Draft System Strength Requirements Methodology

Prepared by:	AEMO System Design
Version:	N/A
Effective date:	N/A
Status:	**Draft issued for consultation on 29 July 2022**

Approved for distribution and use by:

Approved by:	
Title:	
Date:	

aemo.com.au

New South Wales | Queensland | South Australia | Victoria | Australian Capital Territory | Tasmania | Western Australia

Australian Energy Market Operator Ltd ABN 94 072 010 327

Contents

Current version release details 3

1. Introduction 4
1.1. Purpose and scope 4
1.2. Definitions and interpretation 4
1.3. Related documents 5
1.4. Overview of Methodology 5

2. Background and NER requirements 7
2.1. Need and standard for system strength 7
2.2. System strength roles and responsibilities 8
2.3. NER requirements for the Methodology 10

3. System strength nodes 12
3.1. Definition of system strength nodes 12
3.2. Selection of system strength nodes 12
3.3. Process for node declaration 14

4. Minimum fault level methodology 15
4.1. Step 1 – Consider existing requirements 17
4.2. Step 2 – Assess protection system operation needs 17
4.3. Step 3 – Assess voltage control system operation needs 18
4.4. Step 4 – Assess power system stability needs 18
4.5. Step 5 – Select critical planned outages 20
4.6. Step 6 – Determine minimum three phase fault levels 21
4.7. Step 7 – Adjust requirements for application in the operational context 21
4.8. Transitional arrangements for shortfall declarations 22

5. Stable voltage waveforms 23
5.1. Description of stable voltage waveforms 23
5.2. Analysis of stable voltage waveforms 24

6. Future system forecasts 27
6.1. Applying Integrated System Plan forecasts 27
6.2. Form of IBR projections 28
6.3. Departures from the ISP 28
6.4. Other matters 28

Version release history 30

Tables

Table 1 System Strength Requirements Methodology roles and responsibilities ... 8
Table 2 Example system strength node declaration ... 12
Table 3 Key steps in minimum fault level requirement assessment process ... 15
Table 5 Example IBR projection list ... 28

Figures

Figure 1 System Strength Requirements Methodology overview ... 9
Figure 2 General principles for overall system strength node selection ... 12
Figure 3 Potential assessment of IBR electrical proximity to system strength nodes ... 13
Figure 4 Minimum fault level requirement assessment process ... 16
Figure 5 Potential material changes that could affect required minimum three phase fault level ... 17
Figure 6 Determining best assessment for analysing stable voltage waveforms ... 25

Current version release details

Version	Effective date	Summary of changes
N/A	N/A	**Draft issued for consultation on 29 July 2022.**

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

1. Introduction

1.1. Purpose and scope

This is the System Strength Requirements Methodology (Methodology) made under clause 5.20.6 of the National Electricity Rules (NER).

This Methodology has effect only for the purposes set out in the NER. The NER and the National Electricity Law (NEL) prevail over this Methodology to the extent of any inconsistency.

This Methodology provides the process AEMO uses to determine the system strength requirements for each *region* of the National Electricity Market (NEM). This includes:

- Overview of *system strength nodes* and the process to declare them.
- Description of the assumptions AEMO will use about the size, type and operational profile of facilities or classes of *facilities* to be *connected*.
- Description of the modelling and analysis methodologies AEMO will use to determine *system strength nodes* and the minimum *three phase fault levels* at the *system strength nodes*.
- Description of matters relating to forecasts of new *connections* at the *system strength nodes*, and what is meant by stable *voltage* waveforms, for the purpose of noting what may be required to achieve stable operation at the *system strength nodes*.

1.2. Definitions and interpretation

1.2.1. Glossary

Terms defined in the National Electricity Law and the NER have the same meanings in this Methodology unless otherwise specified in this clause. Terms defined in the NER are intended to be identified in this Methodology 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 this Methodology.

Term	Definition
AEMC	Australian Energy Market Commission
Committed	As defined in the current SSIAG
Connecting NSP	The *Network Service Provider* responsible for responding under NER Chapter 5 to an enquiry or application to connect, or a proposal to alter a *generating system*.
DNSP	*Distribution Network Service Provider*
EMT	Electromagnetic transient.
ESOO	AEMO's Electricity *statement of opportunities*
IBL	*inverter based load*
IBR	*inverter based resource*
ISP	AEMO's Integrated System Plan
MNSP	*Market Network Service Provider*
MVA	Megavolt amperes
NEM	*National Electricity Market*

Term	Definition
NEL	National Electricity Law
NER	National Electricity Rules (NER followed by a number refers to that numbered rule or clause of the NER)
NSP	*Network Service Provider*
PV	Photovoltaics
REZ	Renewable energy zone
SSIAG	*system strength impact assessment guidelines*
SSLF	*system strength locational factor*
SSN	*system strength node*
SSRS	*system strength remediation scheme*
SSSP	*System Strength Service Provider*
System Strength Standard Specification	The system strength standard specification referred to in new clause S5.1.14(a)
TNSP	*Transmission Network Service Provider*
VRE	Variable renewable energy

1.2.2. Interpretation

These Procedures are subject to the principles of interpretation set out in Schedule 2 of the NEL.

1.2.3. NER version

This Methodology is published under NER 11.143.2(a). NER references are to rules and clauses of the NER version in force from 1 December 2022, immediately after the *National Electricity amendment (Efficient management of system strength on the power system) Rule 2021* comes into effect.

1.3. Related documents

Title	Location
System Strength Impact Assessment Guidelines	https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag
Power System Stability Guidelines	https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag
AEMO Planning for Operability webpage	https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/planning-for-operability

1.4. Overview of Methodology

The remaining sections of this Methodology are structured as follows:

- Section 2 provides background information, including the NER requirements and principles that underpin the Methodology and prescribe its minimum content.
- Section 3 describes the selection of *system strength nodes*.
- Section 4 sets out the assessment method for calculating *minimum three phase fault level* requirements.

- Section 5 describes stable *voltage* waveforms, to be used in determining efficient levels of system strength for future IBR connection and operation, as well as assessment methods for provision of stable *voltage* waveforms into the future.
- Section 6 sets out AEMO's approach to forecasting future IBR and *synchronous generation*, for the purposes of the *system strength requirements*.

2. Background and NER requirements

2.1. Need and standard for system strength

System strength can broadly be described 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[1].

Declining minimum operational demand caused by increasing distributed PV, changing *dispatch* of *synchronous generating units* and rapid uptake of variable renewable energy (VRE) resources have combined to reduce the levels of system strength available in parts of the NEM *power system.* This has resulted in challenges to support the stable operation of existing equipment and to host further *inverter based resources* (IBR) as the Australian electricity sector transformation continues.

2.1.1. System strength standard specification

Following a final determination by the AEMC in October 2021, the *National Electricity Amendment (Efficient management of system strength on the power system) Rule* 2021 No.11 changed the previous system strength framework in the NER to provide for a system standard (NER S5.1a.9) comprising:

(a) a **minimum three phase fault level** for *power system security* (expressed in megavolt amperes (MVA)), sufficient to enable:

  (i) correct operation of *protection systems* of *networks* and *Network Users* (both *transmission* and *distribution*).

  (ii) stable *voltage control systems*; and

  (iii) the *power system* to remain stable following any *credible contingency event* or *protected event*; and

(b) a requirement for stable *voltage* waveforms at *connection points* (also known as the **efficient level of system strength**), such that:

  (i) in steady state conditions, *plant* does not create, amplify, or reflect instabilities; and

  (ii) avoidance of *voltage* waveform instability following any *credible contingency event* or *protected event* is not dependent on *plant disconnecting* or varying *active power* or *reactive power* transfers, other than in accordance with *performance standards*.

Each NEM *region's jurisdictional planning body* is designated as the *System Strength Service Provider* (SSSP). The SSSP must, under NER S5.1.14, plan to meet the 'system strength standard specification' defined in that clause, for both the *minimum three phase fault level* and the efficient level of system strength. The system strength standard specification is determined by the *system strength requirements* published by AEMO under this Methodology.

[1] For more information on system strength, see AEMO, *Power system* Requirements, July 2020, at https://www.aemo.com.au/-/media/Files/%20Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf and AEMO, System strength explained, March 2020, at https://aemo.com.au/-/media/files/electricity/nem/system-strength-explained.pdf.

2.1.2. System strength requirements

AEMO must publish the *system strength requirements* annually by 1 December. These requirements are, under NER 5.20C.1(c), for each *system strength node*:

(a) the *minimum three phase fault level* for the upcoming year commencing 2 December, to be used for the purposes of maintaining *power system security*.

(b) AEMO's forecast, for each of the next ten years of:

(i) the *minimum three phase fault level*; and

(ii) the projected level and type of IBR and *market network service facilities*,

to be used by SSSPs for the purposes of meeting the system strength standard specification under NER S5.1.14.

As part of the annual publication, AEMO will also seek feedback from stakeholders on important inputs, assumptions, thresholds and margins which are referenced in this Methodology, for example selection of system strength nodes and application of prudent planning margins. AEMO will seek to incorporate feedback in the following year's publication.

2.2. System strength roles and responsibilities

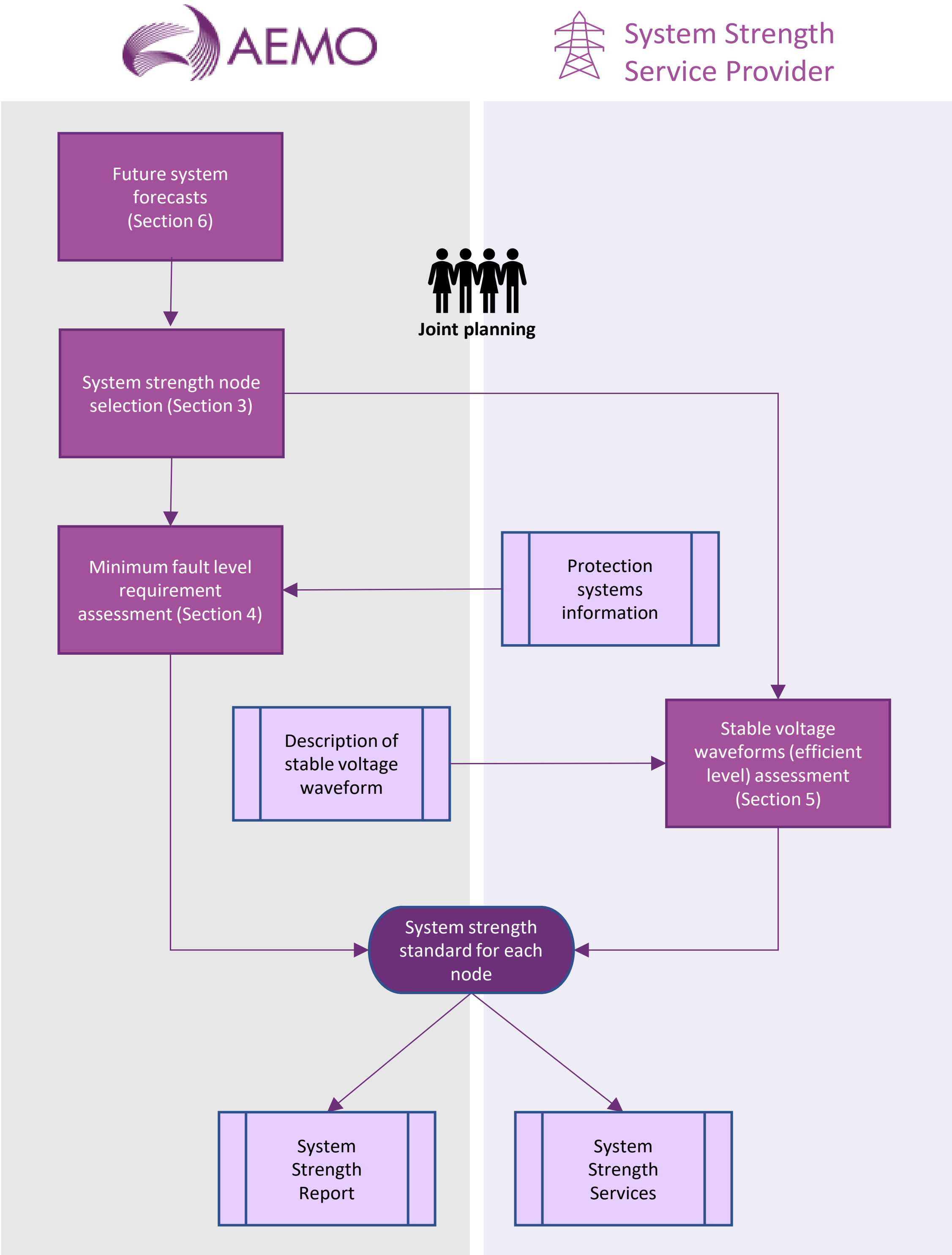
Table 1 describes the roles and responsibilities of the organisations associated with maintaining system strength in the NEM.

Table 1 System Strength Requirements Methodology roles and responsibilities

Organisation	Roles and responsibilities
Australian Energy Market Operator (AEMO)	• Develop and publish a System Strength Requirements Methodology. • Set *power system* standards for minimum three phase fault levels and for stable *voltage* waveforms at *connection points*. • Undertake joint planning with SSSPs with relation to system strength. • Publish a System Strength Report by 1 December each year, including system strength requirements for each *system strength node*. • Use system strength services to maintain the *power system* in a secure operating state.
System Strength Service Providers (SSSPs)	• Undertake joint planning with AEMO, other TNSPs, and DNSPs, in relation to system strength. • Publish information in the *transmission* annual planning report for system strength services for each node, including the technical requirements for the non-*network* options. • Use reasonable endeavours to acquire and make system strength services available to AEMO to meet the system strength standards for both minimum three phase fault levels and for stable *voltage* waveforms at *connection points*. • Apply the System Strength Impact Assessment Guidelines and Australian Energy Regulator [pricing guidelines] to set pricing for system strength services.
Transmission network service providers (TNSPs) which are not SSSPs	• Undertake joint planning with local SSSP(s) with relation to system strength.
Distribution network service providers (DNSPs)	• Undertake joint planning with local SSSP(s) with relation to system strength.
Market network service providers (MNSPs), generators and developers, loads, and equipment manufacturers	• Provide project information to AEMO, SSSPs, TNSPs and DNSPs through existing processes, for incorporation in the system strength standard where appropriate.
Non-network solution providers	• Respond to calls for system strength service provision by SSSPs, including in response to information in the *transmission* annual planning reports.

Figure 1 gives a high-level view of the key processes and inputs involved in the Methodology and the application of the *system strength requirements*.

Figure 1 System Strength Requirements Methodology overview



2.3. NER requirements for the Methodology

2.3.1. Minimum content

NER 5.20.6(f) prescribes the minimum content for this Methodology, which must:

(a) provide an overview of *system strength nodes* and the process to declare them;

(b) describe:

(i) how AEMO forecasts new *connections* and the information it takes into account;

(ii) how AEMO will determine the assumptions it will use about the size, type and operational profile of *facilities* or classes of *facilities* to be *connected* and their contribution to the matters taken into account in determining the *system strength requirements*; and

(iii) the modelling and analysis methodologies AEMO will use to determine *system strength nodes* and *minimum three phase fault levels* at the *system strength nodes* and the matters it will take into account;

(c) provide for AEMO to take the following matters into account in determining the *system strength requirements*:

(i) the *Integrated System Plan* and the *Electricity Statement of Opportunities*;

(ii) the matters in NER 5.20.6 (e)(1) to (7) for each year of the forecast period; and (iii)

(iii) any other matters AEMO considers appropriate; and

(d) provide a description of what is meant by stable *voltage* waveforms for the purposes of NER S5.1.14(b)(2) (in addition to that provided in NER S5.1.14(c)) including the matters that may be taken into account by *System Strength Service Providers* to assess, for the level and type of *inverter based resources* projected by AEMO at *system strength nodes*, what may be required to achieve stable operation.

2.3.2. Specific matters to be taken into account

In addition to the *Integrated System Plan* and the *Electricity Statement of Opportunities*, NER 5.20.6(e) prescribes the following additional matters which AEMO must take into account in determining the *system strength requirements*:

(a) the combination of *three phase fault levels* at each *system strength node* in the *region* that could reasonably be considered to be sufficient for the *power system* to be in a *secure operating state*;

(b) the maximum *load shedding* or *generation shedding* expected to occur on the occurrence of any *credible contingency event* or *protected event* affecting the *region*;

(c) the stability of the *region* following any *credible contingency event* or *protected event*;

(d) the risk of *cascading outages* as a result of any *load shedding* or *generating system* or *market network service facility* tripping as a result of a *credible contingency event* or *protected event* in the *region*;

(e) additional contribution to the *three phase fault level* needed to account for the possibility of a reduction in *the three phase fault level* at a *system strength node* if the *contingency event* that occurs is the loss or unavailability of a *synchronous generating unit* or any other *facility* or service that is material in determining the *three phase fault level* at the *system strength node*;

(f) the stability of any equipment that is materially contributing to the *three phase fault level* or *inertia* within the *region*; and

(g) any other matters as AEMO considers appropriate.

2.3.3. Stable *voltage* waveform description

The NER envisage that the meaning of stable *voltage* waveforms set out in this Methodology will supplement the criteria already in NER S5.14.1(c), which in turn reflect those in the system standard in NER S5.1a.9(b). These are already summarised above in section 2.1.1, for the efficient level of system strength.

3. System strength nodes

This section provides a definition of *system strength nodes* (SSNs), the criteria against which AEMO will consider node creation, and the process for node declaration. This is intended to meet NER 5.20.6(f)(1) and, in relation to SSNs, NER 5.20.6(f)(2)(iii).

3.1. Definition of system strength nodes

An SSN is a physical location on the *transmission network* of an SSSP, at which AEMO must determine *system strength requirements* and apply those requirements for *power system security* purposes under Chapter 4 of the NER.

The SSNs are also used for the application of *system strength locational factors* (SSLF) and system strength charges (SSC) for the purposes of the SSSP's obligations under NER S5.1.14.[2].

An SSN declaration will identify the specific *network* busbar, the *voltage* level, the start date from when the declaration applies, and the end date for the node if applicable[3]. Table 2 provides an example of a node declaration.

Table 2 Example system strength node declaration

Node name	Voltage and busbar	SSSP	Start date	End date
Darlington Point	330 kV Bus A	Transgrid	1 July 2018	NA

3.2. Selection of system strength nodes

AEMO will apply engineering, market and policy judgement to select an appropriate set of SSNs for each *region*. This will consider general principles for factors affecting overall SSN selection for a *region*, as well as a set of criteria to inform individual node selection.

Figure 2 outlines the principles to guide overall SSN selection for a *region*.

Figure 2 General principles for overall system strength node selection

- Collectively the nodes should allow a reasonable representation of the overall *system strength requirements* of the *power system*. It is important to note, however, that system strength is needed throughout the *power system*, not just at SSNs.
- SSNs must be declared within the *transmission network* of an SSSP. It is not possible to declare a node in a *transmission network* which is not owned by a SSSP, or any *distribution network*[4]. However, SSSPs can seek *system strength services* from a variety of sources, including non-*network* options, or from other transmission or distribution networks.
- The total number of SSNs declared per *region* must be limited to a level that is practicable having regard to the effort required to derive *system strength requirements* for each node, and to facilitate holistic *network* planning.

[2] SSLFs are calculated in accordance with the methodology in the System Strength Impact Assessment Guidelines (SSIAG).

[3] AEMO expects that the start and end dates for SSNs will apply for the purpose of SSSPs' provision of services to meet the *system strength requirements* at the node, as well as for connecting parties' understanding of the application of the SSLF and SSC consistent with the SSIAG.

[4] NER 5.20C.1(a)

- SSN selection will have regard to locations where centralised and coordinated SSSP investment or service provision is expected to be most efficient[5]. However, SSSPs need not necessarily deliver *system strength services* at the exact SSN locations.
- SSNs can be selected from future *transmission network* projects, for example *actionable ISP projects*.

AEMO will consider various locations in an SSSP's *transmission network* against the criteria in the following subsections when selecting individual SSNs. If one of the criteria is substantively met for a location, AEMO will consider declaring it as an SSN, but this will be tested against the overall factors affecting SSN selection across a *region*. AEMO will not set specific thresholds for SSN declaration.

3.2.1. Criterion 1 – Projected IBR connections

AEMO will assess whether existing SSNs give sufficient coverage of projected IBR connection and operation, by:

(a) Taking the forecast IBR projections in the NEM (see section 6 for details).

(b) Comparing the location of the projected IBR with the existing SSNs.

(c) Considering declaration of a new node, if a significant amount of forecast IBR is electrically far from the existing SSNs (Figure 3 provides potential assessment of electrical closeness).

A new node may be located at a 'central' point for the bulk of the new *generation* so that the electrical distance to the new node for the new IBR connecting is minimised. AEMO expects that renewable energy zones (REZs) referenced in the *Integrated System Plan* (ISP) are likely to be strong indicators of where a new node would be sensible.

This criterion is inter-related with the SSIAG[6] because node selection will impact SSLFs and SSCs for newly-connecting IBR.

Figure 3 shows an example of an assessment methodology for this criterion.

Figure 3 Potential assessment of IBR electrical proximity to system strength nodes

A simple equivalent impedance study is likely to be used to determine if a particular bus is electrically close to an existing SSN. The methodology is given below:

a) A system normal configuration with all *transmission network* elements in service will be used the basis for this analysis[7].
b) Switch out all in service *generating systems* in the model.
c) An ideal fault level source of size equivalent to the minimum *three phase fault level* at the SSN is placed at the SSN closest to the particular bus.
d) Apply a fault at the particular bus of study and record the equivalent Thevenin impedance from this bus to the only source of fault level – the source placed at the SSN. If the equivalent impedance is below an indicative threshold (for example 5%), the particular bus is considered electrically close to the SSN.
e) The threshold should be chosen as an estimate of the 'range' of effectiveness of system strength remediation beyond which the system strength remediation effects could diminish. In reality, this value will be subject to local *network* characteristics, and AEMO will consult on this value where appropriate.
f) Buses within this threshold radius may be considered as having an appropriate SSN. Buses outside this radius may be considered for declaration of a new node if they meet the criteria for node selection.

[5] AEMC, 2021, *Rule Determination National Electricity Amendment (Efficient Management of System Strength on the Power System) Rule 2021,* Available at https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2021/mass/second-stage/mass-draft-determination-2021.pdf?la=en. Page 17.

[6] See the System Strength Impact Assessment Guidelines for details. Available at (link)

[7] Excluding elements that are out of service as part of the system normal configuration, for example to maintain system security.

It is important to note that this is an RMS-based study that won't accurately demonstrate system strength phenomena in the *network*, it will just give an indication of close coupling subsystems in each *region*.

3.2.2. Criterion 2 – Projected change in synchronous machine operation

Retirement, decommitment or withdrawal of large *synchronous generating units* will significantly reduce system strength in the *power system*. Conversely, the installation of new synchronous machines, including *synchronous condensers* and *generation*, can be expected to significantly increase system strength in the *power system*.

Where a significant change in *synchronous* machine behaviour is expected, AEMO may need to select SSNs to monitor the impact of this change on *power system* requirements and declare *system strength requirements* accordingly. Section 6 provides some information about the modelling AEMO may use to inform this assessment.

3.2.3. Criterion 3 – Existing and future HVDC equipment operation

Similar to IBR, high *voltage* direct current (HVDC) *transmission network* assets typically need a sufficient amount of system strength available in the *power system* to operate stably. HVDC technologies might include assets such as HVDC underground or overhead *transmission* cables connecting two separate sections of the *power system*. AEMO may need to select SSNs to ensure a sufficient amount of system strength is available for existing or future HVDC equipment.

3.2.4. Criterion 4 – Other power system stability issues

A number of expected or unexpected additional *power system* stability issues relating to system strength could necessitate SSN creation. These could include, but are not limited to:

- System strength-related issues arising on the *distribution networks* connected to the SSSP's *network*. This is expected to include ensuring correct protection system operation for *distribution network equipment* and *connected plant*.
- Emerging understanding of *power system* equipment system strength requirements that may emerge as the Australian electricity system transformation continues at pace and as technological innovation continues.

3.3. Process for node declaration

SSN selection will affect where SSSPs focus their delivery of *system strength services*, and will affect the SSLFs and SSCs calculated in accordance with the SSIAG.

AEMO will undertake joint planning with SSSPs each year to seek input on SSN selections in advance of the annual December publication of the *System Strength Report*. In addition, AEMO will welcome feedback on the annual *System Strength Report,* for potential incorporation the following year,

4. Minimum fault level methodology

This section provides AEMO's assessment process for determining the minimum *three phase fault level* for an SSN, including modelling and analysis methodologies and the matters taken into account, which must include the latest ISP and ESOO, and the matters listed in NER 5.20.6(e). This is intended to meet and NER 5.20.6(f)(2)(iii) in relation to minimum *three phase fault levels*.

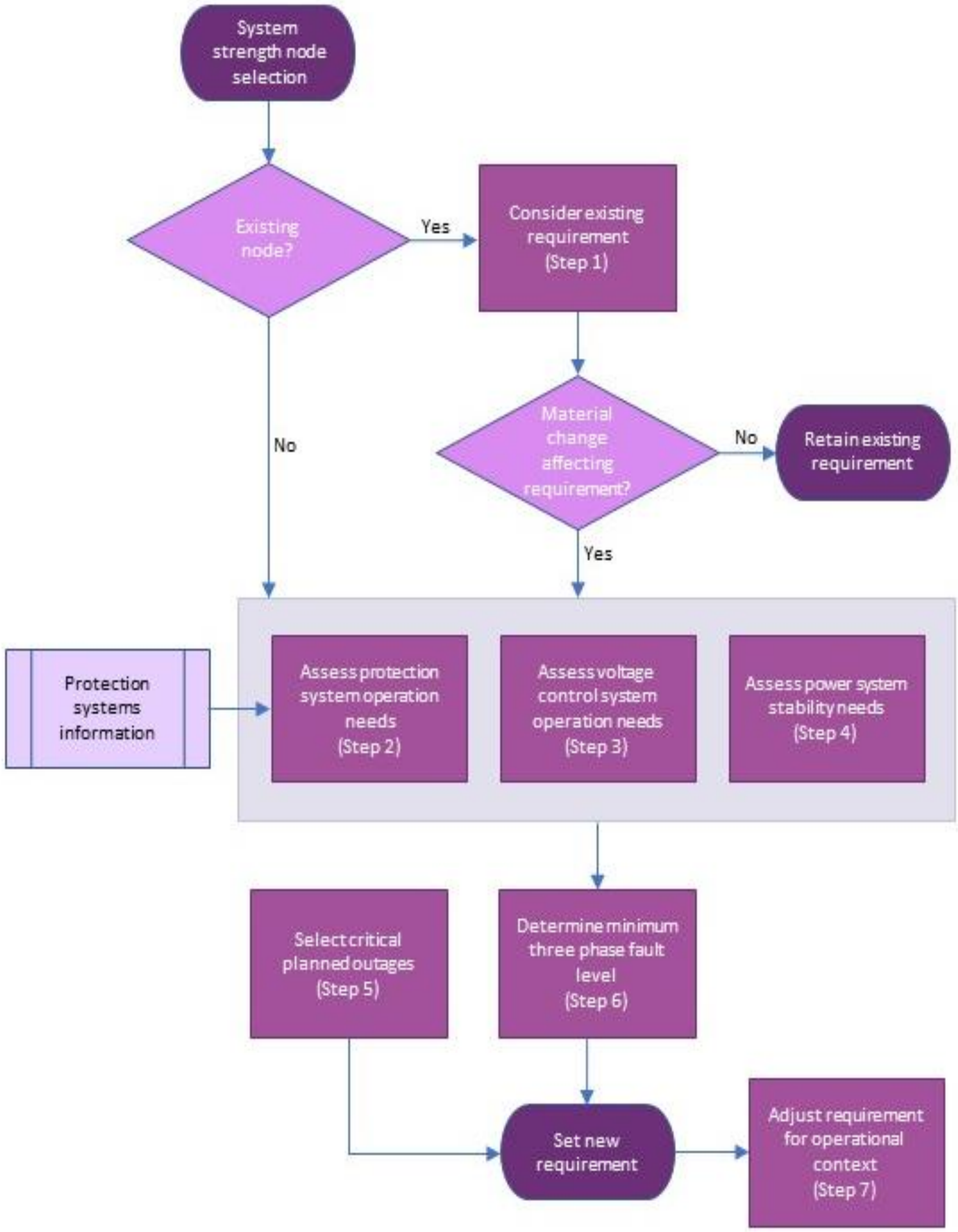
In this section:

- Table 3 lists the key steps in the assessment process and provides links to further detail.
- Figure 4 provides an overview of the process.
- Sections 4.1 to 4.7 provide the details for the key steps in the process.
- Section 4.8 notes the transitional arrangements for shortfall declarations.

Table 3 Key steps in minimum fault level requirement assessment process

Step		Relevant section
1.	**Consider existing requirements**	Section 4.1
2.	**Assess protection system operation needs**	Section 4.2
3.	**Assess voltage control system operation needs**	Section 4.3
4.	**Assess power system stability needs**	Section 4.4
5.	**Select critical planned outages**	Section 4.5
6.	**Determine minimum three phase fault levels**	Section 4.6
7.	**Adjust requirements for application in the operational context**	Section 4.7

Figure 4 Minimum fault level requirement assessment process



4.1. Step 1 – Consider existing requirements

For existing SSNs, AEMO will take the existing requirement as a starting point for the minimum *three phase fault level* assessment.

It is assumed that the existing minimum *three phase fault level* requirement at an SSN is sufficient to meet NER S5.1a.9(a) for the existing[8] *networks* and *Network Users' facilities* under system normal conditions, including for credible contingencies and *protected events*.

In particular, existing requirements are taken to have been set to ensure a secure *power system* for system normal, and to allow correct operation of *protection systems*[9].

As part of the annual system strength assessment process, AEMO will consider whether there has been a material change to the *power system* that would affect the minimum *three phase fault level* requirement at the SSN, or if such a material change is expected within the ten-year forecasting period. Figure 5 describes potential material changes that could affect the required minimum *three phase fault level*.

Figure 5 Potential material changes that could affect required minimum three phase fault level

Any change to the *power system* or *connected* equipment that is likely to significantly impact existing or projected fault levels at an existing SSN could be material. For example:

- *Network augmentation* local to the SSN.
- Retirement, withdrawal or decommitment of *synchronous generation* in the *region*.
- New or amended government policy that could affect fault levels in the *power system*.
- Technological developments becoming sufficiently progressed or certain, for example protection scheme design which is less reliant on fault current, or relevant and large-scale changes to inverter operation.

If a material change is not identified, the existing minimum *three phase fault level* should be maintained. If a material change is identified, AEMO will reassess the minimum *three phase fault level* for the relevant SSN under this Methodology.

4.2. Step 2 – Assess protection system operation needs

The minimum *three phase fault level* at an SSN must be set to ensure correct operation of *protection systems* of *transmission* and *distribution networks* and *Network Users* in accordance with NER S5.1a.9(a). In order to meet this criterion for determining the *system strength requirements*, AEMO relies on information from SSSPs about fault levels required at each SSN to ensure correct operation of both primary and backup *protection systems* for those *networks* and users.

For these purposes, the baseline assumption is that the minimum *three phase fault levels* determined at various nodes as at 30 November 2022 are sufficient to meet the standard in NER S5.1a.9(a) for *protection systems* in operation at that time.

SSSPs should advise AEMO of new or updated operating requirements or limits to facilitate correct operation of *protection systems,* as the SSSP becomes aware of changes. This step in the Methodology provides an opportunity for AEMO to consider whether any such changes are likely to materially affect the *three phase fault level* at a SSN, requiring a reassessment of the minimum *three phase fault level*.

---

[8] 'Existing' refers to the *networks* and *connected facilities* accounted for at the time when minimum *three phase fault level* was last assessed by AEMO, assume compliance with their *performance standards*.

[9] AEMO may reduce minimum levels if SSSPs advise that protection systems can operate at lower levels.

AEMO expects that SSSPs will conduct timely joint planning with the NSPs for its connected *transmission* and *distribution networks* in order to provide this advice to AEMO when necessary, and based on the best available information.

AEMO will continue to undertake joint planning with SSSPs to understand emerging practices in protection scheme design and any opportunities for re-design to accommodate a lower fault level power system environment.

4.3. Step 3 – Assess voltage control system operation needs

The minimum *three phase fault level* must be set so as to enable stable operation of *voltage control systems*, such as *capacitor banks*, *reactors* and dynamic voltage control equipment. AEMO will assess these needs in accordance with the applicable Australian Standard (AS/NZ 61000.3.7:2001) which provides voltage step change limits for switching of *capacitor banks* or *reactors* while remaining stable.

To assess fault level requirements of SSNs near static reactive control devices, AEMO will apply the following formula:

$$Minimum\ Three\ Phase\ Fault\ Level\ (MVA) = Capacitor\ bank\ or\ reactor\ bank\ rating\ (MVAr) \div \Delta\, V(pu)$$

This will provide an indication as to whether following the switching of a large reactive device the *three phase fault level* at the SSN would be sufficient to ensure the *voltage* step change criteria be maintained.

There may be instances in the future where case by case use of detailed power system analysis can be justified as new technologies are introduced into the power system.

4.4. Step 4 – Assess power system stability needs

After considering protection system and *voltage* control equipment requirements, AEMO will consider the minimum fault level requirements for *power system* stability at the SSN over the coming decade.

For this purpose, AEMO interprets the phrase '*power system* to remain stable' in NER S5.1a.9(a)(3) to mean 'stable conditions' consistent with the definition of a *satisfactory operating state* under NER 4.2.2(f), which must be maintained following any *credible contingency event* or *protected event*.

4.4.1. Power system stability study assumptions

AEMO will apply the following *power system* assumptions to consider minimum *three phase fault level* requirements for *power system* stability :

(a) AEMO contingency studies will start from a system normal configuration with all *transmission network* elements in service[10]. Individual *generating units* may be out of service as per expected market behaviour. From this starting point AEMO will assess whether the system can be maintained in a *secure operating state*. This entails assessing whether the system will remain satisfactory from a stability perspective and, on a case by case basis, can be returned to a secure operating state within 30 minutes of a *credible contingency event* or *protected event*.

(b) AEMO contingency studies will assume reasonable worst-case *power system* conditions for the issues being assessed. For example, if a stability issue is most severe in minimum demand periods (for example in the middle of the day during a spring weekend), AEMO will study expected *power system* conditions at those times.

[10] Excluding elements that are out of service as part of the system normal configuration, for example to maintain system security.

(c) When assessing the ability of the system to return to a *secure operating state* within 30 minutes of a *credible contingency event* or *protected event*, AEMO may assume the initial event occurs during reasonable worst-case *power system* conditions for the issues being assessed. AEMO's assessment may factor in the probability of the event occurring during these conditions and the options available for its resolution.

(d) AEMO will apply the planning assumption that no *transmission line* in a *region* may be switched out of service before a *credible contingency event* or *protected event* in order to meet system security and reliability obligations such as addressing high *voltage* levels. Exceptions to this approach may include plausible *network* conditions which permit the assumption that one or more lines may be switched in a *region* (or sub-*region*), informed by operational experience of AEMO and the relevant TNSP.

(e) EMT analysis will be used where reasonably practicable, particularly for the near term where agreed generator models (accepted by the relevant *Connecting NSP* and AEMO) are are available[11]. For the longer term and where EMT analysis is not reasonably practicable, RMS analysis and other available methods will be used[12].

(f) For assessing requirements over the coming decade, AEMO will consider future *power system* conditions consistent with the most recent ISP and ESOO wherever possible, and consistent with the approach described in section 6. Generator technologies and economic drivers are evolving, and these studies will use the inputs and assumptions applied in the ISP and ESOO to inform analysis on minimum *three phase fault level* requirements. An example of this would be the adaptation of coal generators to switching off during low price and/or any other relevant conditions.

(g) *Expected closure years* and announced generator retirements will be considered in the assessment, and AEMO may use the outcomes of the ISP and ESOO (or other reliable and verifiable information that may become available) to inform studies of the potential future need for system strength for the risk of early or delayed *plant retirements* within the forecast period that have not been announced.

(h) *Interconnector* transfers will be assumed at *power transfer* levels appropriate to the given study bounded by the maximum transfer limits, including any forecast increases in those transfer limits arising from the completion of relevant projected *power system* projects (*network* or non-*network*).

(i) Plausible demand levels will be assumed based on AEMO's most recent demand forecasts at the time of assessment, with studies conducted at various demand levels appropriate to the issue being assessed. Loads will be modelled in a manner consistent with the type of study to be performed for determining the minimum *three phase fault level* requirement.

4.4.2. Relevant power system stability considerations

For the purposes of minimum *three phase fault level* analysis, in assessing whether the *power system* will remain stable following a *credible contingency event* or *protected event*, AEMO will consider the following[13] in both the planning and operational timeframes where possible:

---

[11] It is expected that these will only be available for plant connecting in 1-2 years' time, not the entire 10-year horizon required.

[12] For example, high-level metrics could include Weighted Short Circuit Ratio (WSCR), Available Fault Level (AFL), or calculation the instantaneous change in *network voltage* magnitude and angle with reference to small perturbations in ΔP and ΔQ at a given node in the *power system* (for example use of the TYSL function in PSS®E). Another approach may be to approximate the required fault level for the switching of reactive plant.

[13] *Power system* stability guidelines, Section 2.1, Page 13 available at: https://www.aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/power-system-stability-guidelines.pdf

(a) the matters listed in NER 5.20.6(e);

(b) the requirements in NER schedule 5.1, in particular NER S5.1.8, namely that, following any relevant event:

   (i) the *power system* should remain in synchronism;

   (ii) damping of *power system* oscillations should be adequate; and

   (iii) *voltage* stability criteria should be satisfied.

(c) the *system standards* set out in NER schedule 5.1a relating to:

   (a) *frequency* (NER S5.1a.2);

   (b) *power system* stability (NER S5.1a.3); and

   (c) power frequency *voltage* (NER S5.1a.4); and

(d) any other requirements in the NER and AEMO's Power System Stability Guidelines relating to *power system* stability.

4.5. Step 5 – Select critical planned outages

There may be some instances in the NEM where planned *network outages* to maintain critical *power system* equipment will reduce system strength to a level that could cause *power system security* or market efficiency issues.

For the purposes of NER 5.20.6(f)(3)(iii), AEMO will compile a list of critical planned *outages* for each SSN alongside its annual determination of minimum *three phase fault levels*. SSSPs are expected to incorporate the impact of these critical planned *outages* into their planning to ensure the *minimum three phase fault level* is maintained at each impacted SSN for the duration of each relevant *outage* in accordance with the *power system security* principles. For example, this may be achieved through provision of *system strength services*, provision of operational limit advice or operational contingency plans to AEMO, or a combination of measures[14].

This section provides the impact and duration criteria against which AEMO will select any critical planned *outages* for this purpose.

4.5.1. Impact criteria

To be considered critical, a planned *outage* should materially reduce the availability of system strength at an SSN to the point where power system security or market efficiency is in question. Such outages would involve:

(a) *outages* of alternating current *interconnectors* or other material *transmission elements* that support *inter-regional power transfer*;

(b) *outages* of major *transmission elements* that materially reduce *intra-regional power transfer*, including elements connecting major *generation* centres or system strength sources to the remainder of a *region*;

(c) *outages* that remove key *reactive plant* from service; or

[14] See AEMC, Efficient management of system strength on the power system, Rule determination, 21 October 2021, at page 98.

(d) *outages* having a security or market impact that is considered to be critical by AEMO and the relevant SSSP in joint planning processes (e.g. outages resulting in a large quantity of VRE being curtailed).

4.5.2. Duration criteria

To be considered critical, a planned *outage* must meet or exceed the threshold criteria in Table 4 for both total duration and recall period, where:

(a) the duration of the outage is the total time it takes to carry out the planned works on the relevant *power system* element and return it to service, from the time it is first taken out of service; and

(b) the recall period is the longest time it takes to return the relevant element to service at any time during the *outage* (regardless of the status of the planned work) should it be required for *power system security* purposes.

Table 4 Outage duration thresholds to be considered 'critical'

Outage duration type	Outage duration threshold
Total duration of the planned outage	1 hour
Recall period	30 minutes

4.6. Step 6 – Determine minimum three phase fault levels

Following completion of Steps 2, 3 and 4, AEMO will determine the final minimum *three phase fault levels* for each SSN. The requirement may vary over the ten-year horizon. The requirement will typically be the highest fault level value derived through the previous steps.

Consistent with the objective of the NER system strength framework to efficiently maintain adequate system strength with minimal interventions[15], AEMO will incorporate prudent planning margins where appropriate to acknowledge technological and market uncertainty and modelling inaccuracies.

4.7. Step 7 – Adjust requirements for application in the operational context

The minimum *three phase fault levels* set by AEMO each year must be applied by AEMO in operating the *power system* for the following year (NER 5.20C.1(a)(1)).

The minimum *three phase fault levels* determined as part of the *system strength requirements* must be adjusted to account for actual system conditions before they can be applied for *power system security* purposes in operational timeframes. For example, required fault levels may be reduced at night due to the lack of PV *generation*, or in Tasmania during outages of Basslink. In addition, adjustments may be required to accommodate the SSSP outcomes for critical planned *outages* selected in Step 5. Accordingly, TNSPs must provide AEMO with relevant operational and limit advice that accounts for minimum fault levels in a range of operating conditions (e.g. to ensure correct operation of *protection systems*).

[15] AEMC, Efficient Management of system strength on the power system, Rule determination, 21 October 2021, available at https://www.aemc.gov.au/sites/default/files/2021-10/ERC0300%20-%20Final%20determination_for%20publication.pdf

The *system strength requirements* are assessed for normal operating conditions allowing for a *credible contingency event* or *protected event*. For *power system security purposes*, operational and limit advice must also accommodate the impact of prior *network outage* conditions on fault level requirements.

4.8. Transitional arrangements for shortfall declarations

This Methodology provides the process for assessment of system strength standards against which SSSPs must deliver adequate levels of system strength for the NEM from 1 December 2025. Before this date, AEMO is able to declare system strength shortfalls against the standard. SSSPs must address any system strength shortfalls declared by AEMO for this interim period.

To declare a system strength shortfall, AEMO will assess fault level projections for the period to 1 December 2025, will compare the fault level projection results against the minimum fault level requirement for the relevant system strength node, and will form a reasonable opinion of the likelihood of the shortfall existing. AEMO will consider all relevant factors in forming this reasonable opinion, including but not limited to market modelling results, market trends and insights, and relevant government policy announcements. AEMO will declare system strength shortfalls in the annual System Strength Report, or in ad hoc notices throughout the year if required.

5. Stable voltage waveforms

This section describes what is meant by 'stable *voltage* waveforms', and the matters that SSSPs may consider in assessing what is required to achieve stable operation of projected IBR, typically referred to as the efficient level of system strength. This is intended to meet NER 5.20.6(f)(4). The related topic of how AEMO will forecast future IBR *connections* and operation is considered in section 6.

5.1. Description of stable voltage waveforms

AEMO is required to describe in the SSRM what is meant by 'stable *voltage* waveforms' such that: in steady state conditions *inverter based resources* and market *network* service facilities do not create, amplify or reflect instabilities; and avoiding *voltage* waveform instability following any *credible contingency event* or *protected event*.

SSSPs must use reasonable endeavours to plan, design, maintain and operate their *transmission network*, or make system strength services available to AEMO, such that the description in the SSRM is satisfied.

The four criteria below comprise AEMO's description of a stable *voltage* waveform to facilitate the operation of projected *inverter based resources* and *market network service facilities* for the purposes of NER S5.1.14(b) and (c). The description is made up of four key criteria which should be met under both pre- and post-contingency conditions.

This description is intended to focus on the resilience of the *voltage* waveform to instabilities which are particularly relevant for the integration of *inverter based resources*. In addition, this description is designed to facilitate a shift away from considering *voltage* waveform stability largely as an outcome of fault level contribution.

5.1.1. Criterion 1 – Voltage magnitude

The positive-sequence RMS *voltage* magnitude at a *connection point* does not violate the limits in the operational guides for the relevant *network*.

Operational guides agreed between TNSPs and AEMO that include *voltage* metrics such as limits on *voltage* excursions, and the permissible *voltage* step change created by reactive power injection or absorption, are used to assess this criterion.

5.1.2. Criterion 2 – Change in *voltage* phase angle

Change in the *voltage* phase angle at a *connection point* does not exceed 45 electrical degrees following any *credible contingency event* or *protected event*.

For a strong system, phase angle changes after injection or absorption of active power should be relatively small. A large phase angle change at a given *transmission* bus, from pre-contingency to post-contingency conditions, indicates a weak system.

45 electrical degrees has been selected as a reasonable threshold to measure the change in *voltage* phase angle, as most sync check relays are set between 30 and 60 degree phase angle. This is not a hard limit, but is used to monitor for large phase angle changes in the *power system* between pre- and post-contingency conditions, so that the *power system* remains operable while accommodating efficient levels of IBR interconnection.

5.1.3. Criterion 3 – *Voltage* waveform distortion

The three-phase instantaneous *voltage* waveforms at a *connection point* are close to 50 Hz, for pre- and post-contingent conditions, with *voltage* waveform distortion within acceptable levels.

Whether the voltage waveform is 'close' to 50 Hz is assessed with reference to NER Schedule S5.1a. Acceptable *voltage* waveform distortion should be consistent with NER S5.1a.6.

TNSPs and DNSPs may already have existing contracts, background harmonics, or power quality limitations which may need to be exempted from compliance with this criterion.

5.1.4. Criterion 4 – *Voltage* oscillations

Any undamped steady-state RMS *voltage* oscillations anywhere in the *power system* should not exceed an acceptable planning and connection 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 Methodology, these thresholds are in discussion in the Power System Security Working Group and Power System Modelling Reference Group. A proposed threshold for acceptable oscillations, between 0.1% and 0.5% peak-peak RMS *voltage*, is being considered.

5.2. Analysis of stable voltage waveforms

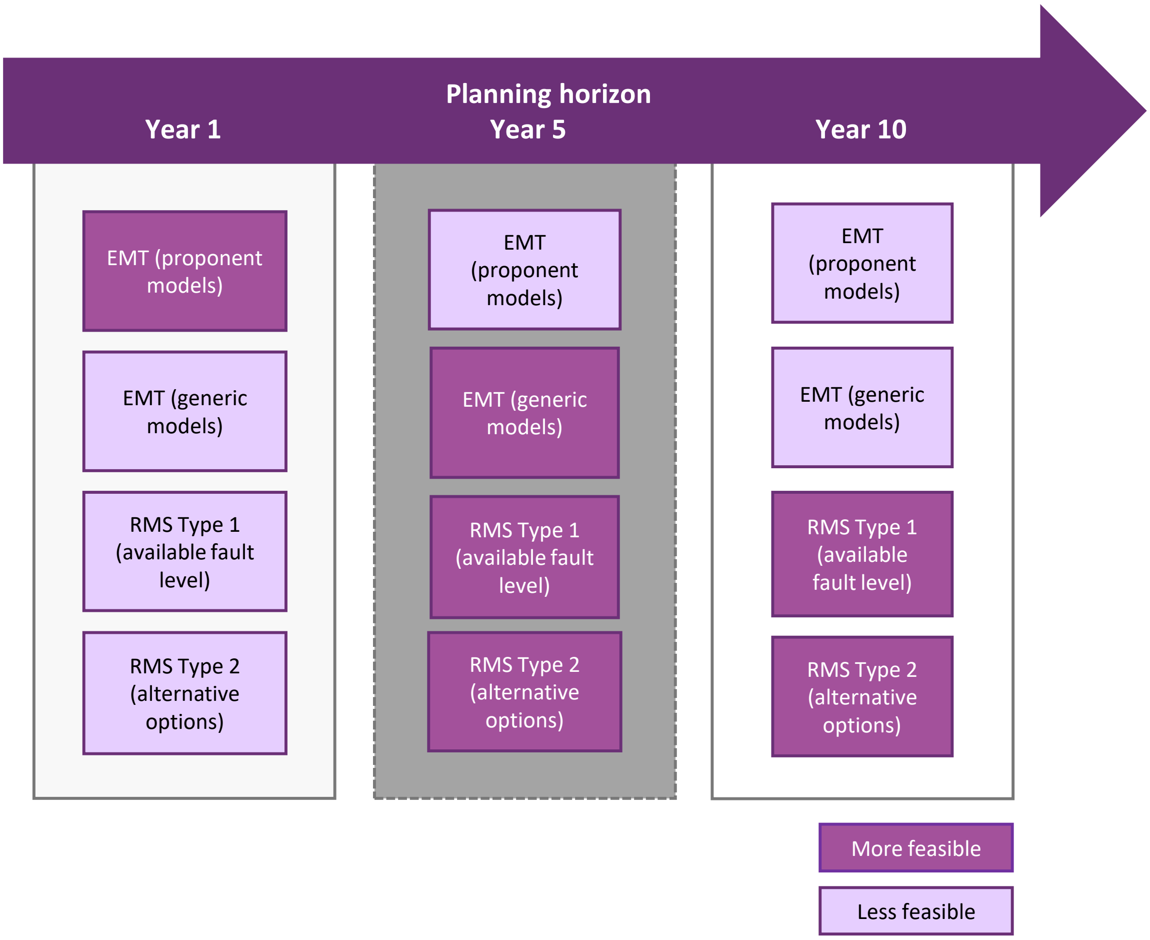
Assessment of stable *voltage* waveforms over the ten-year horizon considered by this Methodology will depend on the availability (or otherwise) of accurate models for power system equipment for the time period being studied.

The use of electromagnetic transient (EMT) analysis is preferred for power system stability studies to identify system strength issues, such as control interactions between IBRs, in time horizons where network and generator models are precise (e.g. 1 to 2 years). However, EMT simulations are not fit-for-purpose in long-term planning studies because their accuracy is limited by the use of generic models for conceptual projects.

The use of steady-state analysis via root mean square (RMS) analysis tools (such as, short-circuit based calculations and balanced switching solution studies) or similar methods will provide results for periods where precise EMT models are not available.

Figure 6 illustrates the proposed analytical options for SSSPs when considering how to assess maintenance of stable *voltage* waveforms for the projected IBR over the 10-year forecasting period.

Figure 6 Determining best assessment for analysing stable voltage waveforms



5.2.1. Use of EMT modelling

If there are accurate EMT models in the timeframe for when the IBR is to connect, they will be incorporated into EMT-based analysis and will be used to investigate if the *network* preserves the criteria of a stable *voltage* waveform as outlined in section 5.1 and NER clause S5.1a.9(b).

If these accurate models do not exist, but the forecasted connection is defined sufficiently that a generic EMT models are appropriate, they will be incorporated into EMT-based analysis and will be used to investigate if the *network* satisfies the criteria of a stable *voltage* waveform as outlined in section 5.1 and NER S5.1.14(c).

5.2.2. Use of RMS modelling

Whilst more accurate than RMS, EMT studies require more complex models than steady state or simplified dynamic models. This complexity not only increases computational burden but these time-intensive studies for future *network* without accurate models can become increasingly imprecise.

Determining the level of system strength required to ensure stable *voltage* waveforms from plant that has not been committed, with no EMT models and no appropriate generic models, may be able to be approximated with RMS-based analysis tools. The following options are suitable for assessing the future *network* without EMT models:

(a) *Available fault level* calculation, an RMS-based proxy study method.

(b) Simplified switching studies to test *voltage* robustness of a system.

(c) Alternative analysis options which may emerge over time.

When performing these RMS-based approximation studies, *region*al threshold values may be used to infer stability of the *voltage* waveform – that is, above the threshold or below it, it is reasonable that *voltage* waveform stability is likely or unlikely respectively.

6. Future system forecasts

AEMO will forecast generator connection and operation into the future, as well as *power system* augmentations, for the purpose of assessing both the minimum *three phase fault levels* and determining the inputs for SSSPs to plan to meet the efficient level of system strength.

This section explains the assumptions and methodology AEMO will use for forecasting the future number, size, type, operational profile and location of *facilities connecting* to the *power system* and *facilities* already connected to the *power system*. This is intended to meet NER 5.20.6(f)(2)(ii), as well as inform the preparation of the ten-year forecasts for minimum *three phase fault levels*.

In this section:

- Section 6.1 notes the use of the ISP as the basis for the future system forecasts.
- Section 6.2 details the projection of generator connections, for the purposes of the efficient level of system strength.
- Section 6.3 describes where deviations from the ISP may occur.
- Section 6.4 covers other forecasting matters, such as projections for connection of new loads.

6.1. Applying Integrated System Plan forecasts

AEMO will take the following steps when applying ISP forecasts for system strength standard assessments.

6.1.1. Scenario selection

As part of the ISP process, AEMO selects the 'most likely' energy transformation scenario at the time of the draft and final ISP publication. AEMO will in general apply the 'most likely' scenario from the most recently published ISP (either draft or final) at the time AEMO is determining the *system strength requirements* each year.

Where there is justification to apply a scenario which is not the current 'most likely' scenario AEMO will provide its reasoning in the System Strength Report, and will consult with SSSPs before applying a scenario which is not the current 'most likely'.

6.1.2. Capacity outlook

Capacity outlook modelling undertaken for the ISP reveals long-term outcomes for generation expansion and retirement, transmission expansion, storage, and dispatch options, in all ISP scenarios.

AEMO will use ISP capacity modelling outputs for the selected scenario as inputs to the assessment of the minimum and efficient levels of system strength for each SSN, and may conduct sensitivities for the latter part of the 10-year horizon based on a number of ISP scenario results.

Future retirement, decommitment, withdrawal and dispatch of synchronous generators will be relevant when assessing forecasts for minimum *three phase fault levels* for the coming decade, from the perspective of *power system* stability in particular, as will projections for *transmission* expansion and storage projects.

Forecast IBR *connections* and operation are required for the purposes of the efficient level of system strength. AEMO will forecast the location of the new IBR relative to an ISP REZ or an ISP sub-*region* of the NEM, and will map these to an appropriate SSN, consistent with 5.20C.1(c)(2)(ii), without accounting for capacity factors or any coincidence factors.

6.1.3. Future *network* developments

Network augmentation can improve system strength and, consequently, support more IBR. Network (or non-network) augmentation projects identified as committed, anticipated or actionable in the ISP within the 10-year outlook period will be included in the assessment. In addition, network augmentations that would be required to feasibly connect the forecast amount of IBR, will be included when AEMO is conducting system strength standard assessments.

However, the ISP does not necessarily identify all *network* projects that are committed or anticipated. In this case, AEMO will draw on information in the NSPs' annual planning reports. Additionally, AEMO will draw on information from annual planning reports for any reconfiguration or retirement of *network* plant.

6.2. Form of IBR projections

At a minimum of yearly intervals (and more frequently if warranted and practicable) AEMO intends to provide IBR projection information to SSSPs comprising, for each forecast year of connection, the technology type, level (in MW), ISP location and SSN. An example of this is shown in Table 5.

Table 5 Example IBR projection list

Year	Technology	Amount	ISP location	Allocated SSN
2024	Wind	100 MW	Central-West Orana	Armidale 330 kV
2024	PV	200 MW	New England	Armidale 330 kV
2024	Battery	100 MW	South West NSW	Newcastle 330 kV
…				

Note, the specific *connection points* (or connection bus) of new IBR are expected to be developed through joint planning with the SSSPs and other relevant NSPs.

6.3. Departures from the ISP

AEMO may depart from ISP future system forecasts when preparing the system strength standards, in cases where updated market modelling is available (for example from the ESOO), where a material market, policy or technology change has occurred but has not led to an ISP Update. AEMO will consult with SSSPs and, where appropriate, other *Registered Participants* to identify where a deviation from the ISP results is warranted.

6.4. Other matters

6.4.1. Forecasting inverter-based loads (IBL)

IBL will need to be accounted for when assessing system strength standards for the 10-year outlook. AEMO will work with relevant SSSPs through joint planning to understand any significant IBLs that could be connected in each *region* that may need to be incorporated into the forecasts for system strength purposes. AEMO may also gather load information from other sources.

6.4.2. Technical capability of IBR

AEMO considers that references to 'type' in NER clauses 5.20.6(f)(2)(ii) and 5.20.6(f)(4) to refer to technical characteristics such as grid following or grid forming for IBR, or *asynchronous* versus *synchronous* connection for pumped hydro projects. As the vast majority of new *connections* in the ISP are development opportunities, and not specific anticipated or committed projects[16], some assumptions about the class of facilities need to be made.

AEMO intends to undertake joint planning each year as it prepares its *System Strength Report*, including consulting with SSSPs about relevant technical capability of future plant. In general, AEMO considers it will be appropriate to make conservative assumptions about technological innovation in the near term, and less so towards the latter part of the planning outlook, subject to evaluation of available evidence about technical capabilities and market trends.

In view of the pace of technological innovation and changing market conditions, this Methodology does not include prescriptive assumptions about those matters.

[16] Definitions of *committed* and *anticipated* generator projects are provided in the Generator Information updates available on the AEMO *Generation* Information Page, accessible via https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nemforecasting-and-planning/forecasting-and-planning-data/*generation*-information.

Version release history

Version	Effective date	Summary of changes
N/A	N/A	**Draft issued for consultation on 29 July 2022.**
1.0	1 July 2018	First issue