Horizon Power PowerFactory Modelling Guideline

February 2022

Acknowledgement of Country

Horizon Power acknowledges the traditional custodians throughout Western Australia and their continuing connection to the land, waters and community. We pay our respects to all members of the Aboriginal communities and their cultures; and to Elders past, present and emerging.

Document Control		
Author	Name: Marjan Ladjavardi Position: Consulting Engineer	Marjan Ladjavardi Digitally signed by Marjan Ladjavardi Date: 2022.02.22 12:57:47 +08'00'
Reviewed By	Name: Justin Scott Position: Power System Simulation Manager	Justin Scott
Endorsed By	Name: Shervin Fani Position: Principal Planning Engineer	Shervin Fani Digitally signed by Shervin Fani Date: 2022.02.22 14:32:59 +08'00'
Approved By	Name: David Stephens Position: Manager System and Network Planning	David Stephens Digitally signed by David Stephens Date: 2022.02.22 14:19:53 +08'00'
Date Created/Last Updated	6 December 2021	

Revision Control		
Revision	Date	Description
0	6/12/2021	Draft
1	17/12/2021	Internal HP review completed
2	15/2/2022	EMT requirements added. Appendix A added. External stakeholder comments addressed.
3	22/2/2022	Issued for Use

STAKEHOLDERS The following positions shall be consulted if an update or review is required:	
Engineering Services Manager	Regional Managers
Project Directors	Regional Asset Managers

Contents

1 Introduction

This document (Horizon Power PowerFactory Modelling Guideline) describes Horizon Power's requirements for computer models of generator systems and loads which may be connected to Horizon Power's networks and the associated documentation. This guideline aims to ensure that complete and accurate models of loads and generators are available to Horizon Power for planning, design and operational purposes[1].

The requirement to provide a computer model of a User Facility are described in the Horizon Power Technical Rules (section 3.2.4, with section 3.3.9 providing further requirements for Generators). Definitions of generator systems are provided in the technical rules, and may refer to inverter based generation, solar and wind generators, batteries, in addition to conventional generators. Loads may include induction machines (motors), equipment starting direct online (DOL), and batteries, amongst other equipment. The Technical Rules and/or Horizon Power should be consulted where it is not clear whether a facility is a load or generator or both.

While the Technical Rules refer only to the final validated model of a facility, Horizon Power uses a staged modelling approach to avoid any unnecessary delay to a project and to enable Horizon Power to undertake studies that may be required to connect a customer as information becomes available. This approach allows the customer's project to progress so long as the necessary information is available at each stage, with a view to achieving a final validated model at project completion.

This guideline applies to all stages of a project listed below and outlines the computer model and documentation requirements:

- Stage 1: Access Application - (R0 model) based on Standard/Preliminary data available at early stage of the project
- Stage 2: Completion of detailed design - (R1 model) based the "issued for construction" information
- Stage 3: After Completion of commissioning tests - (R2 model also referred to as a "validated model") based on "as commissioned" data

Horizon Power may accept any reasonable changes made to a model at any stage of the process, however the provided information should be valid and sufficient to meet the requirements of the relevant system studies. A material change to the provided information or the computer model may require system studies to be repeated and cause delay to a project. A *material change* includes any change to a model which affects the outcome of studies or design work Horizon Power may have undertaken to connect a customer. These include (but are not limited to) a change of the selected technology, a change to the installed capacity, a major design change, or an alteration of control strategy.

Where a material change has occurred, the customer is required to notify Horizon Power of the change and discuss the impact on any work commenced or completed.

[1] Parts of this model guideline are derived from "Western Power's Generator and Load

Model Guidelines"

While this document is predominantly aimed at new facilities these guidelines also apply to computer models which are updated due to changes to a facility. This guideline is tailored to address the modelling requirements for different user facilities at each of the stages of a project.

Specific objectives of the guidelines are:

- To communicate to customers the requirements for computer models of facilities which are connected or proposed to be connected to Horizon Power's networks, including:
  - Model functional requirements
  - Model performance, accuracy, and acceptance requirements
  - Model assessment requirements
  - Documentation requirements

For Low-voltage Embedded Generation connections, Appendix A provides details of model requirements (extracted from the *Low Voltage EG Connection Technical Requirements*, HP standard HPC-9DJ-13-0002-2019)

2 Staged Modelling Requirements

Development of a compliant computer model will be dependent on a number of factors including:

- the quality and availability of any vendor generic models and documentation
- the availability of Balance of Plant information and design data
- the suitability of a model to be used at the grid strength identified at the point of connection
- any requirement for design and modelling of a project specific external controller, if any (e.g., a hybrid controller)
- the applicable technical rules and capability of the proposed technology to meet the requirements through tuning of project specific control parameter settings
- assessment of interactions between the proposed system with the rest of the network through system studies

The activities required to complete and assess the items above will depend on the stage of the project and maturity of the proposed technology. With new and emerging technologies, Horizon Power recognises that achieving a fully compliant model at early stages of the project may not be possible. Where this is the case, some details of the control strategies, modes of operation, and other items may not be finalised until the detailed design stage. To accommodate these cases Horizon Power allows some model details and information to be provided progressively as the project proceeds.

The accuracy and level of detail in the model and the information required will depend on the system studies and design activities to be undertaken by HP at each stage of the project.

The type of system studies is project specific and should be discussed with Horizon Power. Due to this dependence, determining the list of studies to be undertaken at each stage (such as load flow, short circuit, RMS, etc) is outside the scope of this guideline. This document provides information and guidance on the modelling requirements relevant to the studies that may be undertaken.

The staged modelling approach outlined in this guideline is intended to be an effective way to allow the suitability of supplied information to be assessed by Horizon Power at each stage, prior to undertaking any system study activities.

This approach avoids unnecessary delays to a project, while allowing time for progressive completion of the model as more detailed information becomes available. Material changes to the model and/or design are not expected to fit within the staged approach as they may affect any outcomes from previous studies.

Table 1 shows the level of compliance with the modelling guidelines expected at each stage of a project. This chart is provided as a high-level guide on what information is needed to assess the model and documentation at each stage. It should be noted that any negotiated requirements will depend on the model adequacy for undertaking the required system studies at that stage of the project, and will be specific to an individual project.

Table 1 Compliance with the Guideline at each project stage

	Application Stage **(R0 submission)**	**Detailed Design Stage** **(R1 submission)**	**After Commissioning** **(R2 submission)**
General Modelling Requirements	PC	PC	FC
Project specific LF model	FC*	FC	FC
Voltage control strategy	PC	FC	FC
Project specific RMS model	PC	FC	FC
Project specific control parameter settings	PC	PC	FC
Model accuracy	N/A	N/A	FC

Notes

PC — Partial Compliance - some requirements can be negotiated with Horizon Power based on project specific requirements.

FC — Full Compliance is required

FC* — Full compliance based on preliminary/standard information

3 Load and Generating System Model Requirements

As part of the access application and connection procedure, Horizon Power requires certain data and documentation to be provided along with a computer model. Horizon Power uses the provided information to undertake Technical Rules assessment and system studies.

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 apply depending on whether the facility is a generating system, load, or any other type of equipment, such as a dynamic reactive device (STATCOM, SVC, or other).

In general, Horizon Power requires that the model and its associated data and parameters are consistent with the information provided as part of an access application, or a request to modify an existing facility. This should include, but is not limited to:

- Consistency between Single Line Diagram (SLD) layouts and other schematics provided to Horizon Power.
- Consistency between relevant network data provided including all network impedances and ratings, voltage levels, transformer specifics (location, rating, vector groups, winding configuration, tap changer specifics etc), auxiliary loads and reactive devices etc.
- Consistency between generating system or load specifications provided, such as the maximum capability and loading, active and reactive power ranges, generator impedances, etc. Loads (including generator auxiliary loads) must be modelled such that the load power factor is representative of the facility's actual performance under typical operating conditions.

3.1 Computer Software

Horizon Power uses DIgSILENT PowerFactory software for performing load flow, fault level and RMS studies. This software is considered as a standard power system study tool by Horizon Power.

A requirement for an EMT model may be specified by Horizon Power on a per project basis. A requirement to provide an EMT model will depend on the proposed technology, SCR at the point of connection, overall impact of the new connection on the system strength, and operation of other generating units. DIgSILENT PowerFactory is the standard tool for islanded networks. Where projects will connect to the Northwest Interconnected System (NWIS) they will be subject to meeting NWIS modelling requirements as specified by ISOCO.

Horizon Power currently uses version 19 of the PowerFactory software, though upgrades to the software version in use are expected to occur from time to time. It is strongly recommended that customers contact Horizon Power prior to undertaking any modelling work to confirm the version of the software in use.

It should be noted that as the number of inverter based generating units increases, a reduction of the system fault level is experienced across Horizon Power's transmission networks. Some equipment suppliers may determine a minimum level of the system fault level for an acceptable performance of the equipment and the PowerFactory RMS model. If a supplier model has this limitation, the customer will need to discuss and agree with Horizon Power on the computer model requirements.

3.2 General Modelling Requirements

There are several general modelling requirements applicable to the PowerFactory software which need to be taken into consideration when developing a Load Flow and RMS model of a facility.

Compliance with the requirements is generally needed at all stages of the project, but specific requirements may be negotiated with Horizon Power where it makes sense to do so. Section 2 provides more details on the expected data that would be required to be able to complete the system studies at each stage of a project. The general requirements for a model which must be met for all (A) generators and loads are:

General Load Flow and Short Circuit Model Requirements

A-1. The model must be suitable for balanced and unbalanced power flow studies, and for calculation of balanced and unbalanced short-circuit currents using the 'Complete' and 'IEC' methods.

General RMS Model Requirements

A-2. The model must support a minimum step size of 1 msec for PowerFactory RMS simulations. A step size of 2msec or larger is desirable subject to sufficient accuracy being achieved.

A-3. The dynamic model must be able to be initialised from the Load Flow solution without any requirement to manually modify any parameter settings and without any error messages or warning messages. (See negotiated exceptions listed below)

A-4. Where initialising an RMS simulation from a Load Flow solution causes an unsteady response, the time to settle to a steady result should be no longer than 2 seconds (simulation time).

A-5. Dynamic model initialisation must be invariant to the simulation start time (i.e. the simulation must not be required to be initialised at a particular time).

A-6. A model accuracy of ±10% should be demonstrated when validating the model performance against the commissioning tests.

A-7. It is preferred that all model components are developed in PowerFactory software. (See negotiated exceptions listed below)

A-8. The dynamic model must be suitable for RMS studies at the project specific short circuit levels at the point of connection. (See negotiated exceptions listed below)

A-9. The RMS model must accurately represent the equipment response during and after a system event. This includes active and reactive current injection during a system fault or system frequency excursion. This performance must be achieved under a balanced system condition. It is highly desirable for the model to also support unbalanced system faults.

A-10. The model must be developed based on good modelling practice. This includes defining a “Main Slot” in the composite frame, all DSL parameters having descriptions, units and block diagrams. It is preferred that unique control functions are modelled as individual block definitions and DSL code blocks with more than 20 parameters should be avoided.

A-11. The model must be numerically stable for all possible ranges of system strength (short-circuit ratio and X/R ratio) at its planned point of connection.

A-12. The model may include non-convergence warnings for some simulation events, this may indicate issues with the dynamic model and have an adverse impact on simulation performance and/or cause the simulation to collapse. Care should be taken, and unnecessary warnings avoided when developing the model.

A-13. For protection events (e.g. Wind Farm controller operation) the simulation events, including initial detection, operation, and time-out, should be reported to the PowerFactory output window during the simulation.

A-14. The PowerFactory DSL model must compile to C code without warnings or errors.

A-15. The dynamic model must accurately represent the performance of equipment for a minimum duration of 30 seconds following an event.

General EMT Model Requirements

The below requirements apply to an EMT model developed in DIgSILENT PowerFactory software,

A-16. The model must support a minimum step size of 10 µsec. A step size of 50µsec is desirable subject to sufficient accuracy being achieved.

A-17. The model should accurately represent the plant behaviour under all system conditions and fault levels.

A-18. The EMT model must accurately represent the behaviour of the generating system under balanced and unbalanced simulations.

A-19. The model must show accurate current injection during events including reactive current rise time/settling time, negative sequence reactive current injection and active power recovery time.

A-20. The model should include all control loops implemented on the device. Where response time of a control function is outside the EMT simulation range of up to 10sec, that control function may be excluded from the model following discussion and agreement with Horizon Power.

A-21. The model must include all input filters, limiters and protection equipment (such as current limiting devices, over current protection, over/under voltage protection, over/under frequency devices, etc).

A-22. The model should be suitable for assessing the capability of the system to ride through a series of events, where required. This includes a sequency of balanced and unbalanced faults.

A-23. For an inverter based generating facility, the EMT model should include source and system side converters including switches, filters, smoothing reactors and linking capacitors. For source side machines and PV arrays must be able to represent transients being occurring at the DC link.

Some negotiated exceptions to the above requirements may be acceptable after discussion and agreement with Horizon Power:

- Warning Messages – any warning messages resulting from initialisation of the model. Note that in any case an initialisation issue resulting in a warning message should not affect the performance or accuracy of the model.

- DLL Files – the structure of any DLL files that are required by and form part of the model
- Short Circuit Level – alternative modelling options where an RMS model is unable to be used at the short circuit level at the point of connection. This could happen in weak systems where the Short Circuit Ratio (SCR) at the point of connection is low (e.g., SCR<3)

3.3 Model Configuration

The load flow and RMS components of the PowerFactory model must be setup to adequately represent the proposed project. This includes Balance of Plant (BoP) components and equipment as well as control systems.

The control systems must include proposed parameter settings that allow the generator or load to meet the applicable Technical Rules requirements. This generally requires tuning of the control system based on the network conditions at the nominated connection point to best meet the performance requirements of the Technical Rules. Horizon Power can provide (upon request) a range of applicable fault levels and X/R ratios at the point of connection to support customers in tuning a model. Horizon Power will then conduct an independent model assessment.

The accuracy of the BoP and controller system settings depend on the information available at each stage of the project. The model needs to be prepared based on the most accurate information available at the time and should be updated as required. For more information, please refer to the *Staged Modelling Requirements* section.

The sections below provide further information on technology specific modelling requirements.

3.3.1 Synchronous Generating systems (SG)

A power station model comprising of Synchronous Generating units must include:

<u>SG Load Flow and Short Circuit Model Requirements</u>

SG-1. A project specific load flow model based on the best information available (R0, R1 or R2). This model shall include the Balance of Plant (BoP) primary equipment such as transformers, cables, generating units, auxiliary loads, earthing transformers, reactive power components (such as capacitor banks, reactor banks or harmonic filters). Including the BoP protection relays is not necessary unless otherwise advised by Horizon Power.

SG-2. The generating unit's load flow model, including the MVA rating and the power capability curve. Any operational limitation on the active and reactive power must be implemented in the model.

SG-3. Primary element parameters consistent with manufacturers' datasheets.

SG-4. Generator data entered for 35degC ambient temperature. Temperature dependency of the generator output up to the site maximum ambient temperature to be provided.

SG-5. Details of all station controllers for coordination of the generating units active and reactive power, where applicable. The standard PowerFactory elements "External Secondary Controller" and "External Station Controller" shall be used for modelling of the power station controllers, if suitable. If the standard models do not have the required functionality, further modelling requirements shall be discussed and agreed with Horizon Power. RMS modelling of any controller with a response time of more than 30seconds is not necessary for dynamic studies.

SG-6. The power station's voltage control strategy, modelled by including the relevant components such as transformer AVRs, shunt element switching strategies and generating unit voltage control modes.

<u>SG RMS Model Requirements</u>

SG-7. A dynamic model that adequately represents the performance of the equipment over its load range and over the system voltage and frequency operating range.

SG-8. Dynamic model of the power station's voltage and frequency control system including the relevant components such as measurement devices, communication delays, shunt element, generating unit voltage control system, extended ramp rate and any other component necessary to implement the voltage/frequency control strategy.

SG-9. Synchronous machine control system components including:

- Excitation system and load drop compensation,
- Turbine-governor (including speed droop and power control loops, turbine boiler dynamics, temperature and power control/limiting functions and other relevant control mode and protection functions).
- Power System Stabiliser, if available
- Under-excitation limiter (UEL)
- Over-excitation limit (OEL)
- Other limiters (such as stator current limiter(s), volts per hertz limiter(s), over flux limiter(s)).

3.3.2 Inverter Based Generating systems (IBR)

An Inverter based generating system (such as a wind farm or solar farm) must include:

<u>IBR Load Flow and Short Circuit Model Requirements</u>

IBR-1. A project specific load flow model on best information available (R0, R1 or R2). Inverters may be modelled as static generator elements with project specific ratings, voltage dependent capability curves and short circuit current contribution included.

IBR-2. Balance of Plant (BoP) primary equipment (such as transformers, cables, auxiliary loads), reactive power components (such as STATCOMs, capacitor banks, reactor banks or harmonic filters). Including the BoP protection relays is not necessary unless otherwise advised by Horizon Power.

IBR-3. The flicker and harmonic spectrums for each inverter element.

IBR-4. Primary equipment data, consistent with the manufacturer's datasheets.

IBR-5. Generator data entered for the maximum site ambient temperature. Information on the temperature dependency of the generator output is to be provided.

IBR-6. Load flow model should include details of any overall control system (Power Plant Controller), where applicable. The standard "External Secondary Controller" and "External Station Controller" shall be used for modelling of this controller. All modes of operation (e.g., voltage control, Q(V), Power Factor or reactive power control modes) must be defined and all control and measurement points must be specified and be consistent with the proposed voltage control strategy.

IBR-7. In the absence of a power plant controller, the load flow model should include the control methodology modelled on individual inverter elements. This can be done using the standard control functionality available within the static generator element of PowerFactory and may include frequency response, volt-Watt or volt-VAr response.

IBR RMS Model Requirements

IBR-8. RMS model of the facility's voltage control system, modelled by including the relevant components such as communication delays, power plant controller, transformer AVRs, shunt elements switching strategies, dynamic reactive support equipment, and any other component necessary to implement the voltage control strategy.

IBR-9. Control mode and droop settings configured for usual operation, and consistent between both steady-state and dynamic simulations.

IBR-10. All functional controllers and ancillary equipment that may materially affect the performance of the generator over the typical timeframe of a dynamic simulation (no less than 30 seconds). The model(s) must accurately represent performance for all possible conditions where the equipment would be in operation.

IBR-11. All controller components required to model any controlled response of the generating system. This includes those needed to implement current control, fault ride through, current limiting, frequency control, over/under voltage protection, over/under frequency protection, Rate of Change of Frequency (RoCoF) response. Any other components affecting the response of the inverter to a system event within a 30sec time frame shall be included.

IBR-12. Project specific control system parameter settings. These settings should be included in block definitions with no need to create parameter events for a correct model setup.

3.3.3 Battery Energy Storage systems (BESS)

A battery energy storage system must include:

BESS Load Flow and Short Circuit Model Requirements

BESS-1. A project specific load flow model on best information available (R0, R1 or R2). The inverters can be modelled as static generator or rectified elements including the DC link to the battery storage element. The inverter components shall include project specific ratings, capability curves and short circuit current contributions.

BESS-2. The flicker and harmonic spectrums for each inverter element.

BESS-3. The overloading capability of the BESS inverter in the sub-transient fault contribution of the load flow element when modelled as a full size converter.

BESS-4. An inverter capability curve capturing the four quadrant operation during charge and discharge.

BESS-5. Primary equipment data consistent with the manufacturers' datasheets.

BESS-6. Generator data entered for the maximum site ambient temperature. Information on the temperature dependency of the generator output is to be provided.

BESS-7. Detail of any primary and secondary control systems, where applicable. The standard "External Secondary Controller" and "External Station Controller" shall be used for modelling of these controller. All modes of operation (e.g., voltage control, Q(V), Power Factor or reactive power control modes) must be defined and all control and measurement points must be specified and be consistent with the proposed voltage control strategy.

BESS-8. The control methodology (in the absence of a secondary controller) modelled on individual inverters using the standard control functionality available within the static generator element of PowerFactory. This may include frequency response, volt-Watt or volt-VAr response.

BESS RMS Model Requirements

BESS-9. Clearly defined modes of operation for the BESS (e.g., grid forming/grid following and switching between different modes). The RMS model should accurately represent all modes of operations appliable to the project and the relevant settings.

BESS-10. Any additional functionalities of the BESS such as synthetic inertia, frequency response and black starting if they are proposed to be utilised in the project.

BESS-11. If an active power overloading is available in the inverter and energy storage element, it should be clearly mentioned in the documentation. It is preferrable in this case if the energy storage DC components are included in the model.

BESS-12. Control system components representing AVR and frequency Governor functionalities where the BESS includes virtual synchronous machine technology.

BESS-13. Control mode and droop settings configured for usual operation and consistent between both steady-state and dynamic simulations.

BESS-14. All functional controllers and ancillary equipment that may materially affect the performance of the generator over the typical timeframe of a dynamic simulation (up to 30 seconds). The model(s) must accurately represent performance for all possible conditions where the equipment would be in operation.

BESS-15. RMS model of all controller components required to model any controlled response of the generating unit (In the absence of the power plant controller). This includes those needed to implement current control, fault ride through, current limiting, frequency control, over/under voltage protection, over/under frequency protection, Rate of Change of Frequency (RoCoF) response. Any other components affecting the response of the inverter to a system event within a 30sec time frame shall be included.

BESS-16. Project specific control system parameter settings. These settings should be included in block definitions with no need to create parameter events for a correct model setup.

3.3.4 Hybrid systems (HS)

Each component of a hybrid system should meet the applicable modelling requirement as detailed in the previous sections. In addition, a hybrid control system model must include:

HS-1. RMS model of a plant reactive power/voltage control system that coordinates the reactive power contribution from different elements of a hybrid facility.

HS-2. RMS model of a control system that distributes active power across the components of the hybrid plant.

3.3.5 Static load and Motor Model Requirements (L)

The following requirements apply for static load and motor models. These requirements are intended as a guide and should be agreed with Horizon Power prior to model preparation.

Static load or Motor models must include:

L-1. Clearly identified lumped motor models where smaller motors have been lumped into equivalents. This should be clearly identified in the supporting documentation and the PowerFactory model.

L-2. Detailed representation and an aggregated equivalent load where requested by Horizon Power

L-3. Complex load parameters where a number of static loads are represented as a single lumped (static) load. These must be modelled based on the constituent loads (VSD's, induction machines and other loads), and with suitable voltage dependent parameters.

L-4. Appropriately represented equipment fault level contributions. This requires simplification of load models to be consistent with good electricity industry practice.

L-5. Converter controller model(s) for converter connected loads (such as hydrogen electrolysers or fuel cells). These must include the voltage and frequency protection settings and harmonic spectrum. The load may be modelled as a static load with applicable voltage and frequency dependencies.

L-6. Models and descriptions of any load shedding facilities, including under- and over-voltage and under- and over-frequency relays.

L-7. Descriptions of any other special protection schemes.

In addition, for motors or loads with a rating of 1MW or greater the model must include:

L-8. An explicit model of the load.

L-9. A harmonic current emissions model.

L-10. Models for the mechanical characteristics of the drive load (torque-speed characteristic) and the total mechanical inertia parameters.

L-11. For steady state models, starting method parameters defined in the model (e.g. direct online, soft-starter).

3.4 Aggregation

For some detailed load models and for generating systems comprising many individual generating units, there may be a requirement for a model to be aggregated. Where this occurs the methodology for aggregating generating units, loads, other generating equipment and the reticulation system models must be provided, as well as studies demonstrating the equivalence between the detailed and aggregated models. At a minimum this must illustrate the alignment of time-domain simulations (through overlayed plots) for voltage, active power and reactive power for the nearest and farthest generating unit and the aggregated generating unit, for:

L-12. Zero impedance balanced three-phase to earth and zero impedance two-phase to earth faults at the connection point.

L-13. Voltage, reactive power, power factor and active power step responses.

For generating systems, the aggregation should not prevent access to generator terminal quantities such as active/reactive power, active/reactive current and terminal voltage.

3.5 Model Accuracy

3.5.1 Steady State Models

The steady-state computer model accuracy requirements apply to both loads and generating systems, including dynamic reactive plant. The general requirements are as follows:

A-1. The difference between the actual and simulated response of any measured quantity must not exceed 10%.

A-2. The model must represent, as accurately as possible, the performance of the load, generating unit or generating system at its terminals (or connection point for an aggregated model) and only show any characteristics that are present in the actual equipment response.

3.5.2 Dynamic Models

The dynamic model accuracy requirements apply performance measures to assess the alignment between simulated and measured responses of generators and dynamic reactive equipment (e.g. SVCs, STATCOMs, synchronous condensers). At present, Horizon Power has adopted accuracy requirements consistent with those specified by the Australian Energy Market Operator in their Generating System Model Guidelines. These requirements are reproduced below:

A-3. For any control system models, the overall linear response over a frequency bandwidth of at least 0.1 to 5Hz must be within the following tolerances:

- Magnitude must be within 10% of the actual control system magnitude at any particular frequency; and
- Phase must be within 5 degrees of the actual control system phase at any particular frequency.

A-4. For time domain responses that include non-linear response or performance, as well as responses to switching or controlled sequence events (e.g. operation of fault ride-through schemes and converter mode changes), the key features of the response must meet the following tolerances:

- Rapid slopes in the simulated response, compared with the actual equipment response must be within:
  - 10% of the change; or
  - From the start to finish of the slope, 20 milliseconds.
- For rapid events caused by control sequences (such as some fault ride-through control schemes) or switching events, the sizes of peaks and troughs (measured over the total change for that peak or trough) must be within 10% of the change;
- Oscillations in active power, reactive power and voltage in the frequency range 0.1 to 5Hz must have damping and frequency of the oscillation within 10% of the actual response of the equipment. The phase of the oscillations (relative to the other quantities - e.g. active power versus reactive power) must be within 5 degrees in terms of the dominant oscillatory mode. This does not apply to rapid events, but does apply to any subsequent oscillations;
- The timing of the occurrence of the rapid slopes, events or the commencement of oscillation described above must be consistent with the equipment characteristic that initiates the response.

A-5. The deviation of the equipment model response from the actual equipment response for active power and reactive power must not exceed 10% of the total change in that quantity. During periods of oscillatory behaviour, this criterion applies to:

- The first cycle of the oscillatory response after the transient period (i.e. if associated with a fault, then after clearance of the fault and the transient recovery from the fault); and
- After the first cycle of the oscillatory response, to the upper and lower bounds of the envelope of the oscillatory response.

A-6. The final active power or reactive power value at which the model settles is within the more restrictive of:

- The final value at which the actual equipment response would settle ±2% of the equipment's nameplate rating; or
- The final value at which the actual equipment response would settle ±10% of the total change in the final value of the quantity.
- Where measurement results can be shown to have been affected by changes in supply source (e.g. 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.

A-7. The model response must not show characteristics that are not present in the actual equipment response.

3.5.3 Assessment of Model accuracy

Assessment of compliance with the model accuracy requirements can be conducted by a combination of visual inspection of results, results plots including accuracy tolerances, and mathematical calculations. Particularly for cases where the modelled response deviates from the simulated response there is a need to demonstrate the extent of that deviation and the impact on plant performance. It is acceptable to apply accuracy tolerance bands to either the simulated response or the measured response.

4 Model Assessment

Horizon Power undertakes a due diligence assessment (model assessment) of the computer model to assess its performance against the requirements of the Technical Rules.

As part of the model assessment Horizon Power will identify to what extent the computer model meets the relevant criteria defined in the Generator and Load Model Guidelines. Some aspects of Horizon Power's due diligence assessment may be performed using an infinite bus model with no knowledge of the facility's actual connection point to the Horizon Power Network.

Table 2 provides a list of tests which will be required (as a minimum) for tuning of control system(s), and these will typically be undertaken by Horizon Power during a model assessment of the R0 submission package. Before submission of the model to Horizon Power, it is recommended the customer undertakes tuning and assessment of the Technical Rules requirements based on grid information provided by Horizon Power. It should be noted that depending on the size and connection location of the facility, some requirements may not apply to a particular project.

Table 2 Control system tuning tests

	Model performance test
1	LF studies to determine the reactive power capability at the connection point
2	±5% voltage step change at the connection point
3	Zero impedance three-phase fault at the connection point
4	Three phase fault with 40% residual voltage at the connection point
5	Grid frequency change by +/-2Hz with 4Hz/sec RoCoF
6	Grid frequency change by +/-1Hz with 4Hz/sec RoCoF
7	Voltage disturbance ride through based on Figure 3.6 of the Horizon Power Technical Rules
8	Frequency excursion ride through based on Figure 3.4 of the Horizon Power Technical Rules

When undertaking a thorough assessment of a computer model more detailed power system studies will be performed covering steady state, dynamic and small signal studies, where applicable. These studies consider where the facility will connect to Horizon Power's Network so that the impact of the facility on the surrounding network and interaction between the customer's facilities can be assessed. Where these studies identify that the facility does not meet the requirements in the Technical Rules it is possible that the issue may not be a shortcoming of the computer model itself. In some cases, network augmentation and/or installation of additional equipment within a facility may be necessary to fully comply with the Technical Rules.

5 Documentation

This section describes the requirements for model block diagrams, user manuals, other relevant documentation (D) and the ***R2 data, model validation and performance report***.

5.1 Block Diagrams

The following requirements apply to model block diagrams.

D-1. 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.

D-2. The model block diagrams must illustrate all derivative states including derivative state variable names consistent with the block diagrams.

D-3. All required control and output signals should be available for dynamic (RMS) simulations and clearly indicated on the model block diagrams. These signals would typically include, but are not limited to, the following:

- Active and reactive power.
- Applicable set-points, including:
  - Machine and exciter current and voltage.
  - Active power set-point.
  - Frequency and/or speed reference set-point.
  - Voltage set-point.
  - Reactive power and/or power factor set-point.
  - Where applicable, power plant controller, capacitor bank and SVC set-points, etc.
- Other signals depending on the technology type.

D-4. The model block diagrams must clearly illustrate whether limits are windup or non-windup, 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.

D-5. The model block diagram documentation must include descriptions of any arithmetic or mathematical functions, such as protection events (e.g. Wind Farm crow bar controller operation) or voltage ride-through sequences.

D-6. The model block diagrams must show all relevant non-linearities, such as limits, arithmetic or mathematical functions, events, dead bands and saturation.

D-7. The model block diagrams and documentation must show all controller settings and settings ranges. Non-configurable settings should be identified on the block diagrams.

D-8. The model block diagram documentation must identify any internal integration algorithms.

D-9. The model block diagrams must identify the interpolation method for any look-up table (e.g. spline, linear).

D-10. Settings shown on the model block diagrams must align with the computer model.

D-11. Where a controller uses input measurements or control outputs, these must be appropriately configured and identified on the functional block diagrams.

5.2 User Manual

A project specific user manual should be submitted to Horizon Power with the computer model. This user manual and computer model will be based on the best information available at each stage of the project. The user manual must contain sufficient information to enable Horizon Power to use the computer model to carry out power system studies for planning, design and operational purposes. The user manual should not contain any confidential information that cannot be released to third parties.

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

D-12. A description of the model components and parameters, and data category of each parameter.

D-13. 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).

D-14. Protection system settings and algorithms relevant to load flow or dynamic simulation studies (e.g. under- and over-voltage or frequency protection settings).

D-15. 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).

D-16. Details of the connection point including single line diagrams, any parameters and values, its location, any associated network augmentations or modifications (if applicable) and other relevant connection information, sufficient to identify where to connect the equipment in the HP power system model.

D-17. 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 and RMS simulation options, etc.
- Special setup for any associated auxiliary equipment or reactive compensation equipment.
- Special setup required to enable, disable or 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 customer considers relevant to the performance of the equipment for the model's intended use or to achieve the relevant accuracy requirements.

5.3 Other Documentation

As applicable, other documentation should be provided such as:

D-18. Equipment data sheets associated with the computer model.

D-19. If available, a report describing how the model was developed (model development report).

D-20. Protection settings and model tuning report (design report).

D-21. For inverter connected generators, fault ride-through performance and model validation report.

D-22. Other relevant documentation, such as model validation reports or type test reports.

D-23. For synchronous generators, the max stator current limiter, OEL (max field current limiter), UELs (min field current limiter, P-Q limiter), V/Hz and PSS circuit in AVR with their settings and type of the limiter shall be included.

D-24. For synchronous generator type test data including generator impedances, time constants and characteristics curves (Open circuit/short circuit, PQ and V-curve characteristics) should also be provided.

5.4 R2 data, model validation and performance report (V)

Throughout the process of a new connection application or modification to an existing facility, data accuracy is refined over time until it is validated during commissioning tests and R2 validation tests.

Following completion of tests an *R2 data, model validation and performance report* must be submitted to Horizon Power for approval.

The *R2 data, model validation and performance report* must include:

V-1. Details of the tests undertaken.

V-2. Details of any discrepancies between the tests conducted and the agreed test procedures.

V-3. Results, measurements, analysis techniques used and any relevant information to assist Horizon Power with performing a due diligence assessment.

V-4. Specific assessments of the performance against relevant clauses of the Technical Rules.

V-5. Model validation assessment with respect to the requirements outlined in this document, including overlays of measured and simulated responses with accuracy bands.

V-6. Final model and model documentation (computer model, block diagrams and settings, updated user manual, etc).

V-7. Updated documentation with registered (R2) data. For upgrades or modifications this should be the updated R2 data relevant to the upgrade. Parameters to be derived from on-site tests are as follows:

- Parameters designated as "R2" in relevant to the facility.
- Parameters, other than those designated as "R2" in the Technical Rules 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. Where parameters are not designated as "R2" in the Technical Rules, there remains the requirement to validate the value of these

parameters (in aggregate) through the validation of the overall performance of the system, device, unit or controller to which they pertain.

6 Registered Data and Performance Standards

The generator or load’s registered data and performance standards consist of the following:

- Test report(s) including:
  - *R2 data, model validation and performance report* (with R2 data and performance standards attachments).
  - Model tuning report (design report).
  - Various study reports conducted by Horizon Power on behalf of the proponent to assess performance of the facility with respect to the Technical Rules and the relevant connection agreement. This must include any due diligence studies conducted by Horizon Power following receipt of the R2 data, model validation and performance report.
- Final computer model and block diagrams.
- Approved exemptions from the requirements of the relevant version of the Technical Rules.
- For performance covered by a Technical Rules clause, demonstrated performance with respect to the relevant technical requirements prior to the Rules commencement date. It is necessary for the customer to show evidence there has been no degradation in performance over previous agreed performance standards.
- Any special conditions specified with the connection approval.

Appendix A – Low Voltage Embedded Generation (EG) connections

Horizon Power undertakes system impact studies for Low voltage EG installations to ensure the effect of those installations on the power system are appropriately managed.

As part of these studies, the following events and associated boundary conditions are investigated:

- Normal system operation
- Installation energisation and trip scenarios
- System cloud events
- Fault ride through scenarios
- Network voltage and loading assessment
- Fault levels and harmonics assessment

For each of these cases, the effect on system frequency, voltage, loading, and other power quality parameters are assessed. Horizon Power conducts these studies in DigSilent PowerFactory.

Model Requirements

Horizon Power requires a suitable power system simulation model for each type of inverter proposed, which is able to adequately represent the performance of the installation for each of the scenarios and events considered above.

The model should be a configured model that includes parameters and settings that the proponent intends to use.

The model shall be supplied with an instruction manual and description of the control philosophy of the LV EG system.

The model shall have the following functionality:

- Run for steady state, dynamic (RMS), and harmonic simulations.
- Able to adjust active power, reactive power and voltage setpoints in steady state model.
- Able to adjust active power, reactive power and voltage parameters in dynamic model.
- Include frequency out of limit trip settings in accordance with Horizon Power's Technical requirements and AS/NZS 4777, including ability to set trip time delays.
- Include voltage out of limit trip settings in accordance with Horizon Power's Technical requirements and AS/NZS 4777, including ability to set trip time delays.
- Include frequency vs watt droop response in accordance with Horizon Power's Technical requirements and AS/NZS 4777, including ability to set droop response time delays and parameters.
- Include voltage vs watt droop response in accordance with Horizon Power's Technical requirements and AS/NZS 4777, including ability to set droop response time delays and parameters.

- Include voltage vs VAr droop response in accordance with Horizon Power's Technical requirements and AS/NZS 4777, including ability to set droop response time delays and parameters.

The model shall be provided in a DigSilent PowerFactory file with the inverter connected to a single machine infinite bus. The model shall contain step load and bus fault cases which demonstrate suitable performance of the RMS simulation, including satisfactory initialisation of controller initial conditions. Default parameter settings for all common and composite models for the inverter system shall be included.

A technical user guide (instruction manual) shall be provided with the model. This shall include key parameters with a sufficient description of each parameter.

The following table outlines the parameters which must be able to be adjusted within the dynamic plant model:

Table 3 Adjustable Model Parameters

Type	Setting	Description	Units	Default Value
Dynamic model setpoints	P_{set}	Active power setpoint	kW	-
	Q_{set}	Reactive power setpoint	kVAr	-
	Q_{max}	Max reactive power	kVAr	-
	Q_{min}	Min reactive power	kVAr	-
	V_{set}	Voltage setpoint	p.u.	1.0p.u.
	S_{fault_max}	Maximum short circuit contribution	MVA	-
Anti-islanding dynamic model setpoints	f_{max}	Maximum frequency anti-islanding setting	Hz	53Hz
	f_{min}	Minimum frequency anti-islanding setting	Hz	45Hz
	$T_{freq\_disconnect}$	Anti-islanding frequency trip time delay	s	2s
	$T_{freq\_reconnect}$	Anti-islanding frequency reconnection time delay	s	2s
	V_{max}	Maximum voltage anti-islanding setting	p.u.	1.10p.u.
	V_{min}	Minimum voltage anti-islanding setting	p.u.	0.75p.u.
	$T_{volt\_disconnect}$	Anti-islanding voltage trip time delay	s	2s

Type	Setting	Description	Units	Default Value
	$T_{volt\_reconnect}$	Anti-islanding voltage reconnection time delay	s	2s
Volt-watt droop response dynamic model setpoints	$V_{1\_volt\_watt}$	Volt-Watt Response Mode voltage V_1	p.u.	0.86p.u.
	$V_{2\_volt\_watt}$	Volt-Watt Response Mode voltage V_2	p.u.	0.92p.u.
	$V_{3\_volt\_watt}$	Volt-Watt Response Mode voltage V_3	p.u.	1.06p.u.
	$V_{4\_volt\_watt}$	Volt-Watt Response Mode voltage V_4	p.u.	1.10p.u.
	$P_{1\_volt\_watt}$	Volt-Watt Response Mode power setpoint	%	100%
	$P_{2\_volt\_watt}$	Volt-Watt Response Mode power setpoint	%	100%
	$P_{3\_volt\_watt}$	Volt-Watt Response Mode power setpoint	%	100%
	$P_{4\_volt\_watt}$	Volt-Watt Response Mode power setpoint	%	20%
Volt-VAr droop response dynamic model setpoints	$V_{1\_volt\_var}$	Volt-Watt Response Mode voltage V_1	p.u.	0.86p.u.
	$V_{2\_volt\_ var}$	Volt-VAr Response Mode voltage V_2	p.u.	0.96p.u.
	$V_{3\_volt\_ var}$	Volt- VAr Response Mode voltage V_3	p.u.	1.00p.u.
	$V_{4\_volt\_ var}$	Volt- VAr Response Mode voltage V_4	p.u.	1.10p.u.
	$Q_{1\_volt\_ var}$	Volt- VAr Response Mode reactive power setpoint	%	60%
	$Q_{2\_volt\_ var}$	Volt- VAr Response Mode reactive power setpoint	%	0%
	$Q_{3\_volt\_ var}$	Volt- VAr Response Mode reactive power setpoint	%	0%

	$Q_{4\_volt\_var}$	Volt- VAr Response Mode reactive power setpoint	%	-60%
Type	**Setting**	**Description**	**Units**	**Default Value**
Hz-Watt droop response dynamic model setpoints	$f_{stop\_hz\_watt}$	Hz-Watt overfrequency response maximum frequency setpoint	Hz	53Hz
	$f_{start\_hz\_watt}$	Hz-Watt overfrequency response starting frequency setpoint	Hz	50.25Hz
	$P_{stop\_hz\_watt}$	Hz-Watt overfrequency response maximum frequency power setpoint	%	0%
	$P_{start\_hz\_watt}$	Hz-Watt overfrequency response starting frequency power setpoint	%	100%
	$f_{stop\_CH\_hz\_watt}$	Hz-Watt underfrequency response minimum frequency setpoint	Hz	45Hz
	$f_{start\_CH\_hz\_watt}$	Hz-Watt underfrequency response starting frequency setpoint	Hz	49.75Hz
	$P_{stop\_CH\_hz\_watt}$	Hz-Watt underfrequency response minimum frequency power setpoint	%	0%
	$P_{start\_CH\_hz\_watt}$	Hz-Watt underfrequency response starting frequency power setpoint	%	100%

Note that the operating power, reactive power, and voltage setpoints must be accessible and updated via parameter events within the PowerFactory RMS module.

Inverter harmonic current and flicker emission levels must be included in the inverter model. The model should also include relevant protection relays and settings to simulate the performance of the PV system during power system disturbances. This includes, but is not limited to, under and overvoltage protection, under and over-frequency protection etc.

In addition to power system simulation model, the following information is also required for Horizon Power to undertake System Impact Studies:

- Maximum and minimum load at facility (active power and reactive power / power factor).
- Proposed arrangement and site layout of the installation.
- Single line diagram of proposed LV EG system.
- Typical 24 hr load power curve measured at 15 minute intervals or less.
- Inverter capability curves.

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