INTERIM SYSTEM STRENGTH IMPACT ASSESSMENT GUIDELINES

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AUSTRALIAN ENERGY MARKET OPERATOR

VERSION RELEASE HISTORY

Version	Effective Date	Summary of Changes
1	17 Nov 2017	First Issue
2	26 Mar 2018	Section 5.3.3 amended to clarify treatment of other plant.

IMPORTANT NOTICE

This document includes the interim system strength impact assessment guidelines made by AEMO under clauses 11.101.2 and 4.6.6 of the National Electricity Rules, as at 17 November 2017. It also provides information about the process and reasons for AEMO's determination of the interim guidelines.

The interim system strength impact assessment guidelines have effect only for the purposes set out in the National Electricity Rules. The Rules and the National Electricity Law prevail over the interim guidelines to the extent of any inconsistency.

ACRONYMS

Acronym	Meaning
AC	Alternating Current
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
CIGRE	International Council on Large Electric Systems
EMT	Electromagnetic Transient
EMTDC™	Electromagnetic Transient including Direct Current
ERCOT	Electric Reliability Council of Texas
FACTS	Flexible AC Transmission Systems
GPS	Generator Performance Standard
HVDC	High Voltage Direct Current
Hz	Hertz (cycles per second)
IEEE	Institute of Electrical and Electronics Engineers
kV	Kilo Volt
MNSP	Market Network Service Provider
MW	Megawatt
NEL	National Electricity Law
NEM	National Electricity Market
NEMOC	National Electricity Market Operations Committee
NEO	National Electricity Objective
NER	National Electricity Rules
NSP	Network Service Provider
PSCAD™	Power Systems Computer Aided Design
PSMRG	Power System Modelling Reference Group
PSS®E	Power System Simulator for Engineering
PV	Photovoltaic
RMS	Root Mean Square
RoCoF	Rate of Change of Frequency
SCR	Short Circuit Ratio
SIPS	System Integrity Protection Scheme
STATCOM	Static Synchronous Compensator
TNSP	Transmission Network Service Provider

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1. INTRODUCTION

1.1 Purpose

AEMO was required to determine interim system strength impact assessment guidelines (**interim guidelines**) by 17 November 2017, in accordance with clauses 11.101.2 and 4.6.6 of the National Electricity Rules (NER), as amended by the *National Electricity Amendment (Managing power system fault levels) Rule 2017 No. 10* (Fault Levels Rule)[1].

The interim guidelines are set out in sections 4 and 5 of this document. They provide an initial description of the principles and methodologies to be used when assessing the impact on the strength of the electrical system of a proposed new or modified generating system or market network service facility connection to the National Electricity Market (NEM).

The interim guidelines have been developed as a precursor to final guidelines that must be published by 1 July 2018. The final guidelines will need to be developed in accordance with the Rules consultation procedure (rule 8.9 of the NER).

1.2 NER defined terms

Terms that are defined in Chapter 10 of the NER have the same meanings when used in this document unless the context otherwise requires.

1.3 Document structure

Sections 1 to 3 of this document explain:

- The scope of the interim guidelines.
- The process and principles for development of the interim guidelines.
- How the interim guidelines should be applied.
- Considerations for the development of the final guidelines.

Sections 4 and 5 comprise the interim guidelines themselves.

1.4 Task force

The interim guidelines were determined by AEMO, supported by the work of a technical Task Force coordinated by the Power System Modelling Reference Group (PSMRG).

The PSMRG is a standing working group that reports to the National Electricity Market Operations Committee (NEMOC)[2].

1.5 Objectives

Clause 4.6.6(b) of the NER requires that the system strength impact assessment guidelines must:

1. *provide for a two-stage assessment process comprising:*
    - i. *a preliminary assessment to screen for the need for a full assessment; and*
    - ii. *a full assessment;*

[1] Available at: http://www.aemc.gov.au/Rule-Changes/Managing-power-system-fault-levels
[2] Available at: https://www.aemo.com.au/Stakeholder-Consultation/Industry-forums-and-working-groups/Other-meetings/NEM-Operations-Committee

2. *require the full assessment to be carried out using a power system model that is reasonably appropriate for conducting system strength impact assessments and applicable to the location on the transmission network or distribution network at which the facility is or may be connected and specified by AEMO from time to time for this purpose;*
3. *exclude from the assessment of an adverse system strength impact the impact on any protection system for a transmission network or distribution network;*
4. *provide guidance about the different network conditions and dispatch patterns and other relevant matters that should be examined when undertaking a full assessment;*
5. *specify the nature of the impacts that AEMO considers to be adverse system strength impacts and that must be avoided or overcome by undertaking system strength connection works or implementing a system strength remediation scheme in accordance with clause 5.3.4B;*
6. *provide guidance about the matters that must be considered when determining whether a connection or alteration will result in an adverse system strength impact;*
7. *include if applicable any thresholds below which an impact may be disregarded when determining the need for a system strength remediation scheme or system strength connection works under clause 5.3.4B; and*
8. *provide general guidance about options for system strength remediation schemes and system strength connection works.*

1.6 Scope of interim and final guidelines

At the time of producing this report, AEMO is aware of over 100 connection applications being progressed through the various stages of the connections process, a far higher volume than experienced historically. The majority of these proposed connections are for non-synchronous generation, and many applicants wish to connect to parts of the network with a low system strength.

The interim guidelines therefore focus on system strength impact assessment for generation connections, with the aim of providing initial guidance in relation to the matters specifically listed in clause 4.6.6(b) of the NER, so that existing connection applications and enquiries can be progressed on a consistent basis until the final guidelines are determined, with effect from 1 July 2018.

The complexity and novelty of some of the issues involved may necessitate undertaking additional analysis and development, and expanding the coverage of the guidelines for the final version.

In addition to further analysis of these issues, the final guidelines will be informed by feedback from stakeholders on the interim guidelines and through the Rules consultation procedure to be conducted in the first half of 2018.

Matters related to the assessment and management of minimum levels of system strength under various generation dispatch patterns will be addressed in the final guidelines.

However, section 5.3.1 provides guidance on minimum quantity of synchronous generation which can be assumed by NSPs and connecting parties when undertaking system strength impact assessment.

2. APPLICATION AND INTER-DEPENDENCIES

2.1 Use of interim guidelines

The interim guidelines have been developed to provide initial guidance to:

- NSPs performing system strength impact assessments in accordance with the new requirements of clause 5.3.4B of the NER, and
- The proponents of new or modified generation connections to transmission and distribution networks in the National Electricity Market (NEM).

The NER require that a two stage assessment process is developed, whereby the potential system strength impacts of any new or modified Generator or Market Network Service Provider (MNSP) connection are considered at both the connection enquiry as well as the connection application stages. The two assessments are differentiated by the complexity of the analysis processes and corresponding data requirements.

Other parties may also wish to assess or review such analysis. The potential for this is clearly envisaged in clause 4.6.6(e) and (f) of the NER, whereby certain information must be provided to a Generator or Connection Applicant upon request, subject to satisfaction of other NER requirements including Chapter 8.6 (Confidentiality).

2.2 Relation to Power System Stability Guidelines

2.2.1 Current guidelines

AEMO's Power System Stability Guidelines[3] were published in May 2012. The guidelines were made under clause 4.3.4(h) of the NER, and provide guidance for NSPs and other network users on how to determine network limits associated with a range of power system stability phenomena.

The document provides guidance on appropriate system models, operating conditions, and assessment criteria that should be applied when undertaking stability assessments. They are intended to provide a consistent approach for assessing power system stability, including the effect of new or modified generation on stability.

Many of the definitions and much of the terminology used in the guidelines are based on an internationally recognised IEEE reference document[4] originally published in 2004. While many parts of the Power System Stability Guidelines remain appropriate for the NEM, broader changes to the generation fleet occurring across the power system can affect the requirements for assessment of network stability, particularly the large number of proposals for connection of non-synchronous generation in low strength networks.

The scope of change includes the technology and technical performance of new generation technologies (especially of the non-synchronous type), the operating characteristics of intermittent energy sources, changing commitment patterns of large synchronous units, and the increasing presence of embedded generation acting to reduce operational demand.

The combination of these factors can alter the nature of some power system stability phenomena, including what types of stability assessments are required, how these assessments should be undertaken, and what analysis tools are required.

[3] Available at: http://www.aemo.com.au/media/Files/Other/planning/0220_0005.pdf.

[4] "*Definition and Classification of Power System Stability*", IEEE/CIGRE Joint Task Force on Stability Terms and Definitions, 2004

2.2.2 Potential future merger of guidelines

There is an inherent overlap between the existing Power System Stability Guidelines and the matters required to be addressed in the system strength impact assessment guidelines.

As a result, there are benefits in ultimately producing consolidated guidelines that address all issues pertaining to power system stability and security, including the specific issues related to low system strength conditions. In producing the final system strength impact assessment guidelines, AEMO may consider incorporating the final guidelines into the Power System Stability Guidelines, subject to initial discussions with stakeholders, and with consideration of the need for public consultation and associated timeframe as required by the NER for development/revision of both Guidelines.

2.3 Relation to other Rules

2.3.1 Other matters relevant to system strength addressed in this rule

In addition to requiring AEMO to develop system strength impact assessment guidelines, the Fault Levels Rule will introduce other requirements relevant to assessment of the performance of new or modified generation connection under low system strength conditions.

In particular, the Fault Levels Rule requires AEMO to develop a system strength requirements methodology, to determine the minimum required fault level at “fault level nodes” in the transmission network required to maintain power system security. From 1 July 2018, AEMO will use this methodology to assess whether a fault level shortfall exists, or is likely to exist in the future.

Where such a shortfall exists, TNSPs will be required to procure system strength services to maintain the minimum fault levels. AEMO may enable the system strength services provided by TNSPs and third-party providers under specific circumstances, e.g. to maintain power system security. This will be further discussed in the final system strength impact assessment guidelines.

The requirement to maintain minimum fault levels at selected nodes within the transmission network will form a critical assumption to be used when assessing the system strength impact of any new or modified generation connection.

As part of a response to a connection enquiry, an NSP must advise a Connection Applicant of the minimum three phase fault level at the connection point. This value would ultimately depend on maintenance of minimum fault levels at fault level nodes within the transmission system.

The two requirements – to maintain minimum fault levels within the transmission system, and to assess and advise the impact of new or modified generation connection, assuming these minimum requirements are satisfied – are clearly separated in the new Rules. The interim system strength impact assessment guidelines only address the latter.

2.3.2 Power system model guidelines

There has been a growing realisation, both locally and internationally, that traditional positive sequence, Root Mean Square (RMS) based modelling practices are, on their own, inadequate to fully examine the range of new stability issues introduced by the connection of large scale, power electronic based non-synchronous generating systems.

This is especially true for low system strength conditions where the aggregate short circuit ratio (SCR)[5] falls below three. Guidance on calculation of aggregate SCR is presented in a December 2016 CIGRE brochure, “Connection of wind farms to weak AC networks”.[6]

[5] Aggregate short circuit ratio takes into account the interaction of equipment as function of AC system strength and electrically close generating systems.

[6] Available at: https://e-cigre.org/publication/671-connection-of-wind-farms-to-weak-ac-networks.

To address the increasing requirements for more detailed simulation and analysis, AEMO initiated the Generating System Model Guidelines Rule change on 28 October 2016.[7] The Rule change process concluded on 19 September 2017, with the publication of a final determination by the Australian Energy Market Commission (AEMC). A feature of the Rule change is recognition that:

> *"Various changes in power system conditions are making it more difficult to undertake accurate power system studies, particularly the decrease in system strength occurring in many parts of the grid. In order for power system studies to remain accurate and effective, it is becoming increasingly important that the model data used as inputs to these studies is sufficiently detailed to accurately reflect the performance of generating units and other equipment under these changed power system conditions.*
>
> *This final rule is therefore designed to provide various parties with access to the model data that is needed to support effective power system studies in a changing power system environment."*

The final Rule adopted the proposed change from Generating System Model Guidelines to Power System Model Guidelines. The change acknowledges that appropriate modelling data also needs to be supplied by NSPs, MNSPs and Customers if power system security is to be appropriately managed going forward.

The Power System Model Guidelines Rule is a fundamental component of the system strength impact assessment guidelines, as it facilitates access to the technical information and modelling data necessary to perform the required analysis. The exact requirements to be met by all stakeholders will be described in the new Power System Model Guidelines and supported by corresponding power system design data sheets and power system setting data sheets. All documentation is required to be published by July 2018. It is anticipated that all technical data and modelling information described in the interim guidelines will form part of the final requirements.

2.3.3 Generator technical performance standards

The Generator Technical Performance Rule change was initiated by AEMO on 11 August 2017.[8] At the time of publication of this report, the AEMC consultation on the proposed Rule is ongoing. A final determination is expected in the first half of 2018.

The proposed Rule change incorporates two important alterations which help address low system strength operating conditions:

a) Improved clarity in regard to the negotiation framework that applies when considering each of the technical performance standards defined in Schedule 5.2 of the NER (Conditions for connection of generators). The proposed rule change enforces the commencement of negotiations at the automatic access standard, with the obligation of proof as to why such performance is not achievable or economically viable, placed on the generator.

b) Increased performance requirements associated with a number of minimum and automatic access standards, that is, a higher level of performance is required to obtain a network connection. Also included in the proposed rule change is a new technical requirement that specifically addresses compatibility (of connecting equipment) with low system strength conditions.

The intent in each case is to broadly increase the capability of all new generating equipment as a means of maintaining system robustness and operability under a broad range of network operating scenarios. The enhancement in performance introduced by the proposed changes will also improve the ability of networks to 'host' future non-synchronous generator connections. Ensuring that power electronic based non-synchronous generating systems operate satisfactorily under low system strength conditions will be a contributing factor to allow for increased penetration of non-synchronous generation.

[7] Available at: http://www.aemc.gov.au/Rule-Changes/Generating-System-Model-Guidelines.

[8] Available at: http://www.aemc.gov.au/Rule-Changes/Generator-technical-performance-standards

It should be recognised that the ability of generating equipment to better support normal, contingency and emergency operating conditions brings benefits not only to generators, but all network users including customers.

3. GUIDING PRINCIPLES

The Task Force has adopted the following guiding principles during preparation of this interim guideline.

3.1 National Electricity Objective

The Task Force has been cognisant of the National Electricity Objective (NEO) which is embedded in the National Electricity Law (NEL).

The NEO can be summarised as follows:

> *"The objective of this Law is to promote efficient investment in, and efficient operation and use of electricity services for the long term interests of consumers of electricity with respect to price, quality, safety, reliability and security of supply of electricity, and the reliability, safety and security of the national electricity system".*

The interim guidelines aim to promote efficient investment by:

a) Efficient sharing and use of limited resources, especially with respect to available transmission capacity within existing networks, or that which can be achieved through efficient investment in the transmission and distribution grid.

b) Helping to identify network locations that may not support further generation development without significant additional reinforcement costs.

c) Recognising innovation which may result in more efficient use of electricity services necessary to meet consumer interests in the long term.

3.2 Leveraging international best practice

In developing the interim guidelines, the Task Force has attempted to leverage off documented international best practice (as it currently exists), recognising that certain regions of the NEM are world leaders in terms of concentrated non-synchronous generation connections.

A key reference for the interim guidelines has been the CIGRE Technical Brochure TB 671 entitled "Connection of wind farms to weak AC Networks".[9] The brochure was published in December 2016 and addresses a number of common themes including:

a) Identification and assessment of network capability including modelling requirements.

b) Potential issues that should be considered for weak network conditions.

c) Performance improvements through technology selection (to assist with weak network connection situations).

While the brochure was prepared with a specific focus on wind farms and wind turbine technologies, the theory and principles presented are equally applicable to other forms of non-synchronous generation including solar photovoltaics (PV). As such, it is considered a valuable reference despite the specific nature of its title.

[9] Available at: https://e-cigre.org/publication/671-connection-of-wind-farms-to-weak-ac-networks.

Interested stakeholders are also directed to a 2016 assessment of system strength with conditions of high wind generation in the panhandle region of the Texas (ERCOT) power system.[10] This report includes information on a number of modelling and system performance issues of direct relevance to the interim guidelines. This includes the use of weighted short circuit ratio for determining the amount of on-line wind generation in a concentrated area with high amount of installed wind generation.

The Task Force intends to consolidate practices adopted in international jurisdictions with regard to potential adverse impact of generator connection on system strength. Any such additional material will be included in the final guidelines to complement the referenced work from CIGRE.

3.3 Definition of 'do no harm'

A cornerstone of the Fault Levels Rule was the introduction of an obligation on new or modified connecting generators to "do no harm" to system strength levels necessary to maintain power system security. The broad concept, as developed by the AEMC in its final determination[11], is 'to not cause adverse system strength impacts when connecting such that the power system is able to maintain stability in accordance with the NER'.

The Fault Levels Rule did not explicitly define harm (or the counterfactual of "do no harm") and required AEMO to specify the nature of what it considered to be an adverse system strength impact (i.e. doing harm) as part of its system strength impact assessment guidelines.

After consideration, the Task Force propose that the definition of 'harm' for the purposes of the interim guidelines should be guided by existing NER provisions accounting for the impact on both power system security and reliability of supply. In particular, this includes:

1. The general principle in clause 5.1.3(d) that no connection should adversely affect power system security, reflected throughout Chapter 5 including in clauses 5.3.4A, S5.2.5.4, 5.2.5.5, S5.2.5, S5.2.5.7 and S5.2.5.10.
2. Clause S5.2.5.13 – this clause is an access standard that requires that the operation of a new or modified generation connection does not result in instability that would adversely impact existing registered participants.
3. Clause S5.2.5.12 – this clause requires that at the minimum access standard, a new or modified generation connection must not reduce the ability to supply Customer load as a result of a reduction in power transfer capability; or power transfer capabilities into a region by more than the combined sent out generation of its generating units.
4. Clause 5.3.5(d) – this clause requires NSPs to consult with AEMO and other registered participants with whom it has connection agreements, which it believes may be adversely affected by a new or modified generation connection.

The objective of the Task Force was to apply a definition which is consistent with other NER requirements in regards to managing customer impacts. In considering how to interpret this matter, the Task Force also considered clause S5.1.8 (Stability).

A key principle which underpins this interpretation is to not reduce the supportable demand of the NEM in a holistic sense, as well as recognising that certain network locations may be dependent on the available capacity of specific generators.

The connection of a new or modified generation connection that increases the supportable demand across the NEM overall, but reduces the supportable demand in a specific area of the existing network, will also be deemed as having an adverse system strength impact on the basis of local customer impacts.

[10] Available at: http://www.ercot.com/content/news/presentations/2016/Panhandle%20System%20Strength%20Study%20Feb%2023%202016%20(Public).pdf

[11] At page 57

A further key principle considered is the current generator access regime, which may be broadly summarised as providing ‘open access’, but not ‘firm access’. This is relevant to any consideration of ‘harm’, and appropriate mitigation measures that may be adopted by new or modified generation connections. In particular, it excludes a definition of ‘harm’ based solely on the potential for any reduction in network transfer capacity available to existing generators, under foreseeable operating conditions. AEMO considers that the final determination of the Fault Levels Rule[12] makes clear that no change to this principle is intended for system strength issues. Changes were made from the draft Rule expressly to address any inference to the contrary. The Rule does not require new or modified connecting generators to not have *any* adverse impact on an existing generator.

INTERIM GUIDELINES

Sections 4 and 5 comprise the interim system strength impact assessment guidelines for the purposes of clauses 4.6.6 and 11.101.2 of the NER.

4. ADVERSE SYSTEM STRENGTH IMPACT

The NER define an adverse system strength impact as affecting:

> *“…the ability under different operating conditions of:*
>
> *(a) the power system to maintain system stability in accordance with clause S5.1a.3; or*
>
> *(b) a generating system or market network service facility forming part of the power system to maintain stable operation including following any credible contingency event or protected event, so as to maintain the power system in a secure operating state”.*

4.1 Considerations for determining adverse system strength impact

4.1.1 Principles

This sub-section addresses the requirement set out in clauses 4.6.6(b)(5) and 4.6.6(b)(6) of the NER (nature of matters considered to be adverse system strength impacts, and guidance on matters to be considered in the assessment).

An adverse system strength impact should be identified where a new or modified generation connection would result in:

- A reduction in system strength that would have an adverse impact on power system security.
- The inability of existing generating systems to meet any aspect of their performance standards, at any level of MW output of the new or modified generation connection, up to the proposed registered capacity.
- Reduced ability to supply load within a region, which cannot be fully restored by reducing the MW output of the new or modified generation connection, to zero if required, while all generating units of the new or modified generation connection remain connected to the power system.
- An inability of the new or modified generation connection to meet its own performance standards (at any level of MW output and following specified contingency events), for network conditions where sufficient three phase fault level continues to be maintained at each fault level node in accordance with AEMO’s system strength requirements methodology.

[12] Available at: http://www.aemc.gov.au/getattachment/4645acea-e66f-4b5b-94a1-1dd14e7f8a93/Final-determination.aspx.

A common principle underpins each of the above criteria. If power system security cannot be maintained through the use of MW dispatch variations (constraints), recognising that AEMO is not able to control the status[13] of generating units or generating systems via its centralised dispatching system, then the new or modified generation connection is reducing the network's operability and imposes an adverse system strength impact.

4.1.2 Impact threshold

For the purposes of clause 4.6.6(b)(7) of the NER, a new or modified generation connection which results in any of the system strength impacts described in section 4.1.1, at any level of impact, would meet the threshold for an adverse system strength impact. As a result, there would be a need for either a system strength remediation scheme or system strength connection works under clause 5.3.4B.

The system conditions and contingency events for which an adverse system strength impact may be assessed as occurring are outlined in section 5.

4.2 Mitigation of adverse impacts

The NER require that if a generation connection is assessed to have adverse system strength impact:

- The generator may propose to implement a system strength remediation scheme; or
- The local NSP may propose to undertake system strength connection works, at the expense of the connecting party (or parties where suitable agreements are in place).

A combination of the two approaches may be adopted in some circumstances.

This section addresses the requirement set out in clause 4.6.6(b)(8) of the NER, to provide general guidance about options for system strength remediation schemes and system strength connection works.

4.2.1 System strength connection works

The NER define system strength connection works as:

> *"Investment in a transmission or distribution system in order to remedy or avoid an adverse system strength impact arising from establishing a connection for a generating system or market network service facility or from any alteration to a generating system to which clause 5.3.9 applies"*

This would include plant funded by the generation proponent, but provided by the relevant NSP, for the purpose of mitigating adverse system strength impacts.

The following non-exhaustive list of potential system strength connection works has been identified:

- New transmission lines or transformers external to the generating system, potentially remote from the network connection point.
- Upgrading existing transmission lines to operate at a higher voltage level.
- Reconfiguration of existing networks, e.g. alternate switching arrangements involving 'normally open points' in the network, which may require upgrade to primary or secondary equipment.
- Installation of new synchronous condensers.
- Installation of Flexible AC Transmission Systems (FACTS) devices.

Other options may also be identified and proposed. Power system modelling and simulation studies would be required to demonstrate that the application of proposed system strength connection work that mitigates all identified adverse system strength impacts. Plant installed by the NSP in the wider network rather than just at the generator connection point can provide additional benefits, and may be subject to agreed cost sharing arrangements with relevant parties in addition to the connecting generator.

[13] 'Status' in this context simply refers to the generating system or generating unit being online or offline, connected to the power system or not.

4.2.2 System strength remediation schemes

The new rule defines a system strength remediation scheme as:

> *"A scheme agreed or determined under clause 5.3.4B required to be implemented as a condition of a connection agreement to remedy or avoid an adverse system strength impact."*

System strength remediation schemes may include plant behind a connection point (part of the generating system) for the purpose of mitigating adverse system strength impacts.

The following non-exhaustive list of potential system strength remediation schemes has been identified:

- Reduction in the registered capacity of the plant.
- Modifications to control systems forming part of the generating system under consideration.
- Contracting arrangements with other synchronous generators for provision of system strength services.
- Modification to arrangements at or behind the network connection point such as:
  - Use of a higher connection voltage.
  - Use of multiple or lower impedance transformers.
  - Use of lower impedance feeder networks.
  - Installation of synchronous condensers.
  - Installation of local STATCOMs or similar FACTS devices.
- Dispatch constraints.
- Post contingency control schemes (such as a System Integrity Protection Scheme (SIPS)).

Other options may also be identified and proposed. Power system modelling and simulation studies would be required to demonstrate that the application of proposed system strength remediation schemes mitigate all identified adverse system strength impacts.

Further information on the potential use of dispatch constraints or post contingency control schemes as system strength remediation schemes are discussed in more detail below.

4.2.3 Dispatch constraints

The NEM central dispatch process uses dispatch constraints to ensure the secure limits of the power system are considered in the economic dispatch of generation.

Dispatch constraints are well suited to the management of network thermal limits, where marginal adjustment of generator output is used to ensure the network is operated within thermal limits. Dispatch constraints are also used to manage a range of existing voltage and transient stability limits, typically by limiting total power flows on network cut-sets or across defined interface points.

However, it is not yet clear whether dispatch constraints will in future be an optimal mechanism to manage the potential stability impacts caused by new or modified generation connections under low system strength conditions.

In particular, dispatch constraints can only alter or limit the MW output of online generation, and cannot directly alter generation commitment patterns. A non-synchronous generating system may produce a given MW output at its connection point with either half of the individual generating units operating at a particular level, and the other generating units completely disconnected. Alternately, it may operate with all generating units online, but at half the output level.

While these two different scenarios result in the same MW output of the generating system, the impact on network stability may be different, due to the difference in effective size of the generating system. Such scenarios may arise where generation runback schemes are implemented, but where the number of generating units remaining online is not directly managed. Matters such as these may need to be considered if dispatch constraints are proposed to manage an identified adverse system strength impact.

Another challenge with the use of dispatch constraints is a requirement to use Electromagnetic transient (EMT)-type models to accurately assess system stability under low system strength conditions. Due to the high computational (and resulting time) burden, the use of EMT-type models limits the ability to run studies over a broad range of system operating conditions, which are typically required to develop the most precise, and location specific, dispatch constraints.

If dispatch constraints are used to manage power system stability in conditions of low system strength, less precise and more broadly applied constraints on generation may be required. This outcome can blunt, or remove entirely, locational signals with respect to system strength impacts of new generation connections, and more optimal locations to connect.

For these reasons, the potential use of dispatch constraints will require careful assessment by both the connecting NSP and AEMO. They should only ever be considered as a mechanism for managing an adverse system strength impact if it can be clearly demonstrated that limiting the MW output of a new or existing generator will always be an effective mechanism to manage any potential impact arising from its connection.

4.2.4 Post contingency control schemes

Post contingency control schemes have been used successfully at a number of locations in the NEM, and have allowed operation of the power system beyond traditional N-1 security limits.

Such schemes require careful design and assessment to ensure that their operation does not result in other adverse network impacts, such as local voltage control issues, or broader system stability or frequency control impacts. This is particularly true if the generation change caused by the control scheme is large, relative to either the local network capacity, or the capacity of the broader network.

There is very limited experience to date with the use of post contingency tripping or other control schemes to manage network stability issues arising from the connection of generation under low system strength conditions.

Any post contingency control scheme proposal intended to mitigate an adverse system strength impact must demonstrate that the scheme results in no wider system security or operability impacts. This will particularly be the case where multiple control schemes may be proposed for a specific area of the network subject to low system strength conditions, but offering other favourable characteristics (energy resource, land availability etc.). The potential for negative interactions between post contingency control schemes must be carefully considered especially when a common set of contingency events may result in multiple schemes operating simultaneously.

In such areas a single control scheme may, in isolation, have an acceptable impact on power system performance, but multiple similar schemes would not. This is due to the cumulative impact of the different schemes, particularly where the triggering event for action of these schemes may be similar, and their action triggers a reduction in output from one or more generators.

Widespread use of such control schemes across a broad network area comprising several generating systems can introduce significant operational risks. As a result it is unlikely that such proposals would be accepted as a system strength remediation scheme for multiple nearby projects, unless significant design, simulation and reporting activity is undertaken to demonstrate the robustness and security of such a proposal.

The veracity of any proposed post contingency control scheme would not only need to be demonstrated by power system modelling and simulation, but also confirmed by end-to-end commissioning tests.

5. SYSTEM STRENGTH IMPACT ASSESSMENT METHODOLOGIES

The key factors to be assessed are the impact of a proposed new generating system or a modified generating system on the stability of the power system, on the stability of other generators, and on the ability of existing generators to continue to meet their generator performance standards.

Clause 4.6.6(b)(1) of the NER requires a two-stage assessment process:

1. A preliminary impact assessment will be undertaken as part of a connection enquiry. It will only identify the potential for adverse impacts to occur, based on the size of the generator relative to the available fault level in the proposed connection point, the electrical proximity of other generators, and the withstand capability of the proposed physical generating system with respect to low system strength conditions.
   The intent is to provide generation proponents with insight as to the likely complexity of establishing a new or modified generation connection (of a particular size) at the selected point in the network. The preliminary assessment will also provide an indication of the level of complexity involved in undertaking a full impact assessment, particularly the likely simulation model requirements.
2. A full impact assessment will only be undertaken as part of a connection application. This will require assessment of a range of potential impacts, under a range of network conditions, to make a determination as to whether the new or modified generation connection has an adverse system strength impact. This will then determine whether System Strength Connection Works or a System Strength Remediation Scheme will be required as part of establishing a network connection.

5.1 Preliminary impact assessment (connection enquiry)

5.1.1 Overview

The key objective of the preliminary assessment is to identify, through a relatively simple metric, the likelihood of significant system strength issues.

The preliminary assessment is an initial screening tool intended to provide a broad indication of potential system strength issues without the benefit of fine details. The use of simple, readily derived indices for determining the likelihood of adverse system strength impact provides a good basis for a preliminary assessment at the connection enquiry stage. It appropriately balances the need for meaningful insight against the time and cost burden of undertaking more rigorous analysis.

The preliminary assessment will provide stakeholders with the following guidance before a formal connection application is lodged:

- The level of modelling details required (particularly of the surrounding network and nearby generators either already connected or to be assessed in parallel).
- The type of power system simulation tool required (specifically the need for EMT simulations to assess stability phenomena accentuated by low system strength conditions).
- An indication of the adequacy of the generating unit/generating system capability with regard to operation under the prevailing system strength conditions, and
- The scope of necessary power system studies.

It is noted that at this stage it is unlikely that detailed design information would be available for the proposed generating system, hence the associated detailed simulation models may not be available. It follows that the preliminary assessment methodology is based on steady state analysis using a very limited subset of power system modelling data.

In some circumstances, the preliminary assessment is likely to be inconclusive, which will require further detailed investigation as part of the formal connection assessment process. When such analysis does not identify any adverse impact, it should not be considered to guarantee that an adverse impact will not be identified later on when detailed dynamic modelling and analysis is undertaken.

5.1.2 Methodology

In several circumstances, adverse system strength impact is caused by the aggregation of multiple electrically close non-synchronous generating systems. Calculating a screening index accounting for all nearby non-synchronous generation is necessary in these circumstances. Several methods have been developed by leading industry bodies to investigate the impact of multiple electrically close power electronic interfaced generating systems. The Task Force specifically highlights the methods presented in CIGRE Technical Brochure TB 671 which presents various screening indices suitable for initial system strength assessments. These calculation methods presented in this reference can be classified into available fault level, and various short circuit ratio (SCR) calculation methods.

All methods rely on RMS fault current calculation techniques that can be undertaken using standard load flow/fault level analysis software packages. The analysis is thus quasi-steady state in nature.

However, these methods are used to provide insight into the risk of power system dynamic stability for both small- and large-disturbances with varying levels of system strength. To undertake preliminary impact assessments, different NSPs should select the appropriate screening method, or combination of different screening methods, as described in the above CIGRE Technical Brochure.

The choice of exact method will be determined by available network modelling information including the proximity and capacity of connection points harbouring significant embedded generation for which specific modelling data is unlikely to be available. Connection applicants would need to confirm with the relevant NSP as to which screening method best suited for the particular connection assessment, and the extent of network and nearby generating systems that should be included as part of the calculations.

When conducting fault current calculations for determining these indices, it is prudent to consider an intact network with the minimum number of on-line synchronous machines (see Section 5.3.1 for further details) and accounting for an N-1 prior outage in the network that may be associated with maintenance or forced outage conditions, resulting in an N-1-1 outage. When performing the analysis, careful consideration should be given to which network elements provide the greatest support to system strength in the area of interest and thus need to be considered as critical contingencies when determining the lowest fault level seen by the generating system under consideration.

While the screening methods differ slightly in approach, the premise of each is the same. The minimum aggregate SCR / available fault level after connection of the proposed generating system is compared against the minimum SCR / fault level for which the generating system is capable of successfully operating. The same analysis will need to be conducted for the existing and committed generating systems in close proximity of the generating system under assessment which may be adversely impacted or interact with.

In the absence of such design information, it is recommended in accordance with CIGRE TB 671, that a minimum SCR of ‘3’ and a minimum X/R ratio of ‘3’ are appropriate. The headroom (or margin) between the two values (network capability versus the generating systems requirements) provides an initial indication of connection point capability to host the proposed development.

5.2 Full impact assessment (connection application)

This sub-section addresses the requirement set out in clause 4.6.6(b)(2) of the NER.

5.2.1 Overview

The full range of possible interactions between non-synchronous generating systems, synchronous generating units, and the wider power system to which they are connected are more complex than those pertaining to traditional power systems dominated by synchronous generation technologies.

Highly detailed studies are necessary to determine the overall system response and potential adverse system strength impact when accounting for the interaction between multiple generating systems and surrounding network elements.

Such detailed investigation constitutes the second stage of the system strength impact assessment methodology, referred to as a full impact assessment that will occur upon submission of a connection application by the connecting party. This analysis will require an appropriate, project specific simulation model of the entire generating system, in one or more formats including the RMS-type and potentially EMT-type models if there is a possible indication of adverse system strength impact. It will also require suitable models of the nearby network and generating systems in the same simulation software packages.

The use of more detailed modelling and simulation tools serves as solid basis to:

- Assess whether a new or modified generation connection is capable of meeting its own proposed GPS (as proposed by the Connection Applicant and any modifications agreed with the NSP up to the time of the assessment).
- Assess the impact of a new or modified generation connection on the ability of existing generating systems to meet their GPS.
- Assess the impact of a new or modified generation connection on the ability of other committed generating systems to meet their agreed GPS.
- Identify adverse system strength impact due to the interaction of multiple electrically close generating systems, i.e. where the adverse impact is caused by the interaction of multiple generating systems rather than being caused by a particular generating system.
- Evaluate the impact of proposed mitigation measures that could remove the identified adverse system strength impact.

The use of conventional power system modelling and simulation methods, based on RMS-type simulation tools such as PSS®E, may be acceptable if the capability of the generating units as confirmed by the respective manufacturer is sufficiently higher than the minimum calculated aggregate SCR/available fault level in the area under consideration. However, even in such cases it is prudent to gain confidence in the accuracy and adequacy of RMS-type models by comparing the responses against a detailed EMT-type simulation model.

EMT-type simulation tools have been increasingly used by equipment manufacturers for designing and tuning wind turbines and solar inverters' control systems for connection of wind and solar farms in areas of the NEM with low system strength.

PSCAD™/EMTDC™ in particular is widely used by a number of major power system equipment manufacturers, covering equipment such as wind turbines, solar inverters, and High Voltage Direct Current (HVDC) and Flexible AC Transmission System (FACTS) devices.

Detailed power system modelling and simulation with an EMT-type tool such as PSCAD™/EMTDC™ will be necessary for GPS assessment studies in circumstances where the capability of generating units/generating systems is not sufficiently above the minimum calculated aggregate SCR/available fault level determined from the preliminary assessment. For example, with the use of aggregate SCR as the screening index, CIGRE TB 671 suggests that the use of an SCR of 3 and X/R of 3 as the threshold below which EMT-type modelling is necessary.

This is because dynamics associated with very fast acting control systems in non-synchronous plant can have a dominant impact in determining the overall generating system response. This is particularly true as the system strength declines. Such fast acting control systems cannot be accounted for in RMS-type simulation tools, such as PSS®E. Therefore, the use of an RMS-type simulation tool would not allow adequate investigation of operating conditions resulting in potential system instability due to the lack of system strength, or adverse interaction between multiple electrically close generating systems.

5.2.2 Methodology

The full system strength impact assessment may be conducted in two stages:

- A first stage assessment with a detailed EMT-type model of the generating system under consideration can be based on a single machine operating against a lumped network model with progressively reduced system strength.
  This will indicate the margin between expected network conditions, and conditions where the simulation model becomes unstable, for both conditions of no network disturbance, and following a credible contingency event. Such an assessment will also help indicate the capacity of the nearby network to host further generation in future and can be used as a validation of earlier preliminary assessments.
  Additionally, this type of analysis is often valid for assessing GPS clauses for a remote and isolated connection with no nearby generating systems or other dynamic plant that may adversely interact with one another. However, it is noted that the network equivalent used in such an approach should include the dynamics of the wider power system represented in an appropriate manner. Hybrid modelling techniques could be adopted to achieve this with detailed EMT-type model of the plant under consideration, while plant models in remote locations with respect to the plant under consideration can be represented in an RMS-type simulation tool such as PSS®E allowing ease of access to such models.
- In circumstances where there are multiple electrically close generating systems and other plant that can equally impact system dynamics, there is a need for an EMT-type models of a larger extent of the power system that could reasonably impact the response of the generating system under consideration. The required extent of the wider power system for EMT-type modelling will be advised by AEMO and the relevant NSP on a case-by-case basis. The overall power system model chosen for the analysis should include detailed vendor specific EMT-type models of all nearby generating systems and other plant that could reasonably impact the dynamic performance of the generating system under considerations. These generating system models should include adequate representation of all relevant control and protection systems.
- As required by clause 4.6.6(b)(3) of the NER, the impact on any protection system for a transmission network or distribution network is to be excluded.

Following completion of these studies, the criteria set out in Section 5.3 will be applied to determine whether or not an adverse system strength impact will occur, and if so which generating system(s) causes the identified adverse impact. For example, following connection of a proposed generating system, a credible contingency event should not lead to unexpected disconnection of any other generating systems that would otherwise be able to successfully ride-through the same disturbance.

5.3 Scenario selection

In addressing the requirements set out in clause 4.6.6(b)(4) of the NER, this section outlines key factors that need to be taken into consideration when developing an efficient set of simulation scenarios for studies.

5.3.1 Generation dispatch profiles

Synchronous generation commitment patterns are a key variable affecting system strength, along with the electrical impedance of the network between the new generator and major generation centres.

Low levels of synchronous generation commitment are strongly correlated with low system strength. Low synchronous generation may or may not coincide with minimum demand conditions, where other factors such as interconnector flows and the amount of online rooftop PV also come into play. As a result, the minimum demand cases, by themselves, are not the most appropriate predictor of low system strength conditions.

General guidance is provided on the minimum quantity (and combinations if applicable) of synchronous generation that should be considered in each modelling zone (which may comprise more than one region) when conducting studies to identify adverse system strength impacts.

The requirements vary from one region to another, as discussed below. These minimum levels of synchronous generation should be considered for both the preliminary and full impact assessments.

South Australia

Detailed EMT-type studies have been used to determine the minimum levels and combinations of synchronous generation that must be maintained at all times in South Australia, for varying non-synchronous generation dispatch levels. This is required to maintain the power system in a secure operating state, such that it is expected to recover and return to a stable operating point following a credible contingency event. Information on minimum synchronous generation requirements in South Australia is available on AEMO's website.[14]

Tasmania

TasNetworks has identified minimum fault level requirements at the George Town 220 kV bus, and maximum permitted system Rate of Change of Frequency (RoCoF) levels, as a function of generation dispatch, load, and demand contingency size in Tasmania. TasNetworks has determined equations to describe these limits, which AEMO has implemented as dispatch constraints. These constraints are required to maintain power system security, i.e. that the relevant requirement is met after a critical credible contingency event. Additionally, TasNetworks aims to maintain an aggregate SCR of 3.0 at Smithton 110 kV substation. The combination of these three requirements determines minimum requirements for synchronous generation in Tasmania for the existing network. The potential impact of new generation connections on future inertia and fault level requirements will inherently form part of the connection application assessments undertaken at that time.

Other regions

There are currently no identified minimum synchronous generation requirements for Victoria, New South Wales or Queensland. The relevant TNSP should be consulted for advice on minimum acceptable synchronous unit commitment when undertaking a system strength impact assessment.

It should be noted that in some cases synchronous generation patterns in these regions have changed significantly, due to closure of plants, increased competition from new entrant generators, and changing economics of fuel sources. As a result, some long standing historical assumptions about minimum generation levels may no longer remain appropriate.

Minimum generation commitment patterns must respect technical factors such as minimum technical unit operating levels, local requirements for voltage control, and any other limits to the system technical envelope that may be identified by the TNSP. Recent historically observed minimum synchronous dispatch levels should form a starting point, but further reductions below these historical levels should be considered. As a minimum, it is recommended to consider displacement of generators due to committed but yet not operational generators and credible loss of the remaining unit providing the most significant system strength infeed.

[14] Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Congestion-information/Limits-advice

Where synchronous generation local to the new generation connection is vital to local system strength, full outage of this generation should be considered.

5.3.2 Contingency events

Contingency events and network conditions for a system strength impact assessment are broadly similar to those used historically to assess the impact of a new or modified generation connection on network stability.

Preliminary impact assessment

A preliminary impact assessment should consider an intact network (N system), and the most severe single prior transmission outage (N-1). For all screening methods used for the preliminary assessment (see Section 5.1), three-phase symmetrical faults are applied in a conventional quasi-steady-state fault current calculation engine, i.e. no dynamic simulations are involved.

Full impact assessment

Stability should be assessed following the most severe credible contingency event, normally a 2 phase-ground fault at the most onerous location in the network. Stability should be assessed with N system conditions, and worst case planned outage (N-1) conditions.

In an area where certain multiple contingency events can be temporarily assessed as credible, for example multiple line trips due to lightning, stability for these events should be considered as part of a complete assessment. Local policies in relation to protection reclose should also be considered.

Performance with conditions of planned outage plus next most critical contingency (N-1-1) should also be assessed, if there is sufficient network connectivity for these conditions to arise.

Protected events

The NER have recently been amended to provide for the management of non-credible contingencies declared as ‘protected events’.[15] While no such events have yet been declared, future system strength impact assessments may require assessment of certain protected events, to identify the impact of a new or modified generation connection on system performance.

5.3.3 Treatment of other plant

NSPs must take into account the following when undertaking the assessments required by these Guidelines:

- all existing *networks*, *generating units* and other *plant* in close electrical proximity to the proposed 4.6.6 Connection;
- all existing *generating units* and *generating systems* and *market network service facilities* in close electrical proximity to the proposed 4.6.6 Connection;
- all proposed *generating units* or *generating systems* or proposed *market network service facilities* subject to an *application to connect* where:
  - proposed *performance standards* and a site-specific, vendor-specific EMT model have been submitted with the *application to connect* (see clauses 5.3.4(e) and S5.2.4(b) of the NER); and
  - financial close has been achieved; and
- all proposed *network facilities* or proposed retirements of *network facilities* if the consultation period of the project assessment conclusion report during the RIT-T for the proposal has concluded.[16]

[15] Available at: http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen.
[16] See clause 5.16.4 of the NER.

With multiple committed electrically close generating systems, the full impact assessment methodology described in Section 5.2 should be adopted for:

- Each generating system in isolation.
- Parallel assessment of multiple committed projects to allow assessing adverse interaction between generating systems.