System Strength Impact Assessment Guidelines

v1.2

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PowerWater

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Important Notice

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Attribution

This document was developed by considering the information in the publication, "AEMO System Strength Impact Assessment Guidelines v1.0" effective from 01 July 2018 published by the Australian Energy Market Operator (AEMO) and implementing appropriate revisions to align with the requirements in Network Technical Code and Network Planning Criteria Version 4 dated March 2020.

1 Introduction

1.1 Purpose

This document has been prepared in accordance with clause 3.3.5.16 of the Network Technical Code and Network Planning Criteria (referred to as the *NTC* hereafter). The purpose of this document is to serve as guidelines for undertaking system strength impact assessments in relation to a proposed new connection of a generating system or network service facility or an alteration to a generating system connected to one of *Power and Water's Regulated Networks*.

The system strength impact assessment is generally triggered when a party wishing to connect a new generating system or alter an existing generating system (referred to in these guidelines as an "*applicant*") applies to the Network Operator as required by clause 5.3 of the National Electricity Rules (NER) as in force in the Northern Territory (NT).

1.2 Definitions and interpretation

The terms and abbreviations given in Table 1 have definitions as set out against each respective item. Terms defined in *NER (NT)*, *NTC* and any other associated regulations have the same meaning when used in these guidelines unless otherwise specified. This table defines key terms used in this document (these are formatted in italics). Where an italicised term is not listed in this table, its meaning is consistent with that defined in the *NTC* and/or *NT NER*.

Table 1 Glossary of terms and abbreviations

TERM	DEFINITION
AC	Alternating current
AFL	Available Fault Level. The actual *Synchronous Three Phase Fault Level* minus the required *Synchronous Three Phase Fault Level* specified by an AG manufacturer
AG	Asynchronous generating unit(s)
Applicant	A party seeking to connect a new generating system or to alter an existing generating system in accordance with the requirements specified in clause 5.3 of the *NER (NT)*
BESS	Battery energy storage system
CIGRE TB 671	CIGRE Technical Brochure TB 671 entitled "Connection of Wind Farms to Weak AC Networks"
Committed	A relevant generator connection or alteration that satisfies the following criteria: • the Network Operator is satisfied that each specified proposed access standard meets the requirements applicable to the relevant automatic access standard or negotiated access standard under the *NTC*; • the Network Operator has accepted a detailed *EMT* model of that proposed connection provided by or on behalf of the connection *applicant* that meets the requirements of the Generator and Load Modelling Guidelines;

TERM	DEFINITION
	• any required system strength remediation schemes in respect of the relevant generator connection or alteration or system strength connection works have been agreed between the relevant parties; • an offer to connect has been issued by the Network Operator in accordance with clause 5.3.6 of the *NER (NT)*; and • there is no reasonable basis to conclude that the model previously provided is materially inaccurate, including following commissioning of the connection.
Credible contingency event	A contingency event the occurrence of which the System Controller considers to be reasonably possible in the surrounding circumstances
EMT	Electromagnetic transient
FACTS	Flexible AC transmission system
FIA	Full Impact Assessment
IBR	Inverter Based Resources refers to newer technologies such as wind farm, photovoltaic solar farms, and battery energy storage systems that are asynchronously connected to the grid through a power electronic interface. In this document generation provided by *IBR* is referred to as asynchronous generation. *IBR* can be connected by either grid following or grid forming inverters.
Grid Following Inverter	Grid following inverters track the voltage angle of the grid to control their output. Grid-following inverter based generation use a phase-locked loop (PLL) control system to track the power system voltage and control the operation of the inverter to inject current into the power system at the same frequency as the system voltage. The PLL control system relies on a stable grid voltage to provide a reference for stable operation - the grid voltage may be less stable under low system strength conditions. Power systems with low levels of system strength can therefore result in unstable operation of grid following inverters.
Grid Forming Inverters	Grid forming inverters actively control their output. Grid-forming inverters can create their own voltage reference and do not need a reference from the system. While grid forming inverters have been used and proven for several decades in uninterruptible power supplies and in microgrids, the operation of grid forming inverters in utility-scale power systems is less proven. A key challenge is that the grid forming inverters operating in a utility scale power system need to synchronise with the system and successfully operate in parallel with other grid connected generators.
Mitigation Measure	Either or both of the following (as the context requires): • system strength connection works • system strength remediation scheme
MSCR Method	Minimum *SCR* Method - A screening method for the Preliminary Impact Assessment based on 'Available Fault Level' method described in

TERM	DEFINITION
	Appendix A of AEMO System Strength Impact Assessment Guidelines v1.0 and consistent with that documented in *CIGRE TB 671*
NER (NT)	National Electricity Rules as in force in the Northern Territory
Network Operator	*Power and Water* Corporation in its role as the operator of the electricity network
NTC or Technical Code	Network Technical Code and Network Planning Criteria
PIA	Preliminary Impact Assessment
Power System Controller	*Power and Water* Corporation in its role as the *Power System Controller*
proposed generator connection or alteration	A proposed connection of a generating system or network service facility according to clause 3.3 of *NTC*, or proposed alteration to a generating system according to clause 5.3.9 of *NER (NT)*
PV	Photovoltaic
Power and Water	*Power and Water* Corporation - a reference to the *Network Operator* or the *Power System Controller* refers to the appropriate business unit of the *Power and Water* Corporation
Power and Water's Regulated Networks	Darwin-Katherine Alice Springs Tenant Creek
RMS	Root mean square
SCR	Short circuit ratio - The *Synchronous Three Phase Fault Level* in MVA at the connection point divided by the rated output of the generating unit or generating system (expressed in MW). The rated output of a generating system incorporating a *BESS* should be expressed as the sum of the rating of the inverter that connects the *BESS* and those used to connect the generating system.
STATCOM	Static synchronous compensator
Synchronous Three Phase Fault Level	The three phase fault level comprising synchronous machines only, in MVA

1.3 Context

This document is related to other policies, procedures and guidelines produced by *Power and Water*, and should be read in conjunction with the *NER (NT)* and *NTC*. Figure 1 shows the relationship between the system strength impact assessment guidelines and other guidelines and procedures that collectively help to manage power system security. The figure is by no means a complete depiction, but highlights the importance of the system strength impact assessment guidelines in the context of power system security.

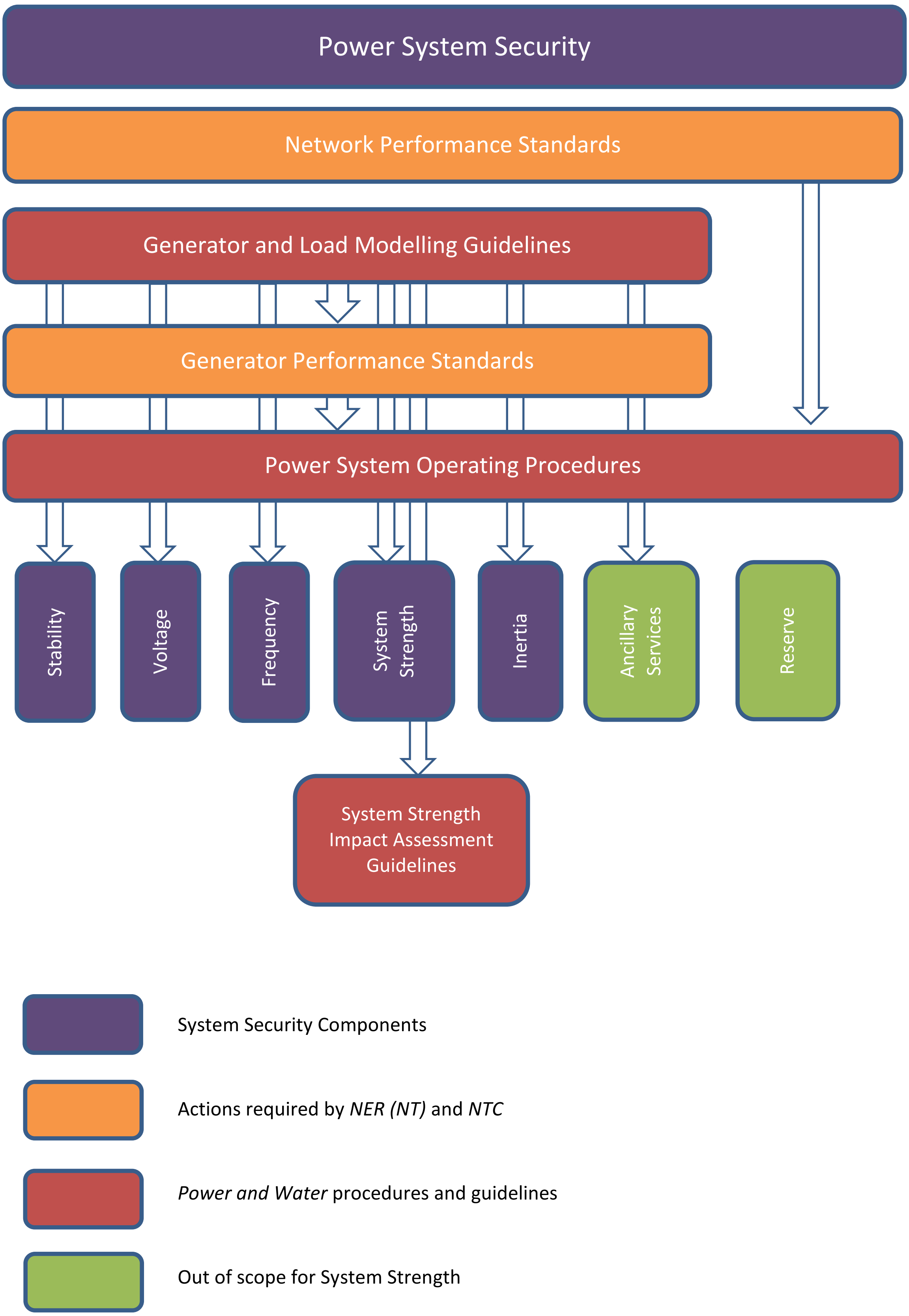

Figure 1 Interrelationship between guidelines and other instruments

The *NTC* mandates that the *Network Operator* develop this system strength impact assessment guidelines for *Power and Water's Regulated Networks*. The first version of this document is derived from *AEMO System Strength Impact Assessment Guidelines v1.0* effective from 1 July 2018[1]. Consistent with clause 3.3.5.16(a) of the *NTC*, the *Network Operator* may amend these guidelines at any time and must assess the need to amend the guidelines when any changes are made to the AEMO guidelines. The Network Operator must consult with *Users* before amending the guidelines.

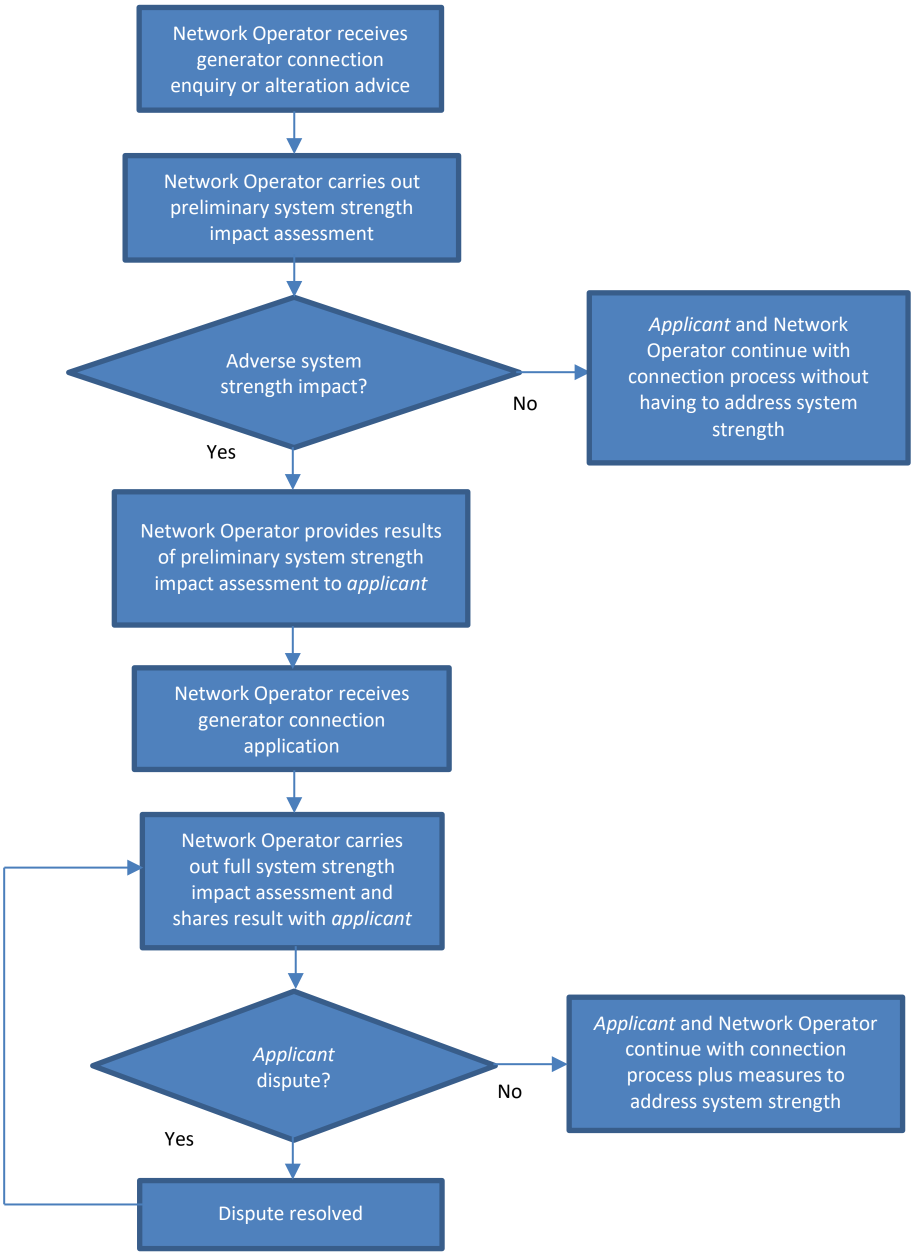

Figure 2 System Strength framework for Power and Water's regulated networks

Figure 2 summarises the system strength assessment framework for *Power and Water's Regulated Networks*. The process is triggered when a generator seeks to connect a new generating system or alter an existing generating system via the processes described in clause 5.3 of the *NER (NT)*.

[1] Available at: https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/system-security-market-frameworks-review

2 Background

2.1 Network Operator

The *Network Operator* has the following system strength obligations:

a. Undertake system strength impact assessments in accordance with these guidelines to determine whether a proposed new generating system or alteration of an existing generating system connected to one of *Power and Water's* Regulated Network in line with the *NTC* will result in an adverse system strength impact. The *Network Operator* shall consider inputs from the *Power System Controller* while carrying out these assessments.

b. Advise *applicants* of the minimum three phase fault level at the proposed connection point and the results of its preliminary impact assessment (*PIA*) when responding to a relevant generator connection enquiry or notification of a relevant alteration to an existing generating system.

c. Advise *applicants* of any adverse system strength impacts and the results of its full assessment.

d. Discuss, assess, agree upon or determine whether adverse system strength impacts will be addressed by a system strength remediation scheme or system strength connection works.

e. Ensure that the *applicant* implements any agreed system strength remediation scheme as part of the generating system.

f. Undertake any required system strength connection works at the cost of the *applicant*.

2.2 Power System Controller

The *Power System Controller* shall provide power system operating scenarios to the *Network Operator* for the purpose of carrying out system strength impact assessments.[2]

2.3 Applicants

Applicants have the following system strength obligations.

2.3.1 Provision of EMT models for Full Impact Assessment

Applicants must provide the *Network Operator* with an appropriate site-specific, vendor-specific detailed *EMT* model representing their generating system and proposed alteration before the *Network Operator* can commence a full impact assessment (*FIA*). The *EMT* model should be provided to the *Network Operator* along with the application to connect and if necessary, an updated model provided with any notice advising of an intention to proceed with an augmentation to the generating system.

Where an *applicant* has previously provided adequate phasor domain models (commonly referred as Root Mean Square (*RMS*)-based models) and associated information to the *Network Operator*, they will be required to provide up-to-date *EMT* models as required by the *Network Operator*.

When such a model is not readily available, the *Network Operator* will not commence the *FIA* until the *applicant* provides the required *EMT* model.

More detailed information on modelling requirements are provided in the *Generator and Load Modelling Guidelines* published by *Power and Water*.

2.3.2 System strength remediation

For system strength remediation, *applicants* have the following obligations:

a. Paying for system strength connection works undertaken by the *Network Operator* to address any adverse system strength impact caused by their proposed connection, or

[2] The *NER (NT)* refers to the Northern Territory Electricity System and Market Operator (NTESMO) as collective term for the entity that either controls the operation of the power system or administers market arrangements. For the purpose of the *Network Technical Code* and this guideline, the Power System Controller is the NTESMO. The Power System Controller is a separately licensed function performed by *Power and Water* Corporation.

b. Implementing any agreed system strength remediation scheme and providing evidence to the *Network Operator* that the facilities installed by the *Applicant* satisfy the requirements of the agreed system strength remediation scheme.

2.4 Relationship with other processes and documents

2.4.1 Stability criteria

Section 16 – Stability Criteria of the *NTC* provides guidance for the *Network Operator* and other network *users* on how to determine network limits associated with a range of power system stability phenomena. That section of the *NTC* also provides guidance on operating conditions and assessment criteria that should be applied when undertaking stability assessments.

There has been a growing realisation, both locally and internationally, that traditional positive sequence, phasor domain based modelling practices are, on their own, inadequate to fully examine the range of new stability issues introduced by the connection of large-scale *inverter based resources* (IBR) utilising *grid following inverters*. This is especially true for low system strength conditions where a network's aggregate short circuit ratio (*SCR*) [3] falls below 3. Guidance on calculation of aggregate *SCR* is presented in CIGRE Technical Brochure 671: "Connection of wind farms to weak AC networks" (*CIGRE TB 671*)[4]. IBR utilising grid forming inverters enhance system strength and hence the inverter technology needs to be appropriately considered when assessing the impact of particular generating systems on system strength and power system stability.

2.4.2 Generation and Load Modelling Guidelines

The completion of a *FIA* depends on the submission of detailed *EMT* models of new or altered generating systems. The Generator and Load Modelling Guidelines detail modelling requirements that, when met, allow a *FIA*. *Applicants* must provide access to technical information and modelling data as specified in those guidelines.

2.4.3 Generator Performance Standards

Section 3.3 of the *NTC* – Requirements for connection of Generators sets out details of the requirements and conditions that Generators must satisfy as a condition of connecting a generating system to the power system.

Extracting appropriate technical capability from new generating systems is critical to maintaining power system robustness and operability under a broad range of network operating scenarios, and will also improve the ability of networks to "host" future *IBR*. Ensuring the *IBR* operate satisfactorily under low system strength conditions will improve the hosting capacity and support additional connection of *IBR*.

It should be recognised that an improved ability of generating systems to support normal, contingency, and emergency operating conditions bring benefits not only to Generators, but all Network *Users* including end-use customers.

2.4.4 System Control Technical Code and Secure System Guidelines

The scenarios agreed by the *Power System Controller* and *Network Operator* for use in the *PIA* and *FIA* will reflect the secure operation of the power system as described in the *System Control Technical Code* and the Secure System Guidelines and the *NTC*.

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[3] Aggregate *SCR* takes into account the interaction of equipment as a function of AC system strength and generating systems within the region of interest or adjacent to it, if they are likely to have a material impact on the Available Fault Level of the proposed generator connection or alteration.

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

3 Application

3.1 Commencement of Guidelines

The *NTC* requires the *Network Operator* to carry out system strength assessments in accordance with these guidelines. An impact assessment is triggered when the *Network Operator* receives:

a. a connection enquiry or application to connect made via clause 5.3 of the *NER (NT)*, or

b. a request to alter an existing generating system made via clause 5.3.9 of the *NER (NT)*.

3.2 Appropriate time for system strength impact assessments

These guidelines recommend a two-stage system strength impact assessment.

Stage 1: A *PIA* will commence following a triggering event and receipt of sufficient modelling information to undertake the assessment. The triggering event could be a connection enquiry in respect of a new generator connection or advice on an intention to alter an existing generating system.

Stage 2: Unless the *PIA* indicates that a *FIA* is not needed, a *FIA* will commence following a triggering event and receipt of sufficient modelling information to undertaken the assessment. The triggering event could be a generator connection application or advice of an intention to alter an existing generating system.

The appropriate time for the *Network Operator* to commence a *FIA* after the submission of an application to connect via clause 5.3 of the *NER (NT)* or submission under clause 5.3.9 of *NER (NT)* is when:

a. the *Network Operator* is satisfied that each access standards proposed for the generating system meets the requirements specified in clause 3.3.3 of the *NTC*;

b. the *Network Operator* has accepted a detailed *EMT* model of the generating system that meets the requirements of the Generator and Load Modelling Guidelines;

c. there is no outstanding data the *Network Operator* needs from the *Applicant* to commence the *FIA*; and

d. the *Network Operator* and the *Power System Controller* have not objected to any assumptions agreed about existing plant, to the extent that *EMT* models of that existing plant are not readily available.

3.3 Dispute resolution

The dispute resolution procedure specified in clause 1.6 of the *NTC* will apply to any disputes regarding the application of the System Strength Impact Assessment Guidelines or the execution of the system strength framework defined in Clause 3.3.5.16 of the *NTC*.

4 Adverse System Strength Impact

4.1 Defining adverse system strength impact

4.1.1 Definition

Adverse system strength impact is defined as follows:

> An adverse impact, assessed in accordance with the *System Strength Impact Assessment Guidelines*, on the ability under different operating conditions of:
>
> - the power system to maintain system stability in accordance with Section 16 – Stability Criteria of the *NTC*; or
> - a generating system or network service facility forming part of the power system to maintain stable operation including following any *credible contingency event*,
>
> so as to maintain the power system in a secure operating state.

The definition can be broken down into the following elements:

> Under all operating conditions the power system will maintain system stability in accordance with Section 16 – Stability Criteria of the *NTC*:
>
> - a generating system will maintain stable operation following any *credible contingency event*; and
> - a network service facility will maintain stable operation, including following any *credible contingency event*.
>
> Regardless of the facility the definition is directed at, an adverse system strength impact will not occur if the relevant generator connection or alteration does not adversely impact the ability to maintain the power system in a secure operating state.

4.1.2 Power system stability

Section 16 of the *NTC* requires the power system to remain in synchronism and be stable in terms of its transient stability, small signal stability, oscillatory stability, voltage stability and frequency stability. It also provides guidance on the circumstances in which this stability should be maintained, including following *credible contingency events* and the halving times for oscillations.

Traditionally, system stability adverse impacts are caused by large disturbances associated with contingencies, but a power system stability adverse impact can also occur due to small disturbances. Additionally, instabilities could arise without any disturbance. An example includes voltage oscillations that may results from the adverse interaction of control systems associated with generating systems and network elements. These types of stability are often referred to as 'control system stability' and it is referred to in AEMO's Power System Stability Guidelines[5] to describe a situation where, for example, harmonic interactions due to the generation of integer or non-integer harmonics by the control systems can cause an adverse interaction of multiple power electronic connected plant leading to possible disconnection of the plant.

Adverse power quality interactions and control system instabilities caused by a relevant generator connection or alteration can cause a breach to Section 16 of the *NTC*. For this reason, when assessing a relevant generator connection or alteration, the *Network Operator* should also consider whether it would give rise to instabilities other than those caused by contingencies, including those solely due to a control system instability.

4.1.3 Generating system stability

The stable operation of a generating system is determined by reference to whether it can meet its performance standards at any level of active power output (MW).

4.1.4 Network service facility stability

The stable operation of a network service facility is determined by reference to whether it can meet its performance standards.

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[5] AEMO power system stability guidelines 25 May 2012 https://aemo.com.au/-/media/files/electricity/nem/security_and_reliability/congestion-information/2016/power-system-stability-guidelines.pdf

4.2 Identifying an adverse system strength impact

System strength is measured by reference to the available *Synchronous Three Phase Fault Level* at the point of connection in the network and assuming that the power system is operated within secure operating limits.

The *Network Operator* must consider whether the following outcomes are likely to occur as a consequence of a relevant generator connection or alteration:

- the inability of existing generating systems to meet any aspect of their performance standards, for any level of active power output from the generator that is proposed to be connected or be altered;
- an inability of the generator that is proposed to be connected or be altered to meet its proposed performance standards (at all levels of active power output and following contingency events);
- stability in the network cannot be maintained in accordance with the parameters specified in Section 16 – Stability Criteria of the *NTC*; or
- a reduction in the network's ability to supply load that cannot be fully restored by reducing the active power output of the generator that is proposed to be connected or be altered to zero, while all generating units within the generating system that is proposed to be connected or be altered remain connected to the power system.

Any one or more of these outcomes will mean that an adverse system strength impact will occur as a result of the *proposed generator connection or alteration*.

There is no materiality threshold below which an impact may be disregarded when determining the need for a system strength remediation scheme or system strength connection works.

4.3 Identifying committed projects

The *Network Operator* will maintain a secure database of each *committed* generation project or network service facility project within the network. Information about new *committed* generation or network service facility or updates to existing *committed* generation or network service facility projects must be entered into the database within two business days of the project becoming *committed* or the relevant update, including any decision to de-commit.

5 System Strength Impact Assessment Process

5.1 Introduction

The key factors to be assessed are the impact of a *proposed generator connection or alteration* on:

- the stability of the power system;
- the stability of other generating systems, and
- the ability of generating systems or network service facilities to continue to meet their performance standards under system normal network conditions, considering the occurrence of *credible contingency events*.

These guidelines recommend a two stage system strength impact assessment:

1. A Preliminary Impact Assessment (*PIA*).
2. A Full Impact Assessment (*FIA*).

While directly assessing the impact of reduced system strength on any transmission or distribution network protection system is excluded, the synchronous generation dispatch scenarios used in the system strength impact assessment should be selected to provide sufficient fault current to allow correct operation of protection systems.

5.2 Facilities to be considered

When undertaking the assessments required by these guidelines, the *Network Operator* must take into account the following types of plant connected (or to be connected) to the same network as the *proposed generator connection or alteration* if they are likely to have a material impact on the Available Fault Level of the *proposed generator connection or alteration*:

- all existing networks, generating units and other plant;
- all committed projects for new generating units, generating systems or network service facilities; 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[6].

The materiality of the impact on the Available Fault Level referred to above is to be determined by the *Network Operator*.

To the extent that *EMT* models of existing plant are not readily available for the *Network Operator* to conduct a *FIA*, subject to any objection from *Power System Controller*, the *Network Operator* and *Applicant* may agree on assumptions about that plant to facilitate the *FIA*.

5.3 Preliminary Impact Assessment

5.3.1 Overview

The objective of a *PIA* is to identify, through a relatively simple metric, the likelihood of an adverse system strength impact caused by the *proposed generator connection or alteration*. It can be used as an initial screening tool using simple, readily derived indices to assess the likelihood of an adverse system strength impact. It balances the need for meaningful insight against the time and cost burden of undertaking more rigorous analysis.

It assesses the potential for adverse system strength impacts based on the size of the *proposed generator connection or alteration* relative to the Available Fault Level at the proposed connection point, the electrical proximity of other generating systems/generating units or network service facilities, and the minimum *SCR* withstand capability of the generating system that is proposed to be connected or altered.

These guidelines recommend that a *PIA* must be undertaken by the *Network Operator* in order to respond to an *Applicant's* connection enquiry or request to alter a generating system. At this stage of the connection/alteration

[6] Refer clause 5.16 of *NER (NT)*

process, it is unlikely that detailed design information would be available for the *proposed generator connection or alteration*, so detailed simulation models are unlikely to be available.

The *PIA* will, therefore, be based on steady state analysis, using a limited subset of power system modelling data.

5.3.2 Methodology

Several methods have been developed by industry bodies to investigate the impact of multiple power electronic interfaced generating systems. Examples of calculation methods and screening indices suitable for use when undertaking a *PIA* are presented in *CIGRE TB 671*. The method the *Network Operator* must use when undertaking a *PIA* is the *MSCR Method*.

Adverse system strength impacts may be caused by the aggregation of multiple asynchronous generating systems utilising *grid following inverters*. Where multiple asynchronous generating systems are connected near each other, a screening index that can account for nearby asynchronous generation is required.

The *MSCR Method* is based on the following premises:

- The Available Fault Level after the *proposed generator connection or alteration* is compared against the minimum *SCR*/fault level for which it is capable of stable operation.
- The headroom (or margin) between the two values (network capability versus the minimum *SCR* withstand capability of the generating system that is proposed to be connected or altered) provides an initial indication of connection point capability to host the *proposed generator connection or alteration* and, therefore, the likelihood of an adverse system strength impact.

Fault level calculations should consider an intact network, with the minimum number of synchronous machines online as detailed in section 3.7.5A. 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. The analysis should include existing and *committed* projects for new generating systems or network service facilities referred to in Section 3.7.2.

Using the *MSCR Method*, a negative available fault level necessitates the performance of a *FIA* with the use of *EMT* models, whereas the use of conventional simulation tools would be adequate when the calculated available fault level is positive.

To determine the fault level “consumption” of each grid following asynchronous generating system to be used in the *MSCR Method*, the minimum *SCR* withstand capability of the generating system is multiplied by the nominal capacity of the generating system. To account for the potential impact of any *BESS* that forms part of the generating system and is connected via separate *grid following inverters*, the nominal capacity of the generating system should consider the sum of the rating of the inverters connecting the generating units and the inverters connecting the *BESS*. The capacity of a *BESS* that is DC coupled and thereby sharing the same inverters as the generating system, should not be considered in calculating the nominal capacity of a generating system.

To determine the fault level at a bus, the contribution from both synchronous generators and generating systems utilising *grid forming inverters* should be considered.

The use of a minimum *SCR* of 3 at the connection point is appropriate when the minimum *SCR* withstand capability of the grid following asynchronous generating system is not known. This is confirmed by power system simulation studies carried out with detailed simulation models from a number of wind turbine and solar inverter manufacturers. These results are shown in Appendix B of *AEMO System Strength Impact Assessment Guidelines*[7] . This is consistent with the recommendations made in *CIGRE TB 671*, however, due to a lack of sufficient data and models used during the *PIA*, the *Network Operator* should interpret its *SCR* outcomes conservatively and deduct 10%; for example, an *SCR* outcome of 3 should be interpreted as 3 minus 10%, or 2.7, which will necessitate a *FIA*, giving all parties more confidence in the outcome.

Further, the results in Appendix B of *AEMO System Strength Impact Assessment Guidelines* show that if the *SCR* is greater than 3, the X/R ratio generally has a greatly reduced effect on the performance of the *proposed generator connection or alteration*. Therefore, the use of the X/R ratio as a secondary screening threshold is not required for the *PIA*.

[7] Available at: https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/system-operations/system-security-market-frameworks-review

No further screening index is required to assess the risk of power quality induced stability adverse impact. This is because while the use of simplified approaches is possible, the robustness of such methods cannot be generalised and results may be inconclusive compared to more detailed assessments using detailed time-domain analysis.

A further consideration is the treatment of Flexible AC Transmission System (*FACTS*) devices in fault level and *SCR* calculations. Appendix C of *AEMO System Strength Impact Assessment Guidelines* present results obtained from detailed simulation models of representative wind turbines and *FACTS* devices. These studies indicate that *FACTS* devices, whether within a generating system or in the network, will not be included in the M*SCR* calculation. Notwithstanding this, if the change in voltage at the busbar of interest is more than 3% due to *FACTS* devices, the *Network Operator* may require a *FIA* to identify possible adverse interactions between asynchronous generating systems and *FACTS* devices.

5.3.3 Consultation between Network Operator and Power System Controller

The *Network Operator* shall consult with the *Power System Controller* regarding the results of the *PIA*, before responding to an *applicant's* connection enquiry. To commence this consultation, the *Network Operator* should forward the results of the *PIA* to the *Power System Controller*. Any concerns are to be discussed between the *Network Operator* and the *Power System Controller* in a timely manner to facilitate the *Network Operator's* response to a connection *applicant* in accordance with the *NER (NT)*.

5.3.4 Results of Preliminary Impact Assessment

Where the *Network Operator's* conclusion is that:

a. an adverse system strength impact will exist if the *proposed generator connection or alteration* proceeds; or

b. the *PIA* was inconclusive[8] ,

a *FIA* will be required if an application to connect is made.

5.3.5 Information to be provided with results of preliminary assessment

Where the conclusion of the preliminary assessment was that an adverse system strength impact will exist if the *proposed generator connection or alteration* proceeds or that it was inconclusive, the *Network Operator* must provide *applicants* with the following information:

a. details of the studies undertaken by the *Network Operator*;

b. details of the assumptions made by the *Network Operator* as to current and future generation patterns, dispatch during contingency events, network configurations, augmentations, and retirement of network plant;

c. how much of the network is intended to be modelled in the *FIA* and how the rest of the network will be addressed;

d. the level of modelling detail required for a *FIA*, particularly of the surrounding network and nearby generating systems either already connected or to be assessed in parallel; and

e. the scope of necessary power system studies required for a *FIA*, including any further data required by the *Network Operator* to complete those studies.

5.4 Full Impact Assessment

Unless the *PIA* indicates that a *FIA* is not needed, a *FIA* must be undertaken by the *Network Operator* upon receipt of an application to connect.

This will require assessment of a range of potential impacts under a range of operating conditions to determine whether the *proposed generator connection or alteration* will have an adverse system strength impact. The range of studies required for a *FIA* necessitates the use of *EMT*-type simulation tools.

As specified in clause 3.3.4 of the *NTC*, generators are required to provide an *EMT* model and that model should meet the requirements specified in the Generator Modelling Guidelines published by the *Network Operator*.

[8] An inconclusive outcome is likely to be the result of a lack of sufficient data, so *applicants* need to be aware that an adverse system strength impact could result from a Full impact assessment in those circumstances.

5.4.1 Contingency induced stability impact assessment

5.4.1.1 Overview

The full range of possible interactions between asynchronous generating systems, synchronous generating systems, and the wider power system to which they are connected is more complex than those pertaining to power systems dominated by synchronous generating systems.

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

This analysis will require an appropriate, project-specific *EMT*-type simulation model of the *proposed generator connection or alteration*. It will also require suitable models of the nearby network and generating systems in the same *EMT* simulation software packages.

The use of more detailed modelling and simulation tools provides a solid basis to:

- assess whether a *proposed generator connection or alteration* can meet its own proposed performance standards;
- assess the impact of a *proposed generator connection or alteration* on the ability of existing generating systems and network service facilities to meet their performance standards;
- assess the impact of a new or altered generation connection on the ability of other *committed* generating systems and network service facilities to meet their proposed performance standards;
- identify whether the adverse system strength impact is caused by the interaction of multiple generating systems, network service facilities and *committed* new connections, rather than by a particular generating system or network service facility or *committed* new connection; and
- evaluate the impact of proposed *Mitigation Measures* that could address the adverse system strength impact.

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 power system with low system strength. This is because the dynamics associated with very fast acting control systems in asynchronous plant can have a dominant impact in determining the overall plant response. This is particularly true as system strength declines. Such fast acting control systems cannot be accounted for in phasor domain based (*RMS*-type) simulation tools, such as PSS®E. Therefore, the use of an *RMS*-type simulation tool will not allow adequate investigation of operating conditions resulting in potential power system instability due to the lack of system strength, or adverse interaction between multiple generating systems and network service facilities.

EMT-type tools are widely used by major power system equipment manufacturers covering equipment such as wind turbines, solar inverters, High Voltage Direct Current (HVDC) and *FACTS* devices. Detailed power system modelling and simulation with an *EMT*-type tool will be used to perform the *FIA*.

5.4.1.2 Methodology

The *FIA* may be conducted in two stages:

1. The first stage will be carried out using a detailed *EMT*-type model of the *proposed generator connection or alteration*, and can be based on the proposed or altered generating system operating against an equivalent 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, under conditions of no network disturbance and following any *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 the *PIA*.

2. A second stage is needed where there are multiple generating systems and other plant that can equally impact system dynamics. In such cases there is a need for an *EMT*-type model of a larger portion of the power system that could reasonably impact the response of the proposed or altered generating system under consideration. The required portion of the power system for *EMT*-type modelling will be considered by the *Network Operator* on a case-by-case basis. Considering the size of the three regulated power systems in the NT, an *EMT* model of each power system will be needed in most cases to support a *FIA*. The model will need to represent all significant generating systems that can impact the assessment of system strength.

   The 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 proposed or altered generating system under consideration. These models should include adequate representation of all relevant control systems and protection systems.

Following completion of these studies, the scenarios set out in Section 5.5 should be applied to determine whether an adverse system strength impact will occur, and which plant is involved.

5.4.2 Control system induced stability impact assessment

5.4.2.1 Overview

Power quality studies are generally conducted by an *applicant* submitting an application to connect a proposed generating system for consideration by the *Network Operator*. These studies do not often encompass potential adverse control system interaction of multiple generating systems and dynamic reactive support plant due to the inferior quality of voltage and current waveforms in low system strength conditions. The methodology discussed below is not aimed at replacing or replicating conventional power quality studies conducted by a Connection *applicant*, but to allow the *Network Operator* to identify power quality issues that can manifest themselves into system stability concerns and an adverse system strength impact. Similar to contingency induced stability impact assessments, these studies are conducted by the *Network Operator*.

5.4.2.2 Methodology

Stage 1 – Estimation of harmonic distortion

Stage 1a – Harmonic impedance scan studies

This assessment is designed to identify power quality issues, e.g. excessive harmonic injection or coincidence of a harmonic frequency with a network resonance point, which could manifest themselves into system stability concerns.

Prior to a *proposed generator connection or alteration*, the *Network Operator* computes the system harmonic impedances at the proposed connection point. A wide range of system operating conditions should be examined to include variations caused by outages of single lines and transformers, plus numerous combinations of in-service shunt capacitor banks.

At each harmonic:

- these impedances are plotted on a resistance-reactance (R-X) plane;
- the harmonic impedances with magnitudes that are exceeded for 5% of calculated values excluded; and
- a polygon (usually with ten vertices) that encloses all the remaining R-X values is defined.

These studies must:

- include all components of a proposed or altered generating system including the collector cables and transformers;
- assess several system-impedance R-X points that lie along the boundary of the system-impedance polygon as determined by the above network scan studies, rather than just the R-X points that define the vertices of the polygon. There is no requirement to assess system-impedance R-X points that lie within the polygons;
- consider the outages of individual collector feeders within the generating system; and
- account for tolerances on the design values of the generating system's balance of plant components, such as transformer series impedances and cable lengths.

Stage 1b – Modelling conducted by the applicant of the proposed generator connection or alteration

The *applicant* is responsible for defining the magnitudes of the harmonic source currents for individual generating units. The origin of these harmonic source currents[9] needs to be documented.

The method applied to summate the effects of several individual harmonic sources in an asynchronous generating system comprising several individual generating units must be justified.[10]

[9] As an example, tests defined in IEC 61400-21 for wind turbines.

[10] In general, multiple harmonic-current sources in an asynchronous generating system will have in-phase characteristics as, for example, discussed in CIGRE TB 672 for solar inverters. This infers that in assessing harmonic-voltage contributions from solar inverters to be connected to a network, the harmonic source currents from all individual generating units can be considered in phase for all harmonic orders. If the proposal from a proposed generator connection or alteration is to apply a harmonic summation method that (at a particular harmonic) considers the harmonic source currents are not in phase, provision of measured harmonic currents substantiating the use of the alternative method is necessary

Stage 1c – Harmonic voltage calculations

The *Network Operator* must calculate the harmonic voltages accounting for the impact of multiple generating systems and dynamic reactive support plant. Connection of passive components (e.g. transformers, capacitors and cables) of a proposed or altered generating system can produce amplification of existing harmonics due to excitation of a harmonic resonance frequency.[11]

The use of conventional harmonic analysis tools is permitted as agreed between the *Network Operator* and the *applicant*, however, the *Network Operator* must advise the *applicant* on the extent to which a second stage assessment based on detailed time-domain *EMT* analysis as discussed below is necessary. Examples of when such an assessment should be conducted include determining:

- the harmonic withstand capability of a new or altered plant as required under clause 3.3.5.6 of the *NTC*; and
- the risk of exciting low order network resonance points caused by:
  - energisation of harmonic filters or grid interface transformers; and
  - adverse interaction with plant control systems.

Stage 2 – Harmonic interaction and susceptibility studies

A *proposed generator connection or alteration* must operate satisfactorily in the presence of a specified level of power quality (as determined by the *Network Operator*)[12] at the connection point, where power quality constitutes of harmonics, flicker and unbalance. The level of susceptibility of inverter controls to power quality may vary depending on the system strength.

The *Network Operator* needs to demonstrate that connection of multiple generating systems and dynamic reactive power support plant does not cause interaction issues that may, in turn, manifest themselves into system stability issues without a contingency being applied.

Similar to contingency-induced stability assessments, this analysis requires an appropriate, project-specific simulation model of the proposed or altered generating system suitable for power quality analysis and control system induced stability impact assessment.

For harmonic interaction and susceptibility analysis, *EMT* models are required with additional modelling details as set out in the Generator and Load Modelling Guidelines. These studies will also require suitable models for the connecting network (or a sufficiently accurate representation of the harmonic signature of the wider network) implemented in the same *EMT*-type simulation software package[13].

5.4.3 Consultation between Network Operator and Power System Controller

The *Network Operator* shall consult with the *Power System Controller* on the results of the *FIA*, before responding to an *applicant*. To commence this consultation, the *Network Operator* should forward the results of the *FIA* to the *Power System Controller*. Any concerns are to be discussed between the *Network Operator* and the *Power System Controller* in a timely manner to facilitate the timely provision of an offer to connect.

5.4.4 Results of Full Impact Assessment and information to be provided with results

The *Network Operator* must advise *applicants* of the results of a *FIA* and provide them the following information:

a. Details of the studies undertaken by the *Network Operator*.
b. Details of the assumptions made by the *Network Operator* as to current and future generation patterns, dispatch during contingency events, network configurations, augmentations, and retirement of network plant.
c. How much of the network was modelled and how the rest of the network was addressed.
d. The level of modelling detail assessed, particularly of the surrounding network and nearby generating systems or network service facilities either already connected or to be assessed in parallel.
e. Whether *FACTS* devices have been included in the analysis.

[11] P D Ross, M P De Carli, P F Ribeiro, "Harmonic distortion assessment related to the connection of wind parks to the Brazilian transmission grid", CIGRE Paper C4- 101, 2016 Paris Session

[12] As required by clause 3.3.5.6 of *NTC*

[13] See also the Generator and Load Modelling Guidelines

f. An indication of the adequacy of the proposed or altered generating system's capability under the prevailing system strength conditions.

5.4.5 Sole or multiple Full Impact Assessments

If a *FIA* of a proposed or altered generating system is impacted by one or more other proposed or altered generating systems that are electrically close to each other, the *Network Operator* may carry out one *FIA* for all of them if the *applicants* have agreed to share the costs of any proposed *Mitigation Measures*. A joint assessment has the potential to be a more efficient process than individual assessments, however this approach would require that all *applicants* have detailed *EMT* models available at the start of the assessment process and have agreed to sharing the costs associated with the assessment. A shared assessment may also require the *Network Operator* to resolve directly with the affected *applicants*, any issues over the use and sharing of confidential information for the purposes of the shared *FIA*.

If a shared assessment is not possible, then individual assessments would be undertaken.

5.5 Scenario Selection

This section outlines key factors that need to be taken into consideration when developing an efficient set of simulation scenarios for the studies carried out as part of a *FIA*. It also provides guidance about the different network conditions, dispatch patterns, and other matters to be considered by the *Network Operator* when carrying out a *FIA*.

5.5.1 Generation dispatch profiles

Synchronous generation commitment patterns are a key variable affecting system strength, along with the electrical impedance of the network between the proposed or altered generating system and major generation centres. Asynchronous generation commitment patterns have very little impact on system strength.

Low levels of synchronous generation commitment patterns 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 photovoltaic (*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 when conducting studies to identify adverse system strength impacts.

It should be noted that in some cases synchronous generation patterns change due to closure of plant, increased competition from new entrants, and changing economics of fuel sources. As a result, some long-standing historical assumptions about minimum generation levels 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 technical envelope that may be identified by the *Network Operator* and the *Power System Controller*. Recently observed minimum synchronous generation dispatch levels should form a starting point, but might require further reductions for further analysis. As a minimum, the *Network Operator* and the *Power System Controller* should consider the displacement of generation due to *committed*, but not operational, generating systems and credible loss of the remaining generating unit(s) providing the most significant system strength infeed. The minimum acceptable synchronous generation dispatch scenarios shall also be selected such that there is sufficient fault current to allow correct operation of protection systems. These minimum levels of synchronous generation should be considered for both the *PIA*s and *FIA*s.

Where synchronous generation local to the proposed or altered generating system is vital to local system strength, full outage of this generation should be considered.

5.5.2 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 proposed or altered generating system on network stability and performance standards. In other words, when assessing system strength, the *Network Operator* and the *Power System Controller* should consider those known contingency events (including historical reclassifications) and network conditions.

1. Preliminary Impact Assessment

   For all *Scr*eening methods used for the *PIA* (see Section 5.3), three phase symmetrical faults are applied in a conventional quasi-steady-state fault current calculation engine using synchronous generation's sub-transient impedance, so no dynamic simulations are involved.

2. Full Impact Assessment

   Stability should be assessed under system normal conditions, considering the most severe *credible contingency event* and other events set out in proposed performance standard (normally a two-phase-to-ground fault at the most onerous location in the network that would likely have highest stability impact on the network). In a part of the network where certain multiple contingency events have been temporarily reclassified as *credible contingency events*, for example multiple line trips due to lightning, stability for these events should be considered. Local operational policies in relation to protection reclose should also be considered. Analysing these types of events will ensure that appropriate operational measures can be put in place to manage power system security risks, however, system strength connection works or system strength remediation schemes are not generally required to address an adverse impact on the power system caused by these types of events.

6 Mitigation Measures

If a proposed or altered generating system is assessed as having an adverse system strength impact, *Mitigation measures* must be taken. There are two types of *Mitigation Measures*:

a. system strength connection works; and
b. system strength remediation schemes.

Where appropriate, more than one *Mitigation Measure* can be adopted. The *Network Operator* will engage with the generator to select the appropriate *mitigation measures*.

6.1 System Strength Connection Works

The following is a non-exhaustive list of potential system strength connection works that could be used by the *Network Operator* to mitigate any adverse system strength impact:

a. new transmission lines or transformers external to the proposed or altered generating system, potentially remote from its proposed connection point;
b. upgrades to existing transmission lines to operate at a higher voltage level;
c. the use of lower impedance transformers at either the collection grid or network interface;
d. reconfiguration of existing networks, for example, alternative switching arrangements involving 'normally open points' in the network, which may require upgrade to primary or secondary equipment;
e. installation of new synchronous condensers;
f. installation of active or passive harmonic filters;
g. modifications to control systems belonging to the *Network Operator* or other Network *Users*; and
h. the use of asynchronous plant[14] based on grid forming converter technologies allowing the plant to stably operate at an *SCR* level of down to zero[15].

The *Network Operator* must carry out power system modelling and simulation studies to demonstrate whether proposed system strength connection works can mitigate all identified adverse system strength impacts.

Plant installed by the *Network Operator* in the wider network, rather than just at the proposed or altered generating system's connection point, can provide additional benefits and may be subject to agreed cost-sharing arrangements between the *applicant* and other parties.

6.2 System Strength remediation schemes

System strength remediation schemes may include plant behind a connection point (that is, part of the proposed or altered generating system).

The following is a non-exhaustive list of potential system strength remediation schemes that could be used by the *Network Operator* to mitigate any adverse system strength impact:

a. Reduction in the registered capacity of the plant.
b. Modifications to control systems forming part of the proposed or altered generating system.
c. Contracting with Generators with synchronous generating systems for the provision of system strength services.
d. Modification to arrangements at or behind the proposed or altered generating system's 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 active or passive harmonic filters; and

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[14] This includes asynchronous generating units and *FACTS* devices

[15] This can be in addition to, or as a replacement for asynchronous generating units already considered by the *applicant*

- installation of local *STATCOMs* or similar *FACTS* devices.

e. Post-contingency control schemes (such as a System Integrity Protection Scheme (SIPS))[16].

f. As a last resort, the use of dispatch constraint equations.

The *Network Operator* must carry out power system modelling and simulation studies to demonstrate whether the application of all proposed system strength remediation schemes can mitigate all identified adverse system strength impacts.

6.3 Use of post-contingency control schemes

Post-contingency control schemes have been used successfully in the NEM[17] , 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 power system stability or frequency control impacts. This is particularly true if the generation change caused by the operation of the control scheme is large, relative to either the local network capacity or the capacity of the broader network.

There is 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. The acceptability of any such control scheme will be subject to both the details of the design and the local characteristics of the network for which it is proposed.

Any post-contingency control scheme proposal intended to mitigate an adverse system strength impact must demonstrate that the scheme results in no wider power 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 (such as energy resource or land availability).

The potential for negative interactions between post-contingency control schemes must be carefully considered, especially when a common set of contingency events can result in multiple schemes operating simultaneously.

Where such negative interactions are likely, a single control scheme may, in isolation, have an acceptable impact on power system performance, but multiple similar schemes would not. This may occur 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 generating systems.

Where a control scheme is proposed as a system strength remediation scheme, the following risks may need to be assessed:

a. The largest total generation or load contingency that may occur due to control scheme action.

b. Local impacts of such a contingency, particularly on network voltage control and thermal loading.

c. Broader system impacts of such a contingency, particularly on frequency control, including the potential cost of frequency control ancillary services, and on power system stability limits.

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.

[16] As required by clause 3.3.5.10 of *NTC*.

[17] National Electricity Market. Refer https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/about-the-national-electricity-market-nem

Document history

DATE OF ISSUE	VERSION	PREPARED BY	DESCRIPTION OF CHANGES
31/7/2020	Draft v1.0	D Bones	Draft for consultation
9/10/2020	Final v1.1	D Bones	Incorporates revisions following consultation
27/10/2020	Final v1.2	Tat Au-Yeung	Minor formatting changes.

8 Appendices

8.1 Appendix A

Reference is made to Appendix A. Practical Examples of *AEMO System Strength Impact Assessment Guidelines* v1.0. This provides practical example of *PIA* and *FIA* for a representative power system.

8.2 Appendix B

Reference is made to Appendix B. Choice of *SCR* as threshold for *PIA* of *AEMO System Strength Impact Assessment Guidelines* v1.0. This demonstrates the impact of variations of *SCR* and X/R ratio on stability of AG systems during fault conditions.

8.3 Appendix C

Reference is made to Appendix C. Consideration of *FACTS* devices during *PIA* of *AEMO System Strength Impact Assessment Guidelines* v1.0. This demonstrates the impact of *FACTS* devices on system stability.