

# Connection Study Requirements for Connecting a New Generating Station

## System Operator

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## IMPORTANT

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## 1. EXECUTIVE SUMMARY

This document has been prepared to assist Asset Owners (AO) in understanding the requirements to be met when requesting connection to the New Zealand power system as depicted in Figure 1. The figure also shows the requirements to complete the connection studies during the commissioning phase of the new generating station.

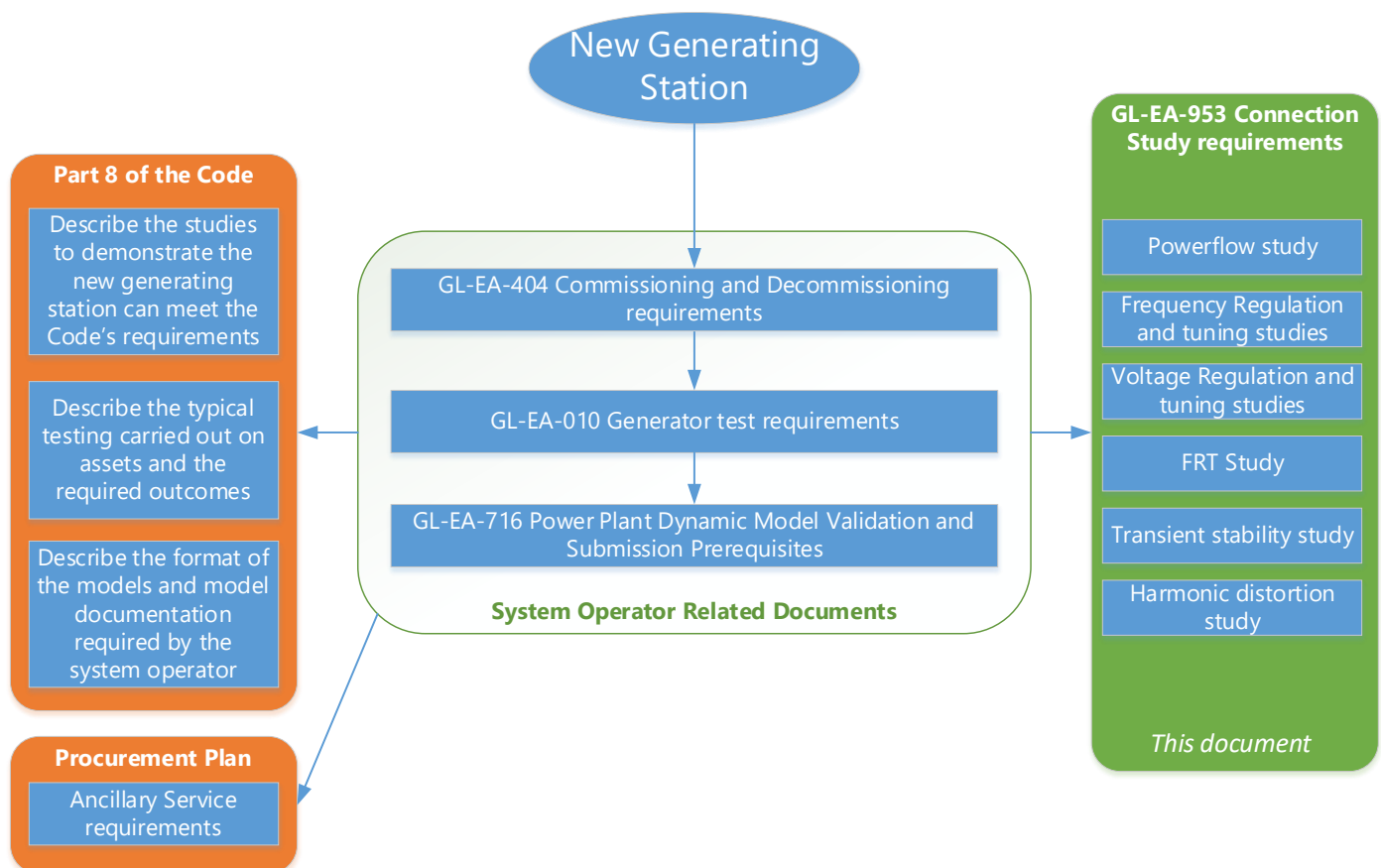
This document sits within a suite of documents around asset testing and modelling published on the system operator's website. Those documents should be read in conjunction with each other.

The connection studies referred to in this document provide:

- a comprehensive and detailed analysis that test the feasibility of the new generating station meeting the requirements set out in the Code
- assurance to the System Operator (SO) that the changes made to the power system, as a direct result of the new generating station, do not affect the system operator's ability to plan and meet the Principal Performance Obligations.

The system operator will use the information provided in these studies to assess the impact of the new generating station on power systems, at their point of connection.

Figure 1 - Supporting Documentation





## 2. DEFINITIONS

Abbreviation	Full Form	Definition
ACS	Asset Capability Statement	A statement of capability and operational limitations that applies to specific assets during the normal and abnormal conditions that may arise on the grid, provided to the system operator in accordance with Clause 2(5) of Technical Code A of Schedule 8.3.
AO	Asset Owner	The owner of the Generating Station is a participant who owns an asset used for the generation or conveyance of electricity and a person who operates such asset and, in the case of Part 8 of the Code, includes a consumer with a point of connection to the grid.
APOO	Asset Owner Performance Obligations	A performance obligation, specified in subpart 2 of Part 8 of the Code, that an Asset Owner must comply with so that the System Operator can plan to comply and comply with its principal performance obligations.
FRT	Fault Ride Through	The capability of electric generators to stay connected to the power system in short periods of lower electric network voltage.
GIP	Grid Injection Point	Point on the grid at which electricity predominantly flows into the grid.
GO	Grid Owner	Referring to Transpower New Zealand Limited as the grid owner.
	Distributor	A business engaged in distribution.
GXP	Grid Exit Point	Point on the grid at which electricity predominantly flows out of the grid.
HVDC	High Voltage Direct Current	
PCC	Point of Common Coupling	A connection point in the grid, or in a local network, at which the grid and the generating station interface occurs.
PoC	Point of Connection	A point, at which electricity may flow into or out of the grid or a local network, may refer to a Grid Injection Point or Grid Exit Point.
PPOs	Principal Performance Obligations	The system operator's obligations set out in any of Clauses 7.2A to 7.2D of the Code.
PSS	Power System Stabiliser	A supplementary control system of the excitation system.
RMS	Root Mean Square	For power system dynamic studies this means consideration of electromechanical transients and fundamental frequency components only.
SCR	Short Circuit Ratio	The ratio of network fault power to the size of the generating station.
SO	System Operator	Referring to Transpower New Zealand Limited as the system operator.
SMIB	Single Machine Infinite Bus	A reduced network model consisting of a single generating unit connected to a power system bus with a fixed voltage magnitude and angled through an equivalent transmission network impedance.
SSF	System Security Forecast	The forecast prepared by the system operator, under Clause 8.15 of the Code, every two years to show its ability to meet the principal performance obligation over a period of three years.
STATCOM	Static synchronous compensator	A device to provide fast-acting reactive power based on voltage source converter technology.



Abbreviation	Full Form	Definition
SVC	Static Var Compensator	A device to provide fast-acting reactive power by using thyristor-controlled reactors and capacitor bank.
TWD	Tail Water Depression	Operating mode for hydro units, synchronised to the grid and absorbing <1 MW. Able to provide reactive support and fast active power response to under-frequency events.
Code	Electricity Industry Participation Code 2010	
	Generating unit	A machine that generates electricity. In this document, it includes all equipment functioning as a single entity to produce electricity which includes, for example, the collective output of a wind farm or a solar farm.
	Generating station	One or more generating units that are directly connected to the grid or to a local network, and that inject into the grid or a local network at a single point of injection.
	Technical Codes	The technical codes set out in Schedule 8.3 of Part 8 of the Code.



## 3. INTRODUCTION

### 3.1. PURPOSE

This document is intended to provide direction to the asset owner who needs to submit connection studies to the system operator as part of ensuring the successful integration of a new generating station to the New Zealand power system. This document forms part of the commissioning process.

Connection of any new generating station to the power system changes the operational environment, which requires assessment to anticipate any challenges the station may introduce.

This document provides a clear and complete technical requirement, study methodology and acceptance criteria to perform the connection studies ensuring:

- new generating stations do not affect supply security and quality
- connection study requirements are consistently applied to all new generating stations
- connection study requirements are fulfilled in a timely manner, helping to meet the commissioning and testing deadlines.

### 3.2. GENERAL REQUIREMENTS

This document outlines the general requirements and scope of the studies that shall be undertaken prior to the commissioning phase.

The asset owner should read this document in conjunction with:

- Part 8 of the Code
- GL-EA-404 – **Generation Commissioning and Decommissioning Requirements**
- GL-EA-010 – **Generator Testing Requirements**
- GL-EA-716 – Power Plant Dynamic Model Validation and Submission Prerequisites
- Benchmark agreement, as outlined in Clauses 12.27 to 12.34 of the Code
- NZECP 36:1993
- Policy statement, as referred to in Part 8 of the Code.

This document does not relieve the asset owner of the need to read, understand and comply with its obligations set out in the Code, nor does this document replace any processes presently used by the system operator to commission a new generating station.

The studies should be submitted in a single report, following the headings in Appendix A, as close as is practical. All models, study cases and supporting information must be included when submitting the report.

### 3.3. INTENDED USE OF THE CONNECTION STUDIES

Generating stations are complex and have many interactions with other assets on the power system. Carrying out a comprehensive set of connection studies for assessment of a new generating station is essential to ensure successful integration into the New Zealand power system.

The connection studies are used by the system operator to:

- assess the new generating station's ability to help the system operator plan and meet the Principal Performance Obligations
- anticipate any potential operational issues that can constrain the operation of the new generating station, such as thermal constraints, transient or voltage stability issues
- assess compliance to the Code, including requirements such as reactive power, frequency control, and fault ride through standards, to ensure the new generating station does not reduce the supply quality and reliability
- minimise risk during commissioning and testing

- assess the impact of the new generation connection on power system stability and supply security
- ensure power system operation and other grid connection parties are not affected by the new generation connection.

### 3.4. COMMISSIONING PROCESS AND TIMELINE

The asset owner must supply the system operator with its plan to complete the connection studies and the connection studies report, before the studies are started. The timeline and deliverables should be clearly identified in a study scope document.

The connection studies shall be commenced during the concept phase (t-12 months) of the commissioning process, when key parameters of the generating station are available and finalised to permit accurate assessment. In order to know which studies are required the obligations of the asset owner need to be determined under Section 4.

The connection studies must be completed, any violations resolved and the final connection studies report submitted to the system operator before the commissioning phase of the new connection.

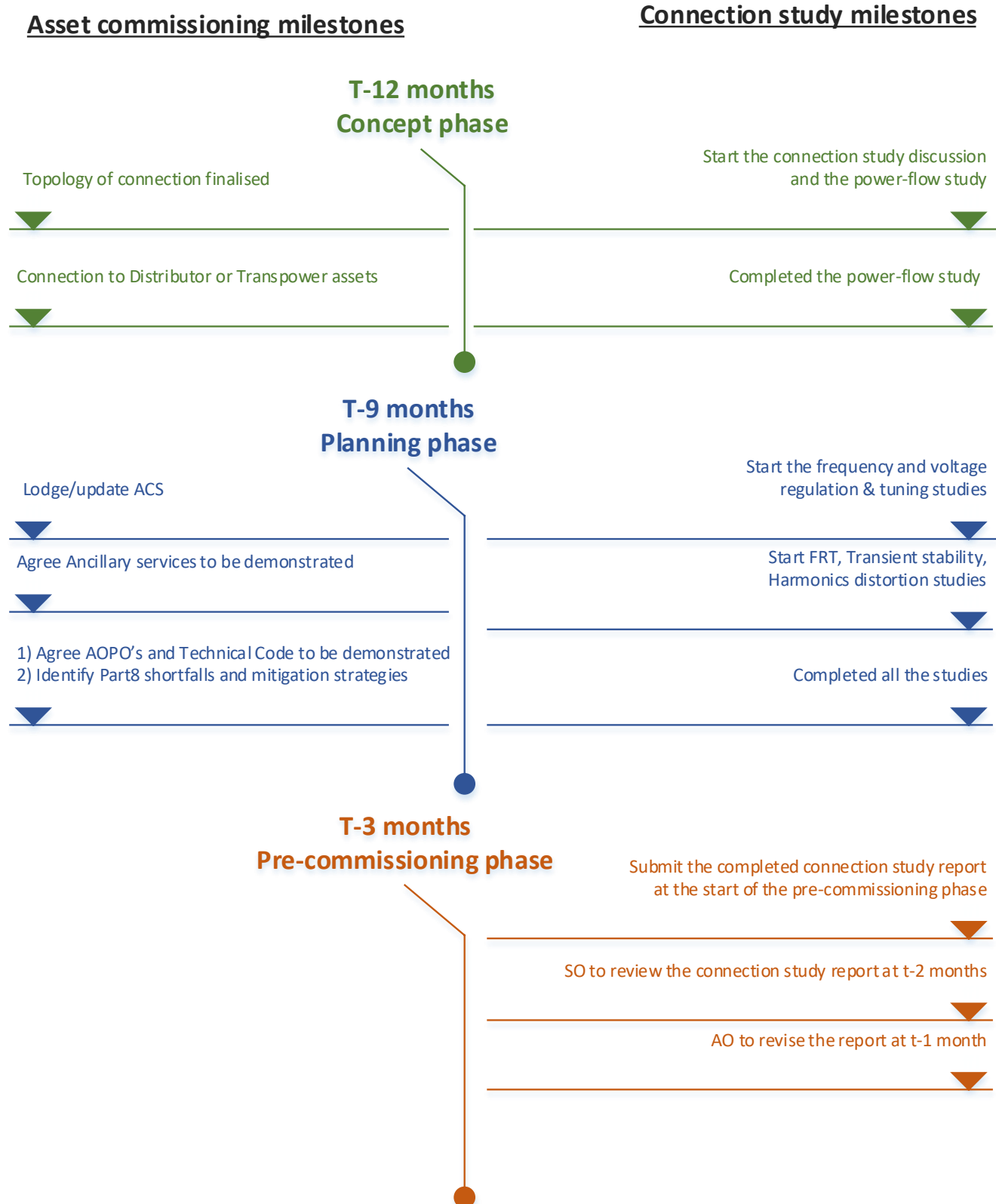
Consequently, early submission of the connection studies, and the connection studies report, is key to ensuring the commissioning timeline can proceed without additional risk of delay. A summary of the key findings of each study, and the full study, should be submitted to the system operator as they are completed.

The first draft of the connection studies report must be submitted to the system operator at the start of the pre-commissioning phase (t-3 months). Following that submission, the system operator will endeavour to provide feedback within 4 weeks (t-2 months) for the asset owner to address and resubmit the final report within 4 weeks (t- 1 month).

Figure 2 shows an overview of the commissioning process.

During the concept and planning phases, the asset owner must discuss with the system operator if they make changes to the key parameters that could affect the results of the connection studies. The asset owner shall discuss and seek resolution with the system operator on any non-compliance and technical requirement violations before commissioning can proceed.

Projects may affect one another especially in constrained grid zones. The system operator should be informed periodically on the progress of the connection studies, timelines and decisions made by the asset owner with regard to the new generating station. The asset owner must inform the system operator at the earliest possible time of any major changes, such as cancelling or delaying the project.

*Figure 2 Expected timeline for executing the connection studies and submission of the report*

## 4. ASSET OWNER OBLIGATIONS

The obligations of the asset owner depend on the size of the generating station, the planned location in the grid that the station is to be connected and whether the station has a point of connection to the grid. These obligations should be discussed and confirmed with the system operator early on during the commissioning process as this will impact which connection studies are required.

Depending on the connection type classification for the generating station, the asset owner may be relieved from some or all the studies outlined in this document.

**Operational requirements require all generating stations:**

- **and associated control systems to support the system operator to comply, and to plan to comply, with the principal performance obligations**
- **above 10MW to offer and provide Operational Communications including SCADA. For embedded stations less than 30 MW these requirements will be confirmed upon formal engagement with the System Operator**
- **with a point of connection to the grid to provide voltage support as per clauses 8.22(2) and 8.23 of the Code**

**It is recommended that all generating stations consider meeting all frequency support and voltage ride through obligations at the design stage**

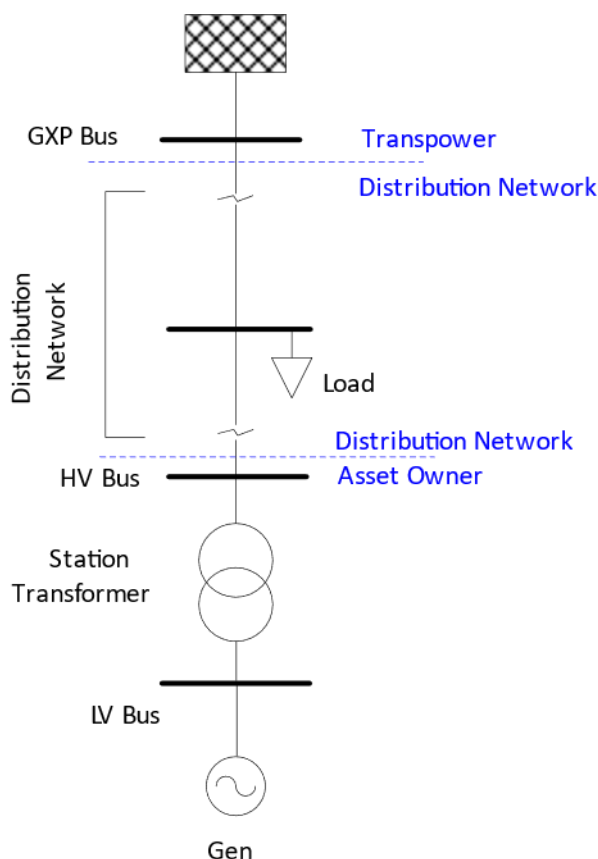
This section provides guidance on how to determine points of connection and the obligations and connection study requirements resulting from that determination.

### 4.1. POINT OF CONNECTION DETERMINATION

A generating station is deemed to have a point of connection to the grid if the Asset Owner has entered into a Transmission Agreement with Transpower as Grid Owner.

If the generating station connects to Distribution Network assets as shown in Figure 3 below then a point of connection to the grid does not exist.

Figure 3 Distribution connected generation example



## 4.2. OBLIGATIONS FOR CONNECTION TYPES

New generating stations can be broadly classified into three types of connection.

- Generating stations having a capacity of greater than, or equal to, 30 MW have an obligation under the Code to provide frequency support and to meet fault ride through (FRT) obligations. Generating stations with a capacity less than 30MW may be required by the Electricity Authority to meet some or all these requirements. The threshold of 30 MW is correct as at the date of publication of this document and is subject to any changes made to Clause 8.21 (1) of the Code.
- Generating units connected directly to the transmission network, and having a capacity of greater than, or equal to, 1 MW, are deemed to be a grid-connected station and have an obligation under the Code to provide voltage support.

The system operator has the discretion to impose any of the obligations described above and set out in Table 1 if it considers that the new generating station may have a material impact on the New Zealand power system.

Table 1 below identifies which obligations apply to each connection type.

Table 1 Connection Types

Obligation	Generating station connection type	
	Output ≥ 30 MW or issued a directive	With a point of connection to the grid
Frequency support	✓	
Voltage support		✓
FRT	✓	

### 4.3. STUDY REQUIREMENTS FOR CONNECTION TYPES

Connection studies play a key role in the successful, secure and efficient integration of new generating stations to the New Zealand power system. The type of studies required will depend on which connection type the generating station is, and what the relevant obligations are.

Table 2 below identifies which studies are required for each connection type obligation

*Table 2 Connection type obligations*

Connection study type	Connection Type Obligations		
	Frequency support	Voltage support	FRT
Power-flow study (Section 6.1)	✓	✓	✓
Reactive power capability study (Section 6.2)		✓	
Frequency regulation and tuning study (Section 6.3)	✓		
Voltage regulation and tuning study (Section 6.4)		✓	
Short circuit study (Section 6.5)	✓	✓	✓
Fault ride through study (Section 6.6)			✓
Transient stability study (Section 6.7)	✓	✓	✓
Harmonics distortion study (Section 6.8)	✓	✓	✓

A brief description of each study type is provided below for the asset owner to understand the main objective(s) of each study.

- **Power-flow study** to assess over/under voltage, overloading, operational constraints and precautions required; the ability of the network to accommodate new generating station.
- **Reactive power capability study** to confirm that the reactive power capability meets the Code requirements.
- **Stability studies** to determine how the power system operates during different disturbances, in particular, how fast the protective devices will clear a fault before the generator and surrounding power system become unstable. Stability studies can be broadly divided into two main categories:
  - **Frequency regulation and tuning study** to confirm the generating station's speed/frequency controllers are coordinated with existing controllers and demonstrate the generating station's block load acceptances and rejections occur in a stable manner. This study investigates frequency stability issues that may arise with different generator combinations, including wind, solar, diesel generator and battery energy storage systems.
  - **Voltage regulation and tuning study** to confirm that the generating station's voltage controllers are coordinated with existing controllers and demonstrate that the generating station can respond to system disturbance in a stable manner. This study investigates voltage stability issues that may arise with different generator combinations, including wind, solar, diesel generator and battery energy storage systems.
- **Short circuit study** to determine the system strength at the point of common coupling which will in turn determine the scope of the fault ride through study and the type of model that the asset owner is required to submit to the system operator.



- **Fault ride through study** to demonstrate that the generating station, when supplying normal load, can ride through a three Phase fault at specific terminals on the reticulation network, such as at MV/LV main board terminals of a step-down transformer.
- **Transient stability study** to determine the critical fault clearing time for the generating station, to ensure the generating units can remain transiently stable after the system fault is cleared.
- **Harmonics distortion study** to ensure that new generating stations do not cause unacceptable power quality in the power system. Harmonic distortion studies determine the level of harmonic distortion at the PCC emitted by the new generating station under all plausible system conditions.

Studies carried out before the commencement of these connection studies, as part of the feasibility assessment of the new generating station (that occurs before the concept phase), can form part of the connection studies report. This is to avoid repeating the same studies and to save cost and time. Any prior feasibility assessment studies must satisfy the requirements below.

- They use the same key parameters as are used in the connection studies.
- They meet the relevant study objectives outlined in this document.
- The key findings are summarised in the connection studies report and the full feasibility assessment studies are attached in an appendix to the report.

## 5. GENERAL REQUIREMENTS FOR CONNECTION STUDIES

### 5.1. INFORMATION PROVIDED BY THE SYSTEM OPERATOR

The system operator will provide the following information to the asset owner to enable the connection studies to be carried out.

- PSCAD Electromagnetic Transients (EMT) model, if required, to assess FRT compliance for low SCR connections.
- Relevant information, depending on the connection study type, that could include:
  - the monitored voltage stability zones
  - allocated harmonic distortion limits
  - information required to model any upcoming network developments
  - automatic under-frequency load shedding scheme
  - over-frequency generators tripping scheme
  - protection fault clearing time
  - special protection scheme.

The system operator has provided links to the following information in Appendix B to enable the asset owner to carry out the connection studies.

- RMS full network model, in DigSILENT Powerfactory format, provided through the Electricity Authority's EMI website.
- The System Security Forecast (SSF) which provides:
  - three year load forecast
  - existing and potential future network issues
  - committed projects for additional generation, transmission, and demand side management in the three year horizon.

### 5.2. INFORMATION REQUIRED FROM THE ASSET OWNER

In order to successfully carry out the connection studies, the asset owner must ensure that the following information is available for the generating station, within the connection studies report.

- Confirmation that the connection studies are based on the submitted Asset Capability Statement (ACS), particularly with respect to capability curves.
- Single line diagrams (including cable collector system, if known, and site layout).
- A generating station connected at the distribution network needs to include distribution-level transformers and other equipment in the network model.
- Representative dynamic models for the generation technology with typical parameter values that adequately represent the generating station's behaviour.

### 5.3. MODELLING OF GENERATING STATION AND THE NEW ZEALAND POWER SYSTEM

Within the system operator's software tools, a model contains certain math equations, a case is a practical application of a model and a project includes the model and all the relevant cases.

Four main models are required for the connection studies:

### 1. RMS full network model

The system operator releases an RMS full network model for power system studies in New Zealand. There are separate project files for the North Island and South Island power systems.

Cases include non-confidential dynamic models for all generation connected to the New Zealand power system. The HVDC, and some wind farms, have a simplified model, so discussion with the system operator may be required if more detailed models are required, particularly if the new generating station is near to an existing station.

### 2. RMS Single Machine Infinite Bus (SMIB)

The SMIB model provides a detailed representation for the connecting generating station. The external transmission or distribution system is equivalenced to an external grid representation at the PCC, validated to the fault level at the PCC. Depending on the application, external grids may need to be configured to represent both minimum and maximum fault level conditions.

Large synchronous generating units can be directly represented in a SMIB case, as such stations normally consist of multiple generating units, unit transformers, and minimal cabling between them and the PCC.

Wind and solar farms typically have many generating units, unit transformers, and large cable networks (collector system). An equivalenced representation may be needed to simplify the connection to the RMS full network model and the inclusion of dynamic models of the generating station. The asset owner has to provide detailed steps in equivalencing the collector system of large wind or solar generating stations or battery energy storage systems.

### 3. EMT model for fault ride through compliance

An EMT model may be required where detailed investigation into a generating station's behaviour, and interaction between multiple units, is required. At this stage, this is only applicable to FRT compliance, under conditions of low SCR connections.

### 4. New generating station model

The asset owner shall develop a generating station model to incorporate into any, or all, of the three network models referred to above, and provided by the system operator. The asset owner can refer to GL-EA-716 to build a model for the generating station. Information used to build the station model shall be included in the connection studies report.

For a synchronous generating station, a full new generating station model, consisting of all the generating units, generator transformers, auxiliary loads and other relevant equipment, must be used for the connection studies.

For wind or solar generating station and battery energy storage system, a full station model or aggregated model is acceptable, depending on the type of studies. Refer to individual study requirements in Section 6. The aggregated model must be calibrated against a full station model and methodology employed to aggregate the station model shall be documented in the final connection studies report.

Full details of each model are set out under the applicable studies in Section 6.

## 5.4. CONTINGENCY ANALYSIS

Many connection studies in the commissioning process involve carrying out contingency analysis. New Zealand runs its power system to N-1, which means that the unplanned outage of a single network element can occur and the power system shall remain in stable operation with minimal disturbance to the wider grid. The following contingency definitions are important.

- **N-1** – All circuits in service following the unplanned outage of a single network element.

- **N-1-1 or N-G-1** – A generator, line, or transformer pre-contingency outage, followed by the unplanned loss of a single network element.

Contingencies include single circuit contingencies, single HVDC pole trips, single generator contingencies and single transformer contingencies. Bus faults, double circuit contingencies, and HVDC bipole trips are only included if specifically mentioned in Section 6.

## 5.5. CONNECTION STUDY SCENARIOS

The RMS full network model projects are published containing two connection study scenarios:

- Summer light load
- Winter peak load.

Both scenarios contain loads for the year the project was published.

When conducting the power-flow study, set out in Section 6.1, a summer peak load case is also required, and assessment needs to be carried out on a three year planning horizon. This information is available in the SSF, which provides forecast load levels for all grid zones.

All grid zones in the relevant island(s) must be checked and scaled if required to match the forecast load levels in the SSF for the current year. When carrying out connection studies using forecast loads, only the grid zone of interest needs to be scaled to determine the operational limits. For example, a constraints study in GZ8 (Wellington) in 2020 may have 2019 summer peak load for the North Island, and 2020 summer peak load in Wellington only. The studies need to consider the neighbouring grid zones if it can affect the power flow significantly.

Depending on the PCC for the new generating station, upcoming network developments may need to be built into the projects. Information on upcoming network developments can be found in the SSF, however, the information required to model the developments in connection studies must be requested from the system operator.

When preparing the study cases the asset owner will:

- self source from the Electricity Authority's EMI website or request the appropriate network model from the system operator
- prepare peak and light loads study cases for the next three years
- prepare low and high short circuit level study cases for FRT studies
- change the location of the slack bus if the slack bus is in the study vicinity.

## 5.6. MANAGEMENT OF NON-COMPLIANCE

Any shortfall in performance and non-compliant behaviour identified shall be addressed and agreed with the system operator before the commissioning phase commences. A management strategy for any non-compliant behaviour may include:

- recommendations to remove any shortfall in performance to meet the APOOs and/or the Technical Codes before the end of any commissioning period
- details of any dispensation applications that have been, or are to be lodged, to manage any shortfall in Code obligations
- details of any equivalent arrangements that have been, or are to be lodged, which the asset owner considers will achieve compliance with the Code if granted by the system operator.

## 5.7. CONNECTION STUDIES REPORT FORMAT

The connection studies report must follow the template set out in Appendix A.



## 5.8. CONNECTION STUDY CASES

All study cases and relevant model libraries used in the connection studies shall be packaged and submitted to the system operator, together with the final connection studies report.

## 6. CONNECTION STUDY TYPES AND REQUIREMENTS

This section describes the type of connection studies that shall be performed to allow the system operator to ensure that connecting a new generating station will not compromise the quality, security or reliability of the New Zealand power system. The studies will:

- assess the network capability to ensure the new generating station can operate to its full capacity without any constraints. Operational limitations identified in the studies will need to be addressed with the grid owner and may involve network reinforcement or operational measures, such as a special protection scheme
- assess the capability of the new generating station to comply with the Code requirements. The studies will recommend actions or measures if any non-compliance is identified. Actions and measures can include dispensation application or equivalent arrangements
- recommend measures for technical requirements that are not fulfilled by the generating station.

### 6.1. POWER-FLOW STUDY

This study examines how the power flow changes as a result of the installation of the new generating station. The inclusion of the new generating station in the model must not result in any operational constraints that limit either the stations' asset capability or the operation of the power system.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

#### 6.1.1 Objectives

The objectives of a power-flow study are to:

- demonstrate the generating station will not overload any equipment
- ensure the generating station does not impose operational constraints under outage conditions.

The study is to:

- demonstrate compliance with Clause 8.22 of Part 8 of the Code
- demonstrate compliance with Clauses 2 (1) (a), (b), (c) of Technical Code A
- demonstrate compliance with Clauses 2 (2) (a), (b) of Technical Code A
- demonstrate the performance will support the system operator to plan to meet, and meet, its obligations in Clauses 11, 12, 17 and 18 of the Policy Statement.

#### 6.1.2 Model preparation

Accurate network and generator models are important for any power-flow study. This section provides general requirements to prepare the new generating station model for the power-flow study, as follows.

- A full new generating station model, including individual generating unit, generating unit transformer and station auxiliary loads, shall be modelled for a synchronous generating station.
- An aggregated new generating station model is acceptable for wind, solar and battery generating stations. It shall include collector system equivalent network model, aggregated transformers and generating units model.
- Relevant station reactive power controller shall be modelled.
- Consider any applicable special protection schemes.
- Connect the model for the new generating station to the RMS full network model.

#### 6.1.3 Study case preparation

This section provides general requirements to schedule the generation in order to study the impacts of the new generating station during different system operating conditions, as follows.

- The study shall consider winter peak, summer light and no generation, scenarios from wind and solar generating stations in the study vicinity.

- Only adjust hydro generation to balance generation and demand with geothermal and thermal generation operating as baseload generation.
- All generating units shall be dispatched within the reactive power limits.
- SVC and STATCOM shall be dispatched up to 75 per cent of its 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 the capability limits before applying a contingency.
- Under extreme light load conditions, switching out transmission circuits to manage pre-contingency voltage is allowed.

#### 6.1.4 Study scope

The main purpose of the N-1 and N-1-1 contingency analysis in this study is to investigate the impact of the new generating station on the loadings of the transmission network and transmission voltages following a contingency. All credible contingencies defined in the Policy Statement, as referred to in Part 8 of the Code, shall be applied to the transmission network in close proximity to the new generating station to study the impacts. The contingencies can include:

- the loss of a single (N-1):
  - transmission circuit
  - interconnecting transformer
  - generating unit
  - reactive power compensation device
- a planned outage of a transmission circuit and unplanned outage of another circuit (N-1-1)
- when appropriate, application of similar N-1-1 study methodology on inter-connecting transformers and reactive power compensation devices
- if the new generating station is located in Grid Zone 8 and 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 generating station.

#### 6.1.5 Assessment criteria

The study results must meet the following criteria.

##### **Transmission circuits thermal overload assessment**

The new generating station shall not cause any transmission circuits or transformers in close proximity to overload. When doing contingency analysis, it is appropriate to use:

- branch ratings for transmission lines
- post-contingency 24-hour branch ratings for transformers.

Although it is an operational reality, there is no modelling of 15-minute offload times in the RMS full network model project cases. Studies should be conducted to 100 per cent thermal loading of transmission circuits. Additional information to consider 15-minute offload times should be requested from the system operator if the circuit is only marginally overloaded in post-contingency. The extra capability unlocked by the 15 -minute offload time is unlikely to help if the circuit is heavily overloaded.

##### **Steady state voltage assessment**

The introduction of a new generating station with a point of connection to the grid must not affect the system operator's ability to operate the grid within the voltages set out in Table 3 below.

*Table 3 Voltage range*

Nominal grid voltage (kV)	Voltage limits			
	Minimum (kV)		Maximum (kV)	
<b>220</b>	198	-10.0%	242	10.0%
<b>110</b>	99	-10.0%	121	10.0%
<b>66</b>	62.7	-5.0%	69.3	5.0%
<b>50</b>	47.5	-5.0%	52.5	5.0%

### 6.1.6 Study outcomes

The following outcomes are expected from the analysis in the power-flow study.

- A table that shows the impact of the new generation on thermal loading and voltages in the region, with any thermal limit and/or voltage limit violations clearly identified.
- Identification of any thermal limit violations that need to be resolved prior to the start of the commissioning phase, to the satisfaction of the system operator. Mitigation measures, such as a special protection scheme, shall be studied and stated clearly in the final connection studies report.
- Identification of any voltage limit violations that need to be resolved prior to the start of the commissioning phase, to the satisfaction of the system operator.

Operational measure may be acceptable to resolve any identified violations if the measure does not cause any limitation to the operation of the power system and nearby connection parties.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

## 6.2. REACTIVE POWER CAPABILITY STUDY

The study examines the reactive power capability of the new generating station to regulate the grid voltage at the PCC under all plausible system conditions.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

### 6.2.1 Objectives

The objectives of a reactive power capability study are to:

- assess the generating station's ability to meet the AOPO requirement, whilst maintaining the voltage at its GIP within the applicable range of voltages set out in Table 3 and:
  - is capable of exporting (over excited) when connected and made available for dispatch by the system operator, a minimum net reactive power which is 50 per cent of the maximum continuous MW output power as measured at the applicable generating unit terminals, and
  - is capable of importing (under excited) when connected and made available for dispatch by the system operator, a minimum net reactive power which is 33 per cent of the maximum continuous MW output power, as measured at the applicable generating unit terminals
- consider the limits resulting from the physical layout or control system of the generating station, such as over-excitation or under-excitation limiters
- where the connection transformer has an off-load transformer, identify the optimal generator transformer tap position for synchronous generation, or the station transformer tap position for solar and wind farm including battery energy storage systems, to enable the generating station to operate in its full reactive power range under all plausible system conditions.
- determine the station's reactive power capability to regulate the grid voltage at the point of common coupling under all plausible system conditions.

The study is to:

- demonstrate compliance with Clause 8.23 of Part 8 of the Code

- demonstrate the performance will support the system operator to plan to meet, and meet, its obligations in Clause 11.4 of the Policy Statement.

### 6.2.2 Model preparation

Accurate network and generating station models are important for any reactive power capability study. This section provides general requirements to prepare the generating station for the reactive power capability, as follows.

- A full new generating station model, including individual generating unit, generator transformer, and station auxillary loads, shall be prepared for a synchronous generating station.
- A full new generating station model, including individual generating unit, generating transformer, collector system network, and station auxillary loads shall be prepared for wind, solar and battery generating stations.
- All reactive power compensation devices installed within the station shall be modelled.
- Generating station internal operational limits shall be modelled.
- Reactive power capability shall be modelled including any voltage dependency. The minimum reactive power capability should be used considering the operating conditions, e.g. ambient temperature or altitude, but not limited to those factors.
- Generator transformer tap changer must be modelled accurately.
- A SMIB network model can be used to assess the generating station's reactive power capability by connecting the full generating station model to the SMIB model.
- If a RMS full network model is used, the point of common coupling for the generating station should be configured to control voltage.
- Connect the model for the new generating station to the RMS full network model or the SMIB model.

### 6.2.3 Study case preparation

This section provides general requirements to prepare the study case for the reactive power capability of the generating station, as follows.

- If the RMS full network model is used, perform the study for winter peak and summer light load conditions.
- If the SMIB network model is used, perform the study with maximum and minimum short circuit levels reflecting winter peak and summer light load conditions.
- Perform the study with current year study cases.
- Create study cases with PCC bus voltage schedule to:
  - 1.1 per unit
  - 0.9 per unit
  - Post-contingency minimum voltage
  - Post-contingency maximum voltage

The post-contingency voltages can be obtained from the power-flow study.

- Station active power shall be scheduled at 100 per cent of the station's rated output and minimum station operating level for a synchronous generating station.
- Wind and solar generating stations shall:
  - Schedule the station's MW output at 100, 50 and 30 per cent of the station rated output.
  - For partial load study cases, the station rating shall represent the number of generating units or inverter string scheduled under the station's MW output level. Any generating units or inverter strings not scheduled to produce electrical power shall be switched off and not contribute to the reactive power output.
- Battery energy storage systems shall also follow the same study case preparation as the wind and solar generating station but shall consider the scenarios when the battery energy storage system is charging and discharging.

### 6.2.4 Study scope

The main purposes of this study are to determine the station's reactive power capability and to demonstrate that the station can meet the Code requirements. The study can be performed by:

- setting the PCC voltage to 1.1 per unit
- scheduling the station's Mvar output from the minimum to maximum
- monitoring the station bus voltage and other operational limits to determine the maximum that the station can import and export Mvar
- setting the PCC voltage to 0.9 per unit, post-contingency minimum and maximum voltage and repeating the study.

The study is to be performed for both winter peak and summer light load system conditions.

#### 6.2.5 Assessment criteria

The study results must demonstrate compliance with Clause 8.23 of Part 8 of the Code.

#### 6.2.6 Study outcomes

The following outcomes are expected from the reactive power capability study.

- A table summarising the study results.
- A station reactive power capability curve with the study results plotted to demonstrate that the generating station can meet the Code requirements.
- The generator transformer, or station transformer (for wind and solar generating stations), tap position to be used during commissioning of the new generating station.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

### 6.3. FREQUENCY REGULATION AND TUNING STUDY

The New Zealand power system is relatively small in size and requires responsive and stable frequency control to maintain its security and quality. This study shall be carried out after the generating station's frequency/speed control system design is finalised, and completed before the commissioning phase starts.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

#### 6.3.1 Objective

The objectives of a frequency regulation and tuning study are to:

- assess the frequency regulation performance of the new generating station in response to grid disturbances to ensure the new station supports management of frequency and does not lead to:
  - constraint of the power system operation, or
  - an increase in the need to procure frequency reserve to maintain the system frequency within the stated limits, or
  - change to the present frequency management strategy
- assess the stability of the speed or frequency controller to regulate system frequency
- determine a suitable speed/frequency droop setting for the station
- determine suitable control system parameter values to be used for commissioning prior to fine tuning at the generating station site.

The study is to:

- demonstrate compliance with Clauses 8.17 and 8.19 of Part 8 of the Code
- demonstrate compliance with Clauses 5 (1) and 5 (3) of Technical Code A
- demonstrate the performance will support the system operator to plan to meet, and meet, its obligations in Clauses 11, 12, 17 and 18 of the Policy Statement.

#### 6.3.2 Model preparation

An accurate speed or frequency controller model is important for any frequency regulation and tuning study. This section provides general requirements to prepare that model, as follows.

- Speed or frequency controller and voltage controller models shall be included.
- Any features that are sensitive to frequency shall be modelled.
- Tail Water depressed (TWD) control for hydro units should be modelled if this feature is available and intended to be used in future.
- Control parameters settings used in the study shall be clearly stated especially the:
  - Deadband, if any
  - Droop settings.
- A full new generating station model, including individual generating unit, generating transformer and station auxiliary loads, shall be prepared for a synchronous generating station.
- An aggregated generating station model is acceptable for wind, solar and battery generating stations that shall include collector system equivalent network model, aggregated transformers and generators model.
- Limiters and power system stabilisers models shall be included.
- Over and under-frequency protection shall be modelled.

#### 6.3.3 Study case preparation

This section provides general requirements to prepare the study cases for the frequency regulation and tuning study, as follows.

- Request over-frequency generators tripping scheme from the system operator.

- Automatic under-frequency load shedding is to be included in relevant study cases by the asset owner, using the percentage set out in the Code, distributed evenly across both the North and the South Islands.
- Only adjust hydro generation to balance generation and demand with geothermal and thermal generation operating as baseload generation.
- Hydro generation dispatch at 80 per cent to provide enough frequency reserve to ensure the biggest single contingency will not cause the island frequency to drop below 48 Hz if a generating unit contingency is applied.
- HVDC is not modelled in the RMS full network model cases and will not contribute to frequency reserve.

#### 6.3.4 Study scope

The main purpose of this study is to determine the performance of the new generating station when responding to a frequency disturbance in the power system. Disturbance-based analysis will be carried out to assess the dynamic performance of the station under all system conditions that are peak and light load conditions.

Nyquist stability criteria can be used to demonstrate that the tuning of the speed or frequency controller has achieved the required stability margin. The general guideline indicates that a well-tuned controller shall have a gain margin between 1.7 and 4 and a phase margin between 30° and 45°. Other stability criteria can be used but shall achieve the same stability margin as defined above.

After tuning the speed or frequency controller, the following disturbances are used to demonstrate the performance in the time domain simulation.

Frequency disturbance to be considered for generators connected to the North Island are:

- Step response test (MW and frequency ref).
- Standard under-frequency injection test.
- Disconnection of the island's largest units
- Disconnection of the HVDC bipole.
- 200 MW or less step decrease in demand to cause the island frequency to raise but stay below the 51 Hz.
- Ramp the North Island demand to 100 MW at ramp rate of:
  - 10 MW per second
  - 1 MW per second
  - 0.5 MW per second.

Frequency disturbance to be considered for generators connected to the South Island are:

- Step response test (MW and frequency ref).
- Standard under-frequency injection test.
- Disconnection of the island's largest units.
- Disconnection of the HVDC bipole.
- 100 MW or less step decrease in demand to cause the island frequency to raise but stay below the 51 Hz.
- Ramp the South Island demand to 50 MW at ramp rate of:
  - 10 MW per second
  - 1 MW per second
  - 0.5 MW per second.

Simulation shall be carried out in peak demand condition to represent high inertia system and in light demand condition to represent low inertia system. The performance under island operation shall be studied if there is a possibility for the generating station to operate in the island under N-1-1 scenario.

#### 6.3.5 Assessment criteria

The generating station must:

- remain connected within the frequency range stated in Clauses 8.19 (1) and (3) of the Code for the North and South Islands respectively
- respond in a correct and stable manner

- the overall response of each generating unit for power system frequency excursions is settable and capable of achieving an increase in the generating unit's active power for reduction in power system frequency for any pre-disturbance output up to 85 per cent of registered maximum active power output, and
- each generating unit is capable of achieving a reduction in the generating unit's active power output for an increase in system frequency, provided this does not require operation below the technical minimum
- thermal generating units are able to at least maintain their pre-disturbance active power output for a reduction of frequency of up to 2 Hz in the North Island
- meet the droop setting requirement stated in Clause 5 (1) (c) (ii) of Technical Code A
- meet the Nyquist stability criteria or equivalent.

The asset owner must also clearly state over-frequency trips in their ACS and include in the models.

#### 6.3.6 Study outcomes

The following outcomes are expected from the speed or frequency regulation and tuning study.

- The speed or frequency controller must respond in a stable manner.
- The responses must meet the stability criteria.
- Time-domain simulation plots shall be included to demonstrate the speed or frequency controller performance.
- Nyquist or frequency response or root-locus shall be used to demonstrate stability.
- A confirmed set of control system parameter values to be used for commissioning prior to fine tuning of the speed or frequency controller at the generating station site.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

### 6.4. VOLTAGE REGULATION AND TUNING STUDY

The New Zealand power system is relatively small in size and built with a single 220 kV transmission backbone supported by 110 kV and 66 kV sub-transmission networks. Load and generation are connected to both the 220 kV and lower voltage systems. At some locations the system strength is very weak, requiring the generating station to operate in low fault level condition providing effective voltage regulation, and to remain connected following a power system fault.

The new generating station will contribute to both fault current and voltage regulation without degrading voltage quality. This study shall be carried out after the generating station's voltage control system design is finalised, and before the station connects to the power system.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

#### 6.4.1 Objectives

The objectives of a voltage regulation and tuning study are to:

- assess the voltage regulation performance of the new generating station in response to grid disturbances to ensure the new connection supports system performance and does not:
  - constrain power system operation
  - affect the voltage regulation capability at the vicinity of the station
  - degrade the damping of the power system, resulting in unstable operation
  - cause instability in equipment operation, e.g. hunting tap-changing or repeated capacitor bank switching
- assess the dynamic responses of the voltage controller to regulate system voltage, during and following a power system fault or disturbance
- assess the respond of the over- and under-excitation limiters
- assess and tune the PSS to dampen plant oscillation and help to dampen network-wide oscillation
- determine suitable control system parameter values to be used for commissioning prior to fine tuning at the generating station site.

The study is to:

- demonstrate compliance with Clauses 8.22 and 8.23 of Part 8 of the Code
- demonstrate compliance with Clauses 5 (2) and 5 (3) of Technical Code A
- demonstrate the performance will support the system operator to plan to meet, and meet, its obligations in Clauses 11,12, 17 and 18 of the Policy Statement.

#### 6.4.2 Model preparation

An accurate automatic voltage regulator (AVR), excitation and its associate limiters controller are important for any voltage regulation and tuning study. This section provides general requirements to prepare those models, as follows.

- Control parameters settings used in the study shall be clearly stated especially the:
  - Deadband, if any
  - Droop settings
  - Reactive current compensation.
- A full generating station model, including individual generating unit, generating transformer and station auxillary loads, shall be prepared for a synchronous generating station.
- An aggregated generating station model is acceptable for wind, solar and battery generating stations. It shall include collector system equivalent network model, aggregated transformers and generator model.
- Detailed voltage controller models shall be included.
- Any station voltage controller that can respond to voltage disturbance shall be modelled.
- Limiters and power system stabilisers models shall be included.
- Other limiters or operational limits for the wind and solar generating station and battery energy storage system shall be modelled.
- Over and under-voltage protection shall be modelled.

#### 6.4.3 Study case preparation

This section provides general requirements to prepare the study case for the voltage regulation and tuning study, as follows.

- Only adjust hydro generation to balance generation and demand with geothermal and thermal generation operating as baseload generation.
- The study shall consider peak and no generation scenarios from wind and solar generating stations in the study vicinity.
- All generators shall be dispatched within their reactive power limits.
- SVC and STATCom shall be dispatched up to 75 per cent of its reactive power capacity.
- All 220 and 110 kV bus voltages shall be scheduled between 1 - 1.06 per unit prior to applying contingencies.
- All 66 kV bus voltages shall be scheduled between 1 - 1.025 per unit prior to applying contingencies.

#### 6.4.4 Voltage regulation and tuning study scope

The main purpose of this study is to determine the performance of the generating station when responding to a voltage disturbance in the power system. Disturbance-based analysis will be carried out to assess the dynamic performance of the station under all system conditions that are peak and light load conditions.

This study should start after the reactive power capability study is completed. Information such as agreed reactive power capability and transformer tap position shall be modelled in this study.

Voltage disturbances to be considered are as follows.

- Step response test (Mvar and voltage ref).
- Disconnection of the Island's largest reactive power compensation device, that can be a generating unit that is absorbing or producing reactive power.
- Disconnection of the closest significant reactive power compensation device, that can be a generating unit that is absorbing or producing reactive power.
- Disconnection of reactive power compensation devices within the station.

- Disconnection of the HVDC bipole.
- Three phase fault with the following characteristics:
  - Fault location to be discussed with the system operator but as a general rule, faults shall be applied on buses up to three buses away from the generating station.
  - Fault clearing time of 120 ms.
  - Remove a circuit or transformer connected to the faulted bus.

Simulation shall be carried out in peak demand condition to represent high system strength condition and light demand condition to represent low system strength condition. The asset owner will use the appropriate SSF study cases and adjust the generation to mimic the appropriate system conditions for the study.

Selected N-1-1 contingencies shall be studied to ensure the voltage controller can perform in a stable manner under extreme system conditions. Performance under island operation shall be studied if there is a possibility for the generating station to operate in the island under N-1-1 scenario.

The asset owner shall adjust the synchronous generating unit excitation appropriately and apply a step disturbance to cause the operating point to move into the limiter zone, in order to check the function of the over- and under-excitation limiter.

#### 6.4.5 Assessment criteria

The generating station must:

- respond to faults and disturbances in a manner that supports system voltage
- respond in a correct and stable manner.

The performance of a voltage control system can be characterised by the response to a step change in voltage, reactive power or power factor set point, moving the signals from an initial value to a settling value, with consideration of the following parameters:

- Overshoot – the amount the peak value exceeds the settling value, expressed as a percentage of the step change difference between settling value and initial value.
- Rise time – the time taken for a signal to move from 10 per cent to 90 per cent of the step change.
- Settling time – the time taken to remain within a specified settling band around the settling value.
- Settling band – the tolerance band around the settling value at which the signal is determined to have reached the set point.

Specified tolerance around settling values to define settling time is given in the GL-EA-010, which makes reference to IEEE Std 421.2-2014 for recommended performance criteria of voltage control systems. Recommended performance criteria are given in Table 4 below.

*Table 4 Voltage control system recommended performance criteria*

Controller Type	Parameter	Recommended performance criteria
Voltage Control	Overshoot	0-15%
	Rise time	0.1s – 2.5s
	Settling time	0.2s – 10s
Settling band		±10% of step change

An example to show the calculation is showed below.

**Initial Value:** 1.016 pu

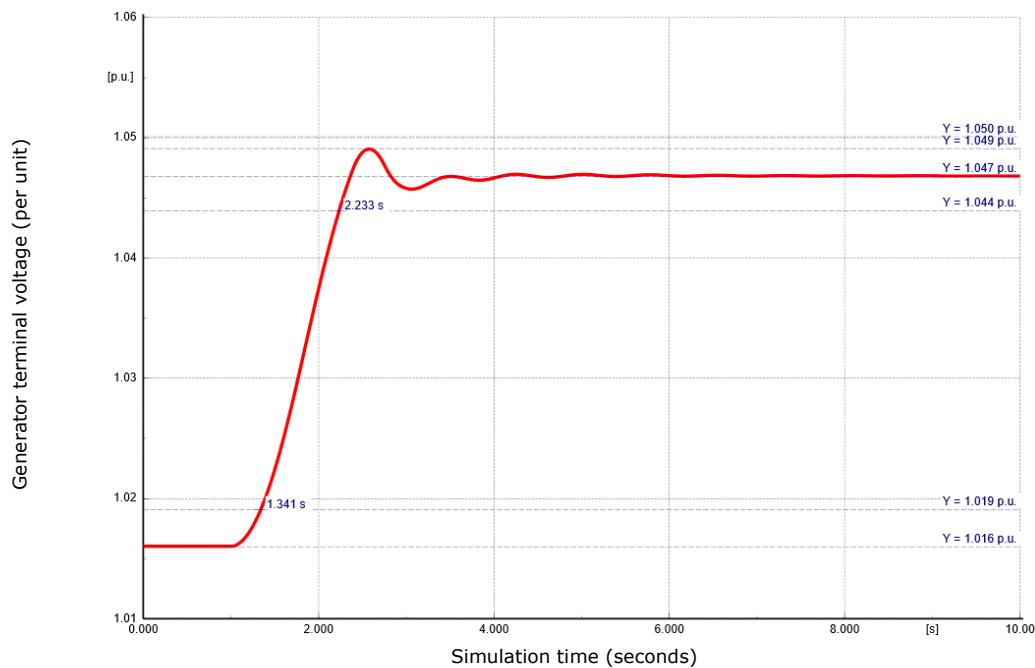
**Settling Value:** 1.047 pu

**Overshoot:**  $\frac{1.049 - 1.047}{1.047 - 1.016} = 6\%$

<b>Rise Time:</b>	$2.233 - 1.341 = 0.892s$
<b>Settling Band:</b>	$\pm(1.047 - 1.016) \times 10\% = \pm 0.0031 pu$
	$1.0439 - 1.0501$
<b>Settling Time:</b>	$1.233s$

An example voltage step response is shown in Figure 4 below. The quantities in Table 4 above are extracted from that response:

*Figure 4 Generating unit voltage output responding to a voltage step response test*



#### 6.4.6 Power system stabiliser tuning study scope

The PSS is a supplementary control system of the excitation system. The excitation system receives an output signal from the PSS to damp out low frequency oscillations of the power system. The PSS is an economical and effective way to dampen low frequency oscillation but it is critical to tune the internal parameters of the PSS to prevent undesirable operation of the control system.

The asset owner can decide on the best method to tune the PSS, however they need to consider the following conditions.

- Existing system frequency responses, which are available on request from the system operator, to understand the oscillation modes in the absence of the PSS.
- All plausible system conditions shall be considered, e.g. N-1 or N-1-1 outage of a transmission circuit.
- Disturbances introduced to assess the PSS performance shall include step change of generator terminal voltage, exciter field voltage or current.
- Phase compensation tuning and gain tuning shall be demonstrated clearly by using a frequency response or root-locus plots.
- The effectiveness of the final settings shall be demonstrated using a time domain simulation.

#### 6.4.7 Assessment criteria

The study shall demonstrate that the power system stabiliser meets the following design requirements.

- The minimum acceptable performance of the PSS must provide a compensated frequency response of the excitation system and synchronous machine such that through the frequency range from 0.1 Hertz to 1.0 Hertz the phase will not exceed  $\pm 30$  degrees. PSS output limits shall be at least  $\pm 5$  per cent of the synchronous machine terminal voltage.
- PSS gain shall be set to provide a gain margin of least 6 dB and no more than 10 dB.
- PSS washout time constant shall be set as low as possible while maintaining the compensated phase criteria.

#### 6.4.8 Study outcomes

The following outcomes are expected from the voltage regulation and tuning study.

- The voltage controller must respond in a stable manner.
- The responses must meet the performance criteria.
- Time-domain simulation plots shall be included to demonstrate the voltage controller performance.
- The study should contain a confirmed set of control system parameter values to be used for commissioning prior to fine tuning of the voltage controller at the generating station site.
- The effectiveness of the PSS shall be demonstrated using:
  - Bode plots
- Excitation response with the generating unit connected to the electrical system, without the PSS in service
- Excitation response with the generating unit connected to the electrical system, with the PSS in service.
  - Time domain plots showing step responses of the generator terminal voltage, field voltage, field current, power, PSS output, AVR output with the PSS in service and out of service.
- The study shall contain recommendations for the key PSS parameters to be used for the site field test for further fine tuning of the parameters.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

## 6.5. SHORT CIRCUIT STUDY

The term “system strength” is more commonly used to refer to the level of short circuit current available at a location in the grid. Short circuit current is typically contributed by assets connected to the power system, with synchronous generation contributing the most, and provides a means for protective equipment to detect faults and remove them.

Short circuit current needs to be managed within an acceptable range – high short circuit current can damage equipment whereas low short circuit current can cause mal-operation of equipment, power system instability and power quality violation.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

### 6.5.1 Objective

The objective of a short circuit study is to determine the Effective Short Circuit Ratio (ESCR) at the point of connection. The level of ESCR will determine:

- the type of model that the asset owner is required to submit to the system operator (GL-EA-716)
- the configuration of the voltage controller and the overload capability of the inverter/STATCOM
- the short circuit current at the PCC for setting out the SMIB and for the FRT study.

### 6.5.2 Model preparation

An accurate new generating station model is important for any short circuit study. This section provides general requirements and details of what components should be included as a minimum to prepare that model.

The asset owner shall provide a detailed model to perform the short circuit study. This section provides general requirements and details of what components should be included as a minimum to prepare that model.

#### **Synchronous generating station**

- Generator.
- Generator transformer.
- Consider short circuit current contributed by the station’s auxiliary loads such as motor, if significant.

#### **Wind and solar generating station and battery energy storage system**

- Transmission circuits connecting the generating station.
- Generating station inter-connecting transformer.
- Collector system including:
  - Cable/line between turbines/inverters or equivalent impedances but with adequate justification
  - Shunt compensation devices
  - Individual generator or inverter or represented as an aggregated generator with adequate justification on the aggregation method
  - Inverter model that is suitable for a short circuit study.
- Modeling fault current contribution according to the station’s asset capability.

### 6.5.3 Study case preparation

This section provides general requirements to schedule the generation in order to study the impacts of the new generating station during different system operating conditions, as follows.

- The study shall consider winter peak, summer light and no generation, scenarios from wind and solar generating stations in the study vicinity.
- Generating units shall be switched out-of-service if they are not generating.

### 6.5.4 Study scope

The main purpose of this study is to determine the maximum and minimum short circuit levels at the PCC and buses in the close vicinity of the new generating station. The study can be performed using International Electrotechnical Commission (IEC) or American National Standards Institute (ANSI) methods. The method employed should be clearly stated in the connection studies report.

The study shall consider the following system conditions:

- Peak and light load conditions
- Full intact system
- N-1 outage system
- Application of a three phase fault.

The lower short circuit level shall be used to determine the Effective Short Circuit Ratio (ESCR) at the PCC. The ESCR is defined by:

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

Where :

- $SCCi$  - Short circuit level (MVA) at the point of common coupling prior to connecting the generating station
- $Qi$  – Shunt compensation at the connection bus
- $Pi$  – WPP rated power (MVA)

### 6.5.5 Assessment criteria

There are no assessment criteria for this study.

### 6.5.6 Study outcomes

The study shall record:

- short circuit fault level for buses in close vicinity to the new generating station. Short circuit level in kA and MVA shall be provided
- the maximum and minimum ESCR at the PCC.

The study results are to be used to configure the SMIB for other studies.

## 6.6. FAULT RIDE THROUGH STUDY

This study examines the dynamic behaviour of the new generating station responding to a system fault, in order to demonstrate the station can remain stable and electrically connected to the power system after the system fault is cleared.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

### 6.6.1 Objective

The objective of a fault ride through study is to prove compliance of the generating station against fault ride through requirements in Clauses 8.25 A to D of the Code.

### 6.6.2 Model preparation

The asset owner shall provide a detailed model to perform the FRT study. This section provides general requirements and details of what components should be included as a minimum to prepare that model.

#### Synchronous generating station

- Generator model.
- Automatic voltage regulator, excitation system and limiters model.
- Power system stabiliser.
- Under- and over-voltage protection.
- Pole slip protection, if applicable.
- Consider any auxillary equipment that can trip during a fault.

#### Wind and solar generating station and battery energy storage system

- The electrical component of the wind or solar generating plant or battery energy storage system must be modelled in detail.
- Any control strategies that are designed to assist riding through system fault shall be modelled in detail.
- A detailed model for the generating plant's shunt reactive devices.
- A full plant model.

#### Network model

- If the ESCR is determined to be greater than three, a detailed station or generating plant model can be connected to the RMS full network model to prepare for the FRT study.
- If the ESCR is determined to be less than, or equal to, three, an EMT model is required to assess the FRT compliance.
  - It is impractical to model the entire New Zealand power system in EMT due to the complexity of the model and the time to complete the simulation. It is a common practice to model the portion of the network that is of interest to the study in detail, then model the remainder with equivalents.
  - The system operator will provide an EMT model for the following areas, on request:
    - Grid Zone 1 network model with equivalent generators to represent the rest of the North Island network connected at HEN 220 kV bus and HEP 110 kV bus
    - Grid Zone 4 network model with equivalent generators to represent the rest of the North Island network connected at ATI and OHK 220 kV bus and KIN 110 kV bus
    - Grid Zone 7 and 8 network model with equivalent generators to represent the rest of the North Island network connected at BPE 220 kV bus, SFD 110 kV bus, WPW 110 kV bus and the HVDC bipole connected at HAY 220 kV bus
    - Grid Zone 9 and 10 network model with equivalent generators to represent the rest of the South Island network connected at ISL 220 kV bus
    - Grid Zone 14 network model with equivalent generators to represent the rest of the South Island network connected at CYD 220 kV bus.

If a network model for another part of the power system is required, the asset owner will request that EMT model from the system operator.

- The detailed network model shall include the bus connecting the generating station, including the transmission circuits that a contingency will be applied to test the FRT capability.
- The equivalent network model parameter values can be derived from short circuit current determined in the short circuit study. Minimum short circuit current should be considered in this study.

### 6.6.3 Study case preparation

Multiple study cases shall be prepared to demonstrate that the new generating station can ride through a system fault. The study cases should cover the following.

- Minimum and maximum short circuit level conditions.
- Outage of transmission circuit connected to the PCC.
- Different station active power output level at 30 per cent, 50 per cent, 80 per cent and 100 per cent of station rated output.
- For a synchronous generating station, the minimum station output level should start at the station's minimum operating level.
- The pre-disturbance voltage at the PCC shall be between 1-1.03 per unit. If reactive support devices, e.g. capacitor banks, harmonic filters or SVC/STATCOM, are to be installed in the station, two scenarios must be assessed:
  - all reactive support devices switched IN, and
  - reactive support devices switched OUT to the minimum station requirements.
- Reactive power output should be varied over the applicable range of voltage at the point of connection (see Table 3 above) to demonstrate a capability described in Clauses 8.23 (a) and (b) of the Code being the importing of 33 per cent to the exporting of 50 per cent, both expressed as a percentage of the maximum continuous MW output. The actual reactive power output used in the simulations should span the range of credible operating conditions for the generation.
- For a synchronous generating station, additional study cases should be created to study the performance of the generating units when operating near to the under- and over-excitation limit.
- For a generating station near to the HVDC terminal, study cases should be created to analyse the HVDC north- and south-flow conditions:
  - For buses in the North Island, a South Island to North Island flow: 1200 MW and 1000 MW with STATCOM STC31 out of service.
  - For buses in the South Island, a North Island to South Island flow: 850 MW.
  - Generation in the Waitaki hydro system around BEN minimised as far as possible while maintaining acceptable voltage support and reserve provision. Note that 2 generators should remain connected at BEN for the existing maximum HVDC transfers of up to 1200 MW North and 850 MW South.

### 6.6.4 Study scope

#### 6.6.4.1 Study using the EMT network model

The study scope described in this section is for the scenario where the ECSR at the PCC is less than, or equal to, 3 and the asset owner is required to use the EMT model to perform the FRT study.

#### Generating station connected to North and South Islands

Clauses 8.25 A to D of the Code states the FRT requirements for any generating units connected to the New Zealand power system. As this FRT capability is location related, and depends on the type of equipment at the close vicinity of the generating station, the Code specified different FRT requirements for:

- a generating unit connected to the North Island power system
- a generating unit connected to the South Island power system
- a generating unit connected close to Haywards or Benmore.

The study must simulate the fault types identified in Tables 5 and 6 to depress voltage at the PCC to assess the station's FRT capability. Fault type F1, F2 and F3 are a three phase fault whereas F4 is a single-phase to ground phase.

F1 and F2 should be applied at the PCC with a suitable fault impedance to depress the voltage at the PCC to the levels described in Tables 5 or 6. The fault and the faulted circuit are to be removed according to the fault duration specified in Tables 5 or 6. Fault type F3 can be applied at a suitable bus to depress the voltage at the PCC to below 0.76 per unit. The voltage at PCC must stay under 0.76 per unit for more than 500 millisecond. One circuit connected to the PCC is to be removed together with the fault according to the fault duration specified in Tables 5 or 6.

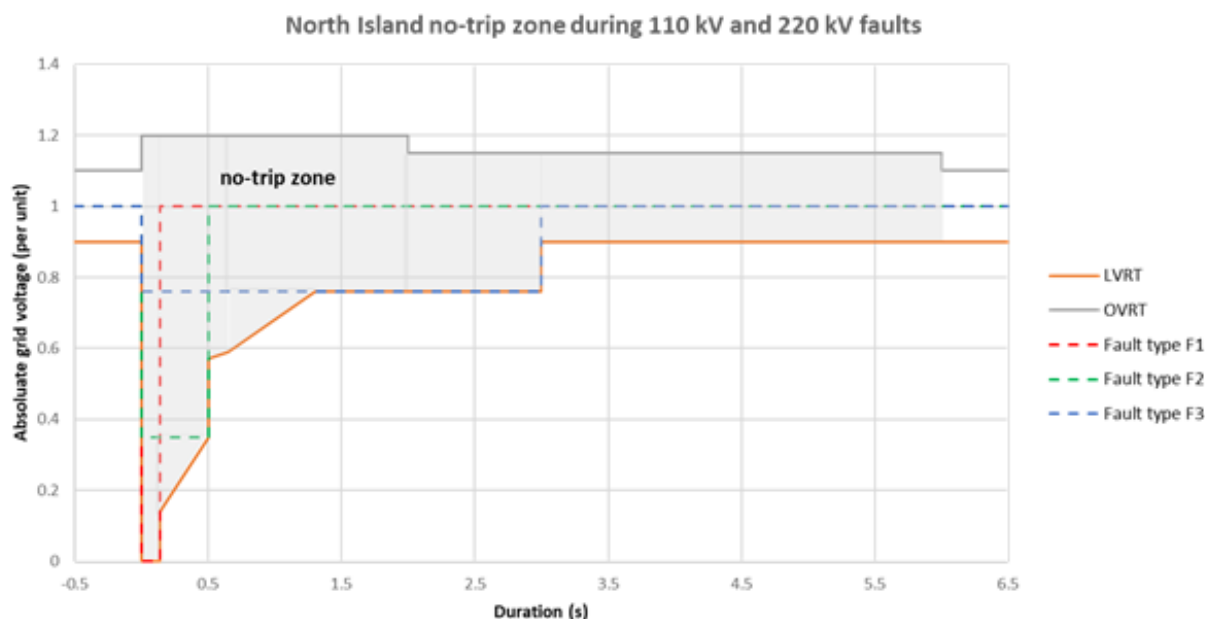
Fault type F4 represented a single-phase-to ground zero impedance fault applied at the PCC only. The fault and the faulted circuit are to be removed at 0.12 sec after the inception of the fault.

The simulations must be run until a new steady state is reached at the PCC, after fault clearance, in terms of system voltage, active power and reactive power output from the generating station. The FRT no-trip zone for the North Island and South Island sections in Figures 6 and 7 describe the fault types to apply if the station is connected to the specific island.

*Table 5 Fault types for the North Island*

Fault type ID	Retained voltage at the PCC (% of nominal)	Duration of the fault (sec)
F1	0	0.12
F2	0.35	0.48
F3	0.76	2.98
F4	0	0.12

*Figure 6*

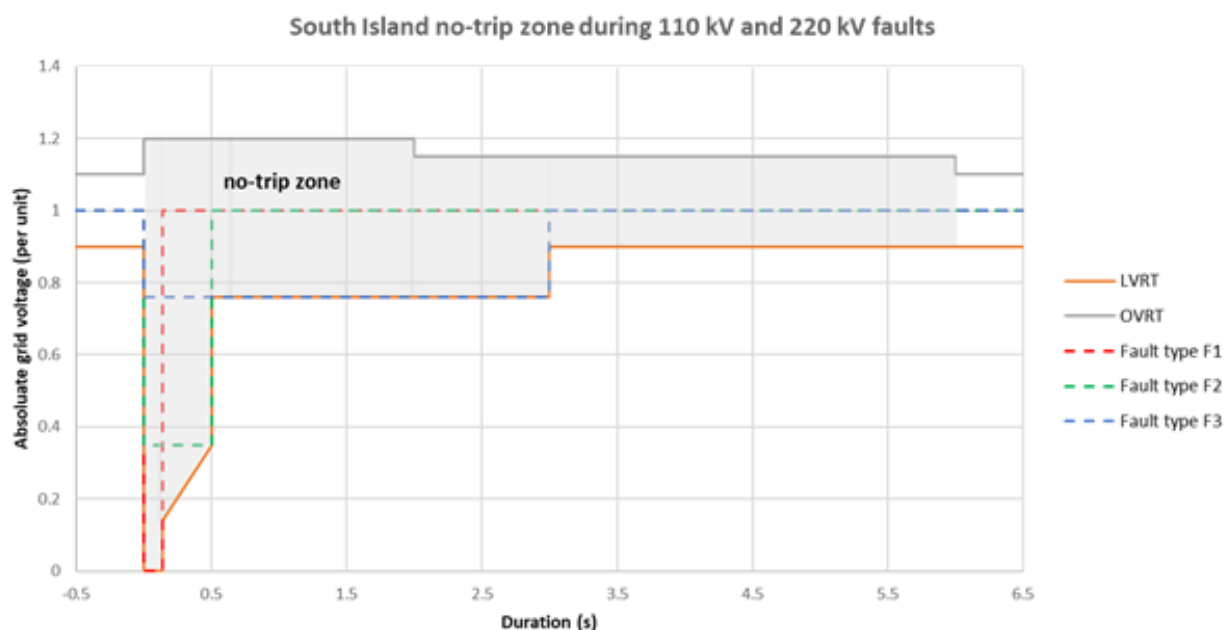


*Table 6 Fault types for the South Island*

Fault type ID	Retained voltage at the PCC (% of nominal)	Duration of the fault (sec)
F1	0	0.12
F2	0.35	0.48

F3	0.76	2.98
F4	0	0.12

Figure 7



### Generating station connected to Grid Zone 8 and Grid Zone 13

For a new generating station connected to Grid Zones 8 and 13, additional studies should be carried out to assess the generating unit(s) capability in riding through:

- over-voltage resulting from bipole power interruption (which can be a trip or a temporary interruption)
- multiple voltage sags resulting from HVDC fault recovery behaviour, e.g. commutation failure or DC line fault re-starts.

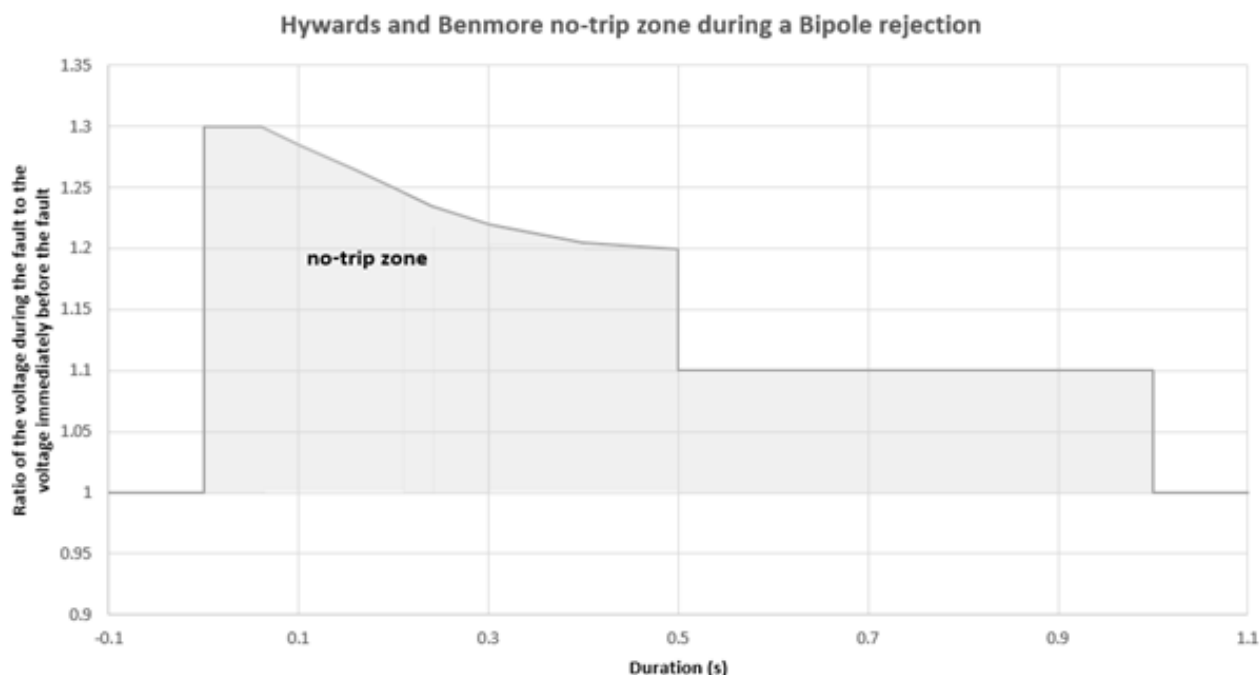
The studies to assess the over-voltage ride through capability are simulated by rejecting the HVDC bipole at high electrical power transfer. The studies should cover both high north and south flow. The generating unit(s) shall remain stable and electrically connected within the no-trip zone depicted in Figure 8.

The additional study scope for the new generating station connected to Grid Zones 8 and 13 are to analyse the effect of:

- a rectifier fault which interrupts the bipole operation and then restores it
- a rejection of the HVDC reactive power alone by changing the Q setpoint
- a HVDC commutation failure
- a DC line fault and then removes it.

The system operator will provide recorded system event files to inject into the HAY 220 kV bus to simulate the HVDC commutation failure and DC line fault disturbance.

Figure 8



The asset owner is to request high speed recording data to study generating units capability to ride through multiple faults resulting from an HVDC commutation failure. The voltage behaviour can be reproduced with a simple HVDC model or can be simulated by injection at the Haywards or Benmore 220 kV bus to simulate the commutation failure behaviour.

#### 6.6.4.2 Study using the RMS full network model

The study scope described in this section is for the scenario where the ECSR at the PCC is greater than three and the asset owner is required to use the RMS full network model to perform the FRT study. A full generating station model should be used in this study.

The study scope shall include the following, in addition to the study scope described in Section 6.6.4.1.

- Apply a three phase fault on buses in the close proximity of the new generating station. The fault and the faulted circuit are to be removed in 120 ms.
- Faults shall be applied on buses up to three buses away from the generating station.

#### 6.6.4.3 Assessment of the station or generating unit protection

The asset owner should report any equipment in the station or generating plant:

- that will trip within the no-trip zone set out in Figures 6, 7 or 8, and
- result in the tripping of a generating unit.

#### 6.6.5 Assessment criteria

The criteria below should form a basis to determine if all of the generating units can meet the FRT requirements.

- The generating units shall remain stable and electrically connected when the line-to-line voltage is within the no-trip zone, set out in Figures 6, 7 or 8.
- The generating units shall provide reactive current to the maximum of its capability to support the voltage during and following the fault.
- The reactive current response shall attempt to control the voltage back toward the nominal, or at least proportional to, voltage dip.
- The reactive current support can come from the generating units or the dynamic reactive power compensation devices within the station or generating plant.

- The generating units shall provide active power in proportion to the residual voltage during the fault and provide at least 95 per cent of the pre-disturbance active power set point following the fault when the system voltage recovers to above 95 per cent of the nominal voltage.
- The generating units shall restore the active power to at least 90 per cent of the pre-disturbance active power set-point within 1 second after the fault is cleared, and the PCC voltage has recovered to at least 90 per cent of the nominal.

#### 6.6.6 Study outcomes

The following outcomes are expected from the FRT study.

The generating units meet all the assessment criteria whilst riding through faults.

The fault ride through strategies shall be fully discussed in the study.

Identification and explanation of any non-compliant, or potentially non-compliant, behaviour.

Confirmation that no protection or control settings at the generating station would result in a breach of the fault ride through requirements.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

### 6.7. TRANSIENT STABILITY STUDY

Transient stability is generally referred to as the ability of the power system to withstand a set of severe but credible contingencies and to regain synchronism following the removal of the contingencies. The power system is expected to transition to an acceptance steady-state condition. Transient stability evaluation, which means Critical Fault Clearing Time (CFCT) evaluation, is often of concern in ensuring secure operation of the power system.

CFCT is defined as maximum fault duration for which the system remains transiently stable. Mathematically, CFCT is a complex function of pre-disturbance system conditions (operating point, topology, system parameters), fault structure (type and location) and post fault conditions that themselves depend on the protective relaying plan employed.

Inverter generation technology exhibits different behaviour during and after a fault. Due to a rapid growth in the penetration level, this type of generation technology is starting to have a large influence on power system stability. This study is extended to inverter generation technology to ensure the introduction of this form of technology will not degrade the dynamic performance of the power system.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

#### 6.7.1 Objective

The objective of a transient stability study is to ensure that the new generating units can remain stable and connected after a three phase bus fault at the PCC is removed.

#### 6.7.2 Model preparation

The network model and the new generating station model developed for the frequency and voltage regulation and tuning studies (Sections 6.3 and 6.4) can be used for this study. Additional modelling requirements are as follows.

- Any algorithm or control that is utilised to maintain synchronism, and to ensure transient stability, shall be modelled and explained.
- Any control parameters, such as post-fault active power ramp up rate, that are sensitive to transient stability performance of the generating station shall be modelled and highlighted.
- Full station model shall be used in this station.
- Parameter values used in the FRT study shall be used in this study.
- Generating station under-voltage protection should be considered.
- Any special protection scheme that can affect the transient stability performance of the station.

### 6.7.3 Study case preparation

This section also provides general requirements to prepare the study case for the transient stability of the generating station, as follows.

- RMS full network model shall be used for this study.
- Generating station absorbing and producing reactive power close to its reactive power capability limits.
- Generating station generating at its maximum MW output.

### 6.7.4 Study scope

The main purpose of this study is to calculate the CFCT to demonstrate that the transmission circuit fault clearing time (including the operation of the backup protection) should be shorter than the CFCT. A three phase fault with the characteristics described below shall be applied at the PCC high-voltage bus to determine the CFCT.

- Fault clearing time of 120 ms
- Remove a circuit connected to the faulted bus.

The study should proceed to increase the fault clearing time until the generating units lose synchronism or become unstable. The CFCT is defined as the maximum time during which a three phase fault can be applied without the system losing its stability.

For wind and solar generating stations and battery energy storage systems, maximum active current/power ramp rate shall be considered to ensure after fault recovery will not cause delay voltage recovery and transient instability to other nearby generating stations.

Studies shall be carried out with a fully intact system and a planned outage system by disconnecting a circuit that is connected directly to the station.

### 6.7.5 Assessment criteria

The CFCT determined from this study must be longer than the protection fault clearing time for the PCC bus and transmission circuits connected to the new generating station. The asset owner is to obtain the fault clearing time from the grid owner or distributor.

### 6.7.6 Study outcomes

The following outcomes are expected for the transient stability study.

- The CFCT is longer than the maximum fault clearing time, demonstrating that the generating units can ride through all the types of transmission faults that occurred on the transmission circuit and the PCC bus.
- Identification and explanation of any non-compliant, or potentially non-compliant, behaviour.
- Confirmation that no protection or control settings at the generating station would result in a breach of the fault ride through requirements.

Any shortfall of asset capability to meet the Code requirements shall be discussed with the system operator and the general requirements set out in Section 5.6 should be followed to address the shortfall.

## 6.8. HARMONICS DISTORTION STUDY

This study investigates the generating station's harmonics distortion and harmonics mitigation design, if needed. It also analyses the penetration of harmonics current from its source into the power system and determines the resulting harmonic voltage distortion.

Wind, solar and other inverter based generating stations are sources of distorted waveforms containing unwanted harmonics components which can cause power quality related issues and, in most severe cases, failure of power system equipment. The continued increase in inverter based generation prompted the requirement to conduct a harmonics distortion study on new generating stations.

This study is not required for synchronous generating stations.

The asset owner will follow the general requirements set out in Section 5, together with the requirements of this section.

### 6.8.1 Objective

The main objective of a harmonics distortion study is to ensure that the quality of supply to all transmission customers remains within the limits specified in the Benchmark Agreement, as outlined in Clauses 12.27 to 12.34 of the Code.

The asset owner shall discuss and agree with the grid owner the allocation assigned to the new generating station.

### 6.8.2 Model preparation

The network model and the new generating station model developed for the frequency and voltage regulation and tuning studies (Sections 6.3 and 6.4) can be used for this study. Additional modelling requirements are listed below.

- Full collector system shall be modelled for wind and solar generating station and battery energy storage system.
- Inverter and filters shall be modelled accurately to represent the harmonics characteristics of the generating station.

### 6.8.3 Study case preparation

This section also provides general requirements to prepare the study case for the harmonics distortion of the generating station, as follows.

- Study cases prepared for the power-flow study can be used.
- Ensure that all filters are modelled correctly.

### 6.8.4 Study scope

The purpose of this study is to demonstrate the impedance magnitude, as seen from the harmonics source, as a function of frequency, generally represented in an impedance versus frequency plot. The study is also used to detect potential resonance and harmonic amplification that can impact filter design and power quality. The frequency scan method can be employed to analyse the harmonics impedance characteristics.

A study using harmonics current injection method can be performed to determine the Total Harmonics Distortion (THD) at the PCC. Distortion magnitude for harmonic order up to 50 should be reported.

The study should consider contingencies such as:

- outage of a filter bank within the generating station
- outage of a filter bank or capacitor bank in the close vicinity of the generating station
- outage of a circuit connected to the point of common coupling
- different generation levels ranging, e.g. 30 per cent, 60 per cent and 100 per cent of generating station output.

Prior to the study, the asset owner should confirm with the grid owner the acceptable harmonic level at the point of common coupling that is allocated to the new generating station. For new generating station installed within the distribution network, the study shall report the level of harmonic emission at the GXP as well.



#### 6.8.5 Assessment criteria

The generating station must follow the standards set out in NZECP 36:1993 for harmonic levels and demonstrate that the new generating unit will not exceed the allocation assigned to the new station.

#### 6.8.6 Study outcomes

Any violations should be documented and mitigation measures agreed with the system operator and the grid owner. The effectiveness of the measures should be demonstrated in the connection studies report.



## Appendix A. CONNECTION STUDIES REPORT TEMPLATE

The connection studies and the connection studies report should be submitted electronically 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 station's location and all relevant station information used in the connection studies
- **Study section** to include detailed discussion on the findings, mitigation measures and recommendations for the following studies.
  - Power-flow study
  - Reactive power capability study
  - Frequency regulation and tuning study
  - Voltage regulation and tuning study
  - Short circuit study
  - Fault ride through study
  - Transient stability study
  - Harmonics distortion study
- Findings and recommendations
- Appendix
  - Reactive power capability curves with all the limits plotted
  - Control block diagram including a table to show the parameter values used in the studies for:
    - Speed/frequency controller
    - Voltage controller including station controller, if applicable
    - PSS
    - Limiters
    - Simulation results

## Appendix B. BIBLIOGRAPHY

1. GL-EA-404, May 2023. Generator Commissioning and Decommissioning Requirements. Transpower New Zealand Limited.
2. GL-EA-010, May 2023. Generator Testing Requirements. Transpower New Zealand Limited.
3. GL-EA-716, May 2023. Power Plant Dynamic Model Validation and Submission Prerequisites. Transpower New Zealand Limited.

All reference documents are provided here - [https://www.transpower.co.nz/resources?keywords=gl-ea-&facets\\_query=&f%5B0%5D=category%3A9003](https://www.transpower.co.nz/resources?keywords=gl-ea-&facets_query=&f%5B0%5D=category%3A9003)

4. Benchmark agreement, as outlined in Clauses 12.27 to 12.34 of the Code
5. NZECP 36:1993. Electrical code of practice for harmonic levels. This Code is based on the Limitation of Harmonic Levels Notice 1981, and sets acceptable levels of harmonic voltages and currents which may be introduced into an electricity supply system by a consumer's installation. WorkSafe, Wellington, New Zealand.
6. Policy statement, Jan 2019. As referred to in Part 8 of the Code and provided here <https://www.ea.govt.nz/code-and-compliance/code/documents-incorporated-into-the-code/>
7. RMS full network model in DIgSILENT Powerfactory, provided through the Electricity Authority's EMI website here <https://www.emi.ea.govt.nz/Wholesale/Datasets/Transmission/PowerSystemAnalysis/PowerFactoryCaseFiles>
8. System Security Forecast, provided here <https://www.transpower.co.nz/system-operator/planning-future/system-security-forecast>
9. IEEE Std 421.2-2014. Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control Systems, presents dynamic performance criteria, definitions, and test objectives for excitation control systems as applied by electric utilities. Institute of Electrical and Electronics Engineers (IEEE) Standards Association.