Public

Root Mean Square (RMS) and Electromagnetic Transient (EMT) Model Requirements and the Approach & Process for Retrospective Submission

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NESO
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Contents

1. Introduction

This document outlines the requirements for Root Mean Square (RMS) and Electro-Magnetic Transient (EMT) models, for Transmission Owner (TO) who are developing and submitting these models of their Plant and Apparatus to the Company. Both models compatible with these requirements will enable The Company to effectively merge the models to the wider network model, setup the study and carry out analysis.

This document also outlines the approach and process for submitting EMT models for retrospective TO assets.

This document contains three parts.

- Part 1 - Provides detailed requirements describing the technical expectations of RMS models.
- Part 2 - Provides detailed requirements describing the technical expectations of EMT models, in terms of efficiency, fidelity, usability, maintenance, and the minimum required documentation.
- Part 3 – Presents the approach and process for submitting retrospective EMT models.

Part 1

RMS Model Requirements

2. RMS Model Requirements

2.1. Software version

The Company requires TOs to submit the RMS models implemented in DIgSILENT PowerFactory. The TO is advised to approach the Company to confirm the PowerFactory version required as the Company upgrades the software' versions from regularly. The currently version for DIgSILENT PowerFactory is 2025 Service Pack 4. The Company will be clearly communicated during the initial meeting with the customer, specifically regarding the timelines for NESO upgrades, ensuring that customer has sufficient time to prepare ahead of model submissions.

2.2. Model performance requirements

The TO shall demonstrate that the RMS model meets the following requirements.

- The TOs shall provide RMS models which represent the Plant and Apparatus and controllers in balanced, RMS, positive phase-sequence, time domain studies.
- The use of any "black boxes" encrypted code or external DLLs is not acceptable.
- The size of the RMS model (in MB) should be optimised to ensure ease of sharing and handling. Extremely large files are not acceptable. Also, the RMS models should be quick enough. Extremely slow models are not acceptable.
- The RMS model shall be self-contained. The combined load-flow and dynamic model shall solve with minimal warnings without the need for manual adjustment or to run external software routines that adjust parameters in either the load-flow case or the dynamic case or both. External software or automation routines to integrate the model are not acceptable. Avoid internal scripts if possible, to minimise potential issues arising from PowerFactory upgrades.
- The RMS model shall automatically initialise its parameters from load flow simulations without errors and with minimal warnings, must not result in run time errors and run with minimal warnings, and there must not be any interactions or conflicts with other models.
- The RMS model initialisation shall be invariant to simulation start time (i.e. not require the simulation to be initialised at a particular time). External software or automation routines to initialise the model are not acceptable. Again, avoid internal scripts if possible, to minimise potential issues arising from PowerFactory upgrades.

- The model shall calculate correctly all the state variable derivatives on initialization (ComInc command in PF), without error messages or warnings relating to the incorrect initialisation of the models. Note that in the default PF parameters, a 0.1% maximum error is used for resolving the dynamic model equations. It is expected that the model shall initialise correctly from any setpoint within the plant operational range for active power, reactive power, and voltage.
- The RMS models must 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.
- It is recognised that some IBR models can inherently deviate from the steady-state load flow values (like the IEC WT type 3A) deviate from the steady-state load flow values. Successful initialisation is demonstrated by a no-disturbance study for at least 20s remaining within the following boundaries:
- For a Power Generation model of Type A, B or C (<50MW and connected at <110kV), generator active power and reactive power stay within 1MW (+/-2%) of initial values of rated MW. For example, a 49.9MW wind farm is allowed to have up to 1MW of disturbance.
- For a Power Generation model of Type D (>=50MW and >=110kV), generator active power and reactive power stay within +/-1% of initial values of rated MW. For example, a 200MW wind farm is allowed to have up to 2MW of disturbance.
- The model shall reach a stable status after a simulation time of 1 second at the latest. This means the above disturbances should be over by 1s after the RMS simulation has been started.
- The RMS model is expected to be numerically stable and must adequately represent the expected equipment behaviour over the operational range of the Plant and Apparatus at the Connection Point. A flat start time domain simulation (no disturbances) lasting at least 50 seconds shall be carried out to demonstrate the numerical stability of the model. i.e., the model must not exhibit any oscillations in Active Power, Reactive Power, Voltage, or Frequency when initiated from the load flow solution under Maximum Capacity or DMOL conditions, including scenarios of Maximum Leading and Maximum Lagging.

- In the case where the User's Plant trips during simulation, the relevant RMS models shall set the flag that indicates that the User's Plant has tripped.
- It is essential that the model runs with an integration step size of 10ms. In addition, the models must not include algorithms that require use of a particular integration step size (for example the control system model should not fail to solve, or the response be materially different for an integration step size of 0.005 s). Currently, the Company tests the model at 10ms, 5ms and 1ms integration step size, and the response with different integration step size shouldn't be materially different. i.e., if the model performs correctly using only a specified integration step size, this will not satisfy the grid code requirements. The model should be Grid Code compliant at 10ms, 5ms and 1ms integration step size.
- Time constants below 0.01s should only be included if their inclusion is critical to the performance of the dynamic model and should be agreed with The Company.
- The model should be able to run with all Solver Options available in PowerFactory, and from PF2025 onwards, able to run with the 'Parallelisation of model equations' enabled.
- Generic models such as IEEE, WECC or IEC might be used to meet the Grid Code requirement for the provision of open-source RMS model.
- It is always preferable for RMS models to use generic types available from the DIgSILENT library. User-specific RMS models are acceptable but can become outdated or fail to work with PowerFactory upgrades.
- The model must allow voltage ranges with control mode and droop settings configured according to the usual operation. The model must allow frequency control mode with droop settings configured according to the usual operation.
- The model submitted must be the same model (except for encryption) used to carry out the simulation studies in grid code ECP A.3. If the submitted model is different from the model used to carry out the simulations, The User must provide a model verification report.
- It is allowed to represent an aggregated model for an IBR 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. The aggregation is not allowed for the Synchronous Power Generating Modules.

- The PowerFactory model for Synchronous Power Generating Modules and Control System Data must use the same data as provided in DRC schedule 1, generator data sheets or other user guide documents. No data discrepancies should exist when comparing the submitted model with UDFS/Week24 DRC Schedule 1 submitted by the user.
- The model parameters must be 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.
- It is recommended to include study cases for reactive capability, voltage control, Fault Ride Through (FRT), and frequency response simulations in the model. While these are not mandatory requirements, their inclusion helps facilitate the validation and review process by the Company.

2.3. Protection requirements

- All the protection functions required to ensure the models remain representative of their system behaviour when responding to FRT events, providing voltage control and frequency response services must be adequately modelled (i.e. if the actual plant is set up to trip for an FRT event lasting beyond the times specified in the Grid Code, then so should the model setting the flag indicating that the unit has tripped)
- The TOs shall discriminate the level of protection modelling required to ensure RMS model remain representative of the actual user system.
- The protection settings should be compatible with supporting documentation provide by the TO.
- Inverter-Based Resources (IBRs), represent all installed protection system in detail for both balanced and unbalanced fault conditions. Any protection which can influence dynamic behaviour or fault ride-through in the simulation period should be included and documented. The model must include at least the following protection schemes applicable to both balanced and unbalanced fault conditions:
    - Fault Ride Through (with applicable site settings to match unit real operation).

- Over/Under Voltage protection applied on units (with site settings to match real operation)
    - Over/ Under Frequency protection applied on units (with site settings to match real operation).
    - Over/Under Voltage at Grid Entry Point for Scotland (In England and Wales if Implemented).
    - Over/Under Frequency at Grid Entry Point for Scotland (In England and Wales if Implemented).
    - Run back schemes if applicable.
    - Rate of Change of Frequency (only required for embedded generators)
- Synchronous Power Generating Modules, represent all installed protection system in detail for both balanced and unbalanced fault conditions. Any protection which can influence dynamic behaviour or fault ride-through in the simulation period should be included and documented. The model must include at least the following protection schemes applicable to both balanced and unbalanced fault conditions:
    - Excitation Limiters (UEL, OEL).
    - Stator Current Limiter and V/Hz limiter.
    - Over/Under Voltage.
    - Over/ Under Frequency
    - Run back schemes if applicable.
    - Reverse power protection
    - Out of step protection
    - loss of field protection
- The model should allow the user to enable and disable these protection systems.
- It is essential to include the relevant protections at both the unit level (either the Power Park Unit (PPU) or the Synchronous Power Generating unit) and the Grid Entry Point level if these are available in practice.
- The Company recommends the inclusion of diagnostic flags within the model to indicate which protection function has been activated and to clarify the reason for any model trip during simulation.

2.4. Co-Located Sites requirements

- 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
- The RMS models for co-located sites (e.g. Wind and BESS or PV and BESS) are expected to include the unencrypted models for each technology type. If a previously existing generation site (e.g. Wind farm) is being co-located with a new technology (e.g. BESS), both models are expected to be submitted unencrypted and with no external scripts/DLL/external automation, even if the previous generation (Wind) has passed the compliance process and the RMS model submitted previously. This is because the control algorithm is now different, and as per Grid Code, the RMS model needs to be re-submitted.
- The Co-Located site will be tested for different running modes. For example, in a Wind + BESS site, it would be help the validation to have Study Cases & Scenario pairs for Max Wind + Max BESS, Max Wind + Min BESS, 0 Wind + Max BESS.

2.5. Model testing on Sample Network

- The TO shall demonstrate that the model(s) remain representative of the user system performance regardless of whether the model(s) is connected to a simple representation of the external network (as it is the case of a Thevenin equivalent) or the model(s) is connected to a multi node power system network.
- The TO should test the model works fine without any errors when integrated into a multi node power system network. For RMS models, it is recommended to use the publicly available Reduced GB network model for this test. The aim is to make sure that the user model can be converted into a template, can be integrated with other models (e.g., wider GB network model), and run without errors after integration.
- It would be helpful (not mandatory) to have a template of the user model provided, packed with all the controllers and references, ready to be exported to a larger network for integration and testing.

2.6. Model User Guide and Supporting Documents

The models should be submitted with a user guide and other supporting documentation.

- The user guide must contain:
  - Information to allow the user to understand the hierarchical structure of the control and protection system model.
  - Information to familiarize the user with the operational modes implemented in the model.
  - Information to allow the user to understand how to set up the model for different operational modes and the parameter changes required to that effect (i.e. LFSM, FSM).
  - Tables containing all the parameters and values required by the model.
  - Operational range for the model which must be consistent with the actual plant.
  - A description of the controllers' logic implemented for meeting the voltage control, frequency response, fault ride through and Fast Fault Current Injection (FFCI) requirements. The description shall include an explanation of the purpose for the main control loops depicted in the controllers' transfer functions associated to these services.
  - An explanation for the purpose and logic of any user defined block definitions developed using DSL language to deliver functionalities not possible using standard library block definitions. Any block diagrams must be clearly visible in the PowerFactory model.
- Where a User specific model is provided sufficient information shall be provided by the TOs to allow for The Company to redevelop RMS models in the event of future software environment changes or version updates. All models shall be accompanied with appropriate documentation with sufficient detail as specified and deemed complete by The Company (such agreement not to be unreasonably withheld).
- If the model is a User specific model, the user guide must include the following information:
  - A full description of the model's structure, functionality and the User's Plant and Apparatus represented.
  - Inputs/outputs and functionality,
  - The information described in PC.A.5 relevant to the technology modelled.

- The Company may, when necessary, require the TOs to provide details of the proper operation of its complete RMS system representation or to facilitate its understanding of the results of a RMS dynamic simulation or request additional information concerning the RMS control system model. This should take place no later than the issuance of the FON.

Part 2

EMT Model Requirements

3. EMT Model Requirements

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.

3.1. 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 Complier version 19.2 and higher, and Visual Studio 2019 and newer. TOs submitting the EMT model from January 2026 shall be 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 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. 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. 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 itself.
    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 run in a 15-minute time frame. In an exceptional circumstance, The TO may be allowed to split the model into 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.

3.2. 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:
   - 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.

3.2.1 Synchronous and Induction generators

Following the points 1-7 above (notes for model fidelity in Section 3.2), 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.
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 μs 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.

3.2.2 Inverter-based resources - IBRs

In addition to points 1-7 provided in section 3.2, 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 TOs 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 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 aggerate the inverters belonging to one Plant (e.g., BESS) in accordance with point number 6 in this section, on representation of aggregated model. Both technology types must be included in the same EMT model.

3.3. 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 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. Notify the model user via a progress output message window when system conditions are beyond Plant operational limits or otherwise not consistent with valid operating conditions for the Plant.
6. 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.
7. 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.
8. 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.
9. 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.
10. Not crash the software platform when the model/Plant is tripped or disconnected during the dynamic simulation run.

11. 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.

3.4. 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.
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 it 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 wind-up) 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:
    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.

3.5. Notes on model maintenance

TOs 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.

Part 2

The Approach and Process for Retrospective Submission

4. Model Submission Process and Approach

4.1. Model Submission Process

When the Company request Transmission Owner (TO) to provide retrospective EMT models, TO 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.

TOs are required to submit the requested EMT models within a period of 3 months from the date of the Company's request, unless otherwise agreed. The three-month submission window is intended to cover the time required to update the available EMT model and submit in PSCAD version 5 and above, thereby ensuring the model meets current technical and compatibility requirements.

If TO does not already possess an EMT model for the retrospective asset, they are permitted to submit the requested EMT model within a period of 9 months from the date of the company's request, unless otherwise agreed. This extended timeline provides additional time to develop a EMT model from the ground up.

4.2. Model Submission Approach

The Company will not request the TOs to submit all retrospective EMT models at the same time. As it is impractical to request all EMT models from TO at the same time, The Company has established a prioritised approach to determine sequence and urgency of required submission. The prioritisation approach is as follows:

- If any new connection compliance study is being conducted in a particular region and requires retrospective EMT models to evaluate system performance, those relevant TO asset models will be requested.
- To investigate any system events that have occurred, EMT models which are directly involved or potentially affected will be prioritised.

5. Potential approaches to develop the legacy plant EMT Models

The Company recognises the challenges that TOs will encounter in developing EMT models for retrospective TO assets based on the requirements provided in Section 2. The primary challenges include:

1. **Lack of Data**: Older assets 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 assets may be obsolete, with detailed specifications or manufacturer support potentially no longer available.
3. **Compatibility Issues**: Integrating models of older assets 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 asset'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 TOs in developing EMT models for legacy assets. For legacy assets which is having difficulties in meeting model accuracy requirements during validation of the developed EMT model for site-specific conditions, The Company should consider acceptable alternatives. TOs should explore the potential modelling approaches for legacy assets 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 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/asset type parametrized to the extent possible to reflect the capabilities and limitations of specific plant make and site settings.

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

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 plants 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.

5.1. Validation Requirements for legacy Plant EMT Models

After developing EMT models for legacy assets using the approaches outlined in Section 4, it is essential for TOs to carry out a thorough validation process. This validation ensures that the models accurately represent the current operational behaviour of the asset under actual site conditions. The Company requires TOs to submit evidence confirming that their models have been validated and that the simulation results are representative of the Plant and Apparatus under equivalent operational scenarios.
TOs 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/asset, 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.