

Electromagnetic Transient (EMT) Model Requirements and the Approach & Process for Retrospective Submission

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Contents

1.	Introduction	3
2.	EMT Model Requirements for Users	5
2.1	Notes on model efficiency	5
2.2	Notes on model fidelity	6
2.2.1	Synchronous and Induction generators	7
2.2.2	Inverter-based resources – IBRs	8
2.3	Notes on model usability	9
2.4	Notes on document requirements	10
2.5	Notes on model maintenance	12
3.	Model Submission Process	14
4.	Model Submission Approach	16
5.	Potential approaches to develop the legacy Plant EMT Models	18
5.1	Validation Requirements for legacy Plant EMT Models	20

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1. Introduction

This document outlines the requirements for Electro-Magnetic Transient (EMT) models, for Users who are developing and submitting EMT models of their Plant and Apparatus in compliance with the Grid Code. EMT models compatible with these requirements will enable The Company to effectively merge the Users' models to the network model, setup the study and carry out analysis. In the event of a dispute, the Grid Code and Bilateral Agreement documents take precedence over this document.

This document also outlines the approach and process for submitting EMT models for legacy power Plants.

This document contains two parts:

- Part 1 – Provides detailed requirements describing the technical expectations of EMT models, in terms of efficiency, fidelity, usability, maintenance, and the minimum required documentation.
- Part 2 – Presents the approach and process for submitting retrospective EMT models.

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Part 1

EMT Model Requirements for Users

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2. EMT Model Requirements for Users

Critical control system elements such as phase-locked loop (PLL) within Inverter-based resources (IBR) affect the interaction with network dynamics. In traditional Root Mean Square (RMS) models of IBRs, these critical control system elements are not included or adequately represented; RMS models-based analysis might not identify potential system risks such as oscillations at sub-synchronous frequencies. EMT models are therefore needed to evaluate system security and identify potential risks, such as system oscillations, in systems with a high penetration of IBR. This document covers the requirements of EMT model development in terms of the following aspects:

- **Efficiency:** specify the software environment and model features which mitigate any compatibility issues.
- **Fidelity:** specify the model contents and parameterisation to ensure accurate representation of the Plant and Apparatus.
- **Usability:** specify the model features that allow the model users to effectively configure parameters, setup and execute the simulation, and analyse the results.
- **Documentation:** specify the items that should be documented.
- **Maintenance:** specify the requirements that ensure maintenance of the model.

2.1 Notes on model efficiency

The EMT model should:

1. Be compatible with PSCAD/EMTDC version 5.0 or above.
2. Be compatible with Intel Fortran Compiler version 19.2 and higher, and Visual Studio 2019 and newer. Users submitting the EMT model from January 2026 shall be compatible with both 32-bit and 64-bit versions of Intel Fortran Compiler.
3. The simulation time step should not be hard-coded but should allow the user flexibility to change the simulation time step. Any accuracy limitations at 20µs time steps must be clearly flagged to The Company in the model documentation.
4. 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. When the “snapshot” function is used, the model must provide the same response with or without snapshot usage.
6. Not use global variables. Allow replication in different PSCAD cases or libraries through the “copy” or “copy transfer” features.
7. Not utilise multiple layers in the PSCAD environment, including ‘disabled’ layers.
8. Be capable of self-initialisation.

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- a. The model should initialise and reach steady state to any user defined and valid operating conditions within 4 to 6 seconds of simulation time.
 - b. The model should initialise and ramp to reference output without external input from simulation engineers.
 - c. Any slower control functions which are included (such as switched shunt controllers, transformer tap changers and other power Plant controllers) 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 initialising, and the model must robustly tolerate these deviations.
 - d. Additionally, be capable of completing a simulation run of 20 seconds within a 15-minute timeframe.
9. Be based on Plant Single Line Diagram and rigorously tested against factory acceptance tests and/or site-specific compliance tests for the corresponding version of Plant.
 10. Be delivered in a format that allows for maintenance of the model for the duration of the life of the asset (e.g., support files).
 11. Not have dependencies on additional external commercial software, however, dependencies on free, commonly available redistributable libraries may be acceptable, subject to discussion with The Company.
 12. Have all Plant and control system models contained within a single EMT case, rather than spanning across multiple projects. The Company understands that, for complex models, it is not possible to meet 20 second simulation runs in a 15-minute time frame. In exceptional circumstances, the User may be allowed to split the model into a reasonable number of project cases, subject to agreement with The Company.
 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.

2.2 Notes on model fidelity

The EMT model should:

1. Work for a range of dynamic simulation solution parameters rather than for specific settings only. It should be numerically stable and accurately reflect the Plant behaviour for the full operating range including:

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- The designed MW and MVar output,
 - The designed range of short circuit ratio (SCR) at the Grid Entry Point, and the grid fault X/R ratio in different operational modes,
 - Any model validity limitations due to system impedance or strength (these should be clearly defined), and
 - Control strategies of SVC and STATCOM, etc.
2. Represent all electrical and mechanical configurations, 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 schemes, including the ability to enable and disable SSO mitigation/protection, if applicable.
 4. Include the transformer magnetising curves.
 5. Include model parameters configured to match expected site-specific equipment settings, not the manufacturer's 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.
 6. Represent the Plant earthing system. The Plant earthing will impact the generator fault contribution and represent the imbalance in the three-phase system.
 7. 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, discretisation 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 pu or higher) in the model.

2.2.1 Synchronous and Induction generators

Following the points 1–7 above (notes for model fidelity in Section 2.2), this section covers additional notes for synchronous machines and induction machines, for example combustion turbine generators, steam turbine generators, hydro generators, and Type 1 and Type 2 wind turbines.

1. 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.

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2. 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.
3. The model should include representation of the machine saturation or magnetising curve.
4. The model should represent the generation excitation system, governor, 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 μ s time step) must be included.
5. The model should represent all installed protection systems 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. The model should represent any run back scheme or special protection scheme in which the machine/Plant participates.
6. The actual hardware code is recommended to be used for protection features. Any protection which can influence dynamic behaviour or fault ride-through in the simulation period should be included and documented.

2.2.2 Inverter-based resources – IBRs

In addition to points 1–7 provided in section 2.2, the EMT model for IBRs should:

1. For power electronic switches, these may be represented as switching type models, detailed equivalent models or through controlled voltage or current source (average type) representation. If the model is based on average type representation of the inverters, the User should verify that the control and protection functionalities are not simplified, are benchmarked with the actual firmware, and that the model is suitable for dynamic response analysis.
2. 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

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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.

3. Represent the full detailed inner and outer control loops for the Plant. This representation should include all fast inner controls implemented in the physical equipment. Models that 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.
4. Represent all installed protection systems 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.
5. 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 that has multiple wind turbines of the 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.
6. The User shall model the co-located 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 aggregate the inverters belonging to one Plant (e.g., BESS) in accordance with point number 5 in this section, on representation of aggregated model. Both technology types must be included in the same EMT model.

2.3 Notes on model usability

The EMT model should:

1. Make the inputs and outputs of control blocks such as Active Power controller, Reactive Power controller, voltage controller and damping controllers accessible to

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the end users. For example, Setpoints for Active Power, Reactive Power, voltage, Power Factor and frequency references, Active Power ramp rates, control modes selection, Fault ride-through activation and deactivation thresholds, dead-band and Droop settings of frequency or voltage control, communication delays, enabling and disabling of sub-synchronous damping controllers.

2. Accept the above reference variables for initialisation and be capable of changing these reference variables mid-simulation, i.e., dynamic signal references.
3. Have an identification mechanism for configuration i.e., control revision codes, settings files, or a combination of these or other identification measures.
4. Have diagnostic flags (e.g., flags to show control modes change or which protection has been activated) which can be reasonably accessible to facilitate analysis and should clearly identify why a model trips during simulations.
5. Include a sample implementation test case such that the model can be tested before being integrated into the wider area model of the GB system. The test case should use a single machine infinite bus representation of the system.
6. 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.
7. Allow the capacity of the model to be scaled if using the same inverter, collector and/or pad-mounted 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.
8. Dispatch its output to values less than the nameplate rating. 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.
9. Not crash the software platform when the model/Plant is tripped or disconnected during the dynamic simulation run.
10. It is desirable that technical support engineers from the model supplier are available to support The Company in setting up and running simulation analysis, to assist with solving any relevant issues.

2.4 Notes on document requirements

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.

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3. Indication of whether the model is real-code or not, and the recommended simulation time step (between 10 – 20us).
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.
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. Notes for setup and running the model. The EMT model User guide document must include the PSCAD and compiler version details that it corresponds to, instructions on loading the model, relevant information on multiple snp files if created during snapshot feature, 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. 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.
10. 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.
11. 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 Company.
12. List and description of control strategies of dynamic Reactive Power equipment, such as SVC, STATCOM, etc.
13. List and description of any modules and functions that are simplified or not included in the model.
14. List and descriptions of the individual model components, including saturation, non-linearity, dead band, time delays and constraint functions (non-windup/anti windup) as well as look-up table data and principles applied to interpolation, etc. Their parameters' values and units should be included.
15. Include descriptions and clear indications of the simulation model's input and output signals, which, as a minimum, must include the following:

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- a. Active Power.
 - b. Reactive Power.
 - c. Set points for:
 - i. Active Power control.
 - ii. Power Factor control.
 - iii. Q control (MVAR control).
 - iv. Voltage control (including parameters for droop/compounding used).
 - v. Frequency control (droop and dead band).
 - vi. System protection measures (final value and gradient for active power control).
 - d. Signal for activation of system protection.
 - e. Control signals for any external grid components, e.g., STATCOMs or energy storage units, etc.
 - f. Active and Reactive Power injection/absorption settings during fault.
16. List and description of the test cases used to verify the response of the model.
 17. List and description of all the protections (both AC and DC protections) and identifying those associated settings accessible to the user.
 18. Model validation and benchmarking against field test data.
 19. Notes on the interpretation of error messages and troubleshooting.

2.5 Notes on model maintenance

Users 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 Owners and The Company. Should this requirement not be achievable, either in practical or commercial terms, then further discussions with The Company are required to seek alternative means of continued model maintenance and supports.

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Part 2

The Approach and Process for Retrospective Submission

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3. Model Submission Process

When The Company requests Users to provide retrospective EMT models (more on the priority order of these requests in Section 4 below), Users shall acknowledge the request and confirm the following details:

- Acceptance of providing the EMT model, with a proposed timeline.
- Level of modelling details that will be provided in the EMT model.
- Confirmation of provision of validation report, as per PC.A.9.7.

A flowchart describing the model submission process is presented in Figure 1.

For EU Code Users with IBR based converters, including Interconnectors, an EMT model is required to be submitted in PSCAD version 5 and above within 3 months. It is likely that these Users may have already developed EMT model in an older version of PSCAD. The three-month window is intended to cover the time required to update and submit the EMT model in PSCAD version 5 and above.

For Synchronous generator-based EU Code Users, an EMT model built in previous versions of PSCAD can be submitted. In case of unavailability of an EMT model of the Synchronous generator Plant, Users can submit the relevant Plant parameters/data as per the requirements in DRC Schedule-1 and Grid Code PC.A.5.3.

For GB Code Users, if the requirement to submit EMT models was captured in the Bilateral Agreement, then the User will be requested to submit the EMT Model in PSCAD version 5 and above within 6 months. For an IBR-based GB Code User, the EMT model in PSCAD version 5 and above can be submitted within 9 months after the request is made from The Company. However, synchronous generator-based GB Code Users are requested to submit the relevant Plant parameter/data as per requirements in DRC Schedule -1 and Grid Code PC.A.5.3 within 3-6 months.

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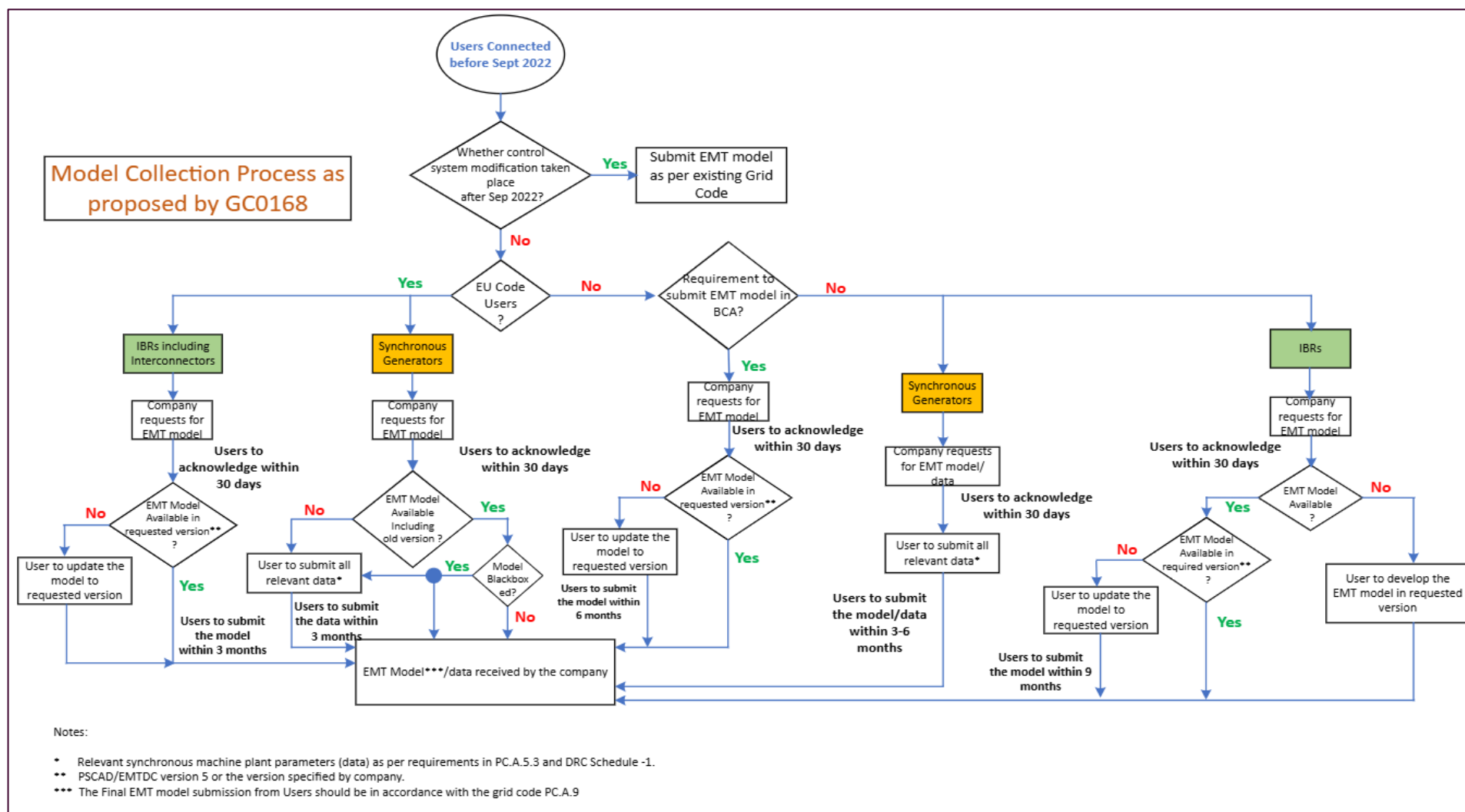


Figure 1: Flowchart highlighting the process for submitting the EMT models/Data from Users connected before September 2022.

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4. Model Submission Approach

This section describes the adopted approach for retrospective submission of EMT models. As it is impractical to request EMT models from all User(s) at the same time, The Company has decided that a priority based on critical regions in the GB system could be followed to collect the EMT models. The GB system is divided into 8 regions as shown in Table 1. Northeast and Northwest Scotland is considered topmost priority due to frequent occurrence of Sub-Synchronous Oscillations (SSO) in the recent past. North Central Scotland and East England regions are being considered as priority order 2 and 3 respectively due to continued IBR proliferation and the evolving risk of sub-synchronous control interactions (SSCI). Southeast England and the London region are considered priority order 4, as there is a need to analyse the risk of growing transient instability in the region due to many IBRs and Interconnectors. South Central Scotland is being considered on priority order 5 due to low short-circuit level concerns.

Table 1: Region wise priority order for collecting EMT Models.

Priority Order	Region (based on EYTS Zones*)
1	Northeast and Northwest Scotland (T1, T2, T3, T4, T5 and T6)
2	North Central Scotland (S5)
3	East England, East Midlands & Humber (D4, D5, J1, J2, J3, J4, J5, J6, J7, K1, K2, K4, K5, K6, L8, P7, P8)
4	Southeast England & London (A1, A3, A4, A6, A7, A8, A9, B1, B2, C1, C2, C3, C4, C5, C6, C7, C8, C9, J8)
5	South Central Scotland (S6)
6	South Central and Southwest England (B3, B4, D6, E1, E7, E8, F6)
7	North Wales, South Wales and West Midlands (G1, G5, G6, G7, H1, H2, H6, L1, L2, L3, L5, L7, M4, M5, M6, M7, M8)
8	Mersey, Northwest England, North and South Yorks (N1, N2, N3, N4, N5, N6, N7, N8, P1, P2, P3, P4, P5, P6, Q2, Q4, Q5, Q6, Q7, Q8, R4, R5, R6)

*EYTS Zones references are considered from [EYTS 2024 Appendix A](#) – Figure A5.

It is important to note that, in situations where there are numerous generation Plants within a single priority region, The Company will not request all Users in that region to submit their EMT models at the same time. Instead, a phased approach to notification and submission will be followed to ensure an orderly and manageable process.

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Within each priority region, The Company will consider the following order to issue notifications for EMT model submissions:

- Generators/Interconnectors that are EU code Users will be notified first, since these Users might have developed EMT models previously.
- The size of the Plant will be considered to prioritise the request; the order will follow from large to small size Plant.
- If any new connection compliance study requires retrospective EMT models in that study region, those Generators will be notified.
- To investigate any system events that have occurred, EMT models from relevant Users will be prioritised.

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5. Potential approaches to develop the legacy Plant EMT Models

The Company recognises the challenges that Users will encounter in developing EMT models for legacy Plants based on the requirements provided in Section 2, as well as in meeting all the requirements outlined in Grid Code PC.A.9. The primary challenges include:

1. **Lack of Data:** Older Plant may have insufficient data available for model development, making it difficult to gather the necessary information for accurate modelling.
2. **Obsolete Technology:** The equipment used in older Plant may be obsolete, with detailed specifications or manufacturer support potentially no longer available.
3. **Compatibility Issues:** Integrating models of older Plant with modern systems and software can present challenges due to compatibility issues.
4. **Regulatory Compliance:** Ensuring that models adhere to current regulatory standards can be difficult if the Plant's original design did not anticipate such requirements.
5. **Operational Data Availability:** The availability of historical operational data, crucial for model validation, may be limited or unavailable.

To address the above challenges, The Company is considering potential approaches or options to assist Users in developing EMT models for legacy Plant. For Users who encounter difficulties in meeting model accuracy requirements during validation of the developed EMT model for site-specific conditions, The Company should consider acceptable alternatives. Users should explore the potential modelling approaches for legacy Plant based on the level of detailed information available to them. These approaches, in order of priority, may include, but are not limited to:

- Vendor specific EMT model for the site-specific equipment, with site-specific parameters provided by its Original Equipment Manufacturer (OEM).
- A model with similar technology from the same OEM, with parameters derived from specific Plant design information and historical operational measurements available to the User.
- A generic model of the correct Plant type parametrized to the extent possible to reflect the capabilities and limitations of specific Plant make and site settings.

The Company recommends Users to adopt Vendor-specific models as the primary approach for developing their Plant models. In circumstances where a Vendor-specific model or a model utilising similar technology is not available, Users may employ a generic model for their Plant model development, subject to prior agreement with The Company.

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When utilising generic models, it is recommended to use a model that has the following features, so that it can be tuned to approximate the measured response of the legacy generating system:

- Ability to set LVRT and HVRT thresholds.
- Ability to set steady state setpoints (e.g., voltage, reactive or power factor setpoints).
- Ability to adjust Active and Reactive Power recovery ramp rate.
- Ability to limit fault current injection to a specified level.
- A generic model of the Power Park Controller (PPC), if the generating system uses such a controller.
 - The general data of the generic model such as Plant type, voltage and MVA rating are known from the data sheet information provided by the vendor. As much as possible, available information should be adopted for the generic representation of the Plant.
 - Legacy Plant are likely to have been in service over a number of years. Thus, their response under various system events were likely captured by digital event recorders / Dynamic Monitoring System (DMS) during their operation. If such information is available, one possible option is to adjust the control and protection parameters of the generic model so that the model response may closely follow the waveforms captured during system events.
- All static and dynamic Reactive Power support Plant modelled in addition to the Generating Unit models.

Developers or manufacturers traditionally developed generating Plant and ensured a smooth connection process to the GB system by adhering to Grid Code requirements. During the compliance process, they will share all related data for the Plant with The Company through the User Defined File Structure (UDFS) process. At a later stage, the generating Plant would be transferred or sold to a third party (Asset Manager) for operation. However, during this transition, developers or manufacturers may not have shared all related data due to intellectual property concerns. For developing an EMT model for any Plant, detailed mathematical descriptions and block diagrams of the controllers are essential. If these details are unavailable to the third parties (Asset Managers), it becomes challenging to develop the Plant's EMT model.

Only where such instances arise, a third party (asset manager) may request the necessary data from The Company to support the development of their Plant models. The Company can establish a Non-Disclosure Agreement with third parties (Asset Managers), allowing them to use this information to create the Plant's EMT model. Please be advised that this process is not standard practice.

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5.1 Validation Requirements for legacy Plant EMT Models

After developing EMT models for legacy Plant using the approaches outlined in Section 5, it is essential for Users to carry out a thorough validation process. This validation ensures that the models accurately represent the current operational behaviour of the Plant under actual site conditions. The Company requires Users to submit evidence confirming that their models have been validated and that the simulation results are representative of the User's Plant and Apparatus under equivalent operational scenarios.

Users may validate legacy Plant EMT models against various forms of available data, depending on the modelling approach chosen. The following sources of evidence should be considered:

- Vendor Specific EMT Model: Where a Vendor Specific EMT model is used to represent the legacy Plant, validation can be conducted using:
 - Factory Acceptance Test (FAT) results
 - Commissioning Test or Compliance Test results
 - Plant responses recorded during system event conditions (as captured by Fault Recorders)
 - RMS model responses that were submitted as part of the compliance process
- Generic or Other Models: If alternative modelling approaches are adopted, the following data sources should be used for validation:
 - Compliance Test results
 - Plant responses recorded during system event conditions (from Fault Recorders)
 - Type test results for the particular technology
 - RMS model responses previously submitted during the compliance process.