviour or fault ride-through in the simulation period should be included and documented.

18. It is allowed to represent an aggregated model for a generating system with many generating units if they are of the same type and size, for example, a wind farm has multiple wind turbines of same type and size. The aggregation method must be clearly documented. Aggregated models should continue to provide access to the LV terminal bus quantities for each aggregate equivalent generating unit, including active power, reactive power, voltage magnitude and phase angle.
19. The co-located User shall model the Plant and Apparatus in accordance with the Single Line Diagram (SLD), accurately reflecting the actual as-built configuration. For example, in the case of a co-located Power Park Module comprising Battery Energy Storage System (BESS) and Photovoltaic (PV) plant, the inverters/converters for each plant should be modelled separately as per the SLD. For the avoidance of doubt, it would be acceptable to aggerate the inverters belonging to one plant (e.g., BESS) in accordance with point number 18 on representation of aggregated model.

Guidance on model usability

The EMT model should

1. Make the inputs and outputs of control/protection blocks such as active power controller, reactive power controller and voltage controller accessible to the end users.
2. Have an identification mechanism for configuration. The model documentation should provide a clear way to identify the specific settings and equipment configuration which will be used in any study, such that during commissioning the settings used in the studies can be checked. This may include control revision codes, settings files, or a combination of these and other identification measures.
3. Have pertinent control or hardware options accessible to the user (e.g., adjustable protection thresholds, real power recovery ramp rates, apparent power injection start time, frequency or voltage droop settings, voltage control response times, or sub-synchronous control interaction damping controllers), although -EMT model must be configured to match site specific settings as far as they are known.
4. Accept external reference values. This includes real power reference (for active power control mode) or frequency reference (for frequency control), and reactive power reference value (for Q control mode), voltage reference value (for V control mode) or

power factor reference value (for PF control mode). Model should accept these reference variables for initialization and be capable of changing these reference variables mid-simulation, i.e., dynamic signal references.

5. Have diagnostic flags (e.g., flags to show control mode changes or which protection has been activated) which can be reasonably accessible to facilitate analysis and should clearly identify why a model trips during simulations.
6. Provide meaningful messages in PSCAD output window in the event when preconfigured network conditions exceed the model design limits.
7. Include a sample implementation test case. Test case models should be configured according to the site-specific real equipment configuration up to the point of interconnection. This includes, but is not limited to: aggregated generator model, aggregated generator transformer, equivalent collector branch, main step-up transformers, generator tie line, and any static/dynamic reactive resources. Test case should use a single machine infinite bus representation of the system, configured with its full operational range of short circuit ratio (SCR).
8. Be capable of initializing itself within 4 to 6 seconds for strong and weak networks. Models should initialize and ramp to reference output without external input from simulation engineers. Any slower control functions which are included (such as switched shunt controllers, transformer tap changers and other power plant controllers) should also accept initial condition variables if required. Note that during the first few seconds of simulation (e.g., 0-2 seconds), the system voltage and corresponding terminal conditions may deviate from nominal values due to other system devices initializing, and the model must robustly tolerate these deviations or provide a variable initialization time. Additionally, it should be capable of executing a real-time simulation run of 20 seconds within a 15-minute timeframe.
9. Allow protection models to be disabled and enabled, if applicable. Many studies result in inadvertent tripping of converter equipment, and the ability to disable protection functions temporarily provides study engineers with valuable system diagnostic information.
10. Allow the capacity of the model to be scaled if using same inverter, collector and/or padmount transformer models. The capacity of the model should be scalable in some way, either internally or through an external scaling component. This is distinct from a

dispatchable power order described below and is used for modelling different plant capacities or breaking a lumped equivalent plant into smaller composite models.

11. Dispatch its output to values less than nameplate. This is distinct from scaling a plant from one unit to more than one and is used for testing plant behaviour at various operating points.
12. Models do not crash the software platform when model/plant is tripped or disconnected during the dynamic simulation run.
13. It is desirable that technical support engineers from the model supplier are available to support the NESO in setup and running simulation analysis and solve any relevant issues.

Document Requirements guidance

The model should be submitted together with a supporting document including the following information:

1. List and description of the files in the submission.
2. Vendor name and model version number
3. Indication of whether the model is real-code or not, and the recommended range of simulation time step.
4. Single-line representation of the simulation model's electrical and mechanical main components up until the point of connection.
5. Indication of any limitations and assumptions of the models, including the full range of grid strength the model is designed for and the acceptable step sizes.
6. Block diagrams of the control system.
7. Description of model structure, including the list and description of all the modules and control functions. This could contain Laplace domain transfer functions, sequence diagrams for applied state-machines and function descriptions of the arithmetical, logical and sequence-controlled modules used in the simulation model. Moreover, the reference component used in control functions should be indicated, for example, the busbar whose voltage is used as a reference in the control of an SVC.

8. Guidance for setup and running of model. The EMT model User guide document must include the PSCAD and complier version details that it corresponds to, instructions on loading the model, setting the specific system strength, updating the settings of the relevant modules/functions, switching the control mode of converters, selecting the test case, and enabling/disabling the protection systems.
9. Description of the module/function settings needed for different operational scenarios, for example, different operational modes of converters, different system strength of the network, different power flow directions for Interconnectors/batteries.
10. Description of how the simulation model can be integrated into a large grid and system model of the public electricity supply grid as used by the transmission system operator.
11. List and description of operating modes of the converters and their applicable network scenarios.
12. List and description of control strategies of dynamic equipment, such as SVC, STATCOM, etc.
13. List and description of all the simplifications used in the model.
14. List and description of any modules and functions that are not included in the model.
15. List and descriptions of the individual model components, including saturation, non-linearity, dead band, time delays and constraint functions (non-windup/anti wind-up) as well as look-up table data and principles applied to interpolation, etc. Their parameters' values and units should be included.
16. Include descriptions and clear indications of the simulation model's input and output signals, which, as a minimum, must include the following:
    - Active power.
    - Reactive power.
    - Set points for:
        - Active power control.
        - Power factor control (cos φ control).
        - Q control (MVAr control).
        - Voltage control including parameters for droop/compounding used.

        - Frequency control (droop and deadband).
        - System protection measures (final value and gradient for active power control).
    - Signal for activation of system protection.
    - Control signals for any external grid components, e.g., STATCOMs or energy storage units, etc.
    - Active and reactive power injection/absorption settings during fault.

17. List and description of the test cases used to verify the response of the model.
18. List and description of all the protections (both AC and DC protections) and identifying those associated settings accessible to the user.
19. Model validation and benchmarking against field test data if the model does not use real code.
20. Guidance on the interpretation of error messages and troubleshooting.

Guidance on model maintenance

Model providers should confirm that they have model maintenance and support frameworks in place with vendors / suppliers for the duration of the designed asset operational lifetime to provide model updates and technical supports to Transmission Owner and NESO. Should this requirement be not achievable either in practical or commercial terms, then further discussions with NESO are required to seek alternative means of continued model maintenance and supports.