AEMO

AUSTRALIAN ENERGY MARKET OPERATOR

Power System Stability Guideline

October 2023

Important notice

Disclaimer

This Power System Stability Guideline is made by AEMO under paragraph 6.1.5 of the WEM Procedure: Power System Security and has effect only for the purposes set out in the procedure. The WEM Rules prevail over this Power System Stability Guideline to the extent of any inconsistency.

Copyright

Version control

Version	Release date	Changes
#1.0	01/10/2023	Initial Release

AEMO acknowledges the Traditional Owners of country throughout Australia and recognises their continuing connection to land, waters and culture. We pay respect to Elders past and present.

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1 Introduction

1.1 Purpose

This guideline contains information pertaining to the assessment of Power System Stability in the South West Interconnected System (SWIS) in accordance with the WEM Procedure: Power System Security. This includes definitions and assessment criteria for the categories of Power System Stability indicated in paragraph 6.1.2 of the WEM Procedure: Power System Security.

The purpose of this guideline is to provide information about how AEMO and the Network Operator consider and assess stability in the SWIS. This guideline is not intended to specify obligations or timing for assessment of stability.

1.2 Definitions and interpretation

- Terms defined in the *Electricity Industry Act 2004* (WA), the WEM Regulations, the WEM Rules and the WEM Procedure: Power System Security have the same meanings in this Guideline unless the context requires otherwise.
- The following definitions apply in this Guideline unless the context requires otherwise.

1.2.1 Glossary

Term	Definition
Non-Thermal Limit Advice	Limit Advice for Non-Thermal Network Limits
Root-Mean-Square	Refers to a positive sequence modelling considering only the fundamental frequency (phasor domain).
SCR	Short-circuit ratio

1.2.2 Interpretation

The following principles of interpretation apply to this Guideline unless otherwise expressly indicated:

- Clauses 1.3 to 1.5 of the WEM Rules apply in this Guideline.
- References to time are references to Australian Western Standard Time.
- Terms that are capitalised, but not defined in this Guideline, have the meaning given in the WEM Rules or the WEM Procedure: Power System Security.
- A reference to the WEM Rules or WEM Procedures includes any associated forms required or contemplated by the WEM Rules or WEM Procedures.

- Words expressed in the singular include the plural and vice versa.
- A reference to a paragraph refers to a paragraph of this Guideline or a WEM Procedure.
- A reference to a clause refers to a clause or section of the WEM Rules, unless otherwise specified.
- References to WEM Rules in this Guideline in bold and square brackets [Clause XXX] are included for convenience only, and do not form part of this Guideline.
- Text located in boxes and headed as Explanatory Note X in this Guideline is included by way of explanation only and does not form part of this Guideline. The Guideline prevails to the extent of any inconsistency with the explanatory notes contained within it.
- The body of this Guideline prevails to the extent of any inconsistency with the appendices, schedules, annexures or attachments contained within this document.
- Terms used in text or definitions from the Technical Rules have the meaning given in the Technical Rules.

1.3 Related documents

Title	Location
Technical Rules (2016)	Western Power Website
WEM Procedure: Power System Security	WEM Website
WEM Procedure: Constraint Formulation	WEM Website

2 Scope

For the purposes of the Guideline, Power System Security and Power System Stability have the meanings given in clause 11 of the WEM Rules:

Power System Security: Means the safe scheduling, operation and control of the SWIS in accordance with the Power System Security Principles.

Power System Stability: Means when the SWIS will return to an acceptable steady-state operating condition following a disturbance.

Considering the purpose of the Guideline and the definition of Power System Stability, this Guideline specifies the different categories of stability considered by AEMO in the WEM. This includes definitions and criteria used for assessment.

Assessment of each category of stability may include criteria specifically determined for credible contingency events. For the purpose of this Guideline, credible contingency event is considered to have the definition found in the Technical Rules published by Western Power.

Credible Contingency Event [Technical Rules, Glossary]

A single contingency event of one of the following types:

(a) for voltages at or below 66kV, a three phase to earth fault cleared by disconnection of the faulted component, with the fastest main protection scheme out of service;

(b) for voltages above 66kV:

(1) a two-phase to earth fault cleared by disconnection of the faulted component, with the fastest main protection scheme out of service; or

(2) a three-phase to earth fault cleared by disconnection of the faulted component, with the fastest main protection scheme out of service. This criterion is to be applied only to transmission elements where the Network Service Provider can demonstrate that the design type, environmental conditions, historic performance or operational parameters results in a material increase in the likelihood of a three-phase to earth fault occurring.

(c) a single-phase to earth fault cleared by the disconnection of the faulted component, with the fastest main protection scheme out of service;

(d) a single-phase to earth fault cleared after unsuccessful high-speed single-phase auto-reclosure onto a persistent fault;

(e) a single-phase to earth small zone fault or a single-phase to earth fault followed by a circuit breaker failure, in either case cleared by the operation of the fastest available protection scheme; or

(f) a sudden disconnection of a system component, e.g. a transmission line or a generation unit.

3 Categories of Stability

3.1 Thermal Stability

3.1.1 Definition

This category of stability is associated with the risk of equipment overloading following disturbances and may be as a result of compensation from an energy producing system. Thermal Stability is defined in paragraph 1.2 of the WEM Procedure: Power System Security. Thermal Stability is assessed as part of the congestion modelling process as required in Clause 2.27A and 2.27B of the WEM Rules.

Thermal Stability Definition [WEM Procedure: Power System Security, Paragraph 1.2]

Is the ability of the SWIS to operate within Thermal Network Limits defined for each Technical Envelope applicable for each SWIS Operating State.

3.1.2 Criteria

The system is considered to achieve thermal stability where it is operated up to the Technical Envelope specified in Table 5 of the WEM Procedure: Power System Security. Table 5 of the Procedure specifies the following for Thermal Network Limits.

Thermal Stability Criteria [WEM Procedure: Power System Security, Table 5]

Limit Category	Satisfactory and Secure	Emergency
Thermal Network Limits	• Up to the Normal Rating. • If applicable, between the Normal Rating and Short-Time Rating (inclusive) for a duration no longer than the Short-Time Rating Duration. • Where a Revised Rating has been provided by a Network Operator: – if the Revised Rating is less restrictive than the Normal Rating, between the Normal Rating and the Revised Rating (inclusive), subject to meeting the Revised Rating Conditions (e.g., maximum applicable duration); or – if the Revised Rating is more restrictive than the Normal Rating, up to the Revised Rating, subject to meeting the Revised Rating Conditions (e.g., maximum applicable duration).	As for Satisfactory and Secure, with allowance to utilise Emergency Ratings with Emergency Duration where available and deemed necessary by AEMO.

3.1.3 Assessment Process

Assessment for planning timeframe

Thermal Stability is considered in the planning timeframe for forecast high demand periods to ensure adequate Network Access Quantities (NAQ) based on available network capacity for the forecast conditions.

Assessment for operational timeframe

Thermal Stability is assessed in formation of constraint equations in the process specified in the WEM Procedure: Constraint Formulation. AEMO's analysis considers the network equipment ratings (Thermal Network Limits) provided by the Network Operator.

As part of the assessment process, network contingencies are applied to various locations to assess steady-state pre- and post-contingent thermal performance according to the Thermal Stability criteria for system normal and under outage conditions.

3.2 Transient Stability

3.2.1 Definition

Transient Stability is defined according to the definition of Transient Rotor Angle Stability in the Technical Rules, but considers the resulting response to involve large excursions of generating unit electrical angles, to include inverter-based generating units.

Transient Stability Definition [Technical Rules, Glossary]

The ability of the power system to maintain synchronism when subjected to severe disturbances, for example a short circuit on a nearby transmission line. The resulting system response involves large excursions of generating unit rotor angles and is influenced by the non-linear power-angle relationship.

3.2.2 Criteria

Transient Stability is assessed against the criteria specified in the Technical Rules for synchronous generating units, but considers non-synchronous generating units to maintain continuous uninterrupted operation following a credible contingency event.

Transient Stability Criteria [Technical Rules, Clause 2.2.7]

All generating units connected to the transmission system and generating units within power stations that are connected to the distribution system and that have a total rated output of 10 MW or more must remain in synchronism following a credible contingency event.

3.2.3 Assessment Process

Assessment for planning timeframe

The Network Operator considers Transient Stability in a planning timeframe to plan for required network investment or during connection assessments. As part of the assessment process, the Network Operator may simulate credible contingency events to assess generating systems and transmission or distribution systems against the Transient Stability criteria.

Assessment for operational timeframe

Non-Thermal Limit Advice provided by the Network Operator considers Transient Stability criteria to form non-thermal limit equations where Transient Stability is identified for a credible network disturbance in system normal or outage conditions.

Transient stability is also assessed where applicable through post-event investigations using high-speed recorder data. An event that is considered not to have met the Transient Stability criteria may be considered.

As part of the assessment process, network disturbances in various locations are simulated to assess dynamic response of the system and to ensure acceptable post-disturbance steady-state conditions are reached according to the Transient Stability criteria.

3.3 Oscillatory Stability

3.3.1 Definition

The Technical Rules incorporates a definition for Oscillatory Rotor Angle Stability that describes a need to minimise system oscillations originating from electro-magnetic phenomenon.

Oscillatory Rotor Angle Stability Definition [Technical Rules, Clause 2.2.8]

System oscillations originating from system electro-mechanical characteristics, electro-magnetic effect or non-linearity of system components, and triggered by any small disturbance or large disturbance in the power system, must remain within the small disturbance rotor angle stability criteria and the power system must return to a stable operating state following the disturbance.

AEMO extends the concepts in this definition to incorporate oscillations that originate from all Facilities irrespective of technology type, therefore for the purpose of the WEM Procedure: Power System Security and the Power System Security Guideline, a new definition and criteria for Oscillatory Stability has been adopted.

Oscillatory Stability Definition and Criteria

a) The power system must be adequately damped after system oscillations triggered by a small disturbance or a large disturbance.

b) A system oscillation triggered by any small disturbance or large disturbance shall conform to the following criteria:

   1) the damping ratio of the oscillation be at least 0.1;

   2) the halving time of any oscillation not to exceed 5 seconds; and

   3) allow Generators to maintain continuous uninterrupted operation.

E[A] Explanatory note – Oscillatory Stability

AEMO considers that the concepts relating to Oscillatory Rotor Angle Stability in Technical Rules 2.2.8 are still generally suitable for use when assessing Power System Stability, however AEMO also considers that limiting this concept to only consider oscillations derived from electromechanical generating Systems is not appropriate given the prevalence of inverter based technologies that are expected to form the basis of a typical Generating System connecting to the SWIS today.

AEMO has consulted the Network Operator and have reached agreement that extending this definition to incorporate all generating technologies is appropriate, noting that the definition contained in the Technical Rules (2016) is proposed to be similarly extended as part of Technical Rules reform activities currently underway.

AEMO will monitor Technical Rules reform activities and will amend the Power System Stability Guideline in the event of any relevant Technical Rules amendments.

3.3.2 Criteria

As per the Oscillatory Stability definition in paragraph 3.3.1, a system oscillation triggered by any small disturbance or large disturbance must conform with the Oscillatory Stability criteria in these Guidelines.

3.3.3 Assessment Process

Assessment for planning timeframe

The Network Operator considers concepts equivalent to Oscillatory Stability as part of connection assessments. In assessment of Oscillatory Stability, the Network Operator may simulate small or large disturbances applied to the power system to consider generating unit performance.

Assessment for operational timeframe

Non-Thermal Limit Advice provided by the Network Operator considers Oscillatory Stability criteria in this Guideline to form non-thermal limit equations where Oscillatory Stability is identified for a small or large disturbance in system normal or outage conditions.

Oscillatory stability may also be assessed through analysis of high-speed recorder data as part of post-event investigations according to the Oscillatory Stability criteria in these Guidelines.

3.4 Voltage Stability

3.4.1 Definition

As defined in the Technical Rules.

Voltage Stability Definition [Technical Rules, Glossary]

The ability of a power system to attain steady voltages at all busbars after being subjected to a disturbance from a given operating condition. Instability that may result occurs in the form of a progressive fall or rise of voltages at some busbars. Possible outcomes of voltage instability are loss of load in an area, or the tripping of transmission lines and other elements, including generating units, by their protective systems leading to cascading outages.

3.4.2 Criteria

As specified in Clauses 2.2.9 and 2.2.11 of the Technical Rules.

Voltage Stability Criteria [Clause 2.2.9 and 2.2.11 of Technical Rules]

2.2.9 Short Term Voltage Stability

a) Short term voltage stability is concerned with the power system surviving an initial disturbance and reaching a satisfactory new steady state.

b) Stable voltage control must be maintained following the most severe credible contingency event.

2.2.11 Long Term Voltage Stability

a) Long term voltage stability includes consideration of slow dynamic processes in the power system that are characterised by time constants of the order of tens of seconds or minutes.

b) The long term voltage stability criterion is that the voltage at all locations in the power system must be stable and controllable following the most onerous post-contingent system state following the occurrence of any credible contingency event under all credible load conditions and generation patterns.

A satisfactory new steady state is reached where steady state transmission system voltages meet criteria specified in Clause 2.2.2 of the Technical Rules.

3.4.3 Assessment Process

Assessment for planning timeframe

The Network Operator considers Voltage Stability in a planning timeframe to plan for required network investment or during connection assessments. As part of the assessment process, the Network Operator may simulate credible contingency events to assess generating systems and transmission or distribution systems against the Voltage Stability criteria.

Assessment for operational timeframe

Voltage Stability is assessed by the Network Operator to form Non-Thermal Limit Advice. Voltage Stability may also be assessed as part of post-event investigations.

As part of the assessment process, electrical faults (or other network disturbances) in various locations are simulated to assess dynamic response of the system and to assess post-disturbance steady-state performance against the Voltage Stability criteria.

3.5 Frequency Stability

3.5.1 Definition

As defined in the Technical Rules.

Frequency Stability Definition [Technical Rules, Glossary]

The ability of a power system to attain a steady frequency following a severe system disturbance that has resulted in a severe imbalance between generation and load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units or loads or both.

3.5.2 Criteria

Frequency stability criteria are assessed as the ability for the SWIS to operate according to the Frequency Operating Standard (FOS) outlined in Appendix 13 of the WEM Rules. The FOS also considers frequency stability criteria for islands that may be operated separately from the SWIS.

3.5.3 Assessment Methodology

Assessment for operational timeframe

AEMO uses a single-frequency model to assess frequency stability across various conditions to assess and review secure dispatch outcomes by ensuring adequate inertia and primary frequency response (PFR). The model is used as part of post-event investigations and future planning studies. Study results from this model are considered in WEM Dispatch Engine (WEMDE) to ensure frequency stability for credible contingencies.

The use of under-frequency load shedding (UFLS) to ensure frequency stability in the event of non-credible contingency events is considered acceptable. The single-frequency model is used to assess adequacy of the existing UFLS scheme.

This model is reviewed and validated to ensure confidence as part of post-event investigations and where network or facility changes require consideration in the model.

3.6 System Strength

3.6.1 Definition

As defined in the WEM Rules.

System Strength Definition [WEM Rules]

Is a measure of how resilient the voltage waveform is to disturbances such as those caused by a sudden change in Load or an Energy Producing System, the switching of a network element, tapping of transformers and other types of faults.

3.6.2 Criteria

The Technical Rules provides criteria for the Network Operator to plan the transmission and distribution systems to maintain sufficient System Strength. Further to this, AEMO considers the use of a minimum three-phase fault level as a screening method to identify potential System Strength issues.

Screening Criteria

As part of the screening assessment of minimum three-phase fault level, the minimum of the following will be considered:

- Minimum plant short-circuit ratio where available from a vendor.
- A short-circuit ratio of 3.

Short-circuit Ratio of 3

CIGRE TB 671, "Connection of Wind Farms to Weak AC networks", converters may not be stable following system disturbances in weak AC systems as represented by low SCRs. The paper suggests SCRs below 3 require modelling in detail using a suitable EMT simulation tool, while SCRs above 5 may be considered a stronger AC network. [insert ref for https://e-cigre.org/publication/671-connection-of-wind-farms-to-weak-ac-networks]

Detailed Criteria of Stable Voltage Waveforms

Where the screening method has identified transmission nodes that fall short of the screening criteria, detailed criteria may be used in further studies to assess system strength. The following criteria are intended to describe criteria to achieve a stable voltage waveform and should be met under pre- and post-contingency conditions.

Voltage magnitude

The positive-sequence RMS voltage magnitude at a connection point does not violate the limits in the Technical Rules. This includes limits on voltage excursions and the permissible voltage step change created by reactive power injection or absorption. Region-specific operational guides that include voltage metrics may also be used to assess this criterion.

Voltage phase angle change

Change in the steady-state RMS voltage phase angle at a connection point should not be excessive following the injection or absorption of active power at a connection point. For a strong system, phase angle changes after injection or absorption of active power at a connection point should be relatively small. For example, to inject 100 megawatts (MW) of active power at a strong location with a high short circuit ratio would result in a small voltage phase angle change of a few degrees in a steady-state study. To inject the same 100 MW at a weak location with a low short circuit ratio would result in a large phase angle change. As such, excessive voltage phase angle changes following active power injection or absorption would indicate a weak system.

A value between 30 and 60 electrical degrees could be used as a reasonable threshold to measure the steady-state change in voltage phase angle following active power injection or absorption at a connection point. However, this is not a hard limit and other metrics could be used. The intent is to measure the sensitivity of change in voltage phase angle with respect to change in active power injection or absorption at a connection point.

Voltage waveform distortion

The three-phase instantaneous voltage waveform distortion at a connection point should not exceed acceptable planning levels of voltage waveform distortion for pre- and post-contingent conditions. This can be assessed with reference to clause 2.2.4 of Technical Rules. The intent of the criterion is to assess the interaction between IBRs or between IBRs and other power system components.

Voltage oscillations

Any undamped steady-state RMS voltage oscillations anywhere in the power system should not exceed an acceptable planning threshold as agreed with AEMO. Thresholds will be determined and may be revised from time to time through representative forums convened by AEMO.

At the time of publication of this guideline, these thresholds are under discussion by the Power System Security Working Group and Power System Modelling Reference Group convened by AEMO. A proposed planning threshold for acceptable oscillations of up to 0.5% peak-peak RMS voltage is being considered.

3.6.3 Assessment Process

Assessment for planning timeframe

System Strength is assessed annually by AEMO using the screening method, which considers the SCR at transmission nodes throughout the SWIS across different times of day across different months to assess nodes with low SCR at any time. Low System Strength nodes may be identified for assessment against detailed criteria.

Assessment for operational timeframe

The Network Operator may also consider System Strength in analysis for the provision of Non-Thermal Limit Advice, which is used in operational constraint equations.