AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

Power System Stability Guidelines

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This document shows changes made between the draft and final PSSG. This document is for information only, not for official use.

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~~N/A~~2.0	~~N/A~~1 December 2022	~~**Draft issued for consultation on 29 July 2022**~~ Updated to new AEMO template, added system strength and converter stability definition.

Note: There is a full version history at the end of this document.

1. Introduction

~~*[Drafting note: Section 1 has been restructured to reflect AEMO's current template. There are no substantive changes from the published version 1 of the Guidelines, so for ease of reading this section is not change-marked]*~~

1.1. Purpose

These are the Power System Stability Guidelines (Guidelines) that detail the policies governing *power system* stability so as to facilitate the operation of the *power system* within stable limits, as required by clause 4.3.4(i) of the National Electricity Rules (NER).

These Procedures have effect only for the purposes set out in the NER. The NER and the National Electricity Law prevail over these Procedures to the extent of any inconsistency.

These Guidelines apply to:

- *AEMO* and *Network Service Providers* (NSPs);
- *Generators*, in respect of *generating system performance standards* and *plant* alteration processes;
- *Connection Applicants*, in respect of *connection applications*.

The Guidelines are intended for use by people experienced in *power systems* who:

- a~~A~~re knowledgeable in *load* flow analysis techniques and the required level of modelling for analyses that can be carried out using *load* flow simulation tools;
- h~~H~~ave an in-depth knowledge of *power system* stability mechanisms;
- a~~A~~re knowledgeable in the modelling requirements for *power system* stability analyses and *power system* stability simulation tools;
- a~~A~~re familiar with the technical standards in the NER that pertain to stability;
- a~~A~~re familiar with the operating procedures and practices of the National Electricity Market (NEM) and within relevant *region(s)* of the NEM;
- w~~W~~here the need arises, are able to envisage valid scenarios outside the present range of NEM operating practice.

1.2. Definitions and interpretation

1.2.1. Glossary

Terms defined in the National Electricity Law and the NER have the same meanings in these Procedures unless otherwise specified in this clause.

Terms defined in the NER are intended to be identified in these Procedures by italicising them, but failure to italicise a defined term does not affect its meaning.

In addition, the words, phrases and abbreviations in the table below have the meanings set out opposite them when used in these Procedures.

Term	Definition
AC	Alternating current
DC	Direct current
FACTS	Flexible alternating current *transmission system*
MNSP	*Market Network Service Provider*
NEM	*National Electricity Market*
NER	National Electricity Rules
NSP	*Network Service Provider*
RIT-T	*Regulatory investment test for transmission*
STATCOM	Static (voltage source converter) compensator
SVC	Static VAr compensator
VAr	Volt-ampere reactive

1.2.2. Interpretation

These Procedures are subject to the principles of interpretation set out in Schedule 2 of the National Electricity Law.

2. Scope

For the purposes of the Guidelines the following definition of *power system* stability has been adopted[1]:

> *Power system* stability is the ability of the electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical or electrical disturbance, with system variables bounded so that practically the entire *power system* remains intact.

Based on this definition and the purpose outlined in section 1, the following are considered to be in scope of the Guidelines:

- stability mechanisms that can result in instability of the *power system*;
- guidelines for planning and operating the *power system* that relate to *power system* stability;
- *generating system connection* and alteration processes relating to *power system* stability including those specifically making reference to the guidelines;
- guidelines related to establishing *power system* control settings;
- guidelines related to calculation of, and operation to, *network* stability limits.

The following are considered outside of the scope of the Guidelines:

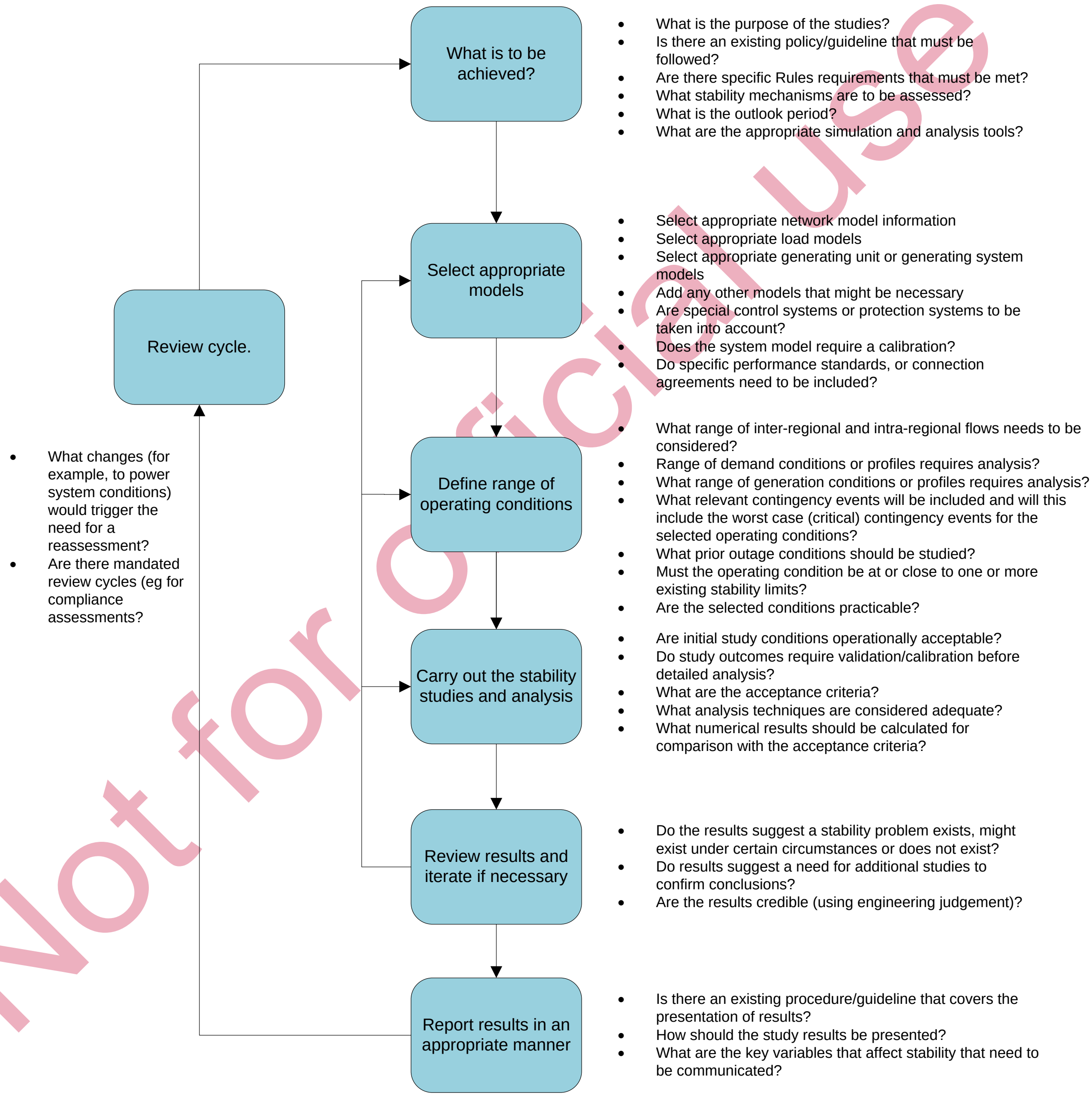
- Harmonic resonance
- Sub-synchronous resonance.

[1] Adapted from the IEEE definition, in "Definition and Classification of Power System Stability", IEEE/CIGRE Joint Task Force on Stability Terms and Definitions", 2004 IEEE

3. Process for assessing stability

Figure 1 illustrates the high level processes used in the assessment of stability. The figure shows the particular considerations that must be taken into account. The analyst must address these considerations and use engineering judgement and apply *good electricity industry practice* to include any other considerations that are relevant to the stability calculations and analysis.

Figure 1 High level overview of the stability assessment process



3.1. What is to be achieved?

Considerations must include:

- What is the purpose of the studies?

- Are there existing policies/guidelines that must be followed? These might include company policies such as planning criteria, or industry guidelines such as the *Generating System Model Guidelines*[2].
- Are there specific ~~*Rules*~~NER requirements that must be met?
- What stability mechanisms are to be assessed?
- What is the outlook period?
- What are the appropriate simulation/analysis tools?

Further considerations might include:

- Typically, stability assessments might consider a range of stability mechanisms. Where there are several stability mechanisms to be assessed then separate stability mechanisms must not be aggregated into a single advice or assessment. For example:
  - t~~T~~ransient stability must be assessed and advised independently and not aggregated with another form of stability;
  - ~~A~~a limit advice for a particular *contingency event* for a particular form of stability must be advised independently and not aggregated with other *contingency events*;
  - e~~E~~ven within a classification of stability, the stability mechanism may vary (e.g. for transient stability, the manner of loss of synchronism may vary according to operating conditions, and so might be considered as a different mechanism).
- Where a simulation tool is not the same tool used by the NSP or *AEMO*, it will require benchmarking according to the requirements of the NSP or *AEMO*.
- In some cases, certain analysis tools have been found by the NSP or *AEMO* to be unacceptable (e.g. ~~p~~Prony analysis for the assessment of damping of some oscillatory stability modes). Where there is any doubt, the analyst should seek the advice of the NSP and *AEMO*.

Advice provided to the NSP or *AEMO* must include a description of the considerations made in this step of the process and any assumptions made according to these considerations.

3.2. Select appropriate models

Models must be selected according to the type of stability under consideration.

Considerations must include:

- Select appropriate *network* model information
- Select appropriate *load* models
- Select appropriate *generating unit* or *generating system* models
- Add any other models that might be necessary for the study
- Are special *control systems* or *protection systems* to be taken into account?

[2] Established under clause S5.5.7 of the *Rules*.

- Does the system model require a calibration[3]?
- Do any specific *performance standards*, technical requirements from *connection* agreements need to be included?

Further considerations might include:

- Model information might be restricted based on confidentiality requirements in the ~~*Rules*~~NER.
- Where available, some model information could be provided by *AEMO* or the NSP. This might include, subject to confidentiality requirements:
  - *Load* model information
  - *Releasable ~~U~~user ~~G~~guide* information
  - Special control scheme information
  - Relevant *protection system* equipment settings (e.g. *fault clearance times*)
  - Some *power system* or *plant* models might require changes that have been determined by calibration of the model against measured responses.

For any type of stability study, if *AEMO* or the NSP has determined that a calibration is required to the *power system* model or any *plant* model, that calibration must be applied to all relevant studies for the stability calculation.

Advice provided to the NSP or *AEMO* must include a description of the considerations made in this step of the process and any assumptions made according to these considerations.

3.3. Define range of operating conditions

Typically, a broad range of operating conditions must be taken into account in stability assessments. The range of conditions studied must be sufficiently thorough for the particular purpose of the assessment, taking into account, for the *plant* under consideration:

- the rating of the *plant*;
- the extent to which the *plant* can affect the *power system* and the local *network*;
- the extent to which the *power system* and local *network* can affect the *plant*; and
- the potential impact of the *plant* on other *network users*.

The studies must identify the most onerous conditions and *contingency events* under which the *plant* would be expected to continue to operate.

Considerations must include:

- What range of *inter-regional* and *intra-regional* flows needs to be considered?
- What range of demand conditions or profiles requires analysis?
- What range of *generation* conditions or profiles requires analysis?
- What relevant *contingency events* will be included and will this include the worst case (critical) *contingency event* for the selected operating conditions?

[3] Note that model calibration is typically carried out by NSPs and *AEMO*.

- What prior *outage* conditions should be studied?
- Must the operating condition be at or close to one or more existing stability limits?
- Are the selected pre-*contingency* study conditions practicable? While studies might sometimes need to study extreme or boundary conditions the studies should reflect conditions that are plausible on a real *power system*.

Further considerations might include:

- Are sensitivity studies required to ensure robust conclusions?
- Do the post-*contingency* conditions lead to other issues that may or may not be stability related?
- Are multiple prior *outages* to be considered?
- Is the range of operationally acceptable *voltage* magnitudes a consideration?
- Should the study assess the power system or the performance of *plant* under conditions where the *power system* is being restored following a *black system* event?
- If the *power system*, *or power system plant*, could be required to operate under unusual conditions, then those conditions should be considered. For example, in assessing the operation of a synchronous generating unit with excitation limiters, in relation to *continuous uninterrupted operation* following a *contingency event*, one potential operating condition should include operation of the *generating unit* at maximum output, while at leading power factor, close to its excitation limit.

In any advice to the NSP or *AEMO*, the range of *power system* operating conditions must be documented. Advice should include the limits of applicability of the studies and, if relevant, the consequences of operation outside of those limits, or what should be done should those limits be exceeded.

3.4. Carry out the stability studies and analysis

Considerations must include:

- Are initial study conditions operationally acceptable? Initial conditions generally should be consistent with the *power system* operating in a *secure operating state*, unless there are valid reasons why other operating conditions are required for the study[4].
- Do study outcomes require validation/calibration before detailed analysis?
- What are the acceptance criteria?
- What analysis techniques are considered adequate?
- What numerical results should be calculated for comparison with the acceptance criteria?

Further considerations might include:

- In the observed responses, have any other stability mechanisms influenced the results for the stability mechanism being assessed? For example, transient instability for some

[4] For example, the initial operating state of the study may not be secure for one or more *network* or stability limits, if the purpose of the study is to establish the boundary conditions for another stability limit.

power system conditions might be characterised by a loss of synchronism of the *power system* on one *interconnector*, whereas for other *power system* conditions the loss of synchronism might occur on another *interconnector*. These are different transient stability mechanisms and consideration should be given as to whether they be treated differently in the analysis (for example, in the development of *network* limit advice).

- For any type of stability study, if *AEMO* or the NSP has determined that a calibration factor is required to be applied to the results of any stability calculation, that calibration factor must be applied to all relevant study results for the stability calculation.
- Advice provided to the NSP or *AEMO* must include a description of the considerations made in this step of the process and any assumptions made according to these considerations.
- To the extent that *frequency* of the system might vary for a particular study, take into account the operation of the FCAS markets.
- To the extent that no specific model is available for a special control scheme, but that control scheme may influence the outcome of a study, take into account that control scheme's impact.

3.5. Review results and iterate as necessary

Considerations must include:

- Do the results suggest a stability problem exists, might exist under certain circumstances or does not exist?
- Do results suggest a need for additional studies to confirm conclusions?
- Are the results credible (using engineering judgement)?

Further considerations might include:

- Given the results, are there any sensitivity studies that should be undertaken to test the range of conditions over which the conclusions are valid?

3.6. Report results in an appropriate manner

Considerations must include:

- Is there an existing procedure/guideline that covers the presentation of results?
- How should the study results be presented?
- What are the key variables that affect stability that need to be communicated?

Further considerations might include:

- How should a new or modified stability limit be expressed (application of regression analysis for instance)?

3.7. Review cycle

Considerations must include:

- What changes (for example, to *power system* conditions, or to model data) would trigger the need for a reassessment?

- For limit equations?
- For maintaining compliance with *performance standards*?

- Are there mandated review cycles?

For example, if *generating unit* data established from testing ("R2" data[5]) differs from the model data that was used to establish *performance standards* related to stability (typically "R1" data), then the *Generator* will need to consider if the differences are sufficiently material that *performance standard* compliance might be affected. If so, the *Generator* should undertake further studies to confirm compliance with its *performance standards*.

Further considerations might include:

- Has any aspect of the *power system* or *plant* changed (e.g. *plant* upgrade, new *plant* installed, or has there been a material change to the *networks* or operation of the power system) that might materially affect the stability of the *power system* or *plant* of interest?
- Is there a regulatory or compliance cycle that must be considered?
- Is there a reasonable, prudent timeframe for review of the stability of the *power system* or *plant* of interest?

4. Definitions and considerations

Appendix 1 provides definitions for stability mechanisms and considerations that must be taken into account when assessing stability.

5. Specific processes

Appendix 2 describes specific processes in the NEM, some of which are processes detailed in the ~~*Rules*~~NER. In addition to the requirements specified in Appendix 2, the processes in Appendix 2 must be carried out in a manner that:

- t~~T~~akes into account the considerations described in the high level process in section 4;
- a~~A~~dopts the definitions and considerations set out in Appendix 1; and
- a~~A~~dopts the requirements set out in Appendix 2 for the relevant processes.

[5] Refer *Rules* clause S5.5.2 and the *Generating System Model Guidelines*

Appendix A. Definitions and considerations

A.1 Definition and classification of stability

Acknowledgement

The Guidelines adopt some of the definitions, terminology and text provided in Sections II and III of "Definition and Classification of Power System Stability", IEEE/CIGRE Joint Task Force on Stability Terms and Definitions", 2004 IEEE, and "Definition and Classification of Power System Stability – Revisited & Extended, 2021 IEEE. While this IEEE document represents a useful technical reference, it does not form a part of the Guidelines.

The following represent each form of stability.

A.1.1 Transient stability

Transient stability is defined by:

- **Large disturbance rotor angle stability**, which is the ability of the *power system* to maintain synchronism when subjected to a *contingency event*. Instability that may result occurs in the form of increasing rotor angle of one or more *synchronous generating units* relative to the rotor angles of other *generating units*, leading to their loss of synchronism with those other *synchronous generating units*. The cause of the loss of synchronism is due to insufficient synchronising or damping torque in the *power system* or one or more *generating units*, or due to *protection system* operation as a consequence of a power swing, and not by *disconnection* of radially *connected network*, *load* or one or more *generating systems* through *protection system* operation in clearing the fault.
- **Large disturbance stability for asynchronous *plant***, for large disturbances, the ability of *asynchronous plant* to reach a state of equilibrium when the *power system* is subjected to a *contingency event*. Instability is characterised either by :
  - a "runaway" or "stall" condition (whether or not that condition manifests itself by variations at the *connection point*) which would result in a *protection* operation to trip the *plant*, or
  - sustained variations in the *active power*, *reactive power* or *voltage* magnitude output of one or more *generating systems*, *Customer plant* or *network plant*, except where such a response is for the purpose of enhancing the performance of the *power system* or the *market* or as a consequence of energy source variability (eg variations in wind or solar energy supply).

A.1.2 Oscillatory stability

Oscillatory stability is defined by:

- **Small-signal rotor angle stability**, which is the ability of the *power system* to maintain synchronism after being subjected to a small perturbation without application of a *contingency event*. With this form of stability, the perturbations are considered to be sufficiently small that linearisation of system equations or, operationally, linear mathematical techniques, are permissible for purposes of analysis. Instability is characterised by sustained or growing oscillations in *active power*, *reactive power*, *voltage* magnitude or *frequency* in the linearised calculation.

A.1.3 Control system stability

This form of stability relates to *control systems* for plant connected to the *network*, for example:

- *Control systems* of *generating units* and *generating systems*;
- Primary *plant* typically used for *reactive power* control, such as static compensators (STATCOMs), static Var compensators (SVCs) and *reactive power* support *plant*; ~~or~~
- Other primary *plant* with power electronic components, including:
  - direct current (DC) links; ~~and~~
  - flexible alternating current *transmission system* (FACTS) devices);
  - any other plant which has a power electronic interface between the *plant* and the *power system*; or
- Transformer *control systems*.

Control system stability is defined by:

- **Large signal *control system* stability**: for large disturbances, the ability of *control systems* within the *power system* to reach a state of equilibrium when the *power system* is subjected to a *contingency event*. Instability is characterised either by :
  - a "runaway" condition (whether or not that condition manifests itself by variations at the *connection point*) which would result in a *protection* operation to trip the *plant*; or
  - sustained variations in the *active power*, *reactive power* or *voltage* magnitude output of one or more *generating systems*, *Customer plant* or *network plant*, except where such a response is for the purpose of enhancing the performance of the *power system* or the *market* or as a consequence of energy source variability (eg variations in wind or solar energy supply).

  This might be caused by:
  - a non-linearity of a *control system*;
  - unintended and undesirable repeated application of a control action in one or more *control systems*; or
  - unintended and undesirable interactions between a *control system* and any other *plant* in the *network*.
- **Small signal *control system* stability**: for small perturbations in the *power system*, the ability of *control systems* of one or more *generating systems*, *Customer* plant or *network plant* to reach equilibrium after a small perturbation in the *power system* without application of a *contingency event*.

  Small signal *control system* instability can manifest itself as a sustained or growing oscillation of *active power*, *reactive power* or *voltage* magnitude between any items of *plant*.

A.1.4 Voltage stability

Voltage stability is the ability of the *power system* to maintain or recover *voltage* magnitudes to acceptable levels following a *contingency event*.

Instability would result in *voltage* magnitudes in part of the *power system* exhibiting an uncontrolled sustained increase or decrease over time (a "run-away" condition) or sustained or undamped oscillatory behaviour. *Voltage* instability can occur rapidly (over seconds) or slowly (over minutes).

A.1.5 *Frequency* stability

Frequency stability is the ability of a *power system* to maintain acceptable *frequency* following a *contingency event*. Typically, that *contingency event* causes an unbalance between *generation* and *load* in the *power system*. It depends on the ability of the *power system* to maintain or restore equilibrium between *generation* and *load* and recover the *power system frequency* to acceptable levels.

Instability results in an uncontrolled sustained increase or decrease over time (a "run-away" condition) or sustained undamped oscillatory behaviour.

A.1.6 Converter-driven stability~~ and System Strength~~

~~System strength is defined as the ability of the *power system* to maintain and control the *voltage* waveform at any given location in the *power system*, both during steady state operation and following a disturbance.~~

~~Traditionally system strength in the NEM *power system* has been provided by prevalent *synchronous generating units*. With the rapid uptake of inverter based resources as well as batteries, declining minimum operational demand and changing patterns of *synchronous generation*, action is needed to ensure *system strength services* are maintained in the grid for a resilient *power system*.~~

The dynamic behaviour of plant interfaced through power-electronic converters is different from conventional *synchronous generating units*. The behaviour of these converters is largely dependent on control loops and logic responding to the system with very fast response times such as the Phase-Lock-Loop (PLL) and the inner control loops. An undesired response from power-electronic interfaced plant may lead to unstable *power system* oscillations over a wide frequency range and can be categorised as slow and fast-interactions.

Slow-interaction converter-driven instability involves system-wide instability driven by slow dynamic interactions of the *control system* of power electronic-interfaced plant with slow response components of the *power system*.

Fast-interaction converter-driven instability involves system-wide stability problems driven by fast dynamic interactions of the *control system* of power electronic-interfaced plant with fast-response component of the *power system*. To a certain extent, converter-driven instability is associated with the power electronics converter controls, coupled with the harmonic impedance of the network and other electrically close power electronics converter control systems.

Appendix B. Considerations for assessment of stability

When planning and operating the *power system*, and when negotiating access arrangements with *Generators*, the NSP and *AEMO* must take into account:

- the ~~*Rules*~~NER criteria around *power system* stability;
- relationships between the *power system* performance and *generating system* performance, including anything in *connection agreements* that might have a bearing on *power system* stability;
- differences between the *system standards* and actual performance of the *power system*; and
- uncertainties in simulation results.

B.1 ~~*Rules*~~NER criteria around *power system* stability

The ~~*Rules*~~NER contain a number of criteria in relation to the requirements around stability. The criteria below describe some of those *Rules* requirements, however there may be other relevant ~~*Rules*~~NER clauses that apply under certain circumstances that must be taken into account.

In assessing whether the *power system* remains intact, the person carrying out the calculation must take into account:

- any requirements in the ~~*Rules*~~NER relating to stability;
- the requirements in schedule 5.1 and, in particular, the requirements in clause S5.1.8;
- the *system standards* set out in schedule 5.1a relating to:
  - *frequency* (clause S5.1a.2);
  - *power system* stability (clause S5.1a.3); and
  - power *frequency voltage* (clause S5.1a.4); and
- the operation of relevant *protection systems* and *control systems*.

B.1.1 Transient stability

~~*Rules*~~NER clause S5.1.8(a) requires the *power system* to remain in synchronism following a *contingency event*. That is, the *power system* must not form “islands”, unless the formation of the island is:

- a direct consequence of the *contingency event* causing the formation of the island (for example, the loss of a radially *connected load* or *generating system*); or
- an intended consequence of the *contingency event* and the result of the action of a *control system* designed for that purpose, put in place by, or with the agreement of, the relevant NSP and advised to *AEMO*.

For the purposes of transient stability in these Guidelines, an island consists of a *network* with one or more *Network Users* connected, which:

- prior to the *contingency event* was *connected* to the rest of the *power system* through an AC *network*; and

- potentially operates at a different *power system frequency* to the rest of the *power system*.

Where the response of the *power system* is such that a *Network User* is permitted, under its *performance standards*, to trip or change the operation of any *plant* or *load*, that *plant* or *load* trip or change in operation:

- must be taken into account in the assessment of transient stability;
- the trip or change in operation is not, in itself, considered to be a transient instability; and
- must not have any consequential impacts, such that criteria relating to transient stability and other forms of stability cannot be met.

Oscillations in *active power*, *reactive power* and *voltage* magnitude at the output of *generating units* and *generating systems* must be in accordance with their *performance standards* and, if the *contingency event* is a fault:

- should be designed and operated to have a halving time of less than 5 seconds in the period between when the *generating unit* or *generating system* output is restored and 10 seconds after fault clearance; and
- after that time, must be *adequately damped*.

B.1.2 Oscillatory stability criteria

The NSP and *AEMO* must take into account the requirements relating to damping in ~~*Rules*~~NER clause S5.1.8.

Under ~~*Rules*~~NER clause S5.1a.3, the *power system* should be planned and operated to achieve oscillations with halving time of 5 seconds or less.

Generators must meet the damping requirements in the ~~*Rules*~~NER, in the assessment of *Generator access standards* for new or altered *plant* at a *connection point*, and, operationally, the equivalent *performance standards*, for example:

- in those *performance standards* that require *generating units* and *generating systems* to be *adequately damped*; and
- their impact on *power system* damping, such as in ~~*Rules*~~NER clause S5.2.5.13(d)(1)(ii).

B.1.3 Large-signal *control system* stability criteria

Under ~~*Rules*~~NER clause S5.1a.3, the *power system* should be planned and operated to achieve oscillations with halving time of 5 seconds or less.

For *generating units* and *generating systems* that can be described in terms of this form of stability, for the calculation of transient stability (or similar types of calculations) and where that *plant* has a requirement in a performance standard for *continuous uninterrupted operation*, variations in *active power*, *reactive power* or *voltage* magnitude output must be in accordance with their *performance standards* and, if the *contingency event* is a fault:

- should be designed and operated to have a halving time of less than 5 seconds in the period between when the *generating unit* or *generating system* output is restored and 10 seconds after fault clearance; and
- after that time, must be *adequately damped*.

For other *plant* that can be described in terms of this form of stability, for the calculation of transient stability (or similar types of calculations) and where that *plant* has a requirement for *continuous uninterrupted operation*, the *plant* should be designed and operated to have variations in *active power*, *reactive power* or *voltage* magnitude output to have a halving time of less than 5 seconds.

B.1.4 Small-signal *control system* stability criteria

Under ~~*Rules*~~NER clause S5.1a.3, the *power system* should be planned and operated to achieve oscillations with halving time of 5 seconds or less.

Generators must meet the damping requirements in the ~~*Rules*~~NER, in the assessment of *Generator access standards* for new or altered *plant* at a *connection point*, and, operationally, the equivalent *performance standards*, for example:

- in those *performance standards* that require *generating units* and *generating systems* to be *adequately damped*; and
- their impact on *power system* damping, such as in ~~*Rules*~~NER clause S5.2.5.13(d)(1)(ii).

B.1.5 *Voltage* stability criteria

For *voltage* stability clause S5.1.8 requires that stable *voltage* control must be maintained following the most severe *credible contingency event*.

This requires that an adequate *reactive power* margin must be maintained at every *connection point* in a *network* with respect to the *voltage* stability limit as determined from the *voltage*/reactive *load* characteristic at that *connection point*. Selection of the appropriate margin at each *connection point* is at the discretion of the relevant NSP subject only to the requirement that the margin (expressed as a capacitive *reactive power* (in MVAr)) must not be less than one percent of the maximum fault level (in MVA) at the *connection point*.

In relation to oscillations in *voltage* magnitude, under ~~*Rules*~~NER clause S5.1a.3, the *power system* should be planned and operated to achieve oscillations with halving time of 5 seconds or less.

Where the response of the *power system* is such that a *Network User* is permitted, under its *performance standards*, to trip or change the operation of any *plant* or *load*, that *plant* or *load* trip or change in operation:

- must be taken into account in the assessment of *voltage* stability;
- the trip or change in operation is not, in itself, considered to be a *voltage* instability; and
- must not have any consequential impacts, such that criteria relating to *voltage* stability and other forms of stability cannot be met.

B.1.6 *Frequency* stability criteria

The *Frequency Operating Standards*[6], referenced in the ~~*Rules*~~NER clause S5.1a.2 define an envelope of acceptable *frequencies* and the maximum durations that the *power system* should operate at those *frequencies* in various circumstances.

[6] See https://www.aemc.gov.au/Panels-and-Committees/Reliability-Panel/Standards.html#Power%20system%20Standard

Under ~~*Rules*~~NER clause 4.4.1(b), *AEMO* must use its reasonable endeavours to "ensure that the *frequency operating standards* set out in the *power system* security and *reliability standards* are achieved."

Where the response of the *power system* is such that a *Network User* is permitted, under its *performance standards*, to trip or change the operation of any *plant* or *load*, that *plant* or *load* trip or change in operation:

- must be taken into account in the assessment of *frequency* stability;
- the trip or change in operation is not, in itself, considered to be a *frequency* instability; and
- must not have any consequential impacts, such that criteria relating to *frequency* stability and other forms of stability cannot be met.

B.1.7 Converter-driven stability and ~~S~~system ~~S~~strength criteria

~~For system strength clause~~NER S5.1.14(c)[7] requires that *inverter based resources* do not cause *voltage* waveform instability following a *credible contingency event*.

For the purposes of the PSSG, AEMO considers converter-driven stability to be a sub-set of the system strength concept.

The *System Strength Report*[8], referenced in NER ~~clause~~ 5.20.7, determines the *system strength requirements* and system strength standard specification at each of the *system strength nodes*.

B.2 Relationships between the *power system* performance and *generating system* performance

There are a number of important links between the *generating system* performance and *power system* performance that should be taken into account when:

- planning the *network*
- operating the *network*
- negotiating *access standards* for *generating system* connections

Performance standards require *generating systems* to remain in *continuous uninterrupted operation* for a range of conditions, but outside of those conditions the requirement does not apply. No *generating unit* is required to perform at a standard higher than the *automatic access standard* for technical requirements of schedule 5.2 of the ~~*Rules*~~NER, and negotiated *access standards* may have lower performance requirements than *automatic access standards*. For example:

- Both *automatic access standards* and *negotiated access standards* allow *generating units* to trip for frequencies and rate of change of *frequency* beyond certain limits (clause S5.2.5.3)

[7] Consistent with National Electricity Amendment (Efficient management of system strength on the power system) Rule 2021 No.11. ~~Athe~~

[8] See https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

- Both automatic and *negotiated access standards* allow *generating units* to trip for *voltage* magnitudes outside of certain *voltage* magnitude recovery profiles (clause S5.2.5.4).
- *Negotiated access standards* for "*Generating system* response to disturbances following *contingency events*" (clause S5.2.5.5) can allow *generating units* to trip following *credible contingency events*, in some instances.

As a result, NSPs must take into account the *performance standards* of existing *plant*, and any other negotiated arrangements in *connection agreements* that could affect *power system* stability when:

a) developing under-*frequency load* shedding schemes;

b) designing any special protection schemes or other controls that could impact *power system* stability;

c) negotiating an *access standard* for a new or altered *generating system* connection;

d) developing stability limits; and

e) undertaking detailed planning for *network augmentations* that impact *power system* stability.

Likewise, NSPs and *AEMO* must take into account relevant *performance standards* of *generating systems* when operating the *power system*.

In respect of negotiation of an access standard for a *Generator connection*, the basis for negotiation should take into account any potential impacts on *power system* stability that could arise from the *negotiated access standard*.

B.3 Differences between the *system standards* and actual performance of the *power system*

While the *system standards* in Schedule 5.1a detail the standards of performance that the *power system* should meet, the *system standards* also acknowledge that the levels of performance specified might not be met in all parts of the *power system*. Performance might also be higher than the *system standards* require in some cases.

Therefore, when planning and operating the *power system*, and when negotiating *access standards*, the NSP and *AEMO* must take into account:

- the actual performance of the existing *power system*;
- the likely performance following installation of *considered projects*; and
- for other relevant projects, the *s~~S~~ystem s~~S~~tandards* requirements or expected performance where the *system standards* do not apply, or improved performance if the NSP considers that a higher standard is appropriate.

B.4 Uncertainties in simulation results

In calculating any form of stability and operating the *power system* to stability limits, the person carrying out the assessment must take into account uncertainties relating to, for example, critical *plant* parameters (e.g. fault clearing times), modelling uncertainties and potential inaccuracies in measurements. In addressing uncertainties, the person carrying out the assessment might also apply calibration factors where the results of simulation and measured *power system* responses have been compared and an empirical calibration is considered necessary or appropriate in the circumstances.

Appendix C. Processes

All studies relevant to the processes described in sections 1 to 6 of this Appendix must adopt the requirements and considerations outlined in those sections, as well as the definitions and considerations described in Appendix 1.

Contingency events

Processes relating to stability include stability assessments that consider system normal operating conditions[9] and may also need to take into account any required prior *outage*[10] conditions:

- *Credible contingency events* (including those *non-credible contingency events* that are, in special circumstances, reclassified as *credible contingency events*)
- *Non-credible contingency events*

The types of ~~Rules~~NER processes that require the assessment of *credible contingency events*[11] in relation to stability include, but are not limited to:

- Detailed planning processes for *network* augmentations
- Stability studies to determine *access standards* for a new *connection* or *performance standards* for upgrade of *plant* for an existing *connection*.
- Determination of *control system* settings.
- Development of stability limits.
- Use of on-line monitoring systems.

For some applications, particularly in an operational context *non-credible contingency events* must be taken into account.

The types of ~~Rules~~NER processes that require the assessment of *non-credible contingency events* in relation to stability include, but are not limited to:

- The design of emergency automated *control systems*.

C.1 Detailed planning processes – *network* augmentations

For the purpose of detailed design or planning studies for *network* augmentation, including for the *Regulatory Investment Tests for Transmission* (RIT-T) for regulated NSPs, where stability of the *power system* would be materially affected, an NSP must:

- Consider stability impacts under a range of plausible *network* conditions, for the purpose of assessing potential net benefit and impact on *network* limits, including those on other *networks*
- Consider any potential stability impacts under relevant *contingency events* and prior *outage* conditions

[9] That is, all *network plant* that is normally available for service for the prevailing generation and *load* conditions are in service, as required.

[10] That is, one or more *network plant* items that might typically be required for service are not available for service.

[11] The Rules have slightly different definitions of *credible contingency event* defined for specific applications. Users of this Guideline should ensure they are using the appropriate definition for the application.

- Consider the impact of any relevant *Registered Participant's performance standards* on the efficacy of the augmentation in increasing stability limits (for example, where *generating systems* are permitted to trip, for particular *power system* conditions that might arise following a large disturbance on the *power system*)
- Consider any potential detrimental impact of the augmentation on any relevant *Registered Participant's performance standards* of which the NSP is aware
- Determine potential *material inter-network impacts*, including, where relevant,- the potential effect of *control system* settings on oscillatory stability performance of the *power system*
- Determine the need for *inter-network tests*
- As part of the *network* augmentation design or other operational arrangements additional studies that might be necessary including assessment of harmonic resonances or sub-synchronous resonance phenomena (this requirement particularly relates to augmentations involving series capacitors and HVDC devices).

These requirements relate to situations where the nature of the augmentation is well defined and there is sufficient knowledge of the design of the augmentation and future *network* conditions (configuration, *network* parameter values and *power system* operating conditions) to be able to carry out meaningful studies. Such studies, for example, may not be suitable for long term planning.

C.2 Connection application and *plant* alteration processes

This section relates to *connection* of *generating systems* and, for some general requirements relating to studies for *connection* or *plant* alteration processes, is also relevant for *connection* of *market network* services.

***Connection* and *plant* alteration**

The *Connection Applicant* must address the assessment of *access standards*, or *performance standards* for existing *plant*, using these Guidelines, in relation to:

- how the *Connection Applicant's plant* behaves on the *network* for those standards relating to *plant* performance for stability-related technical requirements; and
- for generating *plant connection*s, calculation of the impact of the *application to connect* on *network* limits relating to *power system* stability[12].

Studies must consider the range of *power system* conditions under which the *plant* is required to meet the proposed *access standards* or *performance standards*[13]. Matters for consideration include, but are not limited to:

- *Network* and *power system* operating conditions include prior *outage* conditions.

[12] In some regions the assessment of impact on limits can only be accurately undertaken by the NSP, if there is confidential information that is critical to this assessment, and which cannot be provided to a *connection applicant*.

[13] A *Connection Applicant* might choose for their *generating system* not to operate under all potential power system operating conditions and choose, instead, to be constrained under some conditions. Hence this requirement does not attempt to select the most onerous conditions, but only "the range of power system conditions under which the *plant* is required to meet the proposed *access standards* or *performance standards*".

- The range of *generating system* and *interconnector dispatch* conditions must be reasonably practicable.
- Each *network* study solution must have operationally acceptable *voltage* magnitudes.
- The studies should not necessarily be limited to normal operation of the *power system* or single prior *outage* conditions, where the *plant* may be required to operate under unusual operating conditions such as would be experienced under restoration of the *power system* following a *black system* event.
- To confirm the performance of certain *control systems* or protection settings such as under-excitation limiters, specific study conditions must be set up to exercise the particular *control systems* and protection settings. These might not be conditions that would commonly occur on the *power system*.
- Do the post-*contingency* conditions lead to other issues that are not stability related?
- Advice should be sought from the relevant NSP, on a case-by-case basis, as to:
  - any specific modelling requirements for:
    - the relevant NSP's *network*, including any *considered projects*
    - *load* models; and
  - any specific *control systems* or *protection systems*, either existing or committed, that must be taken into account.
- To the extent that model information and other information is provided by, or is available from, *AEMO*, the analyst must take that information into account.

For the assessed range of operating conditions, the *Connection Applicant* must ensure compliance for the most onerous combination of *contingency event* and *plant* and *power system* operating conditions relevant to that performance standard. The range of *power system* conditions under which the *plant* is required to meet the proposed *access standards* or *performance standards* must be described in any advice provided to the NSP or *AEMO*.

In respect of clause S5.2.5.10, the *Connection Applicant* must provide information as to the proposed approach for setting pole slip protection or protection to *disconnect* an asynchronous *generating unit* for instability in *active power*, *reactive power* or *voltage*, and confirm these settings by means of transient stability studies, unless *AEMO* and the NSP agree that transient stability studies are not required. If the *Connection Applicant* proposes not to carry studies for setting and coordination of protection and limiter settings, then the *Connection Applicant* must propose tests to confirm those settings. The NSP should take into account those proposed tests in its assessment of the need for studies.

Consideration of size of *plant*

The range of conditions studied must be sufficiently thorough for the particular purpose of the assessment, taking into account, for the *plant* under consideration:

- the rating of the *plant*;
- the extent to which the *plant* can affect the *power system* and the local *network*;
- the extent to which the *power system* and local *network* can affect the *plant*; and
- the potential impact of the *plant* on other *network users*.

The studies must identify the most onerous conditions and *contingency events* under which the *plant* would be expected to continue to operate.

If a small *generating system* can be demonstrated to have minimal influence on the *transmission system* (for example, for a three phase fault applied at the *generating system*'s *connection point*, a minimal impact on *voltage* at the *transmission system*) then it is unlikely to impact transient or oscillatory stability limits. *Control system* stability and *voltage* stability might still need to be considered in detail, to address local issues.

Consideration of the scope and extent of studies should in the first instance be discussed with the relevant NSP.

***Generator* Compliance**

In order to confirm continued compliance with its *performance standards*, it is recommended that a Generator review its *performance standards* that would require a stability calculation:

- if~~-~~ model data obtained from test differs sufficiently from the data used in developing the *performance standards*, that there is doubt about the *Generator's* compliance with those *performance standards*
- prior to a change to the *power system* that is likely to have a material effect on the relevant *performance standard*.

C.3 Determination of *control system* settings

The person determining the settings of *control systems* must use these Guidelines, in relation to any *power system* or *plant* stability calculations.

Regardless of the analysis approach used to establish the *control system* settings, the final settings must be robust and must consider the following:

- any specific requirements of the *plant* or the *control system* required in accordance with the ~~*Rules*~~NER, a *connection* agreement or proposed *access standards*;
- *network* and *power system* operating conditions including:
  - prior *outage* conditions; and
  - those multiple prior *outage* conditions under which the *plant* is required to operate;
- the range of *power system* operating conditions must be reasonably practicable, given the type of study being carried out;
- the range of possible operating conditions for the *plant*;
- each *network* study solution must have operationally acceptable *voltage* magnitudes for the *power system* condition being studied;
- all *credible contingency events* and *non-credible contingency events* that are relevant to *power system* or *plant* stability for which the *control system* is required to contribute a positive influence;
- the impact on the *power system*, *network plant* and other *Network Users*; and
- potential operating conditions that might be unusual but for which the *power system* or *plant* is required to operate. This might include, for example, those operating conditions

that might apply after a *black system* event. This must be considered for any *plant* that is required to have a *black start capability*, or *network plant* that is required to support the *power system* during the restoration of the *power system* following a *black system* event.

C.4 Development of stability limits

The NSP must provide stability limit advice for each relevant *credible contingency event* (i.e. those that have a material impact on *network capability*) that might result in a reduction to *network capability*, for:

- system normal conditions;
- any potential forced single *network* prior *outage* condition that might result in a reduction to a *network capability* of 50 MW or more;
- all planned *network outage* conditions, in a timeframe in advance of the planned *network outage*, as advised by *AEMO*, that allows *AEMO* to carry out a due diligence assessment on the limit advice and implement the limit equation as a *dispatch constraint* in the *market systems*: and
- some *non-credible contingency events*. In determining which *non-credible contingency events* to consider, the NSP must take into account, in consultation with *AEMO*:
  - the likelihood of occurrence of the *non-credible contingency event* (e.g. loss of a double-circuit *transmission line*, or single-circuit *transmission lines* on an easement, with a lightning storm, bush fire or other environmental effects in the vicinity); and
  - the potential impact on the security of the *power system* or reliability of supply for *Network Users*; and
  - whether there is a history of that *non-credible contingency event* being re-classified as a *credible contingency event*.

In the assessment of an oscillatory stability limit:

- the oscillatory stability must be calculated assuming a *credible contingency event* has just occurred and *power system* re-configuration has not occurred – that is, the *credible contingency event* is included as part of the initial condition for each study condition (e.g. if the *credible contingency event* includes a *transmission line* or circuit *outage*, the *network* solution for each study used as an initial condition has that *transmission line* or circuit removed prior to the oscillatory stability calculation); and
- the limit must be described in terms of that *credible contingency event*.

In carrying out a stability limit assessment and providing advice to *AEMO*, the NSP must:

- provide stability limit advice to *AEMO* in a form suitable to *AEMO*
- carry out the stability studies over a broad range of practicable operating conditions
- include an offset or statistical confidence interval to be applied to the limit equation, equivalent to at least the 95th percentile of the assessed range of operating conditions
- provide documentation to *AEMO* of the calculated stability limit that includes:
  - the stability limit equation;

  - the offset or confidence interval that must be applied and, if a statistical confidence interval, the percentile value of the interval;
  - the range of operating conditions to which the limit advice applies;
  - any particular assumptions relating to the selected operating conditions; and
  - a description of the actions of any *control system* or protection system that materially influences the calculated stability limit with sufficient information to allow *AEMO* to represent that *control system* in its due diligence studies and, if a model exists for that *control system* or protection system, the model.

On receipt of the above information, *AEMO* must:

- carry out a due diligence assessment of the limit advice, using a selection of *power system* operating conditions;
- develop one or more constraint equations from the limit equation
- determine an operational margin to be applied to the constraint equation, based on:
  - for *interconnectors* and large cut-sets:
    - A statistical assessment of the variations in *active power* flows for the relevant *network* cut-set (e.g. *inter-regional* flow) that have been observed to occur; and
    - An assessment of the potential errors in measurement of the *active power* flow.
  - for other *plant*, a value agreed between the NSP and *AEMO*.

Due diligence assessment will include spot checking of the limit advice. *AEMO* may, as a result of its assessment, seek an amendment to the limit advice, if the assessment suggests the limit advice is ineffective or overly conservative.

Each stability limit must be reviewed by the NSP:

- prior to a change to the *power system* that is likely to have a material effect on the stability limit, in a timeframe in advance of that change, as advised by *AEMO*; or
- in any event, after a period not exceeding 5 years.

A stability limit review should include the following:

a) Consider changes in system operating conditions which could have a material impact on an existing stability limit (significant changes in generation dispatch outcomes due to *market*, hydrological or other environmental conditions, natural *load* growth etc).

b) Identify which stability limits may be affected by the identified changes in *power system* conditions.

c) Undertake sensitivity analysis on the existing limit advice to investigate how material the change in system operating conditions is with respect to the stability limit and whether the existing stability limit is still robust for the new conditions.

d) If the stability limit is found to be impacted significantly by the observed changes in system operating conditions (a decision which may involve *AEMO*), then undertake detailed review and revision of the limit advice.

C.5 Use of on-line monitoring systems

Where *AEMO* or the NSP uses on-line analysis systems that calculate the stability of the *power system* for *credible contingency events* or, as required, *non-credible contingency events* declared to be *credible contingency events*, based on real time or near-real time measurements of the *power system*, *AEMO* or the NSP must use these Guidelines in establishing the manner in which those analysis systems calculate stability.

C.6 Emergency automated *control systems*

Where an NSP is required to implement an emergency *control system* (for example, as required under clause S5.1.8 of the ~~*Rules*~~NER), the NSP must:

- Assess stability in accordance with these Guidelines.
- Take into account any applicable Rule requirements relating to stability that are not explicit in these Guidelines, in the design or performance of the *control system*; and
- Take into account all relevant forms of stability described in these Guidelines in:
  - assessing the impacts and consequences of potential *non-credible contingency events* that could endanger the stability of the *power system*;
  - ensuring robust operation of the emergency *control system*;

In the assessment of oscillatory stability:

- In assessing the impact and consequence of the *non-credible contingency event*, the oscillatory stability must be calculated assuming a *contingency event* has just occurred and re-configuration of the *power system* has not occurred – that is, the *contingency event* is included as part of the initial condition for each study condition (e.g. if the *credible contingency event* includes a *transmission line* or circuit *outage*, then the *network* solution for each study used as an initial condition has that *transmission line* or circuit removed prior to the oscillatory stability calculation).
- In ensuring the robust operation of the emergency *control system*, the oscillatory stability must be calculated in a similar manner – that is, the *contingency event* and subsequent operation of the *control system* must both be taken into account in the initial condition for each study condition.

In providing advice to *AEMO* on the *control system*, the NSP must provide documentation to *AEMO* including:

- a description of the actions of the emergency *control system* including settings, trigger levels, timings, the necessary events and pre-conditions for operation of the *control system* and any other information that *AEMO* might reasonably require for due diligence studies and, if a model exists for the emergency *control system*, the model;
- any particular assumptions relating to the stability of the *power system*, including assumptions made in the design studies of the emergency *control system*; and
- a description of the actions of any other *control system* or protection system that materially influences the performance of the *power system* or the emergency *control system* for the *contingency event*.

Appendix D. Legal framework

~~D.1 General~~

~~These *Power System* Stability Guidelines (Guidelines) are made in accordance with clause 4.3.4(h) and (i) of the *Rules*.~~

~~These Guidelines may only be amended in accordance with clause 4.3.4(h) of the *Rules*.~~

~~If there is any inconsistency between these Guidelines and the *Rules*, the (the *Rules* will prevail to the extent of that inconsistency.~~

~~D.2~~D.1 Relevant rules

AEMO is required to make these Guidelines under clause 4.3.4(h) of the ~~*Rules*~~NER, which provides:

(h) AEMO must develop, and may amend, guidelines for *power system* stability but only in consultation with *Registered Participants* in accordance with *the Rules consultation procedures*, and must publish the guidelines for *power system* stability.

Clause 4.3.4(i) provides:

(i) The *power system* stability guidelines developed in accordance with clause 4.3.4(h) must detail the policies governing *power system* stability so as to facilitate the operation of the *power system* within stable limits.

These Guidelines ~~are~~apply for the purposes of clauses 4.3.4(g) and 4.7.1(a) in relation to *Network Service Providers* (NSPs), including *Market Network Service Providers* (MNSPs). The relevant provisions are cited below:

4.3.4 *Network Service Providers*

(g) Each *Network Service Provider* must plan or operate its *transmission system* or *distribution system* in accordance with the *power system* stability guidelines described in clause 4.3.4(h).

4.7.1 Stability analysis co-ordination

(a) *AEMO* must, in cooperation with the relevant *Network Service Providers*, apply the *power system* stability guidelines described in clause 4.3.4(h) to the conduct of all necessary calculations associated with the stable operation of the *power system* and use its reasonable endeavours to coordinate the determination of the settings of equipment used to maintain *power system* stability. The *Network Service Providers* must submit to *AEMO* for approval the settings of any transmission equipment used to maintain the stable operation of the *power system*.

The Guidelines are also relevant for the purposes of clauses S5.2.5.10(a) and S5.2.5.13(k) in relation to *applications to connect* for *generating systems*. Extracts of the relevant provisions are set out below:

S5.2.5.10 Protection to trip *plant* for unstable operation

Automatic *access standard*

(a) The *automatic access standard* is:

(1) a *synchronous generating unit* must have a *protection system* to *disconnect* it promptly when a condition that would lead to pole slipping is detected in order to prevent pole slipping or other conditions where a *generating unit* causes *active power*, *reactive power* or *voltage* at the *connection point* to become unstable as assessed in accordance with the *power system* stability guidelines established under clause 4.3.4(h); and

(2) an *asynchronous generating unit* must have a protection system to *disconnect* it promptly for conditions where the *active power*, *reactive power* or *voltage* at the *connection point* becomes unstable as assessed in accordance with the guidelines for *power system* stability established under clause 4.3.4(h).

S5.2.5.13 *Voltage* and *reactive power* control

(k) The assessment of impact of the *generating units* on *power system* stability and damping of *power system* oscillations shall be in accordance with the guidelines for *power system* stability established under clause 4.3.4(h).

Version release history

Version	Effective date	Summary of changes
2.0~~N/A~~	1 December 2022~~N/A~~	~~**Draft issued for consultation on 29 July 2022.**~~Incorporation of converter-driven stability and references to system strength.
1.0	25 May 2012	First issue