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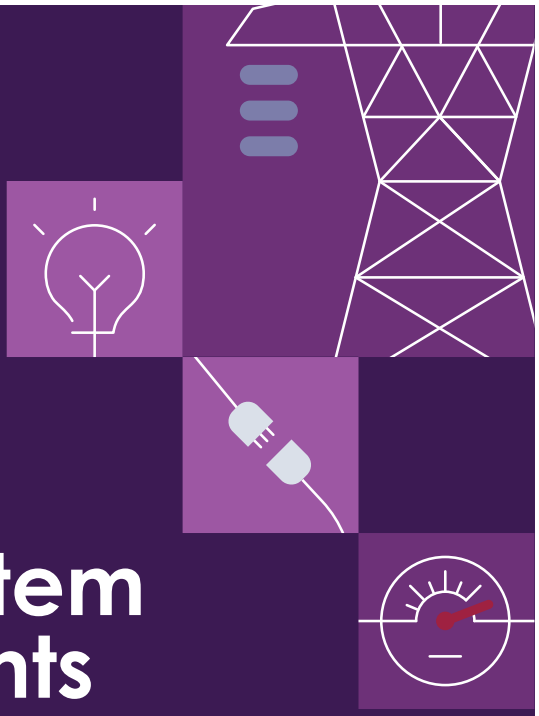

Amendments to System Strength Requirements Methodology and Power System Stability Guidelines

Final Report and Determination – Implementation of Efficient Management of System Strength Rule

Published: 30 September 2022

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Executive summary

Declining minimum operational demand, changing synchronous generator behaviour, and rapid uptake of variable renewable energy (VRE) resources have combined to reduce the levels of system strength available in parts of the National Electricity Market (NEM), both to support stable operation of existing equipment and to host further inverter-based resources (IBR) as the Australian electricity sector transformation continues.

In October 2021, the Australian Energy Market Commission (AEMC) released its final determination and rule on the efficient management of system strength on the power system. The publication of this Final Report and Determination (Final Report) concludes the consultation process conducted by AEMO to amend its System Strength Requirements Methodology (SSRM) and Power System Stability Guidelines (PSSG) to incorporate the outcomes of the system strength framework changes[1].

The new system strength framework represents a step change in system strength management. From 1 December 2022, AEMO will provide an annual assessment of system strength requirements in the NEM for the coming decade, against a **new power system standard** comprising:

- A **minimum fault level requirement** for power system security (expressed in megavolt-amperes [MVA]).
- A requirement for stable voltage waveforms at connection points to host AEMO's forecast levels of new IBR resources (also known as the **efficient level of system strength**).

Each NEM region's jurisdictional planning body for the transmission network, known as the System Strength Service Provider (SSSP), must plan to meet the standard, based on the requirements projected by AEMO, for each year from 2 December 2025. In addition, new minimum access standards will apply to relevant generators, loads and market network service providers, and revised system strength connection options (with a new system strength charging mechanism) will be introduced.

The final SSRM and PSSG released alongside this Final Report have been developed with the benefit of stakeholder feedback received over two stages of formal consultation, as well as technical input from a reference group of network service provider representatives. After consideration of submissions and discussions following the issue of AEMO's Draft Report[2], AEMO's final determination confirms the draft position on some key issues, while adjustments have been made in other areas, as summarised below.

AEMO has maintained its draft position on the following material principles and requirements:

- **AEMO will take a consultative approach to setting the system strength requirements.** AEMO intends to seek stakeholder feedback on key inputs where practical, including using one annual System Strength Report to consult on key factors for the following assessment. AEMO will also leverage the outcomes of existing regular consultation for the Integrated System Plan (ISP).
- **IBR forecasts for the efficient level of system strength will typically be consistent with the Integrated System Plan**. AEMO will provide forecasts for IBR connection and operation which will

[1] Consultation on the System Strength Impact Assessment Guidelines is following a separate consultation pathway. Details are available on AEMO's website via https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.
[2] 29 July 2022. All consultation documents and submissions are available on AEMO's website at https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.

be consistent with the ISP wherever possible, but some changes to reflect the latest power system, market or policy outcomes may be required on a case by case basis.

- **Minimum fault level requirements must be set to ensure power system security, correct protection system operation and voltage control equipment performance**. AEMO will use the existing minimum fault level requirements as a baseline. AEMO may re-assess the requirements to respond to material changes and updated limits advice obtained through effective joint planning processes with SSSPs.
- **Different modelling techniques will be used for different time horizons**. Detailed electromagnetic transient (EMT) analysis will be prioritised for short-term power system stability studies where models are available (for example, 1-2 years). However, for long-term time horizons, and when models are not available, alternative methods will be used.
- **Introduction of grid-forming inverters**. AEMO's NEM Engineering Framework includes a priority action to collaborate with industry on a voluntary specification for grid-forming inverters[3]. Such a document could assist with identifying a standardised way of determining system strength capability from grid-forming inverters.

AEMO has amended its final position from the Draft Report on the following material principles and requirements:

- **Maintaining synchronism of distributed energy resources (DER)**. AEMO does not intend to incorporate synchronisation of DER in the calculation of minimum fault level requirements, as it is considered this will be addressed through other avenues in the NEM planning framework. Based on feedback to the draft SSRM, AEMO will confirm that DER synchronism is to be considered in determining the efficient level of system strength, to be managed through network service provider (NSP) joint planning processes.
- **The annual system strength report will identify critical planned outages that SSSPs will be expected to incorporate into their system strength planning.** This will require the SSSP to plan for the availability of sufficient system strength to maintain power system security during critical network outages. In this Final Report, AEMO has clarified that critical planned outages will be those that present risks to power system security, reliability or market efficiency.
- **Description of stable voltage waveforms**. Although the National Electricity Rules (NER) already describe broad power system standards for voltage, the final SSRM provides a system strength-specific description of stable voltage waveforms, against which SSSPs will need to ensure that projected IBR connections and operation can be facilitated. This description is provided as a set of criteria.
- **Protection scheme operation will be assessed and confirmed by SSSPs and their connected network service providers**. AEMO has confirmed that the responsibility to assess and advise on protection scheme operation rests with SSSPs.
- **System strength nodes will be selected within SSSPs' networks**. In the final SSRM, AEMO has made it clear that system strength services to be delivered by SSSPs need not necessarily be located at the declared system strength node, and that AEMO will retain the flexibility to select system strength nodes with reference to the changing needs of the power system.

[3] AEMO, *NEM Engineering Framework – priority actions,* June 2022, accessible via https://aemo.com.au/-/media/files/initiatives/engineering-framework/2022/nem-engineering-framework-priority-actions.pdf.

The publication of this Final Report and Determination marks the completion of the consultation process for amendments to the SSRM and PSSG. The final SSRM and PSSG are published alongside this document and will come into effect on 1 December 2022. AEMO is grateful for the contribution of all stakeholders who have participated in this consultation process.

1. Stakeholder consultation process

As required by clause 5.20.6 of the NER, AEMO has consulted on the System Strength Requirements Methodology (SSRM) and the Power System Stability Guidelines (PSSG) in accordance with the Rules consultation process in rule 8.9[4]. This Final Report and Determination (Final Report) concludes the consultation on the SSRM and PSSG.

This section provides the consultation timeline, a description of AEMO's stakeholder engagement, and the structure of this Final Report.

1.1. Consultation timeline

AEMO's timeline for this consultation is outlined in Table 1. Consultation on amendments to the System Strength Impact Assessment Guidelines (SSIAG) is now progressing under a separate consultation from the SSRM and PSSG. The issues relating to the SSIAG are not covered by the Final Report other than to note any interdependencies.

Table 1 Consultation timeline

Deliverable	Date
Notice of first stage consultation and Issues Paper published, for the SSRM, PSSG and SSIAG	Complete – 26 April 2022
First stage submissions closed	Complete – 1 June 2022
Notice of second stage consultation, and Draft Report and Determination, and draft SSRM and PSSG, published	Complete – 29 July 2022
Second stage submissions (on SSRM and PSSG) closed	Complete – 19 August 2022
Final Report and Determination, and final SSRM and PSSG, published	30 September 2022

1.2. Stakeholder engagement

The SSRM and SSIAG working group that was established with transmission network service providers (TNSPs) and distribution network service providers (DNSPs) before publication of the Issues Paper has continued to provide input to inform this Final Report. AEMO held a meeting with the working group on 16 August 2022 to discuss the Draft Report, and a dedicated meeting with a sub-set of the working group on 19 August 2022 focused on the criteria for voltage waveform stability.

AEMO received five written submissions in response to the second stage of consultation. AEMO held stakeholder meetings with Connections & Power Systems Advisory (CPSA) and DIgSILENT to seek futher information regarding their submissions. AEMO also held a meeting with Powerlink prior to the close of submissions to clarify aspects of the draft SSRM. AEMO thanks all stakeholders for their considered advice and input on this stage of the consultation.

Copies of all written submissions and brief meeting notes from relevant stakeholder meetings (all excluding any confidential information) have been published on AEMO's website[5]. The website also provides the submisisons and meeting notes for the first stage of consulation.

[4] Rules consultation procedure Version 8.9 has been updated by the Australian Energy Market Commission (AEMC) with changes in effect from Thursday 11 August 2022. However, these changes to the consultation procedures do not affect any consultations that began before this date, such as this Implementation of Efficient Management of System Strength Rule.

[5] At https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.

1.3. Structure of this report

In this Final Report:

- Section 2 provides background on the system strength rule change.
- Section 3 provides a summary of material issues raised in the SSRM and PSSG.
- Section 4 provides a discussion on the material issues raised in the SSRM consultation and AEMO's responses.
- Section 5 provides a discussion on the material issues raised in the PSSG consultation and AEMO's response.
- Section 6 confirms AEMO's final determination.

2. Background

2.1. Regulatory requirements

In October 2021, the Australian Energy Market Commission (AEMC) made the National Electricity Amendment (Efficient management of system strength on the power system) Rule 2021 No. 11 (the Amending Rule).

The Amending Rule requires significant amendments and additions to the SSRM and SSIAG, and will also require some minor consequential changes to the PSSG. This section sets out the amended NER requirements for the SSRM and PSSG, noting that AEMO is progressing consultation on the SSIAG separately.

2.1.1. Changes to the SSRM

AEMO must update the existing SSRM[6] to reflect the Amending Rule by 1 December 2022, incorporating the information needed for the new standards for system strength (with both minimum and efficient levels of system strength).

Required content of the SSRM

New clause 5.20.6(f) of the NER states:

(f) The *system strength requirements methodology* determined by *AEMO* must:

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

(2) describe:

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

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

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

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

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

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

(iii) any other matters *AEMO* considers appropriate; and

(4) provide a description of what is meant by stable *voltage* waveforms for the purposes of clause S5.1.14(b)(2) (in addition to that provided in clause S5.1.14(c)) including the matters that may be taken into account by System *Strength Service Providers* to assess, for the level and

[6] AEMO, System Strength Requirements Methodology, July 2018, at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/System-Security-Market-Frameworks-Review/2018/System_Strength_Requirements_Methodology_PUBLISHED.pdf.

type of *inverter based resources* projected by *AEMO* at *system strength nodes*, what may be required to achieve stable operation.

Mandatory considerations for system strength requirements

The SSRM must provide for AEMO to take the following matters into account in determining the system strength requirements for each region of the NEM (new clause 5.20.6(e) of the NER):

(e) The *system strength requirements methodology* determined by AEMO must provide for AEMO to take the following matters into account in determining the *system strength requirements*:

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

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

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

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

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

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

(7) any other matters AEMO considers appropriate.

Application in System Strength Report

AEMO will apply the amended SSRM to determine system strength nodes and the system strength requirements to be published in its annual System Strength Report under NER 5.20.7, starting from 1 December 2022. Clause 5.20.7 states:

5.20.7 Publication of System Strength Report

AEMO must publish annually by 1 December the *System Strength Report* on its website for the following year which must include:

(a) a description of the *system strength requirements* determined by AEMO under rule 5.20C since the last *System Strength Report*;

(b) the *system strength requirements* determined for each *system strength node*; and

(c) the system strength standard specification (as defined in clause S5.1.14(a)) applicable at each *system strength node* during the 12 months following publication of the *System Strength Report*;

(d) the assumptions used by *AEMO* to determine the *system strength requirements* including assumptions about the size, type and operational profile of *facilities* or classes of *facilities* to be *connected* and their contribution to the matters taken into account in determining the *system strength requirements*;

(e) information about new *system strength nodes* declared since the last *System Strength Report* and an indication of possible future *system strength nodes* and when *AEMO* considers the nodes may be declared; and

(f) information on any other matter that *AEMO* considers relevant.

2.1.2. Changes to the PSSG

The PSSG are made under NER clause 4.3.4(h), with the purpose of detailing the 'policies governing power system stability so as to facilitate the operation of the power system within stable limits' (clause 4.3.4(i)). The current PSSG were published on 25 May 2012 and pre-date any NER changes referencing system strength. AEMO therefore needs to make consequential updates to the PSSG to define system strength in a similar manner to the other types of stability and ensure consistency with the new system strength framework.

2.2. Context for this consultation

System strength can broadly be described as the ability of the power system to maintain and control the voltage waveform at any given location in the power system, both during steady state operation and following a disturbance.

Traditionally, system strength services have been provided by large thermal and hydro synchronous generation units. However, with the rapid uptake of IBR, declining minimum operational demand, and changing synchronous generation behaviour, action is now needed to ensure that system strength services are maintained into the future.

The NEM is already at the international forefront of managing issues associated with low system strength. In South Australia, ElectraNet has met system strength needs by installing four synchronous condensers. In Victoria, AEMO[4] has contracted system strength services from generator-owned synchronous condensers installed alongside solar farms. In Queensland, Powerlink worked with local solar and wind farms to re-tune their inverters and reduce the nearby system strength needs of the system.

Across the NEM, generators have made unique agreements with NSPs to remediate their plant's impact on system strength; and across the industry, technology providers are considering how best to provide system strength in the future.

Following the release of an Issues Paper in April 2022, and a Draft Report and Determination in July 2022, this Final Report concludes AEMO's consultation on amending two of its system strength instruments – the SSRM and the PSSG[7].

[7] The final document, the SSIAG, is progressing along a separate consultation pathway. Details are available at AEMO's website via https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.

3. Summary of material issues

Table 2 provides a summary of the material issues arising from the second stage of consultation[8] conducted by AEMO to amend the SSRM and to make minor updates to the PSSG.

Table 2 Material issues relating to the proposed draft SSRM and draft PSSG

No.	Issue	Instrument	Raised by
1	Whether synchonism of distributed energy resources (DER) is to be accounted for in meeting the system strength standard, and if so, for what part of the standard.	SSRM	Powerlink, Energex and Ergon
2	What are the impact criteria of a critical planned outage, and whether planning processes for critical outages are different for AEMO in its role as Victorian SSSP.	SSRM	Powerlink, AusNet
3	How to define the voltage waveform criteria to best identify areas of low system strength.	SSRM	CPSA, DIgSILENT
4	How best to plan for sufficient system strength required for ongoing operation of protection schemes for distribution networks.	SSRM	DIgSILENT, Energex and Ergon
5	Process for selection of system strength nodes (SSNs) and associated system strength locational factor matters, including location of nodes and consultation on node selection.	SSRM	DIgSILENT
6	Confirming that power quality issues should not be covered.	SSRM	CPSA
7	Differentiation between system strength and converter-driven stability as a measure of system stability.	PSSG	CPSA

Section 4 provides more detail and AEMO's assessment of each of the material issues for the SSRM. Section 5 addresses the material issue relating to the PSSG.

AEMO's consideration and conclusions on other material issues arising from the first consultation conducted by AEMO are considered in detail in the Draft Report and Determination available on AEMO's website[9].

[8] Energex and Ergon's submission responded to consultation questions raised in the Issues Paper and many of the views expressed were covered in the Draft Report. This Final Report responds only to the remaining elements of their submission.

[9] AEMO, *Amendments to System Strength Requirements Methodology and Power System Stability Guidelines. Draft Report and Determination – Implementation of Efficient Management of System Strength Rule*, July 2022. Available at https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.

4. Discussion of material issues for the SSRM

In the second stage of consultation, submissions discussed six material issues in response to AEMO's Draft Report and the draft amendments to the SSRM.

The following sections provide a summary of each material issue and views expressed in submissions, AEMO's consideration of the issue, and its conclusion, reflecting the position reflected in the final SSRM.

4.1. Maintaining synchronism of DER

4.1.1. Issue summary and submissions

AEMO's Issues Paper noted that there were two options for incorporating synchronism of DER into the new system standard – either through the minimum fault level requirement for ensuring the power system remains stable following a credible contingency, or through broader planning activities undertaken by NSPs, including but not limited to the stable voltage waveform element of the system strength standard.

Submissions on this issue in the first stage of consultation were varied[10]. While Powerlink considered that DER synchronism should be captured in the minimum fault level requirements, others such as Energy Queensland and SMA considered that the responsibility should lie within DNSP planning functions. Multiple stakeholders noted the present difficulty in understanding the precise technical nature of this issue, and the need for further investigation to understand the relationship between DER synchronism and system strength (for example, Citipower/Powercor, Siemens Gamesa, Energy Queensland and TasNetworks).

Powerlink and Energex and Ergon commented further on this issue in response to the Draft Report[11]:

Powerlink:

> We recommend that fault level requirements associated with the stable operation of Distributed Energy Resources (DER) be included as a potential material change that could affect the required minimum three-phase fault level in Step 1 of the minimum fault level methodology (Section 4.1). Our experience in the North Queensland region suggests that increases in DER uptake reduce the hosting capacity of large-scale Inverter Based Resources (IBR), such that additional system strength services are required to refill the IBR hosting capacity to its nominated level. We consider the minimum fault level needs to account for DER penetration to ensure existing network users can comply with their performance standards.

Energex and Ergon:

> It is our view that [planning responsibility for the synchronism of DER] should lie within the distribution network service provider's (DNSP's) planning functions. DNSPs are already engaging with significant technologies, volumes and magnitudes of DER within the context of the network for which the DNSP is responsible. Each DNSP has some similarities, but there is also some uniqueness for which the DNSP is best placed to be accountable and responsible.

4.1.2. AEMO's assessment

AEMO understands that DER requires a minimum level of system strength to remain connected and synchronised to the network, and that insufficient system strength could result in higher amounts of DER disconnection after a disturbance. At present, it is not clear how

[10] Section 4.7, Draft Report and Determination, accessible via https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag?First+stage=2.

[11] Note that extracts from submissions quoted in this document are in **this font**.

best to calculate the amount of minimum fault level or system strength required for DER to operate. Submissions received in response to the first and second stages of consultation confirmed this uncertainty.

AEMO understands that the AEMC's primary intent in making the Amending Rule was to provide a framework to ensure proactive provision of system strength to support the connection of utility-scale IBR in the NEM. However, the system strength standards extend to maintaining stable operation for all connected plant across the power system.

AEMO recognises that planning for DER operation and synchronism is critical for ensuring power system stability and adequate system strength. As such, AEMO considers that SSSPs may include DER requirements for system strength within the *efficient* level of the system strength standard, rather than the *minimum* level, depending on the planning circumstances within their region and the emerging understanding of the relationship between system strength and DER synchronism.

AEMO expects that consideration of DER impacts may be undertaken on a case by case basis between SSSPs and their connected TNSPs and DNSPs, and (subject to regulatory approvals) ultimately reflected in the SSSPs' proposals for prescribed transmission services to deliver against the system strength standard in their region. AEMO notes that the Amending Rule defined system strength services as a category of prescribed common transmission services, allowing any residual revenue requirement to meet the cost of system strength services, after deducting system strength charges, to be recovered from transmission customers.

For clarity, AEMO confirms that this is a separate question from AEMO's approach to considering DER disconnection as part of the system security assessment. That is, in order to plan for credible contingency events when and if DER systems disconnect *en masse* from the power system, AEMO confirms it will continue to assess the largest credible contingency size for DER as part of testing appropriate credible contingencies and protected events when setting the minimum fault level requirements[12].

4.1.3. AEMO's conclusion

The final SSRM will confirm that SSSPs may incorporate synchronism of DER into their determination of the efficient level of system strength, on a case by case basis. The final SSRM published alongside this Final Report implements this conclusion, with edits made to sections 5 and 6.

4.2. Critical planned outages

4.2.1. Issue summary and submissions

In section 4.5 of the draft SSRM, AEMO proposed that a 'critical' planned outage from a system strength perspective is one that reduces system strength at a system strength node (SSN) to a level that could cause power system security or market efficiency issues. In the draft SSRM, AEMO proposed a set of impact and duration criteria against which it would select a list of critical planned outages. SSSPs would be expected to plan to ensure the

[12] Further details about how this value has been calculated in the past are available on page 99 of the 2021 System Security reports, accessible via https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/system-security-planning.

minimum three phase fault level is maintained at each impacted SSN for the duration of each relevant outage.

Extracts from submissions on this issue are below.

Powerlink:

> Powerlink supports AEMO's consideration of critical outages when planning for system strength. Powerlink considers any additional procurement of system strength services to account for critical outages should only be made if:
>
> - constraints on IBR plant due to system strength limitations pose a risk to power system security or jurisdictional reliability obligations; and/or
> - it provides net market benefits from the procurement of additional system strength services.
>
> We request these additional considerations are reflected in Step 5 of the methodology (Section 4.5).

AusNet:

> AusNet is supportive of the critical planned outages criteria proposed in its SSRM and thanks AEMO for incorporating our feedback. We also support the requirement for AEMO to publish a list of critical planned outages, which System Strength Service Providers (SSSPs) are expected to incorporate into their planning decisions to ensure fault level is maintained at each impacted system strength node (SSN).
>
> AusNet suggests that there are strong benefits to Victorian consumers from the Victorian SSSP (AEMO) consulting with the Principal Declared Transmission System Operator (AusNet) when incorporating the impact of critical planned outages into their planning decisions (e.g. the provision of system strength services).
>
> …
>
> Under Victoria's unique transmission arrangements, AusNet undertakes planned outages required to conduct essential capital replacement, maintenance, connections, and augmentation works rather than the SSSP (AEMO). This asset management role brings with it practical knowledge about the Victorian transmission network – including details of the current condition of all network assets, planned outage schedule and any associated risks.
>
> TNSPs in other jurisdictions would typically incorporate this information into their planning decisions. This ensures critical planned outages are being planned for in a way that best reduces the risk of asset failure and unplanned outages. AEMO consulting with AusNet would ensure critical planned outages are being planned for with equivalent confidence in Victoria.
>
> …
>
> Renewable energy projects are changing Victoria's existing network characteristics, increasing the complexity of operating the network and undertaking planned outages. At the same time, we are seeing an influx in new transmission augmentations and connections required to facilitate renewable projects which increase the need for planned outages.
>
> SSSPs that explore these challenges and how they are playing out within their region are more likely to deliver solutions that are efficient and timely. This reinforces the need for AEMO to consult with AusNet as it considers how to incorporate planned outages into its planned decisions.
>
> This could be implemented by adding a sentence to Section 4.5 of the SSRM to the effect of:
>
> *"AEMO, in its capacity as the Victorian SSSP, is required to consult with AusNet when considering what services or other mechanisms are required to ensure minimum fault levels can be maintained at each impacted Victorian system strength node for the duration of each relevant outage."*

4.2.2. AEMO's assessment

AEMO agrees with Powerlink that the critical planned outages list should only include those outages that reduce system strength levels and as a result power system security or market efficiency at risk. AEMO does not agree that this would necessarily be limited to outages that require constraints on IBR as there may be other outages which meet these overarching requirements without affecting IBR output. AEMO notes that SSSPs will be able to assess

these matters as part of the regulatory investment tests for transmission (RIT-Ts) to be undertaken when preparing to deliver against the system strength standard.

AEMO has identified an opportunity to simplify the critical planned outages section in the SSRM. The proposed duration criteria in the draft SSRM were set to align with the timing required to return the system to a secure state (within thirty minutes of a contingency). However, this matter is already covered under existing outages processes.

AEMO does not consider it is within the scope of the SSRM to provide specifically for consultation with AusNet in relation to AEMO's exercise of SSSP functions for Victoria. AEMO undertakes these functions as part of its broader Victorian planning functions. Consulation and information flows between AEMO, AusNet and other declared transmission system operators are expected to occur in a timely way for all planning activities.

4.2.3. AEMO's conclusion

AEMO has decided to remove the duration criteria for determining critical planned outages, and otherwise has retained a set of principles and broad examples that will be considered in consultation with SSSPs to prepare the list of outages each year. The final SSRM implements this conclusion, with edits made to section 4.5, including edits to clarify that selection of outages will be focused on power system security, reliability of supply and market efficiency issues.

AEMO has determined not to include specific provision in the final SSRM about the nature of consultation between particular SSSPs and their connected NSPs. Section 2.2 of the SSRM notes the expectations regarding joint planning and system strength.

4.3. Voltage waveform definition

4.3.1. Issue summary and submissions

In the draft SSRM, AEMO proposed a description for a stable voltage waveform for the purpose of enabling future IBR connection and operation, as well as four criteria against which SSSPs may assess the delivery of a stable voltage waveform. The description is designed to focus on voltage waveform stability in the absence of the traditional notion of fault current, and considers pre- and post-fault responses rather than behaviour during a fault.The four criteria proposed were:

- Criterion 1 – The positive-sequence RMS voltage magnitude at a connection point does not violate the limits in the operational guides for the relevant network.
- Criterion 2 – Change in the voltage phase angle at a connection point does not exceed 45 electrical degrees following any credible contingency event or protected event.
- Criterion 3 – The three-phase instantaneous voltage waveforms at a connection point are close to 50 Hz, for pre- and post-contingent conditions, with voltage waveform distortion within acceptable levels.
- Criterion 4 – Any undamped steady-state RMS voltage oscillations anywhere in the power system should not exceed an acceptable planning and connection threshold as agreed with AEMO.

Extracts from submissions on this issue are below.

CPSA:

> Reference to 'voltage waveform instability'

Care should be taken as this term is undefined and is likely to be misinterpreted to be either a power quality issue or a stability issue (or both). Voltage distortion (a power quality issue usually related to harmonic distortion) and voltage stability (a form power system stability) on the other hand are well understood and defined terms.

Criteria 1 – Voltage magnitude

Reference to voltage excursions and voltage step changes are power quality issues, not those related to converter stability. We are concerned that power quality issues are being resolved by solutions intended to resolve converter stability related problems.

Criteria 2 – Change in voltage phase angle

Setting a limit of 45 degrees based on sync check relay settings (between 30 and 60 degrees) is not appropriate in the context of converter stability.

Sync check relays angle thresholds are set to limit the impact on the network and/or to generators when circuit breakers are closed (closing breakers with large angle differences results in mechanical stress to rotating machines).

Angle change limits should be set based on the ability of IBR Phase Locked Loops (PLLs) to accurately track the voltage vector. More research and assessment is required before an angle limit can be settled upon, else it may result in an overbuild of 'system strength' services.

Criteria 3 – voltage waveform distortion

Reference to voltage waveform distortion is a power quality issue. It isn't clear what the acceptable limit is. Voltage waveform distortion is typically managed by the network service provider allocating appropriate emission limits to manage overall harmonic distortion within planning limits. Resolving harmonic issues can only be undertaken efficiently by utilizing harmonic filters to reduce harmonic currents (not by increasing 'system strength' via synchronous generators or additional interconnection).

DIgSILENT:

Criterion 2 – phase angle change

AEMO's proposed criterion 2 for a stable voltage waveform states that the change in voltage phase angle at a connection point must not exceed 45 degrees following any credible contingency event or protected event. AEMO have stated that this is a reasonable threshold as most sync check relays are set between 30 and 60 degree phase angle though a caveat is provided that this is not a "hard requirement". However we consider this requirement and the proposed threshold to not be justified in AEMO's documents.

Firstly, by this definition a post-contingency system response where the voltage phase angle change at a connection point is greater than 45 degrees but which is in reality stable (the system response settles to a new steady state not violating any limits) would be declared as not exhibiting a "stable voltage waveform". This could then trigger the need for the procurement additional system strength services when there is no real stability issue to be resolved. Of course, this is separate from instances where (any level of) phase angle jump results in unstable responses within the power system, which may need to be mitigated with additional system strength services.

Secondly, AEMO's claim in the SSRM that the 45 degree threshold value is justified by the fact that sync check relays have settings between 30 and 60 degrees is not appropriate in our opinion. Sync check relays are used to close a circuit breaker to synchronise (i.e. tie together) two parts of the power system which may not be in synchronism and which may have a large steady state voltage angle difference between them. This is a controlled operation and limiting the phase difference angle at which synchronisation occurs is reasonable as it will reduce the magnitude of torques on synchronous machine shafts and transient power flows within the power system. However, this is entirely different from a scenario in which after a contingency caused by the tripping of one or several network elements, an immediate large change in voltage phase angle occurs which could eventually reach a new steady state value. If the system is stable after such an event, there does not seem to be a need to be concerned with the size of the phase angle jump.

Lastly, AEMO's earlier justification within the April Issues Paper concerned the fact that the average change in frequency over a time window of 500 ms is equal to 0.25 Hz. This is also not an appropriate justification as a phase angle jump is an instantaneous phenomenon (with no change in frequency apart from the instant when it occurs when the rate of change of phase angle is undefined), which is wholly different to phenomenon where system frequency ramps over some time (for instance when a large power imbalance occurs on the power grid). The use of the 500 ms measurement window in this instance is also entirely arbitrary.

Criterion 3 – voltage waveform distortion

AEMO's proposed criterion 3 concerns the level of voltage waveform distortion which is defined as deviations from a 50 Hz sinusoidal waveform. DIgSILENT interprets this criterion to primarily refer to issues of excessive harmonics and harmonic instability resulting from IBRs. However, the definition of stable voltage waveform in the context of the SSRM is concerned with issues which may arise as a result of inadequate system strength, which is primarily to do with the 50 Hz voltage being too sensitive to 50 Hz current injections. Whilst it may be possible to resolve cases of excessive harmonics and harmonic instability in parts of the power system with the provision of additional system strength (for instance by installing a synchronous condenser), these harmonic responses are also significantly influenced by the characteristic of the power system elements (including other IBRs) at the harmonic frequency of concern. In this regard, it is possible that measures which do not involve additional system strength provision such as the installation or modification of a harmonic filter or the retuning of harmonic control loops may be just as or more effective at resolving the issue (neither of which have an effect on system strength as traditionally conceived). In this instance, considering voltage waveform distortion for the requirements concerning system strength would be inappropriate as the fundamental issue is not directly related to system strength in the first place. The fact that some waveform distortion issues may not directly relate to system strength should be captured within the SSRM.

Criterion 4 – RMS voltage oscillations

AEMO's proposal for criterion 4 is that undamped RMS voltage oscillations should not exceed a threshold which could be between 0.1% and 0.5% and is active under discussion within the Power System Stability Working Group and Power System Modelling Reference Group.

We are concerned that the lower end of this threshold range may produce limitations particularly when measuring such responses on the bulk power system. For instance, a precise voltage transformer for revenue metering (class 0.2) may have a ratio error of 0.2%. The second issue is whether noise in the measurement (whether due to interference or harmonics within the voltage waveform which pass through the RMS processing) could cause oscillations to be indistinguishable from noise.

It is important for AEMO to collect evidence to justify the practicality of the threshold which is selected.

4.3.2. AEMO's assessment

Generally

AEMO agrees that *voltage waveform instability* could be futher clarified in the context in which it is used for the purposes of system strength requirements, but notes that the term itself must still be used unaltered in the SSRM because it is the term used in NER S5.1.a.9(b).

Criterion 1 – Voltage magnitude

Although power quality issues may also arise from large changes in voltage or excursion, AEMO is including change in voltage magnitude in the system strength standard to identify system strength issues in the absence of fault current as a metric. AEMO emphasises that the intention is not to monitor power quality. Rather, the intention is to use voltage magnitude as a way to define the stiffness of voltage waveform.

Criterion 2 – Change in voltage phase angle

AEMO agrees with both CPSA and DIgSILENT that measuring the change in voltage phase angle following a credible contingency event or protected event may not fully capture the intent of this criterion. Based on discussion with both stakeholders and NSPs, AEMO considers that the change in voltage phase angle should instead be assessed following the injection or withdrawal of active power at a location on the network. In other words, this criterion is assessing the sensitivity of change in steady-state voltage phase angle to injection or withdrawal of active power at a connection point. An excessive change in phase angle could be considered indictive of low system strength.

Criterion 3 – Voltage waveform distortion

In response to CPSA's submission, AEMO notes that additional system strength measures may not always be the best solution to address voltage waveform or harmonic distortion

issues, and that a combination of mitigation measures may be required in some instances, including installation or modification of power quality issues or re-tuning of harmonic control or IBR loops. These matters may or may not need to be considered under the system strength standard, depending on the matter in question.

AEMO's view is that voltage waveform distortion is a necessary metric in the stable voltage waveform criteria, as it addresses the issue of harmonic instability due to interaction between multiple IBR in close proximity, high frequency distortion from IBR fast-controllers, or power electronic switching with other power system components. These issues can be exacerbated under low system strength conditions.

Criterion 4 – RMS voltage oscillations

AEMO agrees with DIgSILENT's comment that measuring a lower magnitude of oscillations in the field could present challenges, however AEMO highlights that this criterion was proposed as a simulation metric rather than a practical field level measurement metric. AEMO acknowledges that there are ongoing active discussions regarding this criterion with stakeholders.

4.3.3. AEMO's conclusion

AEMO has updated Criterion 2 of the stable voltage waveform criteria in the final SSRM to measure change in voltage phase angle post injection or withdrawal of active power at a location on the network, which is a more direct measure of change in sensitivity to voltage phase angle, rather than following a credible contingency.

AEMO has updated Criteria 2, 3 and 4 to clarify their application in light of the feedback received. For Criterion 4, the floor for the planning threshold for voltage oscillations has been removed, recognising the fact that in-field measurements cannot presently always achieve the desired accuracy at very low oscillation levels.

4.4. Protection scheme requirements

4.4.1. Issue summary and submissions

The Amending Rule requires that the power system should have sufficient minimum three phase fault levels to enable the protection systems of transmission and distribution networks, and network users, to operate correctly. In the draft SSRM, AEMO stated a baseline assumption that the minimum three phase fault levels determined at various nodes as at 30 November 2022 are sufficient to meet the standard for protection systems in operation at that time.

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

Submissions on this issue are extracted below.

DIgSILENT:

> Regarding using adequate protection operation as a criterion for minimum fault level, the relative low cost of modifying or replacing protection systems to the cost of additional system strength services (in the form of additional grid forming inverters or synchronous condensers) must be borne in mind. For instance, if the fault level is so low that a protection scheme is no longer working, the inclusion or exclusion of it as a criterion should be based on whether there is an alternative protection scheme that would work in the circumstances and the cost of changing the protection scheme, relative to cost of system strength mitigation to increase the fault level to the next most limiting

> criterion that would set the minimum fault level. The time and cost associated with reviewing the protection should not be a reason for excluding the criterion because the NSPs will need to ensure that their protection still works for every location in the transmission system at any time in the future whatever minimum fault level is selected.

Energex and Ergon:

> We suggest Network Service Providers (NSPs) should determine the minimum fault level requirements of their protection systems so these can be considered in the determination of minimum fault level requirements.
>
> …
>
> Ergon Energy and Energex note NSPs are currently working through this complex topic. [the future of protection scheme design and operation]
>
> …
>
> Ergon Energy and Energex are currently working through this issue [the proposed approach to incorporating protection scheme operation into the minimum fault level requirements] and suggest future working groups or discussions may present a suitable pathway forward.

4.4.2. AEMO's assessment

AEMO agrees that new or updated operating requirements or limits that ensure correct operation of protection systems must be taken into consideration as they occur. AEMO notes that design and operation of protection schemes is within the responsibility of TNSPs and DNSPs for their respective networks.

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

4.4.3. AEMO's conclusion

AEMO considers the position on protection scheme operation presented in the draft SSRM remains appropriate for the present state. As such, no material amendments have been made in the final SSRM on this matter. AEMO has, however, made a number of drafting changes in section 4.2 to better align with the wording of NER S5.1a.9(a), to highlight the underlying requirements for correct obligation of protection systems in NER S5.1.9, and to clarify the application of the baseline assumption.

4.5. System strength node selection

4.5.1. Issue summary and submissions

The draft SSRM noted that AEMO will apply engineering, market and policy judgement to select an appropriate set of SSNs for each region, and will also consider both a set of general principles for factors affecting overall SSN selection for a region as well as a set of criteria informing individual node selection.

DIgSILENT commented on the draft proposal for SSN selection as follows:

> Aside from an overview, a clear process for how the location of the SSNs would be defined is not provided particularly when some of the requirements above conflict. Since the SSNs will affect the location of system strength services, this is a critical aspect of the proposal. Hence the SSNs must include the location that optimises the services, otherwise generators will be paying too much and the NEO will be not served.
>
> 1. A particular issue is the statement within the Draft SSRM that "total number of SSNs declared per region must be limited to a level which is practicable having regard to the effort required to device system strength requirements for each node." However, DIgSILENT understands the process for determining system strength requirements for SSNs to consist of the following:

2. Determining a set of worst case realistic power system scenarios (for power system demand and dispatch) for minimum system strength. This would include all the criteria detailed within the draft SSRM – projecting future IBR, changes in synchronous machine operation, changes to HVDC equipment etc. These worst case scenarios would need to be robust to ensure that the system strength adequacy is tested across the power system. For example, it is expected that new worst-case realistic power system scenarios and contingencies would need be incorporated into the assessment for the publicly announced renewable energy zones (REZs) which will accommodate GWs of new IBRs. Failure to adequately capture the full range of scenarios and contingencies will result in an incomplete assessment.
3. Assessing the minimum fault level requirement then would involve the following:
    a. Assess protection system operation needs: The fault level calculation must be performed for all nodes against the worst case operating scenarios and contingencies. This assessment is expected to be carried out using phasor based short circuit programs. Hence reporting the results considering a large number of (i.e. nearly all) transmission nodes to be SSNs will not introduce significant effort.
    b. Assess voltage control system operation needs: This assessment must be carried out at all nodes to which voltage control systems connect against the worst case scenarios and contingencies. This assessment is also proposed to be carried out using phasor based short circuit programs. As before, reporting the results considering a large number of transmission nodes to be SSNs will not introduce significant effort.
    c. Assess power system stability needs: This assessment must be carried out by performing detailed wide area EMT simulations using the worst case contingencies and operating scenarios. The number of SSNs is not relevant to this aspect of the assessment as the inputs to it are the operating scenarios and contingencies. The results of the EMT simulations will identify the worst case scenario and contingency pairs (worst case dispatch and events) with respect to stability. These conditions can then be configured within a phasor based short circuit program to determine the equivalent fault level requirements at the SSNs. Again, expanding the set of SSNs will not introduce significant effort in the latter phase of this process (calculating and reporting fault levels). The time intensive aspect of this assessment concerns the breadth of operating scenarios and contingencies considered which are not related to the SSNs.

With the above process outlined, the SSSPs could publish the minimum system strength requirements (expressed as fault level in MVA) at each node from which it will be possible to identify the optimal amount and location of system strength services to serve all the connecting generators that are subscribing to the service. To ensure that the solutions are optimum, particularly when the limiting aspect is power system stability, sensitivity studies using a detailed wide area EMT model can be carried out by applying varying levels of system strength services at the locations in question to determine their influence.

4.5.2. AEMO's assessment

Although SSN locations will influence SSSPs' selection of locations for system strength services, it is clear that SSSPs can deliver services at locations other than the SSNs, as required to provide the required minimum and efficient levels of system strength. SSN location does not dictate location of system strength services, and node selections will have to be made before the optimal services and locations can be determined through the planning processes.

As such, AEMO does not agree that nodes should be selected solely to optimise system strength service location, and in fact does not consider this to be possible. The ongoing consultation on amendments to the SSIAG[13] further discusses the relationship between SSN selection, system strength service delivery, and the system strength locational factors and charging.

AEMO considers the proposed method of SSN selection in the draft SSRM to be sufficient for selecting nodes that holistically capture power system requirements. AEMO also remains of

[13] Consultation materials relating to the SSIAG can be accessed via AEMO's website at https://aemo.com.au/consultations/current-and-closed-consultations/ssrmiag.

the view that the benefits of including nearly all transmission nodes as SSNs would not outweigh the resourcing and time costs associated with such an assessment.

4.5.3. AEMO's conclusion

AEMO has retained the same SSN selection method in the final SSRM as was proposed in the draft SSRM. However, AEMO has amended the general principles for overall system strength node selection in section 3.2 of the final SSRM, to clarify that system strength services need not necessarily be delivered at the node itself and that selection of SSNs is intended to be flexible to allow selection to match the changing needs of the power system.

4.6. Power quality assessment

4.6.1. Issue summary and submissions

CPSA noted that AEMO proposed to assess voltage control system operation needs with reference to AS/NZ 61000.3.7:2001, in Section 4.3 of the draft SSRM, which also refers to stable operation of capacitor banks and reactors. CPSA indicated the importance of differentiating power quality issues that would be present regardless of the connection of IBRs from issues related to converter stability, and noted the SSRM should only address the latter.

With reference to stable operation of capacitor banks and reactors (shunt or series), CPSA commented that shunt devices are not impacted by converter driven instability in that they are passive devices where the output is a function of voltage, and should not be covered by the SSRM.

With reference to AS/NZ 61000-3.7, CPSA said:

> This standard covers limits for short term flicker, long term flicker and rapid voltage changes which are all power quality phenomenon.
>
> Power quality is the responsibility of the Network Service Provider (NSP), hence it is not clear how AEMO's assessment of this will be undertaken , how this will be coordinated with the NSP's obligations and what the outcome of this assessment would entail.
>
> The SSRM should provide more detail on how this will be assessed as power quality issues are often already present in parts of the network in the absence of IBR connections. For example, rapid voltage changes or flicker issues can be caused by large motors starting or operation of electric arc furnace (both of which are not related to converter stability associated with IBRs).
>
> We urge AEMO to provide clarity on how power quality will be considered in the SSRM. Ultimately, converter driven instability or interactions can present as a power quality issue, however the root cause is often poor tuning or coordination of controllers and a lack of damping. Increasing 'system strength' by increasing the synchronous fault level would only mask pure tuning of converters.

4.6.2. AEMO's assessment

AEMO confirms that the reference in the SSRM to the AS/NZ 61000-3.7 standard is intended to provide a planning limit against which to test rapid step changes in voltage. The reference to the standard is for indirectly assessing that there is expected to be adequate fault level at a transmission network busbar, based on voltage step changes after switching a shunt device. It is not intended to require consideration of power quality assessment.

4.6.3. AEMO's conclusion

AEMO does not consider that changes are required to the draft SSRM as it does not require consideration of a power quality assessment for system strength purposes. The final SSRM is consistent with the draft SSRM on this matter.

5. Discussion of material issues for the PSSG

Of the five submissions AEMO received in response to the draft SSRM and draft PSSG, only one provided feedback on the PSSG, which is discussed in this section.

5.1. Issue summary and submissions

CPSA noted that the PSSG currently does not explicitly distinguish converter-driven stability as a measure of stability distinct from system strength. CPSA also noted that the voltage waveform stability criterion could be improved by instead reducing network impedance rather than reducing distorting current. CPSA maintains that references to *resilience* should be clarified or avoided, as the term lacks relevance in the context of power system stability classification, and has differing interpretations across industry.

5.2. AEMO's assessment and conclusion

AEMO agrees that the definition of system strength to explicitly include converter-driven stability as a measurement of stability for IBRs is relevant. Accordingly, AEMO has updated the final PSSG to clarify section A1.6 on converter-driven stability. The corresponding system strength criteria in section B1.7 have also been updated to reflect this change.

Consistent with NER S5.1.14(c), AEMO considers that voltage waveform stability is the reference point for measuring converter-driven stability, in the context of the system strength framework. AEMO agrees that terms referring to the 'resilience' of a power system are open to misinterpretation and has updated the PSSG to reflect this.

6. Final Determination

Having considered the matters raised in submissions and at meetings and forums, AEMO's final determination is to:

- Replace the existing System Strength Requirements Methodology with the final SSRM published with this Final Report and Determination.
- Replace the existing Power System Stability Guidelines with the final SSRM published with this Final Report and Determination.

The final amended SSRM differs from the version published with AEMO's Draft Report as required to incorporate the conclusions set out in Section 4 of this Final Report, including.

- **Maintaining synchronism of DER is to be considered in determining the efficient level of system strength**, to be managed through NSP joint planning processes.
- **The annual system strength report will identify critical planned outages** (presenting a risk to power system security, reliability or market efficiency) to be incorporated in system strength planning, to include sufficient system strength to maintain ensure power system security during critical network outages.
- **Description of stable voltage waveforms**. Although the NER already describe broad power system standards for voltage, the final SSRM provides a system strength-specific description of stable voltage waveforms, against which SSSPs will need to ensure that projected IBR connections and operation can be facilitated. This description is provided as a set of criteria.
- **Protection scheme operation will be assessed and confirmed by SSSPs and their connected network service providers**. AEMO has confirmed that the responsibility to assess and advise on protection scheme operation rests with SSSPs.
- **System strength nodes will be selected within SSSPs' networks**. In the final SSRM, AEMO has made it clear that system strength services to be delivered by SSSPs need not necessarily be located at the declared system strength node, and that AEMO will retain the flexibility to select system strength nodes with reference to the changing needs of the power system.

The final amended PSSG differs from the version published with AEMO's Draft Report as required to incorporate the conclusions set out in Section 5 of this Final Report. In addition, AEMO has made a number of drafting improvements to the SSRM to minimise ambiguity, correct errors (including SSN allocations for forecast IBR in section 6.2), and finalise the document.

AEMO has also published change-tracked versions of the SSRM and PSSG showing differences between the draft and final documents. The change-tracked versions are not to be used for official purposes, and are for information only.

The amended SSRM and PSSG will take effect from 1 December 2022.

As required by the NER, the amended SSRM will be used for the purposes of the System Strength Report to be published by AEMO on 1 December 2022.

Appendix A. Glossary

Term or acronym	Meaning
AEMC	Australian Energy Market Commission
Amending Rule	National Electricity Amendment (Efficient Management of System Strength on the Power System) Rule 2021
DNSP	Distribution Network Service Provider
EMT	Electromagnetic transient
Final Determination	AEMC, Efficient management of system strength on the power system, Rule determination, 21 October 2021, at https://www.aemc.gov.au/sites/default/files/2021-10/ERC0300%20-%20Final%20determination_for%20publication.pdf
IBR	Inverter based resource
NEM	National Electricity Market
NER	National Electricity Rules
NSP	Network Service Provider
PLL	Phase-Locked-Loop
PSSG	Power System Stability Guidelines
REZ	Renewable energy zone
RIT-T	Regulatory investment test for transmission
SSIAG	System Strength Impact Assessment Guidelines
SSN	system strength node
SSRM	System Strength Requirements Methodology
SSSP	System Strength Service Provider
TNSP	Transmission Network Service Provider