Facility Model Guidelines

Transmission Grid Strategy and Planning

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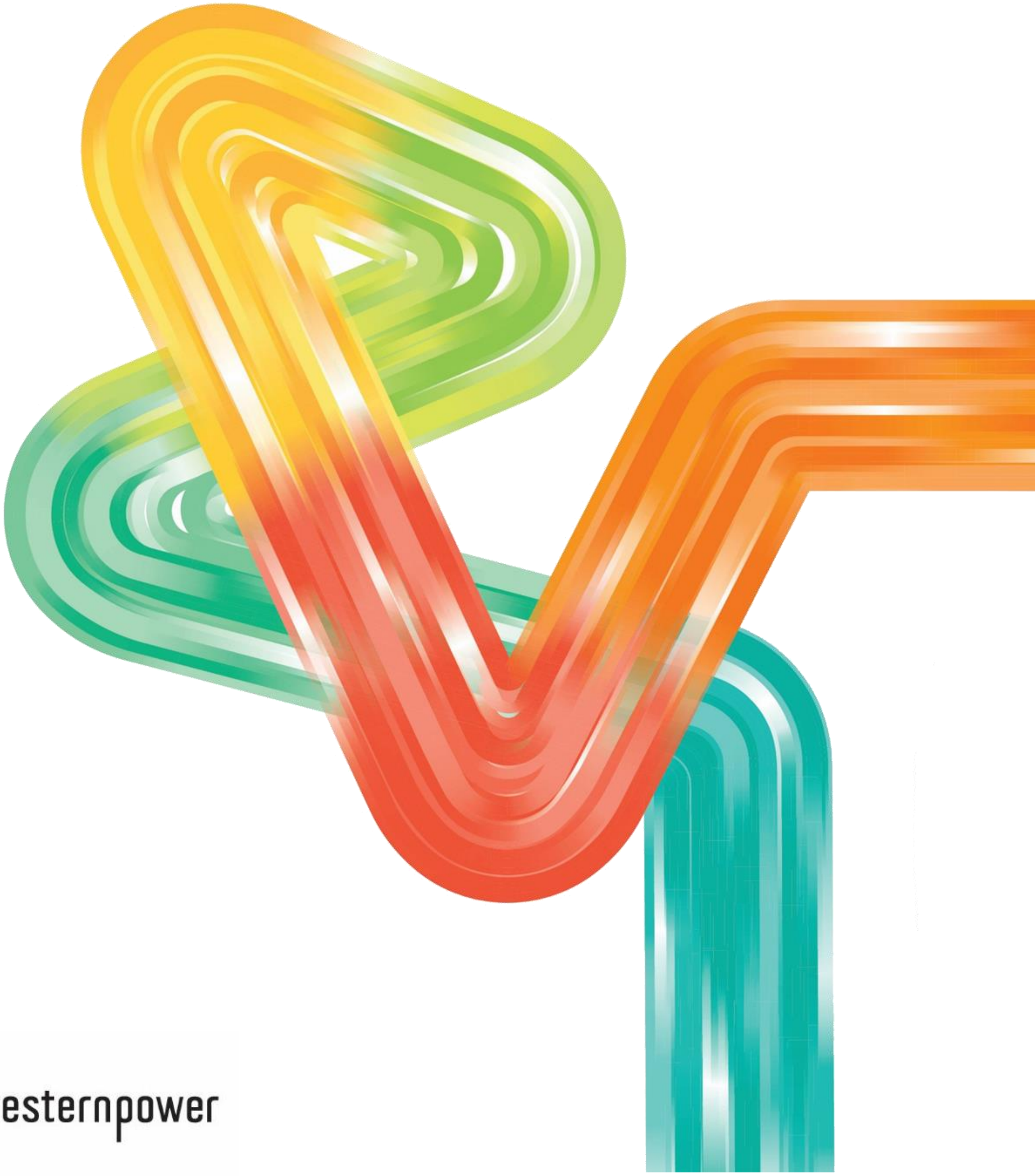

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Document Information

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2	20/05/2024	Tara Mehr	Appendix A updated.
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Contents

Glossary

Term	Definition
Access Application	Refers to either a Transmission Generator or Transmission Load Access Application form and complementary documents submitted by Connection Applicant to Network Service Provider.
Bidirectional Units	A production unit that also consumes electricity. Consumption of electricity: • includes the use of electricity to charge a production unit or to pump water for a pumped hydro production unit; • excludes auxiliary load.
Composite Load Model	A mathematical representation of a load based on separation into explicit components with generic parameterised descriptions.
Connection Applicant	A *User* that has submitted their Access Application to the Network Service Provider.
Connection Point	A point on the network where the Network Service Provider's primary equipment (excluding metering assets) is connected to primary equipment owned by a User.
Consumer	A *User* who consumes electricity supplied through a connection point.
Contingency Event	An event affecting the power system which the *Network Service Provider* expects would be likely to involve the failure or removal from operational service of a *generating unit* or *transmission/distribution* element.
Control System	The means of monitoring and controlling the operation of the power system or equipment including generating units connected to a transmission or distribution system.
Electric Storage Resource	A system or resource capable of receiving and storing energy for later production of electric energy.
Facility	An installation comprising equipment and associated apparatus, buildings and necessary associated supporting resources used for or in connection with generating, conveying, transferring or consuming electricity, and includes: a. a power station; b. a substation; c. equipment by which electricity is consumed; and d. a control centre.
Generating System	A system comprising one or more generating units.
Generator	Any person (including a User or the Network Service Provider) who owns, controls or operates a generating system that supplies electricity to, or who otherwise supplies electricity to, the transmission system or distribution system.
Facility Model Guidelines	This document.
Generator Performance Standard Assessment	A compliance assessment of a Transmission Generator computer model against Appendix 12 of WEM Rules, conducted by Market Participant and validated by Network Service Provider and AEMO and documented in a Works Planning Report. Refer to Section 5.3.2 of these Guidelines.
Generator Performance Standard Assessment Validation	A validation assessment of a submitted GPS by a Transmission Generator, conducted by Network Service Provider in consultation with AEMO. Refer to Section 5.3.2 of this Guideline.

Integrated Resource System	• A system comprising one or more bidirectional units (and which may also comprise one or more generating units or other connected plant that is not part of a bidirectional unit) • A system comprising one or more generating units where the connection point for the system is used to supply electricity for consumption on the system side of the connection point.
Load	As defined in Technical Rules: "Either: a. a connection point at which electric power is made available to a person; or b. the amount of electric power transfer at a defined instant at a specified point on the transmission or distribution system as the case requires."
Load Compliance Assessment	A compliance assessment of a Transmission Load computer model against specific clauses of Technical Rules, documented in a Works Planning Report. Refer to Section 5.3.1 of these Guidelines.
Model Benchmarking Report	A report describing the parameter mapping between the PowerFactory and PSCAD models, e.g. the control parameters name and value and benchmarking results, i.e. overlay of test results conducted in PowerFactory and PSCAD.
Plant	In relation to a *connection point*, includes all equipment involved in generating, utilising or transmitting electrical *energy*. In relation to the *power system*, includes all equipment involved in the generation, transmission or distribution of electrical *energy*.
Power System	The electric power system constituted by the South-West Interconnected Network and its connected generation and loads, operated as an integrated system.
Power System Reliability	Means the safe scheduling, operation and control of the SWIS in accordance with the Power System Reliability Principles.
Power System Security	As defined in Technical Rules: "The safe scheduling, operation and control of the power system on a continuous basis in accordance with the principles set out in clause 5 and the operating procedures of the Network Service Provider or System Management."
Power System Stability	As defined in Technical Rules: "The ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact."
Quality of Supply	As defined in Technical Rules: "With respect to electricity, technical attributes to a standard set out in clause 2.2, unless otherwise stated in these Rules or the relevant connection agreement."
R2 Data, Model Validation and Performance Report	A report providing details of the tests conducted, assessed performance, model validation results, and registered (R2) data including final models and control system settings. Refer to Chapter 4 of Technical Rules for further details.
Reticulation Network	Typically, the medium voltage radial network of feeders that collect the output of the individual production units, supplying the plant step-up transformer(s).
Small Generating Units	A small generating units and groups of small generating units of aggregate rated capacity up to 10 MW (small power stations) connecting to the distribution system where such generating units are not subject to dispatch by System Management in accordance with the Market Rules.

System Strength	Is a measure of how resilient the voltage waveform is to disturbances such as those caused by a sudden change in Load or an Energy Producing System, the switching of a Network element, tapping of transformers and other types of faults.
Technical Data Assessment	An assessment of Users *Access Application*, documented in a Works Planning Report.
User	As defined in Technical Rules: "Users of the transmission or distribution system who, for the purposes of these Rules include: a. every person who seeks access to *spare capacity* or *new capacity* on the *transmission or distribution system* or makes an *access application* under the *Access Code* in order to establish a connection point or modify an existing *connection*; every person to whom access to *transmission* and *distribution* capacity is made available (including every person with whom the *Network Service Provider* has entered into an *access contract* or *connection agreement*)."
User Manual	A document describing the setup and operation of a Transmission Generator or Transmission Load computer model.
Wide Area RMS Studies	A report providing details of the wide area RMS studies in PowerFactory SWIS Base Model, to validate the adequacy of parameter tuning and compliance of the Transmission Generator or Transmission Load computer model against specific clauses of Technical Rules and WEM Rules.
Wide Area EMT Studies	If applicable, a report providing details of the wide area EMT studies in PSCAD™/EMTDC™ Regional SWIS Base Models, to validate the adequacy of parameter tuning and compliance of the Transmission Generator or Transmission Load computer model against specific clauses of Technical Rules and WEM Rules.
Works Planning Report	A consolidated report documenting the outcome of studies undertaken at various stages of the connection process, some of them listed above.

Abbreviations

The following table provides a list of abbreviations and acronyms used throughout this document. Defined terms are identified in this document by capitals.

Term	Definition
AEMO	Australian Energy Market Operator
AVR	Automatic Voltage Regulator
CMD	Contracted Maximum Demand
CT	Current Transformer
DLL	Dynamic Linked Library
DPL	DIgSILENT Programming Language
DSL	DIgSILENT Simulation Language
DSOC	Declared Sent Out Capacity
EMT	Electromagnetic Transient
FACTS	Flexible AC Transmission Systems
FCESS	Frequency Co-optimised Essential System Services
GMP	Generator Monitoring Plan
HIL	Hardware In the Loop
HV	High Voltage
HVRT	High Voltage Ride Through
Hz	Hertz
IBL	Inverter-Based Load
IBR	Inverter-Based Resource
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated Gate Bipolar Transistor
kHz	Kilo-Hertz
LV	Low Voltage
LVRT	Low Voltage Ride Through
MP	Market Participant
µsec	Micro-Second
ms	Mili-Second
MVA	Mega-Volt Ampere
MV	Medium Voltage
MW	Mega-Watt

NCESS	Non-Co-optimised Essential System Services
NSP	Network Service Provider
OEM	Original Equipment Manufacturer
OLTC	On Load Tap Changer
PCC	Point of Common Coupling
PI	Proportional Integral
PID	Proportional Integral Derivative
PLC	Programmable Logic Controller
PLL	Phase Locked Loop
POD	Power Oscillation Damper
PPC	Power Plant Controller
PSCAD™/EMTDC™	Power Systems Computer Aided Design / Electromagnetic Transient with Direct Current, software developed by Manitoba Hydro International.
PWM	Pulse Width Modulation
R0	Pre-connection submitted data for initial Compliance and Confirmation check – refer to Section 5.3 of these Guidelines.
R1	Pre-commissioning submitted data for final Compliance and Confirmation check – refer to Section 5.3 of these Guidelines.
R2	Registered data after connection, as derived from on-system testing and designated as 'R2' in the Data Sheets and as described further in Technical Rules.
RoCoF	Rate of Change of Frequency
RMS	Root Mean Square
RUG	Releasable User Guide
SCADA	Supervisory Control and Data Acquisition
SCR	Short Circuit Ratio
SMIB	Single Machine Infinite Bus
SMVI	Single Machine Variable Impedance
SSCI	Sub-synchronous Control Interaction
SSR	Sub-synchronous Resonance
SWIS	South-West Interconnected System
STATCOM	Static Compensator
SVC	Static VAR Compensator
TNSP	Transmission Network Service Provider
TOV	Temporary Over-Voltage
VT	Voltage Transformer

WPN	Western Power Network
WPR	Works Planning Report

1. Introduction

1.1 Purpose and Scope

These *Facility Model Guidelines* specify Western Power's requirements concerning the information and models that *Users* including *Connection Applicants*, *Market Participants* (MPs) and *Consumers* must provide to the Network Service Provider (NSP) in the circumstances specified in the Technical Rules and Wholesale Electricity Market (WEM) Rules [1]-[2].

The requirements in these Guidelines are applicable to the new connections or modifications[1] to the existing *facilities*. These Guidelines are tools that enable Western Power to obtain the information needed to accurately model the behaviour of the plant connected to the South-West Interconnected System (SWIS) on an ongoing basis to fulfil a number of obligations such as planning, design, network operation and impact assessment of new *facility's* connection on the *Power System Security and Reliability* and *Power System Stability*. Refer to Technical Rules clauses 1.8.2, 3.2.4 and 3.3.9 and Chapter 3 of WEM Rules for further details [2].

1.2 Definitions and Interpretation

The words, phrases and abbreviations used in these Guidelines are defined in the Glossary and Abbreviations Sections.

Terms defined in the Technical Rules and WEM Rules have the same meanings in these Guidelines unless otherwise specified in the Glossary and Abbreviation Sections.

Terms defined in the Technical Rules and WEM Rules (including a future version of these documents) are intended to be identified in these Guidelines by italicising them, but failure to italicise a defined term does not affect its meaning.

[1] Modifications may include upgrades, settings changes and configuration changes.

2. Provisions of Models and Other Information

The *Facility Model Guidelines* apply to all type of *facilities* such as *Synchronous Generating Systems*, *Asynchronous Generating Systems* (including *Synchronous Generating Units and Asynchronous Generating Units*, respectively), bi-directional units, dynamic control reactive plants and *Loads*.

As part of a new or amended *Access Application* of any of the *facilities listed above*, Western Power requires certain data and documentation to be provided along with a computer model. For existing *Users* seeking to modify their *facility* where an *Access Application* is not required, these Guidelines for model provision still apply. For Market Participants (MPs) seeking to modify their *facility* where an *Access Application* is not required, these Guidelines as well as the Relevant Generator Modification Guidelines will apply when submitting the modified model of the *Generating System* [3]. This section provides details of Western Power, Technical Rules and WEM Rules requirements for provision of this information.

When developing a computer model there are general requirements that apply to all models, irrespective of the type of *facility*, as well as specific requirements that are applicable depending on whether the *facility* is a *Generating System*, *Load* or other type of equipment, such as a dynamic reactive device (STATCOM, SVC, etc.). Refer to below Sections for further details.

The Technical Rules clauses below should be reviewed to assist with understanding the need for computer modelling information and the obligations of Western Power and *Users* for provision and maintenance of accurate computer models.

2.1 Generating Systems

A computer model is generally required for all *Generating Systems* whose rating exceeds 10 MW. Technical Rules clauses that provide information on the general requirements for *Generating Systems* model are listed below.

- Clause 3.2.4: Power System Simulation Studies
- Clause 3.3.2: Provision of Information
- Clause 3.3.9: Computer Model
- Clause 4.1.3: Tests to Demonstrate Compliance with Connection Requirements for Generators
- Clause 4.1.7: Power System Tests

For all of the Transmission *Generating Systems* connecting to SWIS, Western Power requires the Root Mean Square (RMS) model in DIgSILENT PowerFactory software as well as Electromagnetic Transient (EMT) model in PSCAD™/EMTDC™ software. Refer to Section 3 and Appendix B of these Guidelines for further details.

2.2 Small Generating Units

For *Generating Units* in a small power station of aggregate between 5 and 10 MW, Western Power will assess the need for computer models to perform dynamic simulation studies. If deemed to be required, the same model requirements as for large *Generating Systems* may apply. Western Power will provide the level of the details required in the model. Technical Rules clauses that provide information on the general requirements for the *Small Generating Units* model are listed below.

- Clause 3.2.4: Power System Simulation Studies
- Clause 3.6.3: Information to be provided by the Generator

2.3 Loads

For *load* connections, Western Power will assess the *Load* characteristics (including size, motor composition, harmonic emissions etc.), *connection point*, and capability of the local *transmission* or *distribution system* in the vicinity of the C*onnection Point* to determine the extent of modelling information required. Western Power may also request a detailed computer model, although typically this would only be required for large Inverter-Base Loads (IBLs) connections or those connections in weaker parts of the Western Power Network.

Technical Rules clauses that provide information on the general requirements for the *load* models are listed below.

- Clause 3.2.4: Power System Simulation Studies
- Clause 3.4.2: Overview
- Clause 3.4.5: Provision of Information

For all of the *loads* connecting to SWIS, Western Power requires the RMS model in DIgSILENT PowerFactory software. The EMT model in PSCAD™/EMTDC™ software will be required for the *loads* where there is in Western Power's reasonable opinion, a risk that the *User*'s plant will:

- adversely impact *Power System Security*, *quality* or *reliability of supply*, or inter-regional power transfer capability, or
- have an adverse impact on *System Strength*.

Refer to Section 3 and Appendix B of these Guidelines for further details.

3. Model Adequacy

Western Power in collaboration with AEMO use *facility*'s models for different purposes such as the assessment of the suitability of proposed plant and its proposed performance standards and determination of plant capability to achieve its performance standards, the ongoing management and assessment of power system security, for instance short-term operational planning and development of constraint equations, stability assessment, use in long-term power system planning, the assessment of other proposed connections, procurement of Frequency Co-optimised Essential System Services (FCESS) and Non-Co-optimised Essential System Services (NCESS) and network event investigations.

For these reasons, models must demonstrate the degree of adequacy and accuracy as specified in these Guidelines.

For each *facility* being assessed, the Applicant must provide a site-specific model in the appropriate tool and consisting of components necessary to facilitate accurate studies as specified in Section 2, 3 and Appendix B of these Guidelines.

3.1 Load Flow Model Requirements

Adequate load flow models must represent the plant steady state conditions for the full operating envelope in the DIgSILENT PowerFactory currently used by Western Power[2].

Where applicable and where the RMS tool allows, load flow models of plant must include the items listed in Table 3.1. The load flow model contents must be consistent with the information provided by the Applicant in the Releasable User Guide (RUG) and *Access Application,* any discrepancy in the *Access Application* data is to be addressed before the load flow model is assessed. The model must be suitable for balanced and unbalanced power flow studies.

Table 3.1: Load flow model requirements

Plant Component	Include
Generating units or bi-directional units, reactive support plants	• MVA base • Source impedance, including positive, negative and zero sequence • Active and reactive power profile • Voltage control scheme • Active/reactive power capability curve • Generator auxiliary loads (if any), the load power factor to represent facility's actual performance under typical operating conditions
Motor loads with rating >1MW	• Starting method parameters to be defined in the model (e.g. direct online, soft-starter)

[2] Contact Western Power to confirm the version of DIgSILENT PowerFactory currently in use.

Plant Component	Include
Facility transformers (including step-up, intermediate and connection point)	• MVA base and ratings • Winding vector group • All winding voltages • Winding impedances, including positive, negative and zero sequence • Grounding arrangements and impedances • Connection code • Magnetising impedance • Tap location, number and voltage range • Voltage control scheme
Reticulation network	• Positive, negative and zero sequence impedance
Over-head transmission lines	• Modelled using the geometric tower data and conductor data
Shunt components	• Shunt elements • Switched shunt elements scheme
Loads	• Active and reactive power levels, in most appropriate format (power, impedance, current)

A. For plant consisting of several distributed generating units or bidirectional units, aggregation principles outlined in Section 3.6 must be used.
B. Consistent with the plant's performance standard.

3.1.1 Format

Refer to Section 3.3.11 for the format of steady state model when represented on RMS simulation tools.

3.2 Fault Level Model Requirements

Provision of short circuit data for the plant to IEC 60909:2016 is sufficient to meet the requirement for short circuit analysis. This short circuit data should be integrated into the load flow model to the extent this is possible in the host software platform.

3.2.1 Format

Refer to Section 3.3.11 for the format of steady state model when represented on RMS simulation tools.

3.3 RMS and EMT Stability Model Requirements

The following criteria apply before an RMS or EMT model can be accepted for assessment by Western Power. The requirements specified in this section apply to all *facilities* except those in Section 3.3.2, which only apply to *load facility* participating in the FCESS market [4] or the provision of other forms of frequency control such as IBLs.

3.3.1 General Requirements

Transient models provided must define the site-specific electromechanical/electromagnetic and *control system* performance of components comprising *facility* under Steady State, set-point change and Disturbance conditions for all levels of system strength and energy source availability that the *facility* is rated to operate.

That *facility* includes:

- the primary or relevant secondary *plant* within the *generating system* or *integrated resource system* that may affect the overall interaction (*active power*, *reactive power* or *voltage*) of the *generating system* or *integrated resource system* with the *power system* (e.g. *reactive power* compensating *plant*); and
- any dynamic *reactive power* or voltage compensation *plant* within the *network* that can have an impact on transient and *voltage* stability. These include the reactive *plant* (static or dynamic) installed to meet the power quality limits allocated to the *facility* by NSP.

Parameters of transient models developed for new and modified *generating systems* or *integrated resource systems* (including any supervisory control) should be refined through extensive connection studies. *Facility* model and parameters must be assessed through the Western Power due diligence process to be qualified as R0 and subsequently R1 pre-connection data.

RMS and EMT models and parameters submitted to Western Power must conform to the following general requirements before being considered for assessment.

Model Compatibility and Stability

Models must:

- be compatible with the power system software simulation products specified by Western Power;
- work for a range of dynamic simulation solution parameters rather than for specific settings only;
- be numerically stable for the full operating range including a wide range of grid Short Circuit Ratio (SCR) and grid and fault X/R ratio
- any model validity limitations due to system impedance or strength should be clearly defined within the Releasable User Guide (RUG);
- be numerically stable up to a simulation time of at least five minutes (have *voltage*, *frequency*, *active power* and *reactive power* remaining constant for dynamic simulation runs with no Disturbance); and
- not show characteristics that are not present in the actual *facility* response.

Model composition and operating range

Models must:

- be a model of the specific *facility* being considered;
- include any relevant non-linearities, such as limits, arithmetic or mathematical functions, deadbands or saturation;
- represent the *generating system* or *integrated resource system* and reactive compensation *plant* performance for all possible Steady State output and system strength levels where the *facility* would be in operation;
- represent *facility* response for set-point changes including *active power, reactive power*, *power factor*, *voltage* and *frequency*, including associated *ramp rates*;
- represent the *generating system* or *integrated resource system* and reactive compensation plant performance for all possible values of energy source variation where the *generating system* or *integrated resource system* would be in operation

- – for *generating units* or *bidirectional units* with an inherently variable power source, the ability to vary the energy source strength must be maintained throughout the simulation study;
- represent all plant within the *generating system* or *integrated resource system*, including *generating units*, *bidirectional units*, governors, Power Plant Controllers (PPCs), tap-changing transformers, and *reactive power* compensating *plant*
  - – relevant protection relays must be included in the model, explicitly where practically possible;
- represent delays between *facility* elements (e.g. SCADA, Programmable Logic Controller (PLC) and PPC communication delays) that have an impact on the performance of the *facility*;
- include adequate modelling of the mechanical components of the *facility*, to the extent that such mechanical components have a significant effect on the stability of the *facility* and its response to Disturbances;
- include models of *generating unit* or *bidirectional unit* energy storage components that would be affected by Disturbances;
- represent *facility* response to any runback scheme or special protection scheme in which the *plant* participates in;
- represent *plant* performance accurately within the normal dispatch range between minimum and maximum *active power* output, but must also be able to be initialised at any *active power dispatch* in the normal dispatchable operating range of the *facility* in MW
  - – Linearised models that are accurate only for a single operating point are not acceptable; and
- initialise correctly (for example, for RMS models from load flow) if dispatched to a power level lower than that available from the energy source.

Model multiple operating modes and control functions

A model must:

- Represent all modes of operation that the physical *plant* is capable of operating in. For example, if applicable to the physical *plant*, the model must be able to represent:
  - – *generation*, *synchronous condenser* and pump modes for relevant hydro-electric generation technologies, e.g. pumped storage;
  - – *voltage* control, *power factor* control and *reactive power* control modes; and
  - – activation/deactivation of *frequency* control and fast *frequency* response features. Represent all modes of operation that the physical *plant* is capable to operate. For example, if applicable to the physical *plant*, the model must be able to represent: − generation, synchronous condenser and pump modes for relevant hydro-electric generation technologies, e.g. pumped storage;
- Represent the simultaneous control functions that are active within the physical *plant* without the need to change model setup, variables or configuration parameters.
  - – For example, a model must be able to represent both *active power* control and *frequency* control functions operating simultaneously.

Mid- and long-term dynamics

Any dynamic models provided for a *facility* must be adequate for simulation of the response of equipment, such as On Load Tap Changer (OLTC) controllers, turbine governors, over-excitation or stator current limiters and any other thermal, *voltage* or *frequency* related controller with a time-delayed response up to 120 seconds.

Additionally, models must not change appreciably[3] during a flat-run (no Disturbance) simulation. Simulation durations for no-Disturbance studies range from 10 to 300 seconds (the latter to verify long-term Steady State stability).

3.3.2 Requirements for Detailed Load Models

Western Power may require more detailed load models than general *load* model or IEEE composite *load* models, in the following circumstances:

- it is necessary to demonstrate compliance to relevant *performance standards* related to load transient performance following *contingency events* [4], or
- the *load* has the potential to have a significant impact on *power system* operation, or and the operation of nearby network *Users*, as determined by Western, or
- if determined by Western Power after considering the factors listed in Section 2.3 of these Guidelines.

Relevant model requirements in the following sub-sections of Section 3.3 of these Guidelines only apply to detailed load models, and not to the general *load* model or the IEEE composite *load* models, unless specifically stated otherwise.

3.3.3 Requirements for Remedial Action Schemes

Western Power may require Remedial Action Schemes (RASs) models where triggering of the scheme could have a material impact on the *power system*. These models should encompass:

- input variables as per the actual RAS.
- Communication, measurement, filtering and processing delays (for example, intentional time delays like timer settings, or inherent delays like relay operating times).
- Calculation algorithms and logic/tripping sequences.
- Output actions including associated delays.
- Parameters, signals and status to be monitored.
- Where possible, RAS models should be represented with standard objects from the model library of the relevant simulation software.

3.3.4 Requirements for Frequency Stability Studies

Provided models are to be useful for frequency stability studies and must:

- Provide an accurate response of the *plant* to changes in *network frequency*, and *active power* supplied to or consumed from the *network,* as determined by the available power;

[3] State changes in RMS models or noise/chatter in both RMS and EMT models are not expected to occur for flat-runs.

- Be an accurate representation of the maximum rate of change of *frequencies* that the *plant* is capable of operating with:
  - For absolute changes in network frequency within the *frequency operating standard* where the *plant* is connected. If the *performance standards* of the *plant* exceed these limits, the models must be accurate for the full range of *network frequency* in which the *plant* can operate;
- Represent the *frequency* and speed filtering applied in the governor system controller and/or time delays in control variable measurement transducers;
- Represent any controller settable control variable position limits, ramp rate limits or deadbands;
- Provide details of the voltage and frequency protections based on which the *facility* will trip, including Rate of Change of Frequency (RoCoF).

3.3.5 RMS Model Requirements

The following are requirements for RMS dynamic models supplied to Western Power:

- Models must have a bandwidth of at least 0.05 Hz to 10 Hz (for that part of the response that is linear) and settle to the correct final value for the applicable power system conditions and applied Disturbance(s);
- Models must initialise themselves in a Steady State consistent with the system conditions in the network load flow model. Initialisation to specific values or manual initialisation is not accepted, also no script should be required for initialisation of the model. When these preconfigured system conditions are beyond plant operational limits or otherwise not consistent with valid operating conditions for the plant, the model must warn the user by way of a message to the progress output device;
- Where special tuning of the load flow case is required to replicate expected operating conditions with given control set-points, acceptability of the tuning procedure must be agreed to by Western Power and documented in the RUG. Where a script is provided to assist with this procedure, it must be provided in the Python language;
- Changes to the Steady State operating point for the modelled element must not require changes to any external dynamic settings except where the change cannot be adequately inferred from the network load flow case. Where the Steady State configuration of the model cannot be uniquely inferred from load flow (for example, Steady State wind speed when operating a wind turbine at 100% output), additional configuration parameters may be provided in runtime settable variables. Reasonable default values must be provided or inferred for any such parameters;
- For models where a PPC is included, the PPC must remain functional when one or more (but not all) plant elements regulated by the PPC are out of service.
- When initialised at a valid Steady State operating point for the plant within operational limits, the model must correctly calculate state derivatives, unless there is a valid reason why this cannot occur. Generally, the derivative of the states should stay close to zero and the state variable should not vary more than 0.1% after first time step.
- To avoid excessive simulation burden when integrating RMS models in to PowerFactory SWIS Base Model, with the minimum permissible values of integration step size being 0.002 s.
- The model must not include algorithms that require use of a particular integration step size (for example the model should not fail to solve, or the response be materially different for an integration step size of 0.001 s).

- Time constants below 5 ms should only be included if their inclusion is critical to the performance of the dynamic model and are required to meet the accuracy requirements (see Section 3).
- Internal integration algorithms should only be included if their inclusion is critical to meeting the accuracy requirements, and should not materially detract from model simulation speed performance.
- RMS model outputs in terms of the *voltage*, *frequency*, *active power* and *reactive power* must be reasonably constant and consistent when doubling and halving the time step;
- Modes must be rigorously tested within the SWIS Base Model for integration compatibility for large-scale power system studies. Also, for the assessment of adverse interactions with other models within the system. Depending on the issue identified by Western Power, the model will require to be modified to address the issue; and
- Models must not prompt any error or warning messages during initialisation.
- Models must not prompt messages to the console during a simulation run other than in response to error conditions to signal abnormal events (such as a protection trip) or when additional model-specific output has been requested by the user. The model RUG must include sufficient description for the error or warning messages built into the model, which can be interpreted by Western Power.
- The functional blocks in the model must be represented using standard Laplace block diagram format to the extent practicable. Use of any "black boxes" encrypted code or external DLLs is not acceptable.
- Use of DIgSILENT Simulation Language (DSL) expressions to represent functions that could otherwise be represented by standard PowerFactory library macro block definitions should be avoided to the extent practicable.
- Inclusion of multiple (unique) equipment control functions within a single macro block definition should be avoided.
- The number of lines of code within a single macro block definition - excluding parameter definitions, initial conditions and comments – should generally not exceed 30. The intent of this requirement, in conjunction with the above item, is to provide guidance to the model developer and to improve macro code readability and model usability (it is not intended to result in increased complexity of macro equations or detract from macro code readability).
- Dynamic model initialisation must be invariant to simulation start time (i.e. not require the simulation to be initialised at a particular time).
- Where parameters need not be recalculated at each time step, the DSL commands selfix(), limfix() and outfix() must be used instead of select(), limits() and output() such that they are only calculated at initialisation.
- The model must include all functional controllers and ancillary equipment that materially impact the performance of the equipment over the typical timeframes of a dynamic simulation (up to several minutes), and accurately represent the performance for all possible conditions where the equipment would be in operation.
- In PowerFactory, each controller is linked to a "slot". To enable the complete dynamic model to be removed from service without the need to remove each of the controllers from service, the "Main Slot" checkbox should be selected for the slot which relates to the generator element (e.g. the synchronous machine).
- The dynamic model must resemble the physical design of the *equipment* and controllers to allow Western Power to assess the suitability of the proposed settings.

- The dynamic model must support both balanced and unbalanced time domain simulations and the response of each of the phases must be observable.
- Where the equipment has the capability to respond per phase, a full three-phase model must be provided.
- The control mode and droop settings must be configured according to the usual operation and configured for both steady-state and dynamic simulations.
- Dynamic model parameters should have parameter names, descriptions and units defined in the DIgSILENT Simulation Language (DSL) models, for example "Kp Proportional gain [pu]".
- The PowerFactory DSL model must compile to C code without warnings or errors.
- The model should include relevant protection relays and settings to simulate the performance of the facility during power system disturbances. This includes, but is not limited to, under and overvoltage protection, under and over-frequency protection, RoCoF protection, etc.
- For protection events (e.g. Wind Farm crow bar controller operation) the simulation events, including initial detection, operation, and time-out, should be reported to the PowerFactory output window during the simulation.
- Explicitly modelled motors with a rating of 5 MW or more must have mechanical characteristics of the drive load (torque-speed characteristic) and total mechanical inertia parameters modelled.
- Load shedding facilities, including under- and over-voltage and under- and over-frequency relays should be described and modelled.
- For *loads* where a model is assessed as being required, in general, all motors with a rating of 1 MW or more should be modelled explicitly. Smaller motors may be lumped into equivalents, however should be clearly identified in the supporting documentation and the PowerFactory model. The model may be required in both a detailed representation and to be aggregated to an equivalent model for integration with Western Power's model of the South-West Interconnected System (SWIS).
- Where various *loads* are represented as a single lumped (static) *load* which mainly contains motor *load* elements, they must be modelled with complex *load* parameters based on the constituent loads (VSD's, induction machines and other loads), and with suitable voltage dependent parameters.
- Simplification of *load* model representation should be consistent with the requirements of AS 3851 and good electricity industry practice to ensure that equipment fault level contributions are appropriately represented.

3.3.6 EMT Model Requirements

The following are requirements for EMT dynamic models supplied to Western Power:

- Have a bandwidth of at least DC to 10 kHz and settle to the correct final value for the applicable power system conditions and applied Disturbance(s);
- Be based on plant design data and rigorously tested against factory acceptance tests for the corresponding version of plant;
- Include detailed representation of all inner and outer control loops for the plant[4];

[4] The model cannot use the same approximations classically used in transient stability modelling, and should fully represent all fast inner controls, as implemented in the real equipment. It is possible to create models which embed (and encrypt) the actual hardware code into an EMT component. This is the recommended type of model.

- Be configured to match expected site-specific equipment settings;
- Allow *plant* capacity to be scaled;
- Represent all electrical, mechanical and control features pertinent to the type of study being done[5];
- Have all pertinent *protection systems* modelled in detail for *power system* transient and voltage stability analysis, including balanced and unbalanced fault conditions, *frequency* and *voltage* Disturbances, and multiple fault conditions and can disable the *protection systems* if required;
- The model should run accurately for the timestep of 50 µsec or above to facilitate integration into Western Power SWIS EMT Model;.
- Support multiple-run features to facilitate iterative studies;
- Allow multiple instances of the model within the same simulation;
- Be capable of self-initialisation, with initialisation to user defined terminal conditions within three seconds of simulation time;
- Warn the user by way of a message to the progress output device when the system conditions are beyond *plant* operational limits or otherwise not consistent with valid operating conditions for the *plant*; and
- Clearly identify the manufacturer's EMT model release version and the applicable corresponding hardware firmware version.

Multiple Voltage Disturbances

Where relevant to *load* models, the following modelling requirements for multiple voltage Disturbance ride-through capability are applicable to user-defined site-specific EMT *load* models, for example where the *load facility* is expected to demonstrate compliance with relevant fault ride through capability *performance standards*.

The EMT model provided must account for the most restrictive[6] electrical, mechanical, or thermal protection of the plant with respect to multiple *voltage* Disturbances in quick succession, and calculate dynamically and accumulatively the impact of multiple *voltage* Disturbances, including but not limited to the following factors:

- Heat dissipation across the dynamic braking resistors (if applicable).
- Capability of auxiliary supplies, for example, uninterrupted power supply (UPS).
- Torsional stress protection on shaft drive train and prime mover (if applicable)[7].
- Protection associated with thermal design limits of the integral assembly of the plant.
- Protection and associated measurements integrated into the control system
- Any other relevant electrical, mechanical or thermal protection.

3.3.7 Accessible Variables

Where applicable, all models must allow alteration to the following:

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5 This may include external voltage controllers, plant level controllers, customized PLLs, ride-through controllers, SSCI damping controllers or others. Further details of required electrical and mechanical components are provided in Appendix B.

6 It is the Applicant's responsibility to determine which protection element(s) will be the most limiting factor for multiple fault ride-through.

7 This is a relatively uncommon protection relay – the Generator must determine whether the exclusion of this relay from the model has a material impact on model accuracy.

- All applicable set-points within all plant including (must be adjustable before and during a simulation run):
  - Active power.
  - Reactive power.
  - Voltage.
  - Power factor.
  - Frequency.

For example, for a generating system or integrated resource system this infers access to all applicable set-points;

- Deadband, droop, delays (including communication delays) and slow[8] outer loop controls for any applicable control system such as *frequency* and *voltage* control;
- Ramp rates for changes in *active power*;
- *Voltage* and *frequency* protection settings, such as over/under *voltage* protection and over/under frequency protection;
- Fault ride-through activation and deactivation thresholds, including any multiple-fault ride-through limits and hysteresis levels;
- Active and reactive current injection/absorption settings during a fault;
- Number of in-service *generating units* or *bidirectional units* and reactive support *plant*, adjustable before and during a simulation run; and
- Energy source input (for example, wind speed or irradiance), adjustable before and during a simulation run without causing any adverse impact on initialisation or dynamic performance.

Additional alterable variables may be required by Western Power to undertake full stability impact assessment, for example, proportional and integral gains for inner/outer current/*voltage* control loops (including PLL, DC link current and *voltage* control, and any other control loops which can have a system strength impact). These variables can be adjusted by means of applying a real number multiplier if the actual values of these gains are preferred to remain black-boxed.

3.3.8 Model Outputs

Table 3.2 outlines the output quantities required to demonstrate model performance for a variety of dynamic analysis scenarios. Quantities used to determine model accuracy are typically a sub-set of these quantities and are described in Appendix C.

[8] Adequate for simulating actions of on-load tap changing transformers, static reactive plant switching.

Table 3.2: **Required model input quantities**

Plant Type	Plant Internal Quantities	Plant terminal measured quantities
Synchronous machines	• Field current • Field voltage • Limiter outputs • Mechanical power or torque • Rotor angle • Power System Stabiliser (PSS) output • Exciter output • Valve position • Guide vane/needle positions • Governor control output • Set-point for active power • Set-point for voltage • External protection relay(s) status	• Active power • Total current • Frequency • Reactive power • Voltage magnitude • Voltage phase angle
Wind (generating units)	• DC link voltage and current • Error/status cods • Generator rotor speed • Active and reactive currents • Mechanical torque or power • Pitch angle • Quantity determining FRT activation • Set-point for active power • Set-point for reactive power, voltage or power factor	
Photovoltaic (generating units)	• DC link voltage and current • Error/status codes[D] • Active and reactive currents • Quantity determining FRT activation • Set-point for active power • Set-point for reactive power, voltage or power factor	
Battery (generating unit or bidirectional unit)	• DC link voltage and current • Energy storage level (if applicable) • Error/status codes[D] • Active and reactive currents • Quantity determining FRT activation • Set-point for active power • Set-point for reactive power, voltage or power factor	

Plant Type	Plant Internal Quantities	Plant terminal measured quantities
Traditional large load	• Largest direct-online (DOL) motor slip • Largest DOL motor active and reactive power • Largest DOL motor terminal voltage • Protection relay(s) trip status[H]	
Inverter based load	• DC link voltage and current • Energy storage level • Active and reactive current • FRT entry and exit status • Controller setpoints • Protection relay(s) trip status[H]	
Reactive compensation plant (such as static VAR compensators (SVCs) or STATCOMs	• DC link voltage and current • Shunt control status/set-points • External plant set-point outputs Error/status codes[D] • Active and reactive currents • Quantity determining activation of blocking modes[J] • Set-point for reactive power, voltage or power factor • External protection relay(s) status[H]	
Centralised controllers (PPC and hybrid controllers)	• Error/status codes[D] • Quantity determining FRT activation • Set-point for active power[F] • Set-point for reactive power, voltage or power factor[F] • External protection relay(s) status[H]	

A. In EMT models only.
B. Relevant limiter outputs, such as over-excitation limiter, under-excitation limiter, V/Hz limiter etc.
C. Including outputs of any compensation components.
D. Only those error/status codes which translate into a distinct electrical system response at the low voltage (LV) terminals of the plant, for example, normal, fault, stop, low voltage ride-through (LVRT) or high voltage ride-through (HVRT) activation, unstable mode identification.
E. Both waveform and RMS values for EMT models.
F. As sent to generating units or bidirectional units within the system.
G. Not applicable for synchronous condensers.
H. External discrete protection relays relevant to the plant. For example, for transient stability studies; this may include over- and under-voltage, over- and under-frequency, RoCoF and reverse-power protection. For black-start studies, this may be extended to include negative sequence, out-of-step, over-fluxing, loss-of-excitation and generator and unit-transformer differential protection.
I. For line-commutated technologies, this would include the voltage-dependent current-order limit (VDCOL), and commutation failure (emulated in RMS models, simulated in EMT models). For both line-commutated and voltage-source technologies, blocking below certain voltage levels or other conditions should be modelled.
J. Include within models the blocking response below certain voltage levels or other conditions.
K. Only applicable to user-defined, site-specific load models, subject to the actual configuration of the load. For example, certain required quantities are not available when the according load component does not exist in the load facility, and does not need to be provided.

In addition to these internal and terminal quantities, models should provide access to the aggregated Reticulation Network and *Point-of-Connection* (POC) or unit transformer low voltage (LV) and high voltage (HV) to demonstrate the complete *generating system* or *integrated resource system* performance.

3.3.9 Integration Compatibility

A model submitted to Western Power for any *power system* element must operate as part of a full *power system* model alongside models of many other *power system* elements. This will inevitably include elements of the same type as the one in question, using either the same or a different release version of the same model code, submitted by the same or another *User*.

It is, therefore, imperative that the model is capable of coexisting and operating correctly alongside other independent instances of the same model, either of the same version or with a different version number. This requires attention as a minimum to the following:

- Naming and referencing models, functions and libraries based on a version number, such that two different versions of a model of the same plant can run within the same simulation environment without interference;
- Creating models to work for a range of time steps and dynamic simulation parameters, rather than for specific settings only;
- Models should, to the maximum extent practical, make use of the mechanisms provided within the host software platform to encapsulate separate model instances

Additionally, for EMT models, integration compatibility is improved by:

- Having 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. Applicants must consult with Western Power if simulation sets are required.
- Having dependencies on a minimal number of external files.
- Model dependencies on external files having user-settable naming references.

Models that prove problematic to integrate into larger cases will need to be rectified before Western Power is able to accept the model for further assessment. Western Power will work with the Applicant to identify the issues.

3.3.10 RMS Model Source Code

Source code of the RMS simulation model must be provided to Western Power, including all elements of the plant that affect its dynamic response, such as:

- For a generating system or integrated resource system, the unit model(s).
- Supervisory controls acting on the plant as a whole.
- Dynamic reactive support plant.
- Coordination of multiple reactive support devices and hybrid facilities.
- Any other plant such as transformer tap-changers whose response can reasonably impact the overall dynamic performance of the generating system or integrated resource system.

The model must be written and prepared using good model writing practices utilising the most recent model writing features and capabilities for the relevant software. For example, this would include the following:

- The models of the controllers and items of plant must be easily identifiable;
- The code should be commented to identify major components;
- Execution of dynamic data documentation commands should not result in model crashing;
- The model code should ensure correct implementation of windup and non-windup limits; and
- The model code should implement division and square root operations in a 'safe' manner to avoid division-by-zero and similar exceptions.

3.3.11 RMS Model Format

Computer models must be in native unencrypted DIgSILENT PowerFactory format suitable for use in the version of DIgSILENT PowerFactory currently used by Western Power[9] and suitable for integration with the Western Power model of the SWIS.

3.3.12 EMT Model Format

EMT models provided to Western Power must be compatible with PSCAD™/EMTDC™ version 5.0 and above and Intel FORTRSN Intel 64 bit Compiler (the 32 bit Compiler will no longer be available). Models must not be dependent on a specific Intel Visual FORTRAN version to run. EMT models compiled in or requiring Compaq Visual FORTRAN to run will not be accepted.

EMT models should not have dependencies on additional external commercial software, however dependencies on free, commonly available redistributable libraries may be acceptable.

3.4 Small-signal Model Requirements

Small-signal stability models are required for plants that contribute to local, intra-regional and inter-regional oscillatory modes in the power system. This includes synchronous generators and their controllers, dynamic reactive support plant and associated controllers including PODs, and any other plant which can reasonably impact damping of power system's oscillatory modes.

Small-signal stability models may also be required for studying the effects of sub-synchronous oscillations, such as sub synchronous resonance. This will include any plant which can potentially contribute to such oscillations as determined by Western Power.

For synchronous machines, a fully validated RMS model including all active controllers is generally sufficient for this analysis, provided that the corresponding small-signal model can be derived from block diagrams or source code using standard mathematical linearisation techniques available in PowerFactory.

3.4.1 Format and Accuracy

Small-signal stability models are submitted as part of the model package. The model must be capable of being executed in Western Power's RMS tool as specified in Section 3.3.11 for eigenvalue studies using both the QR method and Arnoldi method without modification. The small signal model of the facility will have to stay accurate for the range of operating conditions on *voltage*, *active* and *reactive power*.

[9] Contact Western Power to confirm the version of DIgSILENT PowerFactory currently in use.

3.5 Power Quality Model Requirements

3.5.1 Harmonic Emissions

Harmonic current injection models used for harmonic frequency scans and harmonic distortion analysis in conventional power system harmonic analysis tools must provide:

- Frequency-dependent Norton equivalences of each type of generating unit or bidirectional unit;
- Harmonic current injection profiles (for each harmonic order) at each generating unit or bidirectional unit, including:
  - Harmonic current magnitude, for example, in Amperes, or in percentage of fundamental current;
  - Harmonic current phase angle (if the phase angle data from unit's type test is available. The test setup and Norton Equivalent Derivation procedure should also be supplied along the model);
- Adequate model of collector grid[10]; including for IBLs
- *Generating unit* or *bidirectional unit* transformer models and *generating system* or *integrated resource system* transformer models[11];
- When a *Generating System* or *bidirectional unit* exhibit significant difference in harmonic current injection at various operating points (e.g. battery charging or discharging), both harmonic current profiles and associated operating conditions are required.
- Data for harmonic filters (if present), including connection point(s) of the filters, filter layout (for example, single-tuned, double-tuned), quality factor and/or electrical parameters.
- Explicitly modelled motors with a rating of 5 MW or more must have harmonic current emissions modelled.

The origin and methodology of the Norton equivalent sources must be documented and provided. Where harmonic current injections sources are provided in the form of harmonic current magnitude only, a method needs to be applied to summate the effects of the many individual harmonic sources in the *facility*.

Format

Harmonic models must be provided in a format that is compatible with the harmonic analysis software platform nominated by Western Power:

- Harmonic current injection provided in a separate PowerFactoy model of the *facility*.

Depending on the specifics of the connection point and proximity to other sources of harmonics, different type of simulation model may be needed for a given connection.

3.5.2 Flicker

The simulated RMS voltage magnitude/voltage waveform obtained from either RMS or EMT time-domain simulation can be fed into a flicker meter model following IEC 61000-4-15 for assessing the short-term and long-term flicker severity. These time-domain models are expected to include adequate representation of characteristics/functions/control systems involving/causing flicker.

10 Collector conductor models may need to consider skin and conductor proximity effects.

11 Positive, negative and zero sequence impedance of these transformer models must be provided, including any earthing arrangement and transformer vector groups.

Format

Models must comply with the RMS format requirements of Section 3.3.11.

3.5.3 Harmonic Susceptibility, Resonances and Flicker

To account for the harmonic signature of asynchronous plant in harmonic susceptibility and resonance or detailed flicker studies, it is necessary to include appropriate harmonic models of the harmonic generating devices, the harmonic impedance profile of the network, and the frequency dependent behaviour of the network elements. Where EMT harmonic susceptibility and resonance studies are required, model components as outlined within Appendix C for harmonic studies must be included.

Format

Models used for harmonic susceptibility and resonant analysis and detailed flicker studies must be provided as an EMT model complying with the format requirements of Section 3.3.12. The EMT model must comprise all control systems and switching components that contribute to the plant's harmonic profile. Further details of required components are provided in the "Harmonics" entries of the tables in Appendix B.

3.5.4 Voltage Unbalance

Models provided for unbalance load flow are sufficient for voltage unbalance studies from a generator source perspective, however network elements that adequately represent voltage asymmetric elements must also be included.

Models used to investigate this phenomenon must include the following:

- Steady state 50 Hz negative-sequence current injection, both magnitude and phase angle (phase angle is relative to the 50 Hz positive-sequence current phase angle), from the devices connected at the assessed bus must be modelled.
- Transmission lines must be modelled in the form that the information of 50 Hz negative-sequence impedance and the coupling impedance linking 50 Hz negative-sequence voltage and 50 Hz positive-sequence current are captured (for example, geometrical line representation).
- Negative-sequence impedances for synchronous machines and loads must be modelled.
- A variation of different operating conditions including the highest envelope of emission from the *facility* is to be included in the model.

Additionally, known voltage unbalances within the plant must be represented within the voltage unbalance model and provided within documentation.

Format

Models must comply with the RMS format requirements of Section 3.3.11 with a three-phase representation of the model.

3.6 Model Aggregation

Traditionally there has been a one-to-one correspondence between power system elements such as generating units and the models of these elements in simulation software. Thus, each registered unit has been represented individually in the power system model. This is practical when the power system plant is a large power station comprising up to about a dozen individual large generating units.

However, contemporary generating systems or integrated resource systems such as wind and photovoltaic solar farms, grid-scale battery installations or hybrid systems, can include as many as several hundred generating units or bidirectional units. As these units (or many of them) are often identical to one another, representing them individually would multiply the required computational effort and simulation run time for little benefit, compared to representing identical units as a smaller number of aggregates.

For some detailed *load* models and for *generating systems* comprising a large number of *generating units*, there may be a requirement for the model to be aggregated.[12] The methodology[13] for aggregating *generating units*, *loads*, other *generating equipment* and the reticulation system and studies demonstrating the equivalence between the detailed and aggregated models must be provided. The voltage profile and losses when varying the *active* and *reactive power* of the *facility* from minimum to maximum should remain close to each other between detailed and aggregated models. As a minimum this must illustrate the alignment of time-domain simulation overlays for *voltage*, *active power* and *reactive power* for the nearest and farthest generating unit and the aggregated generating unit, for:

- Zero impedance balanced three-phase to earth and zero impedance two-phase to earth faults at the *connection point*.
- *Voltage*, *reactive power*, *power factor* and *active power* step response.

For *generating systems*, the aggregation should not prevent access to generator terminal quantities.

Aggregation should not be used to combine *power system* elements of differing types. These should retain separate explicit model representations, albeit some may be aggregates of identical units of that same type. An exception may be made where elements are similar in all material respects other than size (for example a 3.0 MW and a 3.2 MW wind turbine with the same underlying technology and control systems) and where evidence is provided of this similarity by way of manufacturer documentation, to the satisfaction of the Western Power.

A similar aggregation principle can be applied to large IBLs consisting of small, identical modular components, such as a hydrogen production facility with multiple electrolyser clusters.

3.6.1 Scaling Principles for Derivation of Multiple-unit Aggregates

following general principles are assumed as the default for producing aggregates of N *identical generating units* or *bidirectional units*, where each unit is assumed to consist of a '*plant'* at low *voltage* (LV) in cascade with a *unit transformer* stepping up to medium voltage (MV).

Where the modelling of *plant* requires an aggregation method that varies from these principles, this must be clearly documented in the RUG. Alternative aggregation methods include the provision of a separate aggregate model not directly derived from the individual unit model. Evidence must be submitted to Western Power for the suitability of the aggregation method relative to the simple application of the scaling principles below. Western Power must assess this evidence, and may accept the different method, or determine that the scaling principles would apply if the evidence submitted is weak.

RMS Model Aggregation

The aggregate unit is represented in the model as:

- N parallel unit transformers in cascade with
- N parallel *generating units*

[12] Contact Western Power to discuss the requirement for model aggregation.

[13] For reference, see Kosterov et. al., Method of Equivalencing for a Large Wind Power Plant with Multiple Turbine Representation, NREL, 2009.

- In the associated dynamic model diagram, the aggregate *plant* appears similar to a single unit in the network model in cascade with an equivalent unit transformer
- The MVA rating of the overall aggregate plant is N times the MVA rating for an individual unit
- The LV and MV voltage levels are the same for the aggregate as for the individual units
- The MVA rating of the aggregate unit transformer is N times the MVA rating of each unit transformer as they are paralleled.
- For IBRs, The MVA rating of the aggregate unit inverter is N times the MVA rating of each inverter as they are paralleled. The *Reactive Power* capability curve is provided for each inverter as per the manufacturer data (without any modifications/ aggregation) for ambient temperature and Maximum Temperature advised by AEMO.

Implicit in these scaling principles is a requirement that the underlying model of the unit is also capable of representing the aggregate of N units when configured with the larger MVA rating. If appropriate, the model may be coded to indicate the level of aggregation explicitly in the model configuration (for example, by including either each unit size or the number N of identical units as a configuration parameter). However, any necessary change to model configuration or settings beyond those stated above when switching between an individual unit and aggregate representation, or between aggregate representation, or between aggregate representations with different numbers of units, must be clearly documented in the RUG.

EMT Model Aggregation

As paralleling of the units is not possible in PSCAD™/EMTDC™, simple scaling principal as described below should be applied to the EMT model of the *facility*.

- The aggregate unit is represented in the model in an analogous fashion (size aside) to a single unit. It has the same associated dynamic model and appears similar to a single unit in the network model in cascade with an equivalent unit transformer.
- The LV and MV voltage levels are the same for the aggregate as for the individual units
- The MVA rating of the aggregate plant is N times the MVA rating for an individual unit
- The active power and reactive power of the aggregate are the sums of the individual unit powers. For modelling purposes, there is an underlying methodological assumption that each unit has identical power outputs, although these will vary from unit to unit.
- Any other 'size quantities' specified in SI units, or in per-unit on a fixed system MVA base, are multiplied by N in the aggregate. Examples of size quantities are rated current in Amperes, rated torque in Newton-metres, and inertia constant in Joules or VA-seconds (but not speed or voltage). Where, on the other hand, the model specifies these quantities in a per-unit system on the unit MVA base, their numerical values are identical.
- The MVA rating of the aggregate unit transformer is N times the MVA rating of each unit transformer.
- Any internal series impedances of the aggregate unit, unit transformer and any intervening LV cables, when specified in ohms or in per-unit on a fixed system MVA base, have values 1/N times their values for each corresponding unit. Where, on the other hand, the model specifies these quantities in per-unit on the unit MVA base, their numerical values are identical.
- Any internal shunt admittances of the aggregate unit, unit transformer and LV cables, when specified in siemens or in per-unit on a fixed system MVA base, have values N times their values

for each corresponding unit. Where, on the other hand, the model specifies these quantities in per-unit on the unit MVA base, their numerical values are identical.

3.6.2 General Considerations

For a *generating system* or *integrated resource system* with many generating units or bidirectional units, provision of the required aggregate model will be the primary method considered for wider power system studies.

Aggregate models should continue to provide access to the LV terminal bus quantities for each aggregate equivalent unit, including *active power*, *reactive power* and *voltage* magnitude. This includes EMT models that have been black-boxed.

For model validation purposes, the aggregated unit and aggregated system responses must conform to the accuracy requirements in Section 5.2, where the individual aggregated unit model terminal quantities have a slightly moderated accuracy tolerance compared to the model connection point quantities. The procedure for R2 validation will involve collecting field measurements both for the aggregate system and for one representative unit for validation.

High voltage plant connecting directly to the transmission network is to be explicitly modelled.

3.7 Model and Facility Updates

While each submitted model must be a faithful representation of the *facility* at the time of submission, it is natural to expect that updates to the model will be issued from time to time by the supplier or other party responsible for the model.

It is especially important that alterations to the *facility* or its control firmware that alter the *plant's* dynamic performance are correctly reflected in an updated simulation model. It is also possible for several reasons for model updates to be proposed without any change to the *facility*.

For further details on *Generating System* model modification and update refer to Western Power's Relevant Generator Modification Guidelines [3].

3.7.1 Updates to Account for Simulation Model Improvement

The reasons for model updates relating to simulation improvements include the following:

- to improve computational or numerical performance of the model code;
- to incorporate additional functionality provided with newer versions of the same equipment, or to allow greater flexibility in configuration;
- to broaden the scope of the model code to represent multiple equipment types within the one family, by varying the configuration parameters; or
- to correct 'bugs' or unanticipated performance issues, particularly to reflect novel 'use cases' arising during long term operation.

In general, an update to a model held by Western Power for specific *facility*, in the absence of any alteration to the *facility* itself, will be considered only where it is relevant to the performance of that element in ongoing dynamic assessments (including the performance of the simulation software itself). Where the update is relevant only to accommodating future *facility* using the same model, it is generally expected that the existing *facility* will continue to use the 'old' model, which will continue to perform adequately after new *facility* is introduced using the updated model version.

The updated model's acceptance by Western Power will be subject to additional dynamic model acceptance testing conducted by Western Power at the Applicant's expense.

3.7.2 Updates to Account for Changes in the Plant Including Parameter Changes

Updates to *facility* firmware or settings that alters dynamic performance or protection operation must be captured in a revised dynamic model(s) to be submitted to Western Power. The revised dynamic model(s) must be accompanied by a report that shows the revised model(s) and its settings meets all accuracy requirements to R1 level, prior to acceptance of performance standards for the altered *facility*[14]. This will be followed by on-system tests as part of plant commissioning, including tests to validate the revised dynamic model(s) to R2 level.

The updated model's acceptance by Western Power will be subject to additional dynamic model acceptance testing conducted by Western Power at the Applicant's expense.

3.7.3 Updates to Account for Later Versions of Simulation Tools

Occasionally, it may be necessary for Western Power to move to later versions of RMS and EMT simulation tools. Ideally, later versions of these simulation tools will be backwards-compatible with existing models, or where Western Power have the source code for RMS models, Western Power will independently recompile the model and update model libraries.

However, if Western Power deem it necessary that a later version of a simulation tool is required to undertake studies, and an Applicant's existing model no longer functions correctly in the later version of the simulation tool, an update to the Applicant's model is required to provide compatibility with the later version of simulation tool. This model update is required from the Applicant without cost to Western Power. These updates may be required at any point in the life of the *facility*.

3.7.4 Updates to Account for Additions to Otherwise Unaltered Legacy Plant Behind a Connection Point

During the lifetime of a *generating system*, *integrated resource system,* or customer installation established under superseded modelling requirements, augmentations may be undertaken that have the effect of adding equipment behind the existing connection point but otherwise leaving the established plant unaltered. In these cases, models for the new plant must be provided in accordance with these Guidelines and Relevant Generator Modification Guidelines [4], representing good industry practice;

- to the extent that the legacy plant and the new plant are likely to interact in a manner that materially impacts *power system stability* or security, models for the legacy plant must be provided in accordance with these Guidelines to the extent reasonably practicable; and
- the Applicant may apply for an alternative process for the provision of updated models for legacy plant, to be considered by Western Power, and considering the principle that the model requirements should not present an unnecessary deterrent to augmentation works that are likely to benefit the *power system*.

From a modelling perspective, it is likely that material interactions between legacy and new plant in the power system are most likely to arise from one of the following four components:

- Outer control loops for voltage and/or reactive power within a plant.

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14 As per Technical Rules clause 1.8.2.

- Inner control loops driving unit-level voltage and current, including fault ride-through modes and PLL dynamics for electronic equipment.
- Outer control loops for dispatch and regulation of active power production or consumption by the plant.
- Outer control loops for frequency response and control.

The Applicant is encouraged to utilise all relevant information available to develop the legacy plant model. Generic models can be used to represent legacy plant when, despite its best efforts, the Applicant cannot obtain detailed site-specific models. The generic model should include all information related to the components listed above. Where practical, components which can be validated as per the R2 validation process must be included in legacy plant generic models. Other components of the generic model, which cannot be validated during the R2 validation process, can be validated by the Applicant through the ongoing compliance monitoring scheme. The validated model must be provided to Western Power within an agreed timeframe.

If the Applicant can obtain a vendor-specific model, for the exact or similar type of equipment installed the legacy plant, the vendor-specific model should be used to model the legacy plant. The site-specific model parameters should be used wherever available. In the absence of such site-specific model parameters, the Applicant must provide a set of model parameters which are configured based on relevant information available to the Applicant in respect of the legacy plant, including:

- previous commissioning results and operational records;
- technical documentation of the devices installed at the plant; and
- any other relevant information which the Applicant can reasonably obtain.

The model parameters should be configured so that the legacy plant model can demonstrate similar simulated response as observed in the commissioning or operational records. The model parameter configuration should aim to achieve the accuracy requirements specified in Section 5.2.1 of these Guidelines, with good engineering judgement applied to identify a “close enough” parameterisation outcome to achieve an optimal level of accuracy considering all information available for the model parameterisation.

The parameterisation associated with the model performance that can be validated in the R2 commissioning stage should be prioritised. The vendor-specific model must provide access to model parameters through which the model response can be adjusted. An un-adjustable model with poor correlation with the historical plant performance is likely to be inadequate. Western Power may require the legacy plant model to be validated by the Applicant through the ongoing compliance monitoring scheme.

4. Model Documentation Requirements

Information required for the modelling of *facility* for all applicable studies during Connection Process to connect to Western Power SWIS network is listed below:

- Access Application
- Completed Data Sheets
- Functional block diagram information for RMS models
- The RUG, for both RMS and EMT models
- Model source code information for RMS models
- Parameter mapping and benchmarking report of RMS and EMT models (where EMT model of the *facility* is deemed required)
- Protection Desing Report
- Operating Philosophy Document

This model information must be consistent. For example:

- The specific parameters relevant to a dynamic model required in tabular form by the Data Sheets, must be found in the functional block diagrams, also required by the Data Sheets;
- The functional block diagrams for RMS models and the Data Sheets, must match the functional block diagrams provided in the EMT model.

4.1 Releasable User Guide

A Releasable User Guide (RUG) should be submitted to Western Power with the computer model. The *user manual* must contain sufficient information to enable Western Power to use the computer model to carry out power system studies for planning, design and operational purposes in accordance with clause 1.8.2 (b)(5) of the Technical Rules. The *user manual* should not contain confidential information that cannot be released to third parties under Technical Rules clause 3.2.4 (b).

Information to be provided in the *user manual*, must include, but is not limited to the following:

- A description of the model components and parameters, and data category of each parameter (refer to Schedules of Technical Details in the Western Power Technical Rules - Section A3.5 for a description of data categories).
- Information about how the model parameter values vary with the operating state or output level of the *equipment* or with the operating state or output level of any associated *equipment* (e.g. excitation system automatic and manual control, configuration of voltage and power factor control modes).
- *Protection system* settings and algorithms relevant to load flow or dynamic simulation studies (e.g. under- and over-voltage or frequency protection settings).
- Any special control or protection schemes that are relevant to load flow or dynamic simulation studies (e.g. runback schemes, low voltage ride-through schemes, active power reduction schemes).
- Information provided in accordance with Technical Rules clause 3.3.2 only to the extent that the information is not a part of the model or the model parameters and that it is reasonably

necessary to allow modelling of the *generating unit, generating system*, *load* or related *equipment* in *power system* studies.

- *Connection point* details including single line diagrams, its parameters and values, location, associated *network augmentations* or modifications (if applicable) and other relevant connection information, sufficient to identify where to connect the *equipment* in the Western Power *power system* model.
- How the model is to be set up for *power system* analysis including, but not limited to:
  – Expected operational practice.
  – Specific software simulation setup such as integration algorithm, EMT or RMS simulation options, etc.
  – Special setup for any associated auxiliary *equipment* or reactive compensation *equipment*.
  – Details of modifications required to "scale-up" an aggregated *generating system* model and/or complex *load* model.
  – Special setup required to enable, disable and configure protection functions.
- For a *generating system, generating unit* or *load* incorporating any power electronic devices, a description of how that device should be included in the short-circuit fault calculation.
- Any other information the *User* considers relevant to the performance of the *equipment* for the model's intended use or to achieve the relevant accuracy requirements.

4.2 RMS and EMT Model Documentation

Supporting documentation included in the RUG must be relevant to the site-specific model and must contain sufficient information for Western Power to use the RMS and EMT models to carry out due diligence and power system studies.

The information in the supporting model documentation includes:

- Information that is necessary to allow modelling of the *facility* (in the case of generation, both each *generating unit* and *generating system*) for connection assessment and other power system studies;
- Instructions on the use the RMS and EMT models, including operational limitations;
- Descriptions and setting values for control sequences (for example, fault ride-through control schemes and any other relevant control systems) that are relevant to the intended use of the model;
- Descriptions, site-specific values and ranges of all configuration parameters, component trip/status codes used in the RMS and EMT models; and
- Descriptions, site-specific values and ranges of
- all user-adjustable variables and control system settings contained within the model.

4.2.1 Additional Information Required for Fault Level Calculations

Additionally, plant using converter-connected technologies must:

- State within the RUG timeframes which short circuit related parameters of the supplied model are appropriate; and

- Provide information on the magnitudes and phase angles of the phase-current connection point contributions that their equipment is expected to make (as a function of connection point voltage-dip magnitude and duration) for the following types of *voltage* dips:
  - In only one phase;
  - Equal dips in two phases and none in the third; and
  - Equal dips in three phases.

4.2.2 RMS Model Block Diagram

Block diagrams must be submitted alongside all RMS models. Several attributes will be assessed, with requirements set out below:

- The model block diagrams must illustrate all input and output signals including set-point signals on the model block diagrams and model frames, and clearly illustrate the interconnection of the various functional controllers.
- The model block diagrams must illustrate all derivative states including derivative state variable names consistent with the block diagrams.
- All required control and output signals should be available for dynamic (RMS) simulations and clearly illustrated on the model block diagrams. These signals would typically include, but are not limited to the following:
  - Active and reactive power.
  - Machine and exciter current and voltage.
  - Applicable set-points, including:
    - Active power set-point.
    - Frequency and/or speed reference set-point.
    - Voltage set-point.
    - Reactive power and/or power factor set-point.
    - Where applicable, PPC, capacitor bank and SVC set-points, etc.
  - Other signals depending on the technology type.
- The model block diagrams must clearly illustrate whether limits are windup or non-windup,[15] and provide details as to which state variable is limited and the relationship between the limit value and state variable that is being affected by that limit. For example, for a lead-lag function, whether the state variable or the feedback to the 'integrator' within the equivalent lead-lag representation is limited.[16]
- The model block diagrams must show all relevant non-linearities, such as limits, arithmetic or mathematical functions, events, dead bands and saturation.
- The model block diagrams and documentation must show all controller settings and settings ranges. Non-configurable settings should be identified on the block diagrams.
- The model block diagram documentation must identify any internal integration algorithms.
- The model block diagrams must identify the lookup table interpolation method (e.g. spline, linear).

[15] See Benedito et. al., A Circuit Approach for the Computer Modelling of Control Transfer Functions, PSCC, 2002.

[16] See Kundur, Power System Stability and Control, EPRI, 1994, page 360.

- Settings shown on the model block diagrams must align with the computer model.
- Where a controller uses input measurements or control outputs, these must be appropriately configured and identified on the functional block diagrams.
- The transfer function block diagram must include all functional controllers and plant that materially affects the performance of the model.
  - The models of the controllers and items of plant must be easily identifiable.
  - All individual blocks should be expressed explicitly. The use of black-box type approach for representing any of the individual transfer function blocks is not acceptable.
  - The interconnection of the different functional controllers and the items of plant must be clearly shown.
- Images and tables embedded in documents must be of sufficient resolution to easily identify all components, parameters and values.
- The transfer function block diagram must be described by Laplacian (preferred) or Z-domain transfer functions.
- The transfer function blocks and model parameters must be recognisable in terms of the physical design of the plant and control system settings, to allow the NSP or AEMO to assess control system settings proposed by the Applicant, or design new settings.
- The model parameter values must reflect typical values appropriate for the actual equipment installed. All model parameters and their values must be shown either directly in the transfer function block diagram or in a tabular format.
- Control systems with several discrete states or logic elements may be provided in flowchart format if a block diagram format is not suitable.
- Parameter values that are intended to be (or can be) externally adjusted must be clearly identified in the model block diagram.
- The model block diagram and flowcharts (if applicable) must represent the corresponding model source code.
- The model inputs and outputs shown in the transfer function block diagram representation should match those indicated in the Data Sheets.
- The state variables shown in the transfer function block diagram representation should match those indicated in the Data Sheets.
- Model documentation and transfer function block diagram representation should be provided at the level of detail required for Western Power to derive the corresponding linear small-signal model of the equipment.
- Dynamic data must be provided as ‘per unit’ quantities where the base MVA is provided in the model.

4.3 Small-signal Stability Model Documentation

Supporting documentation for small-signal stability models will depend on the format of the submitted model as set out in Section 3.4. Content of small-signal stability model documentation including benchmarking requirements should be developed through discussion with Western Power, Applicant and OEMs.

4.4 Harmonic Model Documentation

Harmonic model documentation must be sufficient for Western Power to understand and use the harmonic model in the software package of their choice. In case of EMT models, the principles set out in Section 4.2 should be adhered to when developing documentation, with specific differences between the harmonic and transient stability EMT model highlighted.

Additionally, documentation for the harmonic model must include any or all of the following as agreed with the relevant NSP and AEMO on a case-by-case basis:

- Harmonic emission studies:
  - A harmonic profile at different loading levels, between 0 to 100%, in 10% steps if it is demonstrated the harmonic current profile varies linearly as function of the loading;
  - OEM description of test setup or simulation procedure for deriving the harmonic profiles data;
  - A suitable frequency-dependent Norton equivalent for the harmonic injecting device to clearly demonstrate how the current injected and the equivalent impedance vary as function of harmonic order; and/or
  - Documents describing the suitability of the EMT-type model submitted consistent the level of modelling discussed in Appendix B.
- Harmonic susceptibility studies:
  - Documents describing the suitability of the EMT-type model submitted consistent the level of modelling discussed in Appendix B.

5. Model Accuracy Requirements

This section specifies model accuracy requirements. These model accuracy requirements:

- Are applicable regardless of the type of model provided;
- Will apply regardless of the type of *generating system*, *integrated resource system*, network or other *plant*; and
- Will apply to detailed IBL models other than general *load* models and IEEE Composite *load* models (Western Power advice should be sought for the latter).

5.1 Accuracy Locations

Model accuracy must be demonstrated for all components within a plant that impacts the *power system* dynamic performance.

Synchronous plant typically requires demonstration of model accuracy at each unit terminal.

Power electronic interfaced asynchronous technologies (such as wind and photovoltaic solar generating systems) may consist of *several generating units* or *bidirectional units*, plant controllers, Reticulation Networks and dynamic reactive support devices such as STATCOMs and synchronous condensers. As such, demonstration of model accuracy must occur at:

- Connection point or high voltage terminals of plant transformers.
- Reticulation Network collector bus to which an individual item of dynamic plant is connected.
- Generating or bidirectional units (for each different type of unit, including batteries).
- Terminals of each type of dynamic reactive support device, such as STATCOMs and synchronous condensers (if applicable).
- PPC and any other overarching coordinated controllers.

For a Network *User*'s *facility* solely consisting of IBL, demonstration of model accuracy must occur at the *connection point* or high *voltage* terminal of the main supply transformer. For a Network *User*'s *facility* consisting of both IBL and non-IBL components, demonstration of model accuracy may occur at the buses where IBL model aggregation is considered. Demonstration of model accuracy may be conducted at other locations within the Network *User*'s *facility*, subject to agreement between Western Power and the Applicant.

5.2 Model Performance Measures

The performance measures described in this Section must be used to determine the model accuracy, where all accuracy bands are to be referenced to the model's response. A table specifying quantities to which these requirements apply is provided in Appendix C.

General considerations are:

- The term "transient window" is used to describe the moment a reference change or Disturbance commences until the response returns to within ±5% of the model's maximum induced or reference quantity change.

- Accuracy of EMT model responses are evaluated on their simulation-tool calculated RMS quantities[17], with filtering appropriate for a 50 Hz nominal system. Larger filtering time constants on measurements will require justification.

5.2.1 Accuracy Criteria

The following criteria apply, and no criterion should override another, except where noted:

a. For synchronous plant control system models, the overall linear response over the total controller bandwidth or 0.1-5 Hz, whichever greater, must be within the following tolerances:

   (i) Magnitude must be within 10% of the actual control system magnitude at any frequency; and

   (ii) Phase must be within 5 degrees of the actual control system phase at any frequency.

b. For time domain responses that include non-linear responses or performance, as well as responses to switching or controlled sequence events (for example, operation of fault ride-through schemes and converter mode changes), the key features of the response are within the following tolerances:

   (i) Rapid slopes in the actual plant response, compared with the simulated response must be within the less restrictive of:

      A. ±10% of the change for 95% of the samples within the transient window; and

      B. From the start to the finish of the slope, a difference of less than 20 ms.

   (ii) The timing of the occurrence of the rapid slopes, events or the commencement of oscillations described in paragraphs (a)-(c) must be consistent with the plant characteristic that initiates the response[18].

c. Taking into account the *voltage* at the *connection point*, at any point during the simulation, the deviation of the actual measured responses from the simulated response for *active power* and *reactive power* must not exceed 10% of the total change in that quantity for 95% of the samples within the transient window. During periods of oscillatory behaviour, this criterion applies to:

   (i) The first cycle of the oscillatory response after the transient period (that is, if associated with a fault, then after clearance of the fault and the transient recovery from the fault); and

   (ii) After the first cycle of the oscillatory response, to the upper and lower bounds of the envelope of the oscillatory response.

d. Where measurement results can be shown to have been affected by changes in supply source (for example, the wind strength for a wind turbine), this shall be taken into consideration when assessing this criterion, so long as sufficient evidence can be shown to demonstrate the cause of the input power change, and in the case of large variations, sufficient efforts were made to re-test the plant to obtain improved measurement results.

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[17] Per-phase RMS quantities for unbalanced Disturbances.

[18] This is a difficult criterion to specify, as it depends on what initiates the event or oscillation. Switching events or rapid control actions initiated as a result of passing a threshold level in a measured quantity and any time delays in the design of the plant should be straightforward to assess. It is recommended that the fallback criterion for this requirement be that:

(i) the response must be explainable; and

(ii) any inconsistency in the response should lead to an investigation to establish a plausible reason for the inconsistency. A revision to the model should be considered in the latter circumstance.

Note that for all plant closed-loop internal quantities and production unit terminal quantities for aggregated models only, replace all instances of “95%” in Section 5.2.1 (referring to samples within a transient window) with “90%”. Connection point quantities do not have this accuracy moderation applied.

If Western Power agree that dynamic changes in the network or prime mover have contributed to model inaccuracy, they may relax one or more of these accuracy requirements. Additionally, further deviations beyond the model accuracy requirements for plant internal quantities may be permitted when direct measurement of internal quantities is not practicable or there are known model deficiencies[19].

The accuracy criteria listed above do not apply to general *load* models or IEEE composite *load* models, if the use of such models to represent large single loads has been agreed by Western Power. For more detailed IBL models, the accuracy criteria in (c) and (d) listed above will apply. The accuracy criteria in (a) are only applicable to the synchronous plant components within any single large load. The application of the accuracy criteria in (b) are subject to whether the IBL needs to demonstrate compliance with relevant ride through capability performance standards.

5.2.2 Stable Response for the Entire Intended Operating Range

The model initialisation and operating range should be consistent with the actual equipment design in regard to the following:

- The entire range of *active power*.
- The entire range of *reactive power*/*power factor* (including limits of *reactive power* generation and consumption).

5.2.3 Unbalanced Disturbances

When a positive-sequence model fails to meet the accuracy requirements by a material margin for unbalance disturbances, the use of EMT-type or three-phase RMS simulation models is permissible provided that the simulation model chosen can demonstrate compliance with the model accuracy requirements.

5.2.4 Stable But Different Response when Response Becomes Limited

Models must demonstrate accurate and stable behaviour when the limits implemented within the plant control systems are reached. For example, activation of a synchronous plant under- or over-excitation limiter should not cause model instability or produce the same response for a scenario where limiters have not been activated. Output of each limiter must be available for plotting to demonstrate that it acts for intended operating conditions, and do not falsely activate when the limit is not reached.

5.2.5 Unstable Response When Operated Beyond its Intended Operating Range

Where network conditions, energy source limitations, Disturbances or other factors would cause the *facility* to become unstable, activate protection mechanisms, or otherwise cease operation, it is expected that the model would reflect the *plant*’s response. Models should not be created such that they continue to operate stably outside of the *plant*’s operating envelope[20].

19 For example, synchronous generation field current.

20 Models that cease output when exposed to conditions outside the intended operating range are not considered inferior, however, the cessation of the model output must not result in instability or crashing of the underlying simulation tool.

5.2.6 No Unexpected or Uncharacteristic Responses

The model must not show characteristics that are not present in the *facility* response, both in terms of the electrical response and modelling numerical artefacts.

5.3 Model Compliance and Confirmation (Pre-Connection R0 / R1)

Model Compliance and Confirmation for *loads* and *generating systems* is conducted during R0 and R1 stages of the *facility* connection process in which:

- compliance assessment for *loads* is in accordance with specific clauses of Technical Rules; and
- compliance assessment of the *generating systems* is in accordance with the Generator Performance Standard (GPS) as captured in Appendix 12 of WEM Rules.

Below subsections provide further details.

5.3.1 Load Compliance Assessment Against Technical Rules

Requirements for connection of *loads* is summarised in Section 3.4 of the Technical Rules and other relevant clauses of Technical Rules as summarised in 2.3 [1]. As per clause 3.4.1 of the Technical Rules:

a. *A Consumer*[21] *must ensure that all facilities associated with the relevant connection point at all times comply with the applicable requirements and conditions of connection for loads:*

   (i) As set out in TR clause 3.4; and

   (ii) In accordance with the relevant connection agreement with the Network Service Provider

b. *A Consumer must operate its facilities and equipment in accordance with any and all directions given by System Management or the Network Service Provider under these Rules or under written law.*

The purpose of compliance assessment of loads is to evaluate the RMS model of the loads provided to Western Power against the Technical Rules criteria summarised in Table 5.1 and other criteria as captured in Sections 2, 3, and 4 of this Guideline.

Table 5.1: TR clauses relevant to Load Compliance Assessment

TR Clause Number	Technical Requirement
2.2.8.	Power Oscillation Damping
2.2.10.	Temporary Over-Voltages
3.2.1.(f)	Fault Levels
3.4.2.(c)	Excessive load fluctuations, Reactive Power draw, stalling of motor loads with Adverse Impact
3.4.3.	Power Frequency Variations
3.4.4.	Power Frequency Voltage Variations
3.4.7.	Power Factor Requirements

21 A *User* who consumes electricity supplied through a connection point.

5.3.2 Generator Compliance Assessment Against Appendix 12 of Wholesale Electricity Market Rules

In 2021, the Wholesale Electricity Market (WEM) Rules introduced the Generator Performance Standards (GPS) for Market Participants responsible for a Transmission Connected *Generating System* connected to the South-West Interconnected System (SWIS). GPS is described in Chapter 3A and Appendix 12 of the WEM Rules and other associated documentations [2]. GPS clauses are listed in Table 5.2 below.

In accordance with WEM Rules clause 3A.4.4, Western Power developed the "Generator Performance Standards: Guideline for the Assessment of Technical Requirements", which provides the Market Participants with the detailed assessment methodology against each clause of Appendix 12 of the WEM Rules with respect to the type of the *Generating System*.

Western Power undertakes Generator Performance Standard validation (GPS Validation) of the submitted GPS Package including the computer model to WP to assess its performance against the requirements of these Guidelines as well as Appendix 12 of WEM Rules.

As part of the GPS Validation, Western Power will identify to what extent the computer model meets the relevant criteria defined in these Facility Model Guidelines.

In the process of the *Generator Performance Standard (GPS) Assessment* the Market Participant must:

- request AEMO to provide the Maximum Temperature at the site location and all temperature dependant clauses are assessed at ambient temperature and all temperatures up to and including the Maximum Temperature;
- prepare one draft Generator Performance Standard Report [5] (R0, R1, or R2 GPS depending on the project connection status) for validation by Western Power and subsequently AEMO / one final Generator Performance Standard Report (R0, R1, or R2 GPS depending on the project connection status) for approval by Western Power and AEMO;
- along with each version of the report, submit below items to Western Power:
  - GPS template [6];
  - temperature dependant data of the facility, submitted in the same format as per the template spreadsheet [7];
  - separate files attached to the GPS report that include all simulation results for the relevant clauses. The documents are to be named after the clause number, for example Attachment B (A12.3), Attachment C (A12.4), etc;
  - unencrypted PowerFactory Model of the *generating system* including behind the meter reactive plant (if any reactive plant included in the scope);
  - R0 GPS submission should contain the PSCAD™/EMTDC™ model of the *generating system* if used for the assessment of any of the GPS clauses. The model should include any additional behind the meter reactive plant;
  - R1 and R2 GPS submissions must contain the PSCAD™/EMTDC™ model of the *generating system*. The model should include any additional behind the meter reactive plant;
  - any other relevant documents that are used as a reference for justification of the performance level and compliance assessment of the facility. For example, the Power Quality Assessment Report.

After each GPS submission, Western Power will:

- review the draft Generator Performance Standard Report prepared by the Market Participant, the unencrypted *generating system* model as well as other complementary documents submitted along with the GPS Package and provide comments in the GPS Assessment Validation Spreadsheet;

- upload the received GPS package on AEMO's portal along with GPS Assessment Validation Spreadsheet;
- consolidate the comments provided by WP and AEMO in the GPS Assessment Validation Spreadsheet;
- submit the consolidated comments via the GPS Validation Spreadsheet to the Market Participant and initiate discussion with Market Participant if required for that submission;
- review and, at Western Power and AEMO's absolute discretion, approve the final Generator Performance Standard Report.

Note that if the submitted GPS package is deemed to be **incomplete**, Western Power will notify Market Participant and provide instructions for subsequent submission of the GPS package.

Table 5.2: WEM Rules clauses to be assessed for GPS Assessment

Appendix 12 Clause Number	Technical Requirement
A12.2.	Active Power Capability
A12.3	Reactive Power Capability
A12.4	Voltage and Reactive Power Control
A12.5	Active Power Control
A12.6.	Inertia and Frequency Control
A12.7.	Disturbance Ride Through for a Frequency Disturbance
A12.8.	Disturbance Ride Through for a Voltage Disturbance
A12.9.	Disturbance Ride Through for Multiple Disturbances
A12.10.	Disturbance Ride Through for Partial Load Rejection
A12.11.	Disturbance Ride Through for Quality of Supply
A12.12.	Quality of Electricity Generated
A12.13.	Generation Protection Systems
A12.14.	Remote Monitoring Requirements
A12.15.	Remote Control Requirements
A12.16.	Communications Equipment Requirements
A12.17	Generation System Model

All simulation plots must, as a minimum, include terminal *voltage*, *active power*, *reactive power*, applied input signal (e.g. *voltage* reference step change, grid *voltage* step change) and other relevant signals (e.g. PSS output, SVC reactive power).

5.3.3 Model Tuning

Adequacy of the Model Tuning will be assessed through the RMS and EMT Wide Area Studies. Majority of the GPS clauses listed in Table 5.2 are to be assessed in Single-Machine Infinite Bus (SMIB) model, however certain clauses in GPS and Technical Rules which are relevant to *Adequacy of Model Tuning* are to be assessed in the Wide Area Root Mean Square (RMS) model and/or Wide Area Electromagnetic Transient (EMT) model of SWIS. The relevant clauses of the GPS which require network studies are listed below and are in accordance with the type of the facility:

- A12.4.2.2.(a) A12.4.3.2.(a): Power system oscillations damping adequacy
- A12.4.2.2.(b), A12.4.3.2.(b): No degradation of damping performance of power system
- A12.4.2.2.(c): Power system stability requirement
- A12.4.2.5.(b): Voltage Control System - support network voltage during fault
- A12.9.2.2., A12.9.3.2.: Continuous Un-interrupted Operation

As part of the above assessment related to the system stability and power oscillation damping adequacy, the requirement of Technical Rules clauses as listed below are applicable:

- Technical Rules Clause 2.2.7: Transient Rotor Angle Stability
- Technical Rules Clause 2.2.8: Oscillatory Rotor Angle Stability
- Technical Rules Clause 2.3.7: Power System Stability and Dynamic Performance

In case of any issue identified in the Wide Area RMS and EMT studies, retuning of the *facility* controller can be investigated as the first solution. When such changes in setting is advised by Wide Area Studies, the new settings will require to be approved by the OEM for application. If the identified issue is deemed not to be related to controller tuning, other solutions such as installation of additional equipment might be required to achieve the compliance (e.g. installation of a dynamic controlled reactive plant for instance STATCOMs to be considered to resolve voltage stability issue, etc).

5.3.4 Model Acceptance Tests

In cases where a *User* seeks to develop a *facility* with a particular technology type, but where a site and/or *connection point* has not yet been selected (e.g. as part of an Enquiry), the *User* may seek to have Western Power provide an initial assessment of the computer model and associated information against the requirements of the Technical Rules or WEM Rules (depending in the type of the facility, i.e. load or generating system) and the *Facility Model Guidelines*.

This assessment would be conducted using an infinite bus model for a range of system strengths to emulate different connection locations. This assessment would therefore not assess electromechanical interactions with generators, which could later be assessed using the complete model of the SWIS once the *connection point* is known.

5.3.5 RMS and EMT Model Benchmarking

Confirmation of RMS- and EMT-type model adequacy prior to detailed connection studies is prudent to minimise risks that may multiply the time and effort in assessing a specific plant connection and alterations.

The following principles will apply to pre-connection model confirmation tests:

- Among Disturbances applied for model confirmation tests, there should be a two-phase-ground or three-phase fault equivalent to what might be experienced by a generating unit or bidirectional unit upon installation. The same should be applied to IBLs which are expected to be compliant with relevant ride through capability *performance standards*.

- The post-fault fault level and network impedances used for the testing should be reasonably representative of the post-fault fault level that the plant would experience.
- Changes in the control systems or settings of individual items of *plant* are necessary if the submitted EMT-type model exhibits uncharacteristic or unexpected responses.
- Model response should be generally aligned with expected response. The model accuracy requirements set out in Section 5.2.1 will not strictly apply during this stage.
- Where both RMS and EMT models are provided, responses of the two models should be benchmarked against one another. While the accuracy requirements in Section 5.2.1 will not apply in the absence of actual plant response data, the criteria in this section may be applied as guidance for assessing benchmarking performance with the EMT model response in place of the '*plant*' response and the RMS as the 'model' response. Divergences in model responses from the strict criteria should be expected, especially on sub-cycle time scales following the application of a large Disturbance. For small Disturbance response, such as a control system reference step change, both RMS and EMT should provide reasonably close responses (<10% discrepancy) in terms of rise time, overshoot, and settling time, and should achieve the same steady-state value following the same reference step change. If this accuracy cannot be achieved, the Applicant must provide reasons to the Western Power.
- Tests should be conducted across a range of operating conditions including pre-Disturbance active power and reactive power levels.

Western Power must provide the range of operating conditions, including pre-Disturbance levels of active power and reactive power and a list of required tests for the required tests to be carried out. The benchmarking test set aim to cross compare RMS and EMT model for all control modes and operating ranges. The following are the main category of tests to be applied:

- Step into setpoint for all control modes of voltage and frequency controllers for permutation of system impedance and generating facility's operating point.
- Step into limiters for all control modes of voltage for permutation of system impedance and generating facility's operating point.
- Step into voltage and frequency of the system when the generating facility is operating at various outputs.
- Ramp up and down test for active power.
- Balanced and unbalanced faults with various residual voltages for permutation of system impedance and generating facility's operating point.
- Auto reclose events and switch onto fault

5.4 Model Validation (Post-Connection R2)

Each model must be developed and tested to the extent reasonably necessary to establish that it will meet the accuracy requirements. To achieve this:

- During the plant design and development stages (R0 and R1 stages), it is expected that the model is rigorously checked against design information and its performance is confirmed against the actual plant response; and
- R2 models and parameters must be derived from on-site data and performance tests.

Parameters, other than R2, that contribute most significantly to the accuracy of the model for fault, *voltage* and *frequency* Disturbances in the *power system*, must be derived from on-site tests, where possible. Test results from the commissioning tests (used to confirm compliance of the plant with *performance standards*) may also provide, or contribute to, R2 data values[22]. These parameters must still be validated (in aggregate) through the validation of the overall performance of the plant, network element, device, unit or controller to which they pertain.

Results obtained from off-site tests or factory tests may be used for model confirmation tests. Another approach adopted by power system equipment manufacturers is Hardware in Loop (HIL) testing to simulate Disturbances well before plant undergoes on-site commissioning and R2 model validation.

5.4.1 Post-Connection Model Validation (R2)

R2 model validation is the final stage of providing evidence that the models submitted to Western Power are of adequate quality to be used in power system studies to determine how to operate the power system securely. It is validated by comparing RMS and EMT model response to the test data of the plant installed at the site of interest.

For each relevant *performance standard* arising out of the technical requirements in GPS, Table 5.3 below describes the model validation required from the Applicant. For further information on the Commissioning Tests, refer to Section 3.21A of the WEM Rules [2].

The plant tested has identical control system settings to the one being installed, or the difference in settings can be translated into appropriate model parameter values applicable to the plant to be installed.

The accuracy and adequacy of EMT-type models must be confirmed against the response of individual items of plant, including generating units, bidirectional units and dynamic reactive power support plant (if applicable), and IBLs for the conditions specified above, or against the validated EMT-type models.

Table 5.3: Simulation tools required for R2 model validation (generating systems and integrated resource systems)

GPS Clause	RMS Simulation Tool	EMT Simulation Tool
A12.3 – Reactive Power Capability	✓	-
A12.4 – Voltage and Reactive Power Control	✓	✓
A12.5 – Active Power Control	✓	✓
A12.6 – Inertia and Frequency Control	✓	✓
A12.7 – Frequency Disturbance Ride Through	✓	✓
A12.8 – Voltage Disturbance Ride Through	✓	✓
A12.10 – Disturbance Ride Through for Partial Load Rejection	✓	-
A12.11 – Disturbance Ride Through for Quality of Supply	✓	✓
A12.12 – Quality of Electricity Generated	✓	-
A12.13 – Generation Protection System	-	-
A12.16 – Communications Equipment Requirements	-	-

22 Refer to Attachment 11 of Technical Rules for further details.

On-site tests

During commissioning, validation of model performance can be demonstrated by model overlays based on the tests outlined in AEMO's R2 test procedure template, and by continuous monitoring described below [9]. For further information on the Commissioning Tests, refer to Section 3.21A of the WEM Rules [2].

Continuous monitoring of disturbances

Congruence between plant and model dynamic responses for some aspects may be difficult to demonstrate until a network Disturbance occurs. It is, therefore, necessary that the Applicant develops a continuous monitoring program to demonstrate model accuracy for all major items comprising the plant (that is, both at a system and unit level). As part of the Generator Monitoring Plan (GPM), Market Participants that are aware of a non-compliance or suspected non-compliance against any of the Registered Generator Performance Standards or GMP must notify AEMO immediately [9]. The Applicant must submit the model overlays to Western Power for analysis and model verification as soon as possible following such a Disturbance.

A non-compliance or suspected non-compliance can also be raised by the Network Operator (Western Power) or by AEMO as part of which, high speed data collected during a Disturbance can be overlaid to demonstrate correct model responses.

Validation of Network User's model (for load)

Currently there is no R2 test template or guideline for a Network User's (load) facility. In the absence of a detailed R2 commissioning process for a Network User's (load) facility, Western Power will seek to determine the scope of model validation for these facilities based on the following guiding principles:

- model validation may rely on the measurement, or other relevant information, obtained from project-specific commissioning activities as a part of the load connection process, which may be required by Western Power.
- The detailed models of IBL facilities, or aggregated IBL components within a Network *User*'s (*load*) *facility*, should be subject to the same model validation process as that applicable to models for *generating units* and *bidirectional units*, as specified in these Guidelines.
- For non-IBL facilities, or non-IBL components within a Network *User*'s (*load*) *facility*, the Applicant must seek Western Power's advice on the requirement of *load facility* commissioning.
- Overlays of high speed data collected during a Disturbance and model results can be used to demonstrate correct model responses at point of connection.

These principles should not be taken to preclude different practices that may be prescribed in any future *load* R2 commissioning guideline.

5.4.2 Numerical Modelling Artefacts and Implication for Model Confirmation

Inaccuracies or undesired behaviours may be identified during validation or benchmarking tests on models, as well as prospective modelling results obtained in advance of field tests. For example:

- The simulation software crashes, or otherwise cannot complete the simulation.
- The model output oscillates between two distinct values on alternate time steps.
- Spikes or large instantaneous changes in electrical quantities are observed in RMS simulations that are not reproduced in EMT simulations of the same event.

Such inaccuracies or undesired behaviours may arise due to numerical factors inherent in the model software environment, rather than the actual performance of the plant. Conversely, oscillatory responses or output changes that follow reasonably smooth trajectories in time and persist for one or more AC cycles are more likely to reflect real plant performance, particularly where these are seen in EMT modelling results.

The Applicant in consultation with its OEM(s) should take all reasonable steps to resolve any inaccuracies or undesired behaviours within the model, such that their impact on key output quantities is within the accuracy tolerances in Section 5.2 of these Guidelines, subject to the following general guidance:

- Where a numerical artefact in a model materially restricts the conduct of reasonable due diligence on plant performance (and provision of reliable alternative evidence by the Applicant is not possible), resolution is required within the timeframe for assessment of proposed access standards by the Western Power.
- Otherwise, resolution is required prior to registration of the Applicant (where applicable) or, where registration is not applicable, prior to commencing commissioning of the relevant new or altered plant.
- When OEM remedies are not available, for example when updated models are required for legacy plant under Section 3.7.4 of these Guidelines:
  - A numerical artefact in a legacy plant model is acceptable to the extent it does not materially restrict the conduct of reasonable due diligence on plant performance.
  - EMT modelling evidence may be accepted in the absence of RMS modelling evidence to assess performance for specific access standards where the RMS model evidence is precluded by model performance issues.
  - Where available field test results for the existing (prior to any proposed alteration or change) legacy plant confirm the undesired model behaviour is not observed in reality, assessment of a new or altered connection may proceed on the basis of the test results. This does not otherwise affect the Applicant’s obligations under Section 3.7.4 of these Guidelines.
  - Any permitted undesirable legacy model behaviours should to the extent practicable be contained to specific documented study scenarios.

5.5 Non-conformance with Model Accuracy Requirements

Where Western Power determines that model inaccuracy outside the tolerances specified in Section 5.2.1 presents a risk to *power system security*, adverse impact on the performance of other Network *Users*, or inability meet *performance standards*, the following action may be required by Western Power:

- Additional testing;
- Operational constraints imposed until the modelling issue can be resolved;
- Revised models or parameters verified by pre-commissioning model confirmation tests be submitted and accepted (revision may result in submission of a detailed vendor-specific model); or
- Any combination of these.

These requirements may persist or be repeated until the model accurately reflects the *facilityt*’s response, and hence the *facility*’s performance can be adequately predicted by *power system* studies.

6. Confidentiality of the Information and Models Provided

6.1 Storage and Use by Western Power

Western Power's personnel have restricted access to data provided to Western Power by *User*.

Information obtained by Western Power and covered by these Guidelines is to be stored by Western Power document control systems. All information and models are used for the purpose for which they are intended to be used, consistent with the Technical Rules and WEM Rules.

6.2 Intellectual Property

These Guidelines do not affect or substitute the intellectual property rights in the information and models obtained by Western Power.

6.3 EMT Model Black-boxing, Compilation or Encryption

As Western Power may be obliged to disclose models to AEMO or other third parties, model owners may wish to black-box, compile or otherwise encrypt portions of an EMT model that are commercially sensitive, or where additional intellectual property protection is desired.

Provided the requirements in these Guidelines as to the model's utility are met, and a legitimate user of the model is not hampered in their ability to carry out legitimate studies using the model, black-boxing is acceptable.

Model owners remain responsible for the adequacy of the black-boxing, compilation or other encryption of their model.

6.4 Provision of Information and Models to Third Parties

Information provided to Western Power may be released to third parties in accordance with Technical Rules clause 3.2.4(b).

"The Network Service Provider may provide any information it so receives to any User who intends to connect any equipment to the transmission system for the purposes of enabling that User to undertake any power system simulation studies it wishes to undertake, subject to that User entering into a confidentiality agreement with the Network Service Provider, to apply for the benefit of the Network Service Provider and any User whose information is so provided, in such form as the Network Service Provider may require."

In addition, the information provided to Western Power shall be released to AEMO as per WEM Rules clause 2.28.3A.

7. Variation Requests

Unless Western Power agrees otherwise in writing, a *User* must provide all of the information required by these *Facility Model Guidelines*. If the Applicant cannot meet the requirement criteria defined in these Guidelines an application for providing alternative model or information with certain level of details is to be provided to Western Power. Refer to the application form in Appendix D.

8. References

[1] Western Power | Technical Rules

[2] Wholesale Electricity Market Rules 1 April 2024

[3] Western Power | Relevant Generator Modification Guideline

[4] AEMO | Seeking Accreditation for FCESS

[5] Western Power | GPS Report Template

[6] Western Power | GPS Template

[7] Western Power | Temperature Dependant Data Template

[8] Western Power | Generator Performance Standards: Guideline for the Assessment of Technical Requirements

[9] AEMO | Generator Performance Testing and Monitoring

Appendix A

Western Power Data and Model Requirements

A.1 Connection Process Data and Model Requirements

Data provided to Western Power for both new connections and existing *facility* modifications or upgrades should be refined throughout the project as updated information becomes available.

Figure A.1 provides an overview of the sequence of connection network studies applicable to new *facilities*. For an existing *facility* undergoing alterations or upgrades aspects of this process may apply, depending on the nature of the change. In general, for a change that results in a change to plant performance and/or computer model an updated *access application* should be submitted to Western Power with relevant information.

The data and model prerequisites for each phase of the connection process are listed below:

- **With Connection Application:** Standard Planning Data (S data) including *Access Application* and Steady State Model;
- **Before Access Offer (R0):** Detailed Planning Data (D data) along with Updated Access Application, dynamic model and associated documents for loads and R0 GPS Package for *generating systems* which includes the RMS model of the *facility*. EMT model of the generating system is also to be submitted at this stage if used for the R0 GPS assessment of any of the clauses. If the EMT model is not submitted as part of the R0 GPS package, it has to be submitted following finalisation of the Wide Area RMS Studies.
- **Pre-commissioning (R1):** R1 Data along with Updated Access Application, dynamic model and associated documents for *loads* and R1 GPS Package for *generating systems* which includes the RMS and EMT models of the *facility*;
- **Post-commissioning (R2):** R2 Data along with Updated Access Application, dynamic model and associated documents for *loads* and R2 GPS package for *generating systems* which includes the RMS and EMT models of the *facility* with the commissioning tests settings;

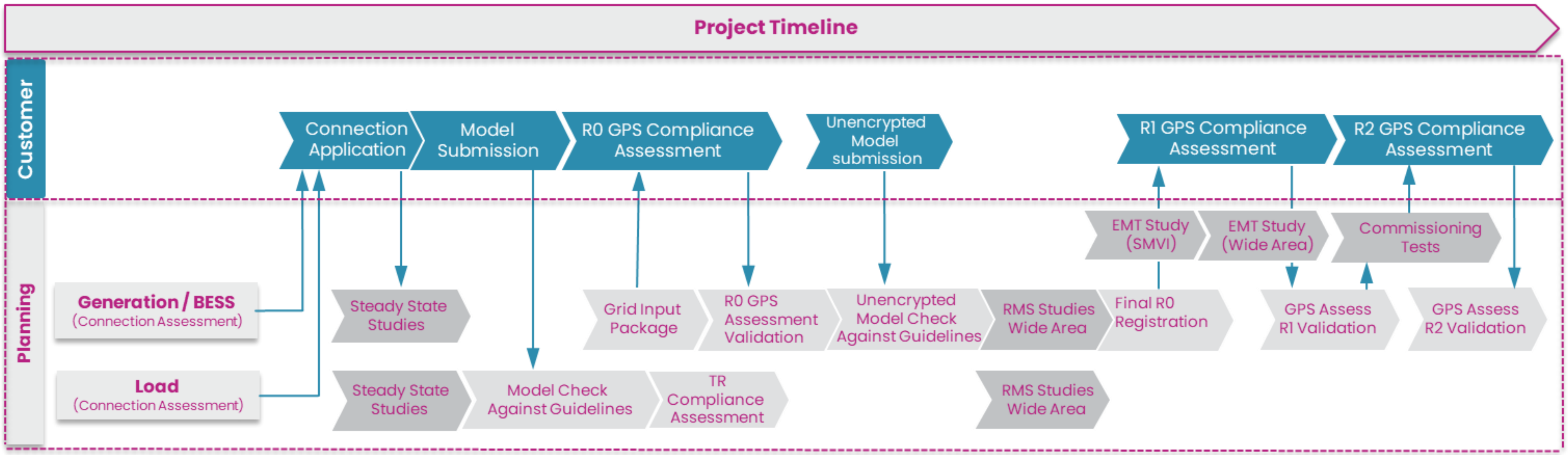
For additional information, refer to:

1. Western Power's website[23] for detailed information on the end-to-end connection process and specific activities conducted at each stage.
2. The Applications and Queuing Policy[24].
3. Schedules of Technical Details (Western Power Technical Rules [1]- Section A3.5).

[23] Transmission loads & large generators (westernpower.com.au)

[24] Application and Queuing Policy (ERA)

Figure A.1: Western Power Connection Studies Sequence



Appendix B

Modelling Components Requirements

B.1 Definition and Notes

B.1.1 Protection Systems

Experience has shown that protective functions of *plant* can have a major impact on stability of the *generating system* or *integrated resource system* and the *power system*. Reference to "protection" in the following table and footnotes includes:

- High and low *voltage* protection;
- Over- and under-*frequency* protection;
- Rate of change of *frequency* protection;
- Multiple fault ride-through protection;
- Loss of excitation protection;
- Over-flux (V/Hz) protection;
- Out-of-step protection;
- Negative phase sequence (voltage unbalance) protection[25];
- Reverse *active power* protection;
- Unit transformer and generator differential protection; and
- Any Remedial Action Schemes that have been deemed to have material impact on the system.
- Any protection function implemented in plant control systems which is affected by external system disturbances;
- All protection systems included in the models must be consistent with the plant's performance standard.

B.1.2 Control Loops

The representation of control loops in converter-connected technology is of particular importance for assessing stability of plant. Where the following terms are included within tables, the sub-points indicate the control loops that are expected to be represented within the model.

Outer loop converter control

- Active power and reactive power control.
- Active torsional damping (if applicable).
- Fast acting *voltage* control (if applicable).
- Fast acting *frequency* control (if applicable).

Inner control loop

- DC link current control.
- DC link *voltage* control.
- Rotor-side current control (if applicable).

[25] Where the underlying simulation tool allows negative phase sequences to be evaluated.

- Grid-side current control (if applicable)

The transitioning between control mode during system disturbances and step tests are required to be modelled accurately. If a control mode become inactive, appropriate freezing of the states of inactive controller must be implemented to represent the site actual controller setup. It includes provisions for burpless transfer between controllers.

B.2 Wind Generation

- Models to be aggregated as per Section 3.6.
- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.

B.2.1 Turbine Model Components

Table B.1: Turbine Model Components

Model	Aerodynamics	Pitch controller	Mechanical drive train	Torsional damping	Electrical generator[A]	Dynamic braking resistor / chopper	DC link	IGBT switches and PWM switching	Unit transformer[B]	Internal filters	Inner loop converter control	Outer loop converter control	Phase locked loop[C]	Frequency control[D]	High voltage ride-through	Low voltage ride-through	Multiple fault ride-through limitations	Protection
RMS	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	-	✓	-	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

A. Filter-order generator
B. Including saturation for EMT models
C. Explicit representation.
D. Including frequency raise and lower, frequency droop and deadbands.

B.2.2 Balance of Plant Model Components

Table B.2: Plant Components

Model	Park controller[A]	Other coordinated control systems	Reticulation Network	Static reactive support plant[B]	Dynamic reactive support plant[C]	Connection point transformers[D]	Transformer onload tap
RMS	✓	✓	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓

A. Including delays that affect performance, controls and outputs for reactive power support plant, controls for active power, reactive power, voltage, power factor and frequency, and any participation in fault ride-through protection.
B. Details of switching philosophy to be provided in the RUG.
C. Including full voltage controller representation and relevant protection mechanisms.
D. Including saturation for EMT models.

B.3 Photovoltaic Generation

- Models to be aggregated as per Section 3.6.
- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.

B.3.1 Inverter Model Components

Table B.3: PV Inverter Model Components

Model	Solar Cells	DC-DC converter	DC link	IGBT switches	PWM switching	Unit transformer[A]	Internal filters	Inner loop converter control	Outer loop converter control	Phase locked loop[B]	Frequency control[C]	High voltage ride-through	Low voltage ride-through	Multiple fault ride-through limitations	Protection
RMS	-	✓	✓	-	-	✓	✓	-	✓	-	✓	✓	✓	✓	✓
EMT	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-	✓

A. Including saturation for EMT models.
B. Explicit representation.
C. Including frequency raise and lower, frequency droop and deadbands.

B.3.2 Balance of Plant Model Components

Table B.4: PV Plant Components

Model	Park controller[A]	Other coordinated control systems	Reticulation Network	Static reactive support plant[B]	Dynamic reactive support plant[C]	Connection point transformers[D]	Transformer onload tap
RMS	✓	✓	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓

A. Including delays that affect performance, controls and outputs for reactive power support plant, controls for active power, reactive power, voltage, power factor and frequency, and any participation in fault ride-through protection.
B. Details of switching philosophy to be provided in the RUG.
C. Including full voltage controller representation and relevant protection mechanisms.
D. Including saturation for EMT models.

B.4 Converter Based Energy Storage Systems

- Models to be aggregated as per Section 3.6.
- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.

B.4.1 Converter Model Components

Table B.5: Converter Model Components

Model	Energy storage (battery, super-capacitor)	DC-DC converter	DC link	IGBT switches	PWM switching	Unit transformer[A]	Internal filters	Inner loop converter control	Outer loop converter control	Phase locked loop[B]	Frequency control[C]	High voltage ride-through	Low voltage ride-through	Multiple fault ride-through limitations	Protection
RMS	-	✓	✓	-	-	✓	✓	-	✓	-	✓	✓	✓	✓	✓
EMT	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-	✓

A. Including saturation for EMT models.
B. Explicit representation.
C. Including frequency raise and lower, frequency droop and deadbands.

B.4.2 Balance of Plant Model Components

Table B.6: Plant Components

Model	Park controller[A]	Other coordinated control systems	Reticulation Network	Static reactive support plant[B]	Dynamic reactive support plant[C]	Connection point transformers[D]	Transformer onload tap
RMS	✓	✓	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓

A. Including delays that affect performance, controls and outputs for reactive power support plant, controls for active power, reactive power, voltage, power factor and frequency, and any participation in fault ride-through protection.
B. Details of switching philosophy to be provided in the RUG.
C. Including full voltage controller representation and relevant protection mechanisms.
D. Including saturation for EMT models.

B.5 Inverter Based Loads

- Models to be aggregated as per Section 3.6.
- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.
- Inclusion of model components depends on actual load configuration.
- Applicable to detailed load models only (not applicable to general load model or IEEE Composite load model)

B.5.1 Converter Model Components

Table B.7: BESS Convertor Components

Model	Energy storage (battery, super-capacitor)	DC-DC converter	DC link	IGBT switches	PWM switching	Unit transformer[A]	Internal filters	Inner loop converter control	Outer loop converter control	Phase locked loop[B]	Frequency control[C]	High voltage ride-through	Low voltage ride-through	Multiple fault ride-through limitations	ProtectionC[D]
RMS	-	✓	✓	-	-	✓	✓	-	✓	-	✓	✓	✓	✓	✓
EMT	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	✓	-	✓

A. Including saturation for EMT models.
B. Explicit representation.
C. Including frequency raise and lower, frequency droop and deadbands.
D. The Applicant should seek the NSP's advice on the level of details to be included for the protection system models for non-IBL facilities

B.5.2 Balance of Plant Model Components

Table B.8: Plant Components

Model	Park controller[A]	Other coordinated control systems	Reticulation Network	Static reactive support plant[B]	Dynamic reactive support plant[C]	Connection point transformers[D]	Transformer onload tap
RMS	✓	✓	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓

A. Including delays that affect performance, controls and outputs for reactive power support plant, controls for active power, reactive power, voltage, power factor and frequency, and any participation in fault ride-through protection.
B. Details of switching philosophy to be provided in the RUG.
C. Including full voltage controller representation and relevant protection mechanisms.
D. Including saturation for EMT models.

B.6 Synchronous Machines and Generators

- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.

B.6.1 Generator Model Components

Table B.9: Generator Model Components

Model	Generator[A]	Mechanical drive train (inc. turbine, flywheel etc.)	Torsional damping	Governor[B]	Power system stabiliser	Unit transformer[C]	Exciter	Automatic voltage regulator[D]	Excitation limiters[E]	Transformer onload tap changer controllers	Multiple fault ride-through limitations	Protection
RMS	✓	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓
EMT	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓

A. Full saturation curve required for EMT models.
B. Including frequency control, droop, deadbands and isochronous mode.
C. Including saturation characteristics for EMT models.
D. Including compensator and derived measurements.
E. Including all applicable limiters in over- and under-excited range (for example, over-excitation limiter, under-excitation limiter, V/Hz limiter, PQ limiters).

B.7 Convertor Based Reactive Plant

- Including SVCs, STATCOMs.
- Measurements feeding into controls must include relevant filtering and delays.
- Winding ratios of VTs and CTs feeding protection mechanisms must be provided.

B.7.1 Reactive Plant Model Components

Table B.10: Reactive plant model components

Model	DC link componentry	Thyristor / IGBT switches	PWM switching / firing control	Unit transformer[A]	Internal filters	External shunt devices and filters[B]	Inner loop converter control	Outer loop converter control	Phase locked loop[C]	Frequency control[D]	Power oscillation damping control	High voltage ride-through	Low voltage ride-through	Multiple fault ride-through limitations	Protection
RMS	-	-	-	✓	✓	✓	-	✓	-	✓	✓	✓	✓	✓	✓
EMT	-	-	-	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	-	✓

A. Including saturation for EMT models.
B. Including any control of external shunts from plant controller.
C. Explicit representation.
D. Including frequency raise and lower, frequency droop and deadbands.

Appendix C

Transient and Voltage Analysis

C.1 Quantities to be Assessed for Transient and Voltage Analysis

Table C.1: Quantities to be assessed for transient and voltage analysis

Test/Disturbance	Perturbed Quantity	Measured Quantity
• Voltage Reference Step • Power Factor Reference Step • Reactive Power Reference Step • Active Power Reference Step External • Voltage Step	• Voltage reference (production unit or centralised controller) • Power factor reference (production unit or centralised controller) • Reactive power reference (production unit or centralised controller) • Active power reference (production unit or centralised controller) • Switched shunt, transformer tap, or other external voltage change	• Plant terminal active power • Plant terminal reactive power • Connection point active power • Connection point reactive power • Centralised controller dispatch Pref • Centralised controller dispatch Qref • Field voltage • Field current (EMT only) • Relevant limiter output • Stabiliser output • AVR output Stator voltage • Plant terminal voltage • Connection point voltage • Centralised controller dispatch Vref
Energy Source Change	Wind Speed or Solar Irradiance	• Plant terminal active power • Plant terminal reactive power • Connection point active power • Connection point reactive power • Centralised controller dispatch Pref • Centralised controller dispatch Qref • Plant terminal voltage • Connection point voltage • Centralised controller dispatch Vref
Voltage Disturbance	Connection point voltage (network fault)	• Plant terminal active power • Plant terminal reactive power • Point of Connection active power • Point of Connection reactive power • Centralised controller dispatch Pref • Centralised controller dispatch Qref • Field voltage • Field current (EMT only) • Rotor Angle • Stabiliser output • Stator voltage • Relevant limiter output • AVR output • Plant terminal voltage • Point of Connection voltage • Centralised controller dispatch Vref

Test/Disturbance	Perturbed Quantity	Measured Quantity
• Frequency Disturbance • External Frequency change	• Connection point frequency (network event) • Production unit or centralised controller frequency bias injection	• Plant terminal active power • Centralised controller dispatch Pref • Stabiliser output • AVR output • Governor control output • Governor valve position • Relevant limiter output

Appendix D

Application to Provide Alternative Model or Information

D.1 Application to Provide Alternative Information or Information Specified in the Facility Model Guidelines

To enable a timely response to your Application please complete all sections of this form. Please use additional pages and attach supporting documentation where required.

Table D.1: Alternative Information Form

Required Information	Description
Contact Details	
Name	
Phone	
Email	
Postal Address	
Date of Application	
Information or model requirement that cannot be met: Include reference to section in the Guidelines where the requirement is specified.	
Why the requirement cannot be met. Include: • Evidence to substantiate reasons for being unable to meet the requirement; • Consideration of how this might affect Western Power's ability to assess proposed access standards; and • Discussion of alternative options considered, sufficient to satisfy Western Power that meeting the requirement is technically unachievable.	
Proposed Alternative Information or Model to be provided: Include a description of the discrepancy between the relevant requirement and what is proposed to be provided and a discussion of how the alternative is a reasonable equivalent of the requirement that cannot be met.	
Proposed date by which Alternative Information or Model will be provided	

Please send this application to: system.analysis@westernpower.com.au