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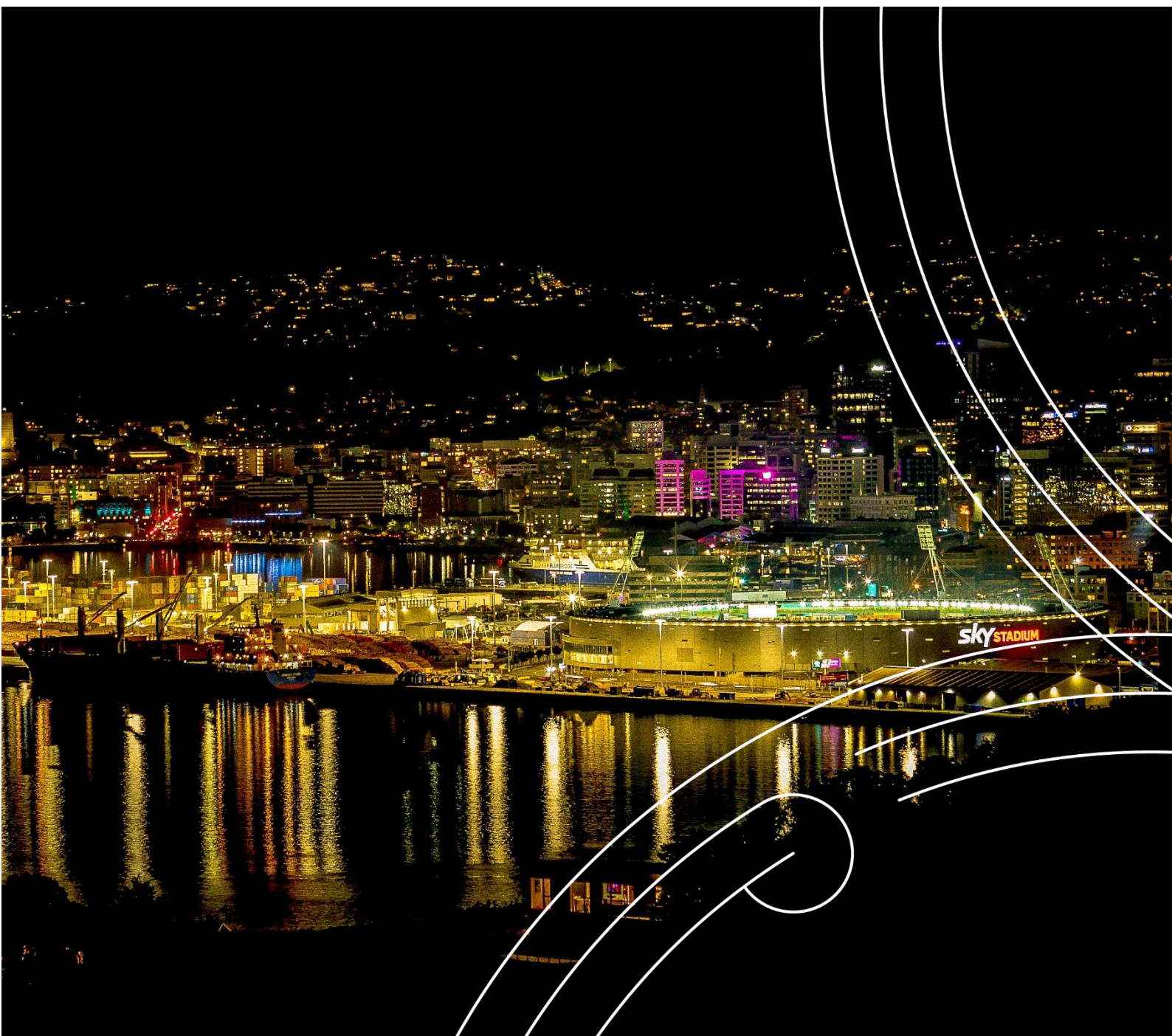
Technical Guideline for Commissioning Large Loads

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IMPORTANT

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Abbreviations

Abbreviation	Full Form/Explanation
AC	Alternating Current
ACS	Asset Capability Statement
ANSI	American National Standards Institute
AVR	Automatic Voltage Regulator
BESS	Battery Energy Storage System
CACTIS	Connected Asset Commissioning, Testing, and Information Standard
CMLD	Composite Load Model
DC	Direct Current
DSL	Dynamic Simulation Language (PowerFactory software)
EMT	Electromagnetic Transient
ESCR	Effective Short Circuit Ratio
GXP	Grid Exit Point
IBR	Inverter Based Resource (generation)
IEC	International Electrotechnical Commission
IEEE	The Institute of Electrical and Electronics Engineers
IP	Intellectual Property
NERC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory (USA)
OEM	Original Equipment Manufacturer
PERC1	Power Electronic Reconnecting and Ceasing Load Model
PID	Proportional-Integral-Derivative
PPO	Principal Performance Obligations
PSS	Power System Stabilizer
PSS/E	Power System Simulator for Engineering (Software package used to conduct RMS type studies)
RMS	Root Mean Square
SMIB	Single Machine Infinite Bus
The Code	Electricity Industry Participation Code 2010
UDM	User Defined Model
UPS	Uninterruptible Power Supply
WECC	The Western Electricity Coordinating Council

1 Introduction

1.1 Background

Rapidly evolving technologies are transforming power systems around the world, unlocking new capabilities. These technological advancements come with many benefits, though the complexities of integrating them also create new challenges. As the System Operator of New Zealand's power system, we have a responsibility to forecast and prepare for these challenges in order to ensure the provision of electricity remains secure and reliable. We are actively monitoring international experience with large load integration and are also considering those lessons within the context of the New Zealand power system.

In 2026, we are preparing to welcome more 'large loads' on the New Zealand power system. The Transmission Planning Report 2025 [1] lists industries contributing to accelerated demand growth, many of which can be large single connections:

- Process heat electrification
- Transport electrification
- Data centres
- Green hydrogen

These developing industries bring system characteristics and behaviours that must be managed prudently. Large power electronic loads, or loads with particular active power cycle characteristics, may interact in unprecedented ways with other assets on the system. To support power system stability, we must strive to represent the different characteristics accurately in our tools and models and to define minimum performance requirements. As more of these loads connect, access to accurate information will ensure that our modelling of the power system remains fit for purpose, enabling us to meet our Principal Performance Obligations (PPOs) and the dispatch objective.

Note on this version: This document is the **initial release** of the System Operator's guideline for commissioning large loads. Given the increasing penetration of large loads in power systems worldwide and the rapidly evolving impacts within the electricity industry and beyond, we are undertaking a staged approach to the development and implementation of our guidance. We are undergoing further technical reviews at pace, in parallel with this release – expect further refinements in the near future.

1.2 Scope

The System Operator provides this guideline to support large load customers in the process of commissioning and connecting to the power system. This document covers:

- Information sharing
- Performance requirements
- Connection studies
- Modelling requirements
- Testing requirements
- Operational communication and high-speed data requirements

We expect you to read this document alongside the following:

- the [Electricity Industry Participation Code 2010](#) (the Code), especially Part 8;
- the [Connected Asset Commissioning, Testing, and Information Standard](#) (CACTIS), which features up-to-date performance obligations;
- the [Commissioning Load](#) webpage on the Transpower website; and
- the [Asset Owner Requirements](#) webpage and subpages on the Transpower website, providing further information on System Operator processes and expectations.



1.3 Applicability

This guideline applies to large loads connecting to New Zealand's power system, whether directly to Transpower's transmission network or embedded within a distribution network, particularly where the load can materially influence network planning, operational decision-making, or system security.

1.3.1 Definitions

For the purposes of this document, where the bolded terms below are used, they have the following meanings:

Large load refers to a consuming plant that is determined by the System Operator, acting reasonably and prudently, to warrant assessment under this guideline. We consider the consuming plant, or an aggregation of consuming plants, to be a large load if it has a capacity of at least 10 MW and:

1. It is directly connected to the grid; or
2. It is embedded within a distribution network and has been identified through prudent power system analysis that the electrical disconnection of this plant could cause voltage to deviate by more than 0.5%:
 - a. at the point of connection to the grid; or
 - b. at the grid exit point (GXP) nearest to the point of connection to a distribution network.

Large load customer refers to the consumer that owns or operates a large load and is responsible for demonstrating compliance with Code obligations and meeting the requirements of this guideline.

Large load site refers to the collection of loads, equipment, and associated facilities behind a common point of connection, comprising a large load. A large load site may include generation plant, energy storage systems, or other equipment operating behind the same point of connection.

1.3.2 Load Varieties

While this document covers large loads of all types, specific requirements may apply for various load types, sizes, and technologies. Data centres, for example, pose unique stability challenges which necessitate specific modelling and power system study requirements. Conversely, some industrial loads with predictable and well-understood characteristics may be sufficiently represented with standard models.

It is important to discuss with the System Operator which requirements are applicable to your connection, and the level of detail required.

1.3.3 Loads with Onsite BESS

If a large load site has an accompanying battery energy storage system (BESS) to support the overall connection, the BESS will have its own set of performance requirements to adhere to, and may require additional studies, modelling, testing and monitoring.

Asset owners with onsite BESS are advised to consult the [Commissioning Generation](#) webpage for more information and discuss with the System Operator what the overall requirements will be to commission their large load alongside the BESS.

1.4 Load Commissioning Process

The System Operator's commissioning process follows six phases: feasibility, initiation, planning, delivery, commissioning, and closeout. You can signal your readiness to engage with the System Operator by filling out our [Commissioning Initiation Form](#). We will assign a lead commissioning engineer who will then support you through the rest of the process.



1.5 Confidentiality

To meet its statutory responsibilities for operating the power system and maintaining system security and reliability, the System Operator requires access to accurate and complete asset information. The System Operator receives and uses this model information in line with the provisions of our regulatory framework, including as set out in clauses 3(2) and (2A) of [Schedule 8.3, Technical Code A](#) in the Code, which contains strict restrictions on disclosure. We manage asset information within this framework and apply rigorous controls to ensure it is handled consistently with our statutory obligations and the needs of the power system.

For more information on how we handle the storage of sensitive model information specifically, see the Confidentiality section of our [Power System Studies and Modelling](#) webpage.

2 Asset Capability Statement Information Sharing

An asset capability statement (ACS) allows us to understand and have visibility of the characteristics and composition of large loads on the system. We currently require large load customers to submit and maintain an up-to-date ACS.

The format is provided on the [System Operator website](#), which includes a template Excel spreadsheet for submission – see the “Submitting an ACS” section relevant to large loads.

The ACS Excel spreadsheet includes information such as:

- Active power of the load (maximum, seasonal variation, load cycling behaviour)
- Power factor during various modes of operation
- Load composition e.g. motor loads, electronic loads
- High voltage assets e.g. transformers, shunt capacitors
- High level protection information and expected ride-through behaviour during network disturbances.

3 Performance Requirements

We expect large loads to meet the performance requirements indicated in this section. The first subsection provides an outline of those requirements. Refer to subsections that follow for a more detailed explanation of each.

3.1 Requirements at a Glance

#	Requirement	High-level Details
1	Active power ramp rate	Aligned with the change limits and net rate of change in the Policy Statement, cl. 39B (see link on the Authority's website): 40 MW/min 75 MW over 5-minute period or as otherwise specified by the System Operator under cl. 39C.
2	Steady state voltage range	Align with Code clause 8.22 (1) (b) for generators: +/-10% for 220kV and 110kV +/-5% for 66kV and 50kV
3	Voltage ride-through capability	Voltage envelope to align with envelope presented in the Code 8.25A fault ride through requirements for generators.
4	Active power recovery following voltage ride-through event	For an under-voltage event, active power must be recovered to: - At least 76% of its pre-disturbance value within 500 ms of voltage recovering above 0.76 pu - At least 90% of its pre-disturbance value within 500 ms of voltage recovering above 0.90 pu For an over-voltage event, active power must be recovered to: - Between 90% and 100% of its pre-disturbance value within 500 ms of voltage recovering below 1.2 pu
5	Frequency ride-through capability	Align ride-through requirements with Code cl. 8.19 (1) and (3) for North Island (NI) and South Island (SI) frequency envelopes. Must ride through over-frequency events up to 52 Hz in NI and up to 55 Hz in SI.
6	Voltage phase-jump withstand capability	Withstand a voltage phase jump of up to 25 degrees.
7	Reconnection following a disconnection from the grid	Must only reconnect demand with the System Operator's approval, unless otherwise permitted under the Code.

#	Requirement	High-level Details
8	Power quality requirements	Requirements are as per default transmission agreement covering: - Power factor - Harmonics - Voltage imbalance - Voltage flicker
9	Automatic under frequency load shedding (AUFLS)	Each North Island connected asset owner has AUFLS obligations. Each South Island connected asset owner must co-operate fully with the grid owner in relation to grid owner's AUFLS obligations in the South Island.

3.2 Active Power Ramp Rates

Ramp rate requirements are specified in clause 39B of the [Policy Statement](#): a maximum ramp rate of 40 MW per minute, with no more than a 75 MW change in any 5-minute period.

This ramp rate applies to start up, shut down, and normal operation. The requirement ensures active power swings remain manageable for the size of New Zealand's power system and assists us to maintain frequency within the normal band (49.8-50.2 Hz) through dispatch and frequency-keeping services.

Alternative ramp rates may be specified by the System Operator under clause 39C.

3.3 Steady State Voltage Range

Large load customers must at all times ensure that their assets are capable of being operated, and do operate, when the power system is operated within the range of voltages set out in 8.22 (1) (b) of the Code, in line with generator asset owner performance requirements. The voltage ranges are shown below in Table 1.

Table 1: Voltage range AOPs as defined for generation in the Code

Nominal Grid Voltage (kV)	Voltage Limits			
	Minimum (kV)		Maximum (kV)	
220	198	-10.0%	242	10.0%
110	99	-10.0%	121	10.0%
66	62.7	-5.0%	69.3	5.0%
50	47.5	-5.0%	52.5	5.0%

This steady state voltage range requirement ensures the continuous operation of large loads while the voltage is within the normal operating limits, minimising the risk of tripping due to network conditions.

3.4 Voltage Ride-through Capability

The voltage ride-through requirements cover both over- and under-voltage and differ between North and South Islands. The ride-through envelopes imposed on large loads match the fault ride-through requirements imposed on generation; the System Operator expects this to be the voltage recovery standard that the grid is operated to.

Unless circuit breakers have operated to clear a fault directly, the circuit breakers connecting the large load to the power system must remain closed for any disturbance where the voltage falls within the ride-through requirements specified below. If a load must momentarily cease drawing current from the power system during a network disturbance, the load must rapidly re-establish drawing current (and active power) following voltage recovery according to requirements in section 3.5 of this guideline.

See section 8.25A of the Code for the generation voltage ride-through North Island and South Island envelopes, as well as the transient over-voltage envelopes at Haywards and Benmore for a HVDC bipole trip, all of which are applicable to large loads depending on their location.

The fault ride-through requirements for North and South Island are given below in Figure 1 and Figure 2.

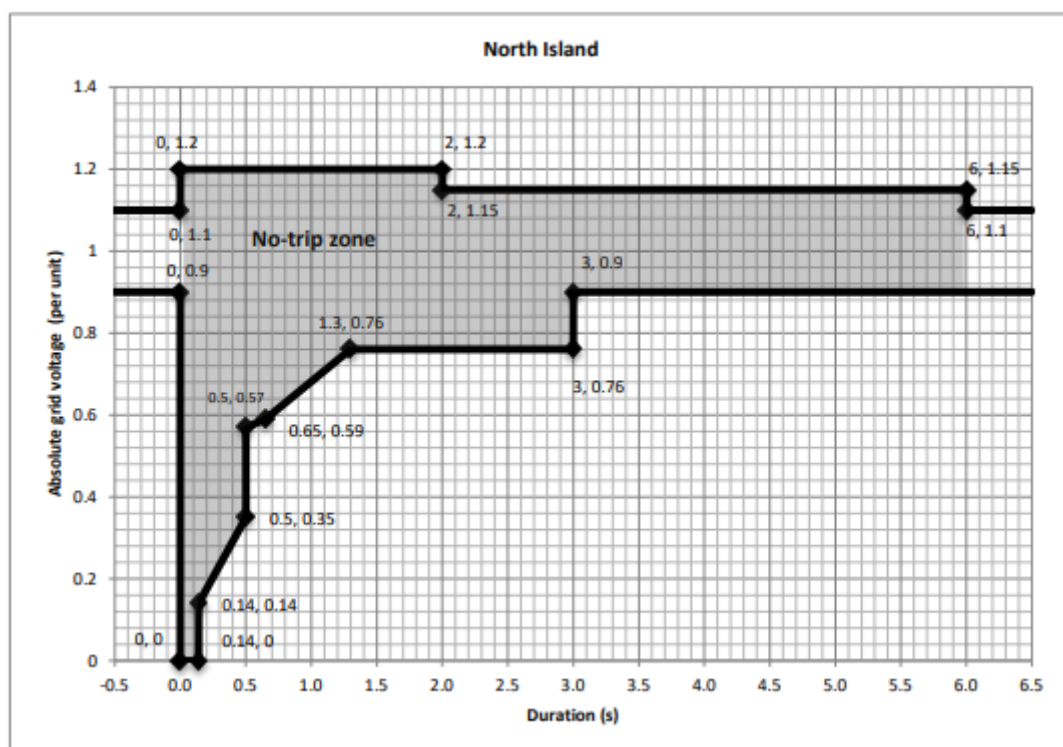


Figure 1: North Island no trip zone for 110 kV or 220 kV faults

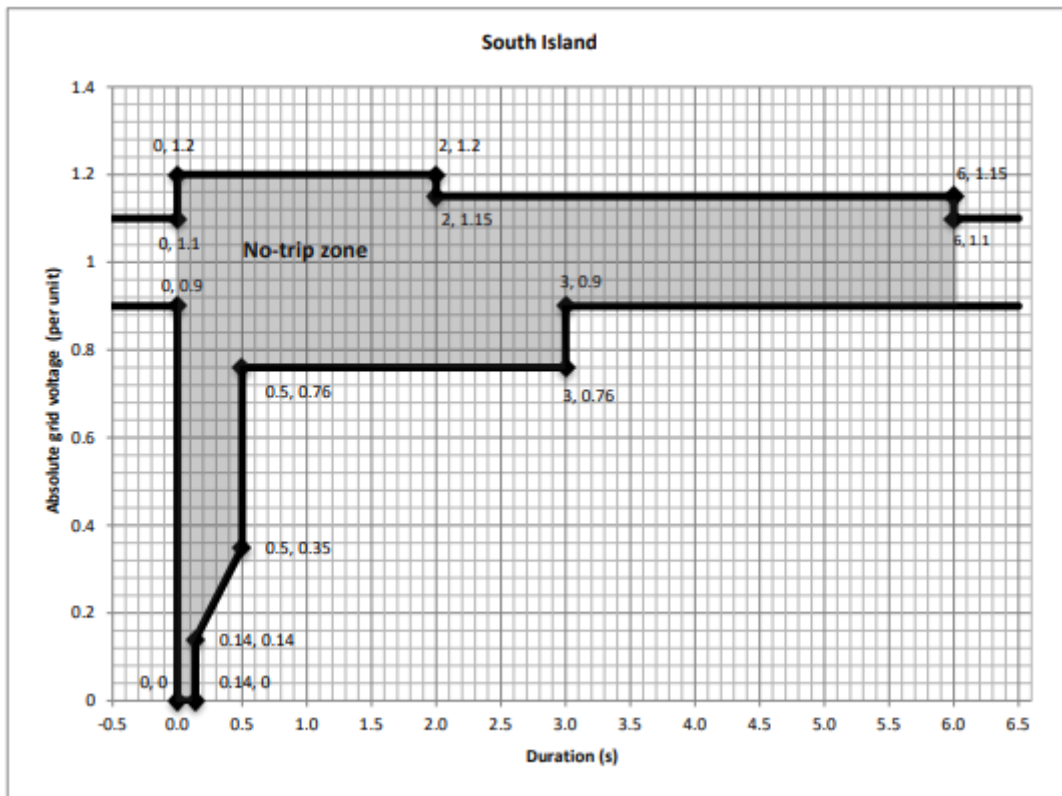


Figure 2: South Island no trip zone for 110 kV or 220 kV faults

Ensuring loads can ride through voltage disturbances will mitigate the risk of over-frequency issues arising from an imbalance of generation and load following a grid disturbance. This requirement is specified in section 3.5 in conjunction with active power recovery following a voltage ride-through event.

3.5 Active Power Recovery Following Voltage Ride-through Event

If voltage-sensitive loads momentarily cease drawing power from the power system during a low or high voltage event, the load must return to:

- In the case of an under-voltage event:
 - At least 76% of its pre-event value within 500 ms of voltage recovering above 0.76 pu, and
 - At least 90% of its pre-event value within 500 ms of voltage recovering above 0.90 pu.
- In the case of an over-voltage event:
 - Between 90% and 100% of its pre-disturbance value within 500 ms of voltage dropping below 1.2 pu.

Note: The above requirements must not override loads modulating active power to support frequency stability, such as:

- Load tripping as part of providing interruptible load for under-frequency reserves.
- Load tripping as part of AUFLS, or any equivalence arrangement which has been agreed with the System Operator or Grid Owner.



3.6 Frequency Ride-through Capability

Large load ride-through capability requirements for frequency events match the frequency envelopes given for generation contributions to frequency support. The under-frequency event contribution requirements are given in 8.19 (1) and (3) of the Code. Large loads must maintain their pre-disturbance active power output (excluding any control action to support frequency security) for the frequency ranges listed below:

For **under-frequency**:

- all large loads must remain connected and sustain pre-event output:
 - At all times when the frequency is above 47.5 Hertz; and
 - For at least 120 seconds when the frequency is 47.5 Hertz; and
 - For at least 20 seconds when the frequency is 47.3 Hertz; and
 - For at least 5 seconds when the frequency is 47.1 Hertz; and
 - For at least 0.1 seconds when the frequency is 47.0 Hertz; and
 - At any frequencies between those specified above for times derived by linear interpolation.
- In the South Island, large loads must also remain connected and sustain pre-event output:
 - At all times when frequency is above 47 Hz, and
 - For 30 seconds if the frequency falls below 47 Hz but not below 45 Hz.

For **over-frequency**, large loads must remain connected:

- In the North Island:
 - At all times when frequency is below 51.2 Hz, and
 - For at least 60 seconds when frequency is above 51.2 Hz and below 52 Hz.
- In the South Island:
 - At all times when frequency remains below 52 Hz, and
 - For at least 60 seconds when frequency is above 52 Hz and below 55 Hz.

Note: The above requirements must not override loads modulating active power to support frequency stability, such as:

- Load tripping as part of providing interruptible load for under-frequency reserves.
- Load tripping as part of AUFLS, or any equivalence arrangement which has been agreed with the System Operator or Grid Owner.

3.7 Voltage Phase-jump Withstand Capability

Voltage phase-jump withstand capability represents an asset's ability to ride through network disturbances including switching operations during highly loaded conditions. Large loads must have the capability to withstand a voltage phase jump of up to 25 degrees without disconnecting from the power system.

3.8 Reconnection Following Disconnection

If a large load partially or completely disconnects from the power system following a system disturbance, permission must be sought from the System Operator before reconnection and restoration can take place. Load restoration must adhere to the ramp rate requirement in section 3.2.



3.9 Power Quality

Default power quality requirements are given in the [default transmission agreement](#), included by reference into the Code [3], while final requirements are subject to agreement between Transpower as Grid Owner and connected customers.

If a large load is connected to a distribution network, the distributor will have power quality requirements in their transmission agreement with Transpower, and these will be passed onto customers in their network as necessary.

The default transmission agreement generally covers:

- power factor requirements
- harmonics
- voltage imbalance
- voltage flicker.

Large load customers must consult the transmission or distribution network owner for their power quality obligations.

3.10 Automatic Under-frequency Load Shedding (AUFLS)

North Island

Each North Island connected asset owner (including distributors and direct consumers) has obligations to provide, maintain, and operate an AUFLS system in accordance with Schedule 8.3, Technical Code B of the Code and [AUFLS Technical Requirements \(ATR\)](#).

An AUFLS system must disconnect four blocks of demand at minimum pre-event demand size of 10/10/6/6% of pre-event demand, electrically disconnecting at pre-determined frequencies between 48.0-47.0 Hertz, with block four also having a rate-of-change of frequency setting.

South Island

Transpower as Grid Owner has obligations to provide, maintain, and operate an AUFLS system in accordance with Schedule 8.3, Technical Code B of the Code. Each South Island connected asset owner must co-operate fully with respect to these obligations.

The AUFLS system must disconnect two blocks of demand at 47.5 and 46.5 Hertz.

General

AUFLS obligations for both islands also cover the requirements for:

- periodic testing of AUFLS systems,
- periodic submission of AUFLS load profile information to the System Operator,
- collection of event data and submission to the System Operator for analysis.

Participants can seek an [equivalence arrangement](#) to be approved by the System Operator if they cannot meet AUFLS obligations as specified.

4 Connection Studies

Large load customers must conduct connection studies according to the table in section 4.1 below.

4.1 Study Requirements at a Glance

#	Power System Study	Purpose	Applicability
1	Power-flow study	Identify any thermal, voltage and voltage stability issues on the power system which the new connection may exacerbate	All large loads
2	Short circuit study	Calculate effective short circuit ratio (ESCR) as a high-level indicator for stability	Large loads with inverter-based load components
3	Fault Ride-through (FRT) study	Demonstrate ability of asset to ride through system disturbances	All large loads
4	Transient stability study	Identify any stability issues related to the new connection	As directed by the System Operator to study impacts on known transient stability issues in the area or nearby generation
5	Oscillations due to active power cycling	Determine whether the active power cycling of a large load causes oscillatory issues on the power system	All large loads, depending on their active power load profile
6	Over-frequency study	Determine the impact a large load contingency may have on frequency stability	All large loads

4.2 Information to Support your Studies

We provide the following information to support connection studies:

- The RMS full network model in DiGSILENT PowerFactory format, provided on the [Electricity Authority's website](#).
- The PSCAD Electromagnetic Transients (EMT) network model, provided on our [Power System Studies and Modelling](#) webpage. Additionally, look for the FRT assumptions document for the appropriate grid zone on that webpage.
- The [System Security Forecast](#) (SSF), which includes helpful information on known issues for each grid zone and the North and South Island grid backbones.

Ensure that you discuss your connection studies with the System Operator.

4.3 Connection Studies Report

You must present your connection studies in a report following the template set out in Appendix A. The report should include the following information for your load:

- confirmation that your connection studies are based on the submitted Asset Capability Statement (ACS);



- single line diagrams (including cable collector system, if known, and site layout);
- dynamic models for the load with typical parameter values that adequately represent site behaviour (see section 5);
- dynamic models for other assets such as STATCOM, generation or BESS;
- distribution-level transformers and other equipment in the network model (only if your load connects to a distribution network).

Note: Following commissioning, if you need to update asset capability information, including parameters in the dynamic model, then you may need to update some of your connection studies. Engage and agree with the System Operator on these as part of the final compliance assessment during the closeout phase.

Along with the final connection studies report, you must package all study cases, result files and relevant model libraries used in your studies.

4.4 Power-flow Study

This study examines how the power flow changes as a result of the installation of the new large load. Its inclusion must not impose any operational constraints that limit either the site's asset capability or the operation of the power system.

4.4.1 Objectives

Objectives: the study aims to...

- demonstrate the connecting load will not overload any equipment;
- ensure the connecting load does not impose operational constraints under normal and outage conditions;
- determine whether connecting the load introduces new credible risks such as risk groups from N-1 or N-1-1 contingencies.

4.4.2 Study Case Preparation

Adhere to the following:

- Consider winter peak, summer light-load, no-generation scenarios from wind and solar generating stations in the study vicinity covering a three-year horizon. Also consider other scenarios which may demonstrate a worst case for thermal and voltage issues.
- Use hydro generation to balance supply and demand, while geothermal and thermal generation operate as baseload sources.
- Ensure that all generating units are dispatched within the reactive power limits.
- Ensure that SVC and STATCOMs are dispatched up to 75% of their reactive power capacity.
- All voltage at network buses should be within the Code's limits, as stated in Clause 8.22.
- All assets should stay within capability limits before applying a contingency.
- Under extreme light load conditions, switching out transmission circuits to manage pre-contingency voltage is allowed.

Note: If you have performed a power-flow study as part of the concept assessment of your new load (a stage which occurs before the feasibility phase of the commissioning process), then you can include it as part of your connection studies report. This is to avoid repetition and to save cost and time. The study must satisfy the following pre-requisites:

- The study uses the same key parameters as are used in the rest of the connection studies.
- The network has not significantly changed to affect the outcomes of the power-flow study.
- The study meets the relevant study objectives outlined in this document.
- The key findings are summarised in the connection studies report and the full feasibility assessment study is attached in an appendix to the report.

4.4.3 Study Scope

The N-1 and N-1-1 contingency analysis in this study aims to investigate how the new load will impact the loadings of the transmission network and transmission voltages following a contingency. You must apply all credible contingencies to the transmission network in close proximity to the new load. These are defined in the Policy Statement and can include:

N-1 Contingencies	N-1-1 Contingencies
the loss of a single: - transmission circuit - interconnecting transformer - generating unit - reactive power compensation device - large load	- a planned outage of a transmission circuit and unplanned outage of another circuit - when appropriate, application of similar N-1-1 study methodology on inter-connecting transformers and reactive power compensation devices - if the new load is located in Grid Zone 8 or Grid Zone 13, analysis of the N-1 and N-1-1 contingency on the HVDC link.

The study should also consider other credible outage scenarios to ensure any long-term outage will not affect the operation of the transmission network and the new load.

4.4.4 Assessment Criteria

Your study must meet the following criteria:

Assessment	Criteria
Transmission Circuits Thermal Overload	The new load must not cause the overload of any transmission circuits or transformers in close proximity. For contingency analysis, it is appropriate to use: - branch ratings for transmission lines; and - post-contingency 24-hour branch ratings for transformers. Although they are an operational reality, 15-minute offload ratings are not modelled in the RMS full network model project cases. Studies should be conducted to 100% thermal loading of transmission circuits. You should request additional information to include and assess 15-minute offload ratings from the System Operator if the circuit is only marginally overloaded in post-contingency. The extra capability unlocked by the 15-minute offload ratings is unlikely to help if the circuit is heavily overloaded.
Steady State Voltage	The new load must not adversely affect the System Operator's ability to operate the power system within the nominal grid voltage range.

4.4.5 Study Outcomes

We expect the following outcomes from an analysis of the study's results:

- a table showing the impact of the new load on thermal loading and voltages in the region, with any thermal limit and/or voltage limit violations clearly identified;
- identification of any thermal and voltage limit violations that need to be resolved prior to the start of the commissioning phase, to the satisfaction of the System Operator. You should clearly state and study any mitigation measures, such as a special protection schemes, in the final connection studies report.
- identification of potential load risk groups (a group of loads which could be disconnected by a single contingency) due to the connection of the new load; this may be directly due to an outage or indirectly due to a special protection scheme action during normal or outage conditions.

We may accept operational measures to resolve any identified violations if the measures do not cause any limitation to the operation of the power system and nearby connection parties.



4.5 Short Circuit Study

This study determines the Effective Short Circuit Ratio (ESCR) at the point of connection. If the large load site has components which provide fault current (e.g. onsite BESS), you must document the impact of your asset's short circuit current for protection operation, equipment ratings, and wider power system design.

4.5.1 Objective

The study aims to identify the short circuit level at the site, which will help determine:

- the ESCR across different network conditions;
- the parameters of the voltage controller (if used in FRT study).

4.5.2 Study Case Preparation

To study the impacts of the new load during different system operating conditions, adhere to the following:

- Consider winter peak, summer light-load, and peak-generation and no-generation scenarios for wind, solar, and BESS generating stations in the study vicinity.
- Switch synchronous generating units out of service if they are not generating.
- For wind, solar, and BESS generation, it is acceptable to leave the full station in service at reduced output levels.

4.5.3 Study Scope

For ESCR calculations, there are several short-circuit calculation methods available such as IEC (International Electrotechnical Commission) or ANSI (American National Standards Institute). However, the System Operator prefers the use of the complete short-circuit method in PowerFactory for ESCR calculation. Once you have chosen a method, clearly state it in the connection study report.

In your study, consider the following system conditions:

- peak and light load conditions;
- full intact system and relevant power system re-configuration (as advised by the System Operator);
- N-1 and N-1-1 outage scenario; and
- the application of a three-phase zero impedance fault.

Use the lowest short circuit level after a contingency has been applied to determine the ESCR at the point of connection.

4.5.3.1 Classic ESCR Calculation

Classic ESCR is suitable for strong networks where the system impedance and short circuit levels are stable, and synchronous machines dominate the generation mix. It provides a quick screening metric for system strength and is used to assess the ability of the network to support new connections.

Classic ESCR is defined by:

$$ESCR = \frac{SCCi - Qi}{Pi}$$

where: $SCCi$: short circuit level (MVA) at the POC prior to connecting the asset

Qi : shunt compensation at POC bus

Pi : Rated power of the new asset (MW)

4.5.4 Study outcomes

We expect that the study will record:

- short circuit fault level for buses in close vicinity to the new load (provide short circuit level in kA and MVA); and



- the maximum and minimum ESCR including network scenario that results in minimum ESCR at point of connection.

If needed, use these ESCR values to set up the single machine infinite bus (SMIB) case.

4.6 Fault Ride Through (FRT) Study

This study aims to assess the capability of the new large load to remain connected, maintain stable operation, and demonstrate active power recovery behaviour in line with large load performance requirements during grid disturbances, including voltage depressions, short-circuit faults, and other transient events. The System Operator provides a regional fault ride through (FRT) assumptions document (see section 4.2) which details information that you must consider when performing this study.

Conduct your FRT studies according to the rated capacity of your large load:

Total load, MW	Required FRT Studies*
$10 \leq x < 30$ MW	▪ RMS studies in this section
$30 \text{ MW} \leq x$	▪ RMS and EMT studies in this section
If the large load site contains no power electronic component, conduct the FRT study using RMS simulations only.	

4.6.1 Objective

The study aims to demonstrate your load's ability to ride through system faults. Requirements may differ depending on where your load is connected – either the North Island's power system, or the South Island's, or in the vicinity of Haywards or Benmore.

The study must also highlight any other large loads which see common faults to the connecting load which trigger any fault ride through behaviour and identify any frequency security risks associated with their ride-through and active power recovery behaviour.

4.6.2 Study Case Preparation

Prepare your study cases to cover the requirements provided in your FRT assumptions document.

4.6.3 Study Scope

Adhere to the study scope provided in the FRT assumptions document.

Typically, an FRT study consists of:

- RMS domain studies using the RMS network model published by the [Electricity Authority](#) to identify worst-case fault performance. These studies shall capture conditions associated with weak grid operation, high levels of IBR penetration, and potential control interactions for a range of load operating conditions (active and reactive power).
- Targeted EMT domain studies using detailed network and control models to assess the worst-case scenarios identified from RMS analysis, where fast control dynamics, protection operation, or converter interactions materially affect FRT performance. EMT studies typically consider:
 - maximum active power demand and corresponding power factor;
 - components which provide reactive support or draw reactive power (e.g motor load, cooling load) – these must be represented in the model;
 - relevant fault types (e.g. single-phase-to-ground, phase-to-phase, and three-phase faults as applicable);
 - up to three fault locations, including electrically close and remote faults from the point of connection; and



- up to three system short-circuit strength conditions representative of strong, intermediate, and weak grid operation.
- Additional EMT assessments must include, where relevant:
 - post-fault voltage recovery and active/reactive power recovery behaviour;
 - correct operation of inverter current limits, fault current injection logic, and control mode transitions during and after faults;
 - protection interaction and non-maloperation during fault and clearance;
 - sensitivity to fault clearing times, including delayed fault clearance;
- sensitivity to voltage recovery; and
- system response following single-shot and automatic reclosing events (if applicable).

Note: If any control system settings are modified:

- **During FRT studies**, asset owners must notify the System Operator and repeat the FRT studies using the revised settings.
- **During or after commissioning**, asset owners must notify the System Operator and repeat the FRT studies using the revised settings.

4.6.3.1 Loads Connected to Grid Zone 8 (Wellington) and Grid Zone 13 (Otago)

Loads connecting in Grid Zones 8 and 13 require additional studies to assess your generating asset's capability in riding through:

Requirement	How to Simulate
1. the specific over-voltage FRT curves (provided in Code Clause 8.25A) at the Haywards or Benmore 220 kV bus resulting from bipole power interruption (which can be a trip or temporary interruption)	Disconnect the HVDC bipole at high electrical power transfer. The studies should cover both high north and high south flow. The load should remain stable and electrically connected.
2. multiple voltage sags resulting from HVDC fault recovery behaviour, e.g. commutation failure.	Request specific fault data to inject from the System Operator.

This additional study scope for Grid Zone 8 and 13 is designed to analyse the effect of HVDC-related system interaction, specifically:

- a bipole trip;
- a rectifier fault which interrupts the bipole operation and then restores it (which can be represented by a bipole trip); and
- HVDC commutation failure.

The System Operator can provide recorded system event data to demonstrate the expected voltage behaviour for the above HVDC events.

4.6.4 Studies Involving Models of Generating assets or Other Large Loads – System Operator Support

For cases where the performance of a new asset must be assessed in conjunction with models of other assets, the asset owner may adopt one of the following approaches:



Option 1: Asset Owner-led	Option 2: System Operator-led
Obtain explicit consent from the relevant asset owner or OEM for the use of their models. Access such models through the System Operator where required, noting that: ▪ Models are typically provided in encrypted or compiled form. ▪ Model access may be restricted to defined study purposes only. ▪ Modification of third-party models is not permitted.	Request the System Operator to conduct EMT studies on your behalf. This is suitable in cases where: ▪ Third-party models are not available to the asset owner, or ▪ Model confidentiality, encryption, or licensing constraints prevent direct access. Under this option: ▪ The System Operator will use secure, internally-held models. ▪ Study scope, assumptions, and deliverables will be agreed prior to commencement. ▪ Only study results and conclusions will be shared with the asset owner; third-party models will not be released. ▪ Where the EMT studies identify any non-compliance or deficiencies (including FRT performance), the System Operator shall coordinate with the relevant asset owner and OEM to define and assess corrective actions. Note: with this option, cost recovery must be agreed with the System Operator along with timelines, ahead of the studies.

4.6.5 Assessment Criteria

Your load must:

- remain stable and electrically connected when the grid voltage is within the applicable no-trip zone;
- ensure its active power recovery meets the specified requirements;
- ensure that any temporary cessation of active power during a system disturbance and time taken to re-establish connection to the grid do not cause any over-frequency issues, or trigger over-frequency arming on the power system. This assessment must also take into account behaviour of nearby large loads which can be affected by a common disturbance on the system.

4.6.6 Study Outcomes

We expect the following outcomes from your study:

- Loads meet all the assessment criteria whilst riding through faults.
- Your study document fully discusses the fault ride through strategies.
- You identify and explain any non-compliant, or potentially non-compliant, behaviour.
- You confirm that no protection or control settings at the load would result in a breach of the fault ride through requirements.
- You confirm that no aggregate intermittent loss of load and subsequent reconnection causes any over-frequency issues, triggers over-frequency arming or results in any load reconnecting following operation of over-frequency arming.

Note: You must report any equipment in your load site that will trip within the applicable no-trip zone, and/or result in the tripping of another generating asset.



4.7 Transient Stability Study

This study examines a generating asset's ability to withstand severe and credible contingencies, then return to stable operation. For a load connection, the purpose of this study is to capture the effect the large load has on the transient stability of nearby generation. The System Operator will assist in the scoping of this study depending on the location of the large load.

4.7.1 Objective

The study aims to demonstrate that your new load does not negatively impact the transient stability of nearby generation.

4.7.2 Study Case Preparation

Adhere to the following:

- Use the RMS full network model.
- Ensure the load is at upper and lower limits of active and reactive power to capture a range potential impacts to the system.
- Components which provide reactive support or draw reactive power (e.g motor load, cooling load) must be represented in the model.
- Ensure that studied generation is absorbing and producing reactive power close to its reactive power capability limits.
- Ensure that any studied generation asset is generating at its maximum MW output.
- Ensure that load dynamic characteristics including ride-through capability are modelled in the case.

The above points can be discussed and agreed with System Operator prior to conducting the study.

4.7.3 Study Scope

Determine the stability of the system by applying faults with the following characteristics on circuits at generator point of connection high-voltage buses:

- zero impedance three-phase faults;
- fault clearing time of 120 ms for 220 kV, and 200 ms for 110 kV; and
- faults applied to circuits connected to generator bus, close to the generator bus with circuits removed following fault clearance.

4.7.4 Assessment Criteria

The study must show that the load does not negatively impact the transient stability of nearby generation. This may be proved by comparing study results with and without the connecting load. Transient stability can be quantified by:

- Calculating the critical fault clearance time for a given station active power output, or
- Calculating the maximum station active power output, or interface active power flow, for a given fault clearance time.

4.7.5 Study Outcomes

We expect the following outcomes from your study:

- Generation is stable for the studied fault clearance times, and the stability of generation is not negatively impacted by the connecting load.
- Any non-compliant, or potentially non-compliant, behaviour is identified and explained.

4.8 Active Power Oscillation Study

This study examines the impact that active power load cycling can have on the power system, particularly in the way it may force oscillations in nearby active and reactive power control systems.

4.8.1 Objective

The study aims to demonstrate that your new load does not drive oscillations in nearby generation, reactive power control devices, or HVDC.

4.8.2 Study Case Preparation

Adhere to the following:

- Use the RMS full network model for initial screening, EMT model if issues are flagged in RMS model study.
- Ensure the load is at upper and lower limits of active and reactive power to capture a range potential impacts to the system.
- Ensure that nearby generation is absorbing and producing reactive power close to its reactive power capability limits.
- Study cases must have time series active and reactive power data representing modes of operation which have fast changing or cyclic active or reactive power ramps.
- The above points can be discussed and agreed with the System Operator prior to conducting the study.

4.8.3 Study Scope

Run a time-domain simulation with active and reactive power characteristics fed into the load and determine any oscillation modes which are excited in nearby generation, reactive power devices, HVDC, or any other control systems on the power system.

4.8.4 Assessment Criteria

The study must show that the load does not induce oscillations in any control systems on the power system which may cause additional stress or sources of instability in nearby plant.

4.8.5 Study Outcomes

We expect the following outcomes from your study:

- Any cyclic behaviour is minimal and oscillations are well damped.
- Any impact to surrounding generation in the system is minimal.

4.9 Over-frequency Study

This study examines the effect the loss of the connecting large load has on over-frequency management in the power system. A loss of a large load can cause an imbalance to the system which results in frequency rising, potentially leading to an over-frequency event. The System Operator manages this through active power control from generation and through generators being armed for over-frequency reserve, which trips generators once a certain frequency trigger point has been reached.

4.9.1 Objective

This study aims to highlights any risks to frequency security resulting from the connection of the large load.

4.9.2 Study Case Preparation

Adhere to the following:

- Use the RMS full network model.
- Ensure the load is at upper limit of active power for the largest potential impact to the system.
- Ensure study case presents worst cases for over-frequency stability, e.g. lightly loaded, HVDC outage.
- The above points can be discussed and agreed with System Operator prior to conducting the study.



4.9.3 Study Scope

Run a time-domain simulation tripping the new large load and determine the effect on frequency. Assess whether any over-frequency arming can be triggered by the loss of the load, and highlight any issues which may affect over-frequency management.

4.9.4 Assessment Criteria

The study must show that over-frequency reserve can be triggered, or that frequency security can be maintained on the power system due to the loss of the large load.

4.9.5 Study Outcomes

We expect the following outcomes from your study:

- Over-frequency risks are manageable with existing practices.
- Any effect on over-frequency arming is highlighted and explained.



5 Modelling Requirements

Large load customers must submit models in accordance with the table below, following the specifications in sections that follow (note the stages outlined in section 5.2, and the software formats explained in section 5.3).

5.1 Requirements at a Glance

#	Model type	Description	Applicability
1	Power-flow studies model	Assets impacting power-flow and dynamic studies such as high voltage transformers, shunt reactors and capacitors, transmission lines or cables. Load profile, load cycling behaviour.	All large loads
2	Static ZIP model	Static load modelling assumptions providing the voltage dependency characteristic. Specify suitability for powerflow and dynamic studies.	All large loads
3	Dynamic studies standard models	Standard models established in industry for generic or aggregated representation covering motor loads, electronic loads, and static loads.	Large loads which can be adequately represented in a standard model.
4	Dynamic studies RMS user-defined models	Bespoke user defined RMS models to capture specialised characteristics of loads e.g. power electronic based loads, UPSs characteristics, or any active control systems which affect power system dynamics.	Large loads whose bespoke characteristics cannot be represented sufficiently with standard models. Loads sharing control systems with nearby BESS or generation require a User Defined Model (UDM).
5	Dynamic studies EMT user-defined models	Bespoke user defined EMT models to capture specialised characteristics of loads e.g. power electronic based loads, UPS characteristics, or any active control systems which affect power system dynamics.	Large loads requiring a UDM, with high frequency characteristics which cannot be adequately represented in a standard model. Data centres and other inverter-based loads require EMT models.
6	Protection and ride through capability	Voltage and frequency ride-through capability, trip % and reconnection characteristics. May be categorised across the site to apply different ride-through characteristics for different load components.	All large loads

5.1.1 Intended Use of Models

The System Operator uses models to conduct accurate load-flow analysis, dynamic stability assessments and other system studies. Models are used at appropriate stages of the commissioning process and throughout the operational life of the asset.



The accuracy of these assessments helps us to:

- demonstrate performance for power system conditions that cannot be readily replicated during onsite testing
- assess the steady-state and dynamic performance of the power system, including the determination of operating and stability limits that define the boundaries of secure operation
- perform studies to ascertain the frequency capabilities of equipment, including the reserve assessments (where offered) and incident investigations
- perform system frequency response and voltage stability studies in the context of contingent and extended contingent events
- perform post-event analysis to better understand system events and support ongoing management of power system stability.

5.2 Staged Model Submission

In accordance with chapters 1 and 4 of the [CACTIS](#), models must be submitted in two stages:

- **M1 model before commissioning, during the connection study phase:** this model must reflect the intended operating configuration at the time of connection, demonstrating the dynamic behaviour to sufficiently perform connection studies and determine stability of the system.
- **M2 model validated against the commissioned load:** this model must reflect the confirmed operating configuration of the commissioned asset, demonstrating its expected dynamic behaviour on the system.

5.3 Software Specifications

5.3.1 Software Packages and Versions

You must submit models using the following software formats:

- DIgSILENT's PowerFactory V2024
- PowerTech's Transient Security Assessment Tool (TSAT) V24
- Power System Computer Aided Design (PSCAD) V5.02
- For PSCAD models, **Intel Fortran Classic 2021.12.0** 32bit and 64bit compiler

The System Operator maintains and updates the approved software to the versions referenced above. Before submitting models, we recommend confirming the latest accepted software versions with us.

The above software versions will allow you to utilise up-to-date PowerFactory case files of the New Zealand power system that the Electricity Authority [makes available for system studies](#). For EMT studies you can utilise the EMT zonal model provided on [Power System Studies and Modelling](#) webpage.

*Note: If your original equipment manufacturer (OEM) deems that their PowerFactory model is confidential and therefore not shareable, then you must **additionally** provide the System Operator with a generic RMS stability model. We will accept such a generic model provided that it fulfils the following criteria:*

- The model is prepared as per WECC generic model specifications.
- The model can represent the dynamic behaviour of the load with sufficient accuracy.

5.3.2 File Structures

5.3.2.1 PowerFactory

- To facilitate your model's integration into System Operator model cases, use the study case and library structures and naming conventions in Table 2. For further guidance, refer to the example PowerFactory model and accompanying readme file on our [Power System Studies and Modelling](#) webpage.

You should also:



- organise your models into the appropriate folders named after the equipment type they belong in. Place the models in the standard "Equipment Type Library" folder;
- store the user macros of each component in the individual component library pack (pack macros);
- store the Element.dsl in the relevant component library with the as-left controller parameters; and
- provide the model in a ready-to-run validation case or project. As part of the initial checks of your submission, the System Operator must be able to activate the project and easily replicate all test results and graphs included in the model validation report.

Table 2: Study Case and Library Structures for Submitting DigSILENT PowerFactory Models

Study Case Structure	Library Structure
- Study Cases - Active Power / Frequency Response Tests - Reactive Power Step Tests - Small Voltage Disturbance Tests - Voltage Step Tests - Network Variations (0, 0 active) (no active Expansion Stage) - Test 5.1 49.5 Hz - Test 5.1 49.9 Hz - Test 5.1 50.1 Hz - Test 5.1 50.5 Hz - Test 5.2 OLTC step down - Test 5.2 OLTC step up - Test 5.3 Voltage step neg - Test 5.3 Voltage step pos - Test 5.4 Reactive step - Test 5.5 OLTC step down - Test 5.5 OLTC step up - Test 5.6 Voltage step neg - Test 5.6 Voltage step pos	- Library - Library - Operational Library - Scripts - Templates - Wind33 - DFIG-33kV - TAPwind110Enc - WPP - WPP - Library - WPP - IEC61400-27-1 (2015) - Constant Q limitation model - Current limitation model - Grid Protection Model - P control model type 4B - Q control model - QP and QU limitation model - Reference frame rotation model (PLL) - Two mass model (Type 3) - Type 4 generator set model

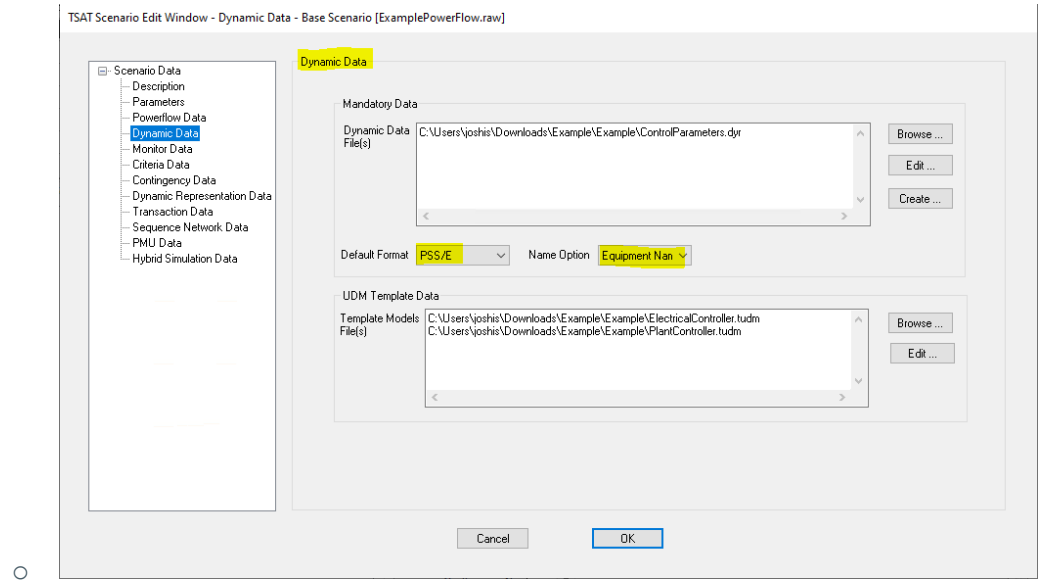
5.3.2.2 TSAT

Use the study case and library structures and naming conventions in Table 3 below to help you organise your TSAT models.

Table 3: Study Case and Library Structures for Submitting PowerTech TSAT Models

Study Case Structure	TSAT - [Example.tsa]		
	File Run View Options Auto Help		
	Scenario		Basecase Analysis
	No.	ID	Security Status
	1	NoDisturbanceTest	
	2	ActivePowerStepTest	
	3	ReactivePowerStepTest	
	4	VoltageStepTest	
	5	SmallVoltageDisturbanceTest	
	6	FrequencyResponseTest	

Library Structure



You should also:

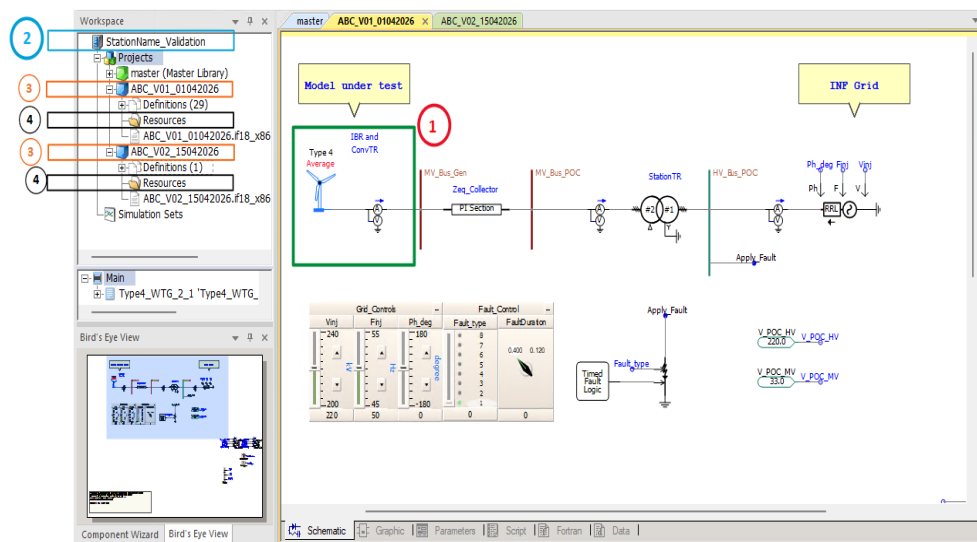
- ensure that the TSAT user-defined model (UDM) is compatible with the equipment name format;
- ensure that the UDM canvas is not password-protected; and
- ensure that the UDM accepts spaces in load equipment name.

5.3.2.3 PSCAD

- Use the study case and library structures and naming conventions in below to help you organise your PSCAD models.

Table 4: Study Case and Library Structures for Submitting PSCAD Models

Study Case Structure

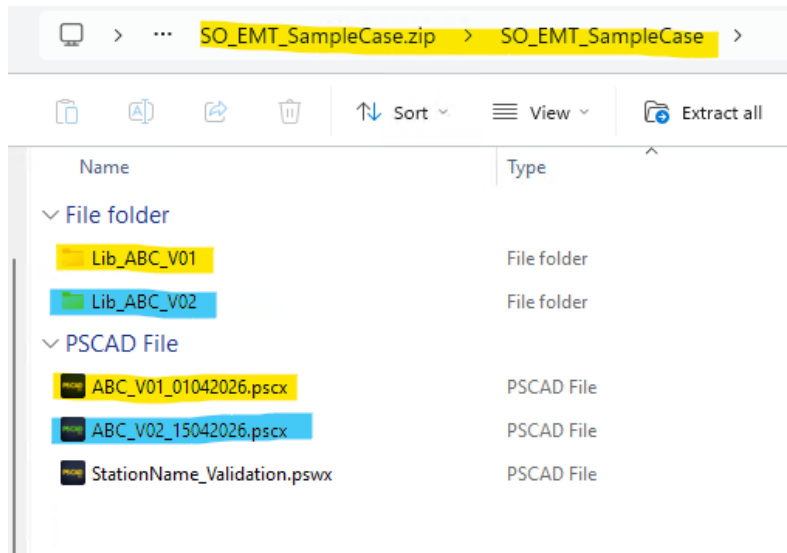


Name the workspace and file name as outlined below:

- | | | |
|---|-----------------|--|
| 1 | Model placement | Replace the model with the model of your asset |
| 2 | Workspace name | (Station name)_Validation |
| 3 | Project name | ABC (Station 3 digit code)_ V01 (Version of model)_20260601 (validation date yyyymmdd) |
| 4 | Resources | Library files / Measurement files / Scripts |



Library Structure



Place the library files in the respective folders named as:
Lib_ABC(Station 3 digit code)_**V01**(Version of model)

5.3.3 File Names

When submitting models or combined .zip files via ACS or any data-sharing platform, ensure that your files utilise the following standard naming convention:

M1 model : ABC_M1 model_Vx_YYYYMMDD

M2 model : ABC_M2 model_Vx_YYYYMMDD

Where:

- ABC = Station three-letter code
- Vx = Version number (e.g. V1, V2.1)
- YYYYMMDD = Submission date

5.3.4 User Guide and Version Control

Models must be accompanied by user guide documentation containing all the information required to use the model as part of system studies without needing to have any prior knowledge of the equipment, content of validation package, or validation techniques in question. You can either provide a separate guide document for each software package, or you can combine them into one document with separate sections. The guide should include:

- block diagrams showing all control system components and how they are interlinked;
- a complete parameter list with definitions and impact on model behaviour;
- clear instructions for the System Operator to replicate model setup, including external dependencies;
- a description of the calculation methods, control logic, or design assumptions used to derive or configure key parameters and functions such as FRT behaviour, current limiting strategies, and any other control features;
- known limitations of the model during initialisation, normal operation or abnormal operation of asset;
- a description of a secondary or station control system able to act within 5 minutes to change the active or reactive power output;
- details of any OEM specific UDM or control block diagrams that the System Operator could use to rebuild the models in other software (if needed);
- a clear description of any aggregation methodology applied to represent multiple load components, feeders, transformers, motors, or plant sections as an equivalent model, including the rationale for aggregation;
- if applicable, the benchmarking report undertaken between the RMS/phaser-domain model and the corresponding validated EMT model, including the scope, objectives, and limitations;
- details of any model encryption or simplification, including associated assumptions and limitations; and

- where a generic model is provided, a description of the derivation methodology (e.g. curve-fitting or response matching), including source data, assumptions, and limitations.

Note: When submitting an unencrypted M2 model, ensure your user guide includes sufficient information to enable integration into the System Operator's PowerFactory environment.

To ensure traceability and consistency between submitted models, the user guide must also include version control information, including:

- software version used to develop the model;
- model version number and author;
- date of last modification;
- data or information sources;
- a discrete list of changes since the previous version;
- compiler version (where applicable, typically for PSCAD models); and
- versioning of individual model components where supported by the software.

5.4 Power-flow Model

Power-flow studies (see section 4.4) are typically carried out with a constant P and constant Q characteristic. Large load customers must inform Transpower if another ZIP load characteristic should be used to represent their plant for power-flow studies.

Modelling information for onsite static components and those connecting to the site must be provided, including:

- station transformers;
- transmission lines or cables connecting the large load to the GXP; and
- shunt capacitors or reactors on site.

All large loads are required to provide power-flow modelling information.

5.5 Models for Dynamic Studies

5.5.1 Modelling Detail

The level of detail required in dynamic models will depend on the specific load site and type. Components with similar characteristics such as transformers and motors of a similar type can be paralleled for a lumped representation.

An example level of representation for a data centre load is given in Figure 3 below [4], with lumped representations for HV, MV and LV transformers, IT load, motor drives, and static load.

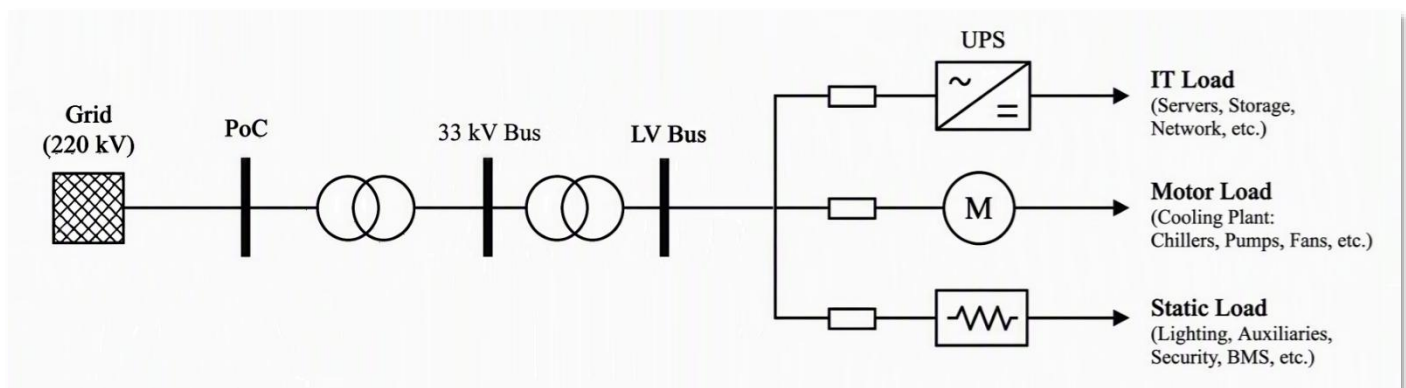


Figure 3: Level of representation required for a typical data centre load



5.5.2 Static ZIP Load Models

Many dynamic studies are run using a ZIP model where a simple representation of load characteristics is sufficient for the study. All large load customers must provide a representative ZIP model of their load. The large load customer must provide the representative proportion of constant power, constant current, and constant impedance load for both active and reactive power.

If known, provide the voltage range over which this characteristic is valid for.

5.5.3 Standard Dynamic Load Models

Dynamic standard load models are required from large-embedded load customers when ZIP models are not sufficient to capture the load characteristics.

Loads which are heavily characterised by motors may use the CMLD (composite load) standard model format. Loads which are dominated by power electronic loads may use standard models such as PERC1 (Power Electronic Reconnecting and Ceasing) model.

Capturing any transient behaviour during voltage disturbances is critical, including any disconnection and reconnection characteristics loads will have on the power system. The PERC1 model has been developed to represent these characteristics for large electronic loads and may be used if deemed the best representation of your load.

It is the responsibility of the large load customer to ensure the load is represented as best as possible if standard models are used, and that user-defined models (UDM) are used if standard model representation is not practical.

5.5.4 User-defined Dynamic Load Models

Where more detailed and bespoke characteristics are required, a UDM must be submitted by the large load customer. This depends on:

- the ability of the plant to be adequately represented by standard models;
- whether there are any shared control systems or switching logic with onsite BESS or generation; and
- any bespoke characteristics in equipment such as power electronic converters or uninterruptible power supplies.

UDMs must be submitted in:

- RMS format (TSAT or PowerFactory); and
- Depending on the load type, EMT format (PSCAD)

EMT models are required when RMS models will not adequately represent short-time frame phenomena, such as high frequency converter switching characteristics. **Inverter-based loads such as data centres are required to submit EMT models.**

UDMs must meet the System Operator's performance criteria in section 5.6. The UDM must:

- represent plant characteristics during voltage transients, including:
 - active and reactive power during voltage dips and recovery; and
 - any disconnection and reconnection characteristics due to voltage or frequency
- represent the various components of the load site, e.g. motor loads, power electronic load, UPS/BESS;
- include time series active power data, particularly representing any cyclic behaviour in various operation modes;¹
- be valid for small signal analysis for sub-harmonic and super-harmonic frequency ranges.

5.5.5 Voltage and Frequency Ride-through Capability

Dynamic models must include frequency and voltage protection models which can be used to represent the ride-through capability of large loads in power system simulation studies. These must be incorporated in the submitted model format, whether it is a standard model or UDM (e.g. CMLD models allow for multiple frequency and voltage trip settings to be added [5]).

¹ Cyclic loads may excite oscillation modes on the power system so are important to be able to assess through power system simulations



5.6 Model Quality

5.6.1 Model Encryption

5.6.1.1 PowerFactory Model

Submitted **M1** PowerFactory models may be **encrypted**, while **M2** PowerFactory models must be **unencrypted**. This allows the System Operator to:

- fully access, review, and understand the internal structure and behaviour of the model;
- understand the control logic and mathematical implementation;
- access and modify all signals, equations, and initial conditions;
- use the model for operational and planning studies over the life of the asset (only applicable to M2 models); and
- validate model performance and investigate asset compliance following system disturbances (only applicable to M2 models).

Models must be developed in accordance with the model format requirements specified in Section 5.6.1.3 below.

5.6.1.2 TSAT and PSCAD Models

Submitted TSAT and PSCAD models may be **encrypted**, provided that the encryption does not prevent the System Operator from accessing the minimum information required to assess model behaviour and performance.

At a minimum, your models must meet the following requirements:

- The System Operator has access to the following signals (as applicable):
 - V_d , V_q ;
 - I_d , I_q ;
 - measured or calculated PLL frequency (F_{pll}); and
 - all trip and protection status flags.
- Tap-changer control logic, switchable shunt control logic and timing parameters are provided in an editable format for fast initialisation.
- Model parameter names and parameter values are **not** encrypted.
- Encryption does not prevent the System Operator from:
 - accessing and modifying all signals;
 - understanding protection actions; and
 - validating model response under disturbance and steady-state conditions (applicable to M2 models).
- The model is developed in accordance with the model format requirements specified in Section 5.6.1.3 below.

5.6.1.3 Model Development Formats

The model can be developed and submitted in one of the following formats:

5.6.1.3.1 Model Block Diagram Format

In this format, the model is constructed using basic control blocks with a graphical representation of the control system components. This format requires that:

- all control blocks, logic, mathematical equations, signal flows, and programming code are visible and accessible to the System Operator;
- no parts of the model are hidden, locked, or compiled in a manner that prevents inspection or modification; and
- the internal structure of excitation systems, governors, limiters, and supplementary controls can be reviewed and validated.



5.6.1.3.2 Model Source Code Format

In this format, the model is provided in a form that enables the control system functions to be implemented using written and organised programming logic that is accessible to the System Operator within the relevant simulation tool. The implementation may be provided using tool-specific mechanisms, including compiled libraries, subject to the encryption and accessibility requirements specified in Sections 5.6.1.1 and 5.6.1.2.

The model source code format must satisfy the following criteria depending on the software platform:

PowerFactory	The control logic and mathematical implementation must be readable and interrogable within PowerFactory, allowing the System Operator to inspect, trace, and understand signals, parameters, and control actions, and be provided without encryption or obfuscation that would restrict such access.
TSAT and PSCAD	The control system implementation may be provided in compiled or encrypted library form, provided the model exposes clearly defined inputs, outputs, parameters, and documented behaviour sufficient for validation, testing, and operational studies.

Note: PSCAD models must be developed in full three-phase (ABC) representation, without positive-sequence or reduced-order approximations, and must incorporate sufficient control system detail to accurately capture asymmetrical faults, converter control dynamics and fast electromagnetic transients across the relevant frequency range.

Refer to our [Power System Studies and Modelling](#) page for information about how we manage confidential models.

5.6.2 Root Mean Square (RMS) Model

5.6.2.1 RMS Model Component

As a minimum, the RMS model must include:

- aggregated load components of similar type and characteristics, modelling electrical characteristics and control behaviour;
- high voltage assets such as transformers, cables, shunt capacitors and reactors, and relevant network interfaces;
- control systems (if applicable) for any load component, including active power, reactive power/voltage control, frequency response functions, and associated limiters; and
- any control, protection, or interlocking functions capable of reducing output or disconnecting the load within a simulation timeframe of up to 60 seconds.

As a minimum, the model must include all relevant physical components, control systems, protection functions, limits, and mode-dependent logic.

In addition, the RMS model must:

- represent all intended operating modes within the active power, reactive power, voltage, and frequency control systems, including the ability to transition between modes and accept external control signals for use in real-time operation;
- use signals as inputs and outputs of DSL models for simulation (e.g. use a model signal such as 'ut' instead of a network measurement value such as 'u:bus1' for a machine terminal voltage, and use the provided measurement device models to provide network quantities as signals);
- not contain any unused, inactive, or redundant control blocks or program code.

5.6.2.2 RMS Model Initialisation

Models submitted to the System Operator must initialise correctly from load-flow solutions within the normal operating envelope of the equipment.



To ensure successful model initialisation, the RMS model must:

- initialise without run-time errors or run-time warnings related to incorrect or incomplete model initialisation;
- initialise successfully across the full operating range of active and reactive power;
- initialise successfully across the allowable voltage range at the point of connection; and
- use numerical integration time steps appropriate to the model, and should be **5 ms** or greater.

*You must demonstrate successful initialisation through a no-disturbance simulation of at least **120 seconds**, during which the model must remain within the limits specified in*

Note: If initialisation problems occur, you must resolve these before validating the model. Submitted models with unresolved initialisation problems will fail the System Operator's verification.

Table 5.

Table 5: Acceptable range of simulated response

Quantity	Acceptable range
Load MW and MVAR	Within $\pm 1\%$ of MW and MVAR setpoint
Controlled voltages (if applicable)	Within ± 0.005 pu of voltage setpoint

5.6.2.3 RMS Model Dynamic Performance

Models submitted to the System Operator must demonstrate adequate numerical performance and reliability across a representative range of operating and system conditions.

The model must be numerically stable for:

- a suitable range of ESCR and fault-level X/R ratios at the point of connection;
- operation across the intended active and reactive power operating envelope, including leading, lagging, and unity power factor operation, when network circuits closest to the point of connection are subjected to balanced and unbalanced faults;
- if applicable, step changes to:
 - voltage, reactive power, or power-factor set-points of the voltage/reactive power control system;
 - frequency, active power, or power reference set-points of the active power/ frequency control system;
- system faults that are cleared by normal protection relay operation.

To demonstrate adequacy, simulations must include, where applicable:

- defined step changes to controller set-point references or inputs;
- defined signal injections to controller inputs;
- switching of static reactive devices;
- load rejection events;
- operation at maximum and minimum transformer tap positions; and
- correct application of rate-of-change limits (both positive and negative) where these are implemented in plant controls.

During testing and simulation, you must record sufficient data to enable meaningful comparison between simulation results and commissioning or test data, where such data is available.

Demonstrate model performance and reliability by running dynamic simulations of at least 60-seconds duration, sufficient to identify any numerical issues, with reference to:



- active power,
- reactive power,
- voltage, and
- frequency.

5.6.3 Electromagnetic Transient (EMT) Model

5.6.3.1 EMT Model Components

The EMT model must represent the instantaneous electrical and control behaviour of the asset with sufficient fidelity to assess large-disturbance responses, any converter control behaviour, protection operation, mode switching, non-linear limiting behaviour, and interaction with the connected network under balanced and unbalanced disturbances.

As a minimum, the model must include all relevant physical components, control systems, protection functions, limits, and mode-dependent logic.

5.6.3.2 EMT Model Initialisation

EMT models submitted to the System Operator must initialise correctly from load-flow solutions across the normal operating range of the asset.

To ensure successful model initialisation, the EMT model must:

- initialise without run-time errors or warnings related to incorrect or incomplete model initialisation;
- initialise successfully across the full active and reactive power operating range;
- initialise successfully across the allowable voltage range at the point of connection;
- use numerical integration time step of **10µS** or greater;
- initialise within **3 seconds** of the start of a simulation and support snapshot capability; and
- be compiled using both 32-bit **and** 64-bit Intel Fortran compiler.

Demonstrate successful initialisation through a no-disturbance simulation of at least 30 seconds, during which the model remains within the limits specified in

Table 5 above.

5.6.3.3 EMT Model Dynamic Performance – Large Disturbance

EMT models submitted must demonstrate robust numerical performance and reliable dynamic behaviour when subjected to large disturbances. The model must:

- correctly represent converter current limiting, active/reactive current allocation, limit recovery, and associated non-linear control behaviour;
- demonstrate stable and physically-realistic PLL behaviour across a representative range of ESCR values and fault-level X/R ratios at the point of connection;
- correctly represent:
 - balanced and unbalanced fault ride-through behaviour and post-fault recovery for faults cleared by normal protection operation;
 - plant response to step changes in voltage, reactive power, power factor, frequency, active power, and active power reference, as applicable; and
 - implemented rate limits, mode switching behaviour, and protection or control function activation under stressed conditions;
- produce responses that are technically consistent with the modelled control structure, implemented settings, and expected plant behaviour;
- avoid numerical artefacts related to discretisation, saturation, or control wind-up;

- exhibit appropriate separation of control bandwidths between inner, outer, and plant-level controls to avoid control interactions.

5.6.3.4 EMT Model Dynamic Performance – Small Disturbance

The EMT model must be capable of reproducing small-signal and control interaction behaviour when subjected to small disturbances around relevant steady-state operating points. The model must:

- accurately represent small-signal and control-interaction dynamics, including oscillatory behaviour in both synchronous and sub-synchronous frequency ranges;
- support frequency-domain or dq-frame interrogation (e.g. impedance or admittance scanning) such that plant behaviour can be characterised at relevant operating points;
- produce impedance or frequency-response characteristics that are consistent with the underlying control system behaviour and suitable for use in small-signal or eigenvalue-based analysis;
- demonstrate robustness under reduced system strength conditions, including behaviour approaching instability;
- produce responses consistent with derived small-signal (eigenvalue) and/or impedance-based assessments; and
- enable identification of adverse control interaction, insufficient damping, or instability arising from interaction between plant control systems and network dynamics, particularly under weak-grid conditions.

Where impedance or frequency-domain representations are derived from the EMT model, ensure that sufficient detail and access is provided to the System Operator to enable independent verification of the derived characteristics.

5.6.3.5 Simulation Coverage and Performance Demonstration

The adequacy of the EMT model must be demonstrated through dynamic simulations covering the full intended operating range and representative system conditions. Such assessments must include:

- operation across the full active and reactive power range, including leading, lagging, and unity power factor conditions;
- response to both large disturbances (e.g. faults) and small disturbances (e.g. set-point changes or perturbations);
- defined step changes to controller set-points or reference inputs;
- defined small-signal perturbations or injected signals to enable assessment of control interaction behaviour;
- switching of static or dynamic reactive devices;
- load rejection events;
- operation at maximum and minimum transformer tap positions; and
- correct implementation of rate-of-change limits.

The simulations must also be of sufficient duration and resolution to capture:

- oscillatory behaviour and damping characteristics;
- adverse control interaction between plant and network; and
- numerical instability or non-physical artefacts.

As a minimum, assessments must monitor:

- active power,
- reactive power,
- voltage, and
- frequency.

6 Testing Requirements

Testing is an important part of proving compliance and model validity. Applicable tests will vary depending on load type and the testing functionality available. The principles which should underpin the testing are:

- proving compliance to performance requirements where it is practical to do so;
- validating power system models against test data; and
- if applicable, proving stability of any the large load's control systems.

Any onsite BESS, generation, dynamic reactive power compensation devices, shunt capacitors, shunt reactors, and reactors must follow testing requirements as per CACTIS [6]. AUFLS systems must also be tested as per CACTIS and [AUFLS Technical Requirement Report](#).

Ahead of testing, large load customers must submit a test plan to the System Operator for review. The test plan must cover the areas below.

6.1 Response to Voltage Variations

Tests must assess the load's response to voltage variations on the network. A voltage step change event can be induced at the load by:

- tapping a transformer;
- switching a shunt capacitor or reactor; or
- another method proposed by the load customer and approved by System Operator.

The test must demonstrate the resilience and behaviour of the load during voltage changes. Any onsite BESS or generation should be disconnected for this test to ensure that the response of the load is observed without the presence of corrective action from another source.

If the load site contains a BESS, generator or other reactive power device, a voltage step change can also be applied by the controller and the response of the load observed.

6.2 Response to Frequency Variations

Understanding how the load behaves under frequency fluctuations helps to ensure representative models are fit for purpose. Load sites with BESS or generation can test the response to frequency by applying a positive and negative step change to the active power output and moving the frequency by a small amount. The load response to the resulting change in frequency can be observed.

Discuss with the System Operator to agree the amount of active power to step. In general, a frequency deviation of 0.1 Hz is appropriate as the frequency can remain within the normal band.

Load sites without onsite BESS and generation must fulfil this test with a period of monitoring the load while connected to the system, assessing how the load responds to system events. This is discussed further in Section 6.4.

6.3 Overall Site Response with Onsite BESS or Generation

You must also consider the response to voltage and frequency disturbances as a site containing any load, BESS, generation and reactive power devices.

Tests discussed in Section 6.1 for voltage disturbances must be conducted with all onsite components connected, and the individual responses of all components observed.

Frequency tests can also be conducted by injecting an active power step as discussed in Section 6.2.



6.4 Monitoring Behaviour during System Disturbances

Some behaviours may be impractical to observe during dedicated system tests, as faults and large frequency deviations must not be triggered on the power system at any time.

Certain behaviours can only be proven through online monitoring while being connected to the grid, so that behaviour can be observed when disturbances occur on the power system.

Large load customers must discuss with the System Operator a period of time to remain connected and continually monitoring behaviour during the compliance testing phase for this purpose. Ongoing monitoring of behaviour once commissioned is also expected, with monitoring requirements discussed further in Section 7.2.



7 Operational Communication and High-Speed Data Requirements

7.1 Operational Communication Requirements

Operational communication requirements for large loads align with what is required for generation in Chapter 8 of CACTIS. Load customers are advised to review CACTIS [6] requirements for more detail on communication standards between System Operator and asset owners. Key clauses are highlighted below:

1. All communications between System Operator and load customer must be logged by both the System Operator and the large load customer.
2. Each large load customer must have a means of communicating by voice to the System Operator.
3. Large load customers are required to provide SCADA indications as specified in Table 6 below.

Table 6: Indications and measurement requirements for large loads

Indication or Measurement	Values Required
Grid interface circuit breaker status	Open/closed/in transition/indication error
Grid interface disconnecter status	Open/closed/in transition/indication error
Shunt capacitors/inductors MVAR	Import and export
Station net MW	Import and export
Station net MVAR	Import and export
Active power load for specific load components as agreed with System Operator (e.g. IT compute load, air-conditioning load)	Import
Reactive power load for specific load components as agreed with System Operator (e.g. IT compute load, air-conditioning load)	Import
Frequency control mode if applicable	Enabled/disabled
Voltage control mode if applicable	Enabled/disabled
Station HV Busbar voltage	kV
Station MV Busbar voltage	kV
Demand provided for AUFLS blocks	MW

If load sites have BESS or generation, those components are subject to indication requirements as per CACTIS. Indications for each separate component are expected.



7.2 High-Speed Data Requirements

High-speed data recording is important for ongoing monitoring of compliance of assets connected to the power system and for event analysis. High-speed data requirements for large loads align with what is required for generation in Chapter 9 of CACTIS. Large load customers are advised to review CACTIS [6] requirements for more detail on communication standards between System Operator and asset owners. Key clauses are highlighted below:

1. All large load customers must install a high-speed monitor (e.g. a PMU) at each large load site and provide event data from the high-speed monitor to the System Operator for post-event analysis.
2. High-speed monitor data must include the following values:
 - Station active power (MW)
 - Station reactive power (MVar)
 - Generation station frequency (Hz)
 - Voltage at point of connection (kV)
 - Current at point of connection (A)
3. Data must be kept for at least one month to allow for provision to the System Operator.



8 References

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Appendix A. Connection Studies Report Template

You must electronically submit your connection studies files (including test cases, scenarios and models) along with your connection studies report, which must be in Adobe Portable Document format (PDF) or Word Document format (DOCX).

The report must include:

- **Executive summary:** to summarise the studies, findings, non-compliance (if any), and recommendations;
- **Background:** to describe the new generating asset's location and all relevant station information used in the connection studies; and
- **Discussion of studies:** to include detailed discussion on the findings, mitigation measures and recommendations for the applicable studies discussed in Section 4 of this report.
- **Findings and recommendations:** to summarise the key mitigating actions that the asset owner will take in order to comply with their obligations and ensure reliable results.
- **Appendix:** to include:
 - Operating modes showing expected active and reactive power profiles
 - Load composition and modelling details
 - If applicable, control block diagrams, including a table to show the parameter values used in the studies for:
 - Frequency controller
 - Voltage controller, including station controller
 - Limiters
 - Simulation results.



9 Document Information

9.1 Metadata

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