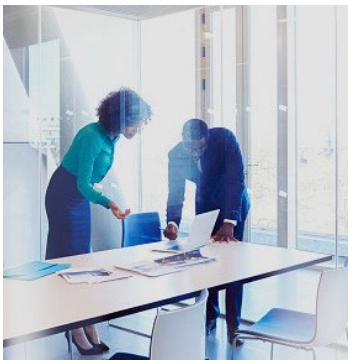
GHD Advisory



Technical advice on performance standards for stand-alone power systems

Australian Energy Market Commission

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1. Introduction

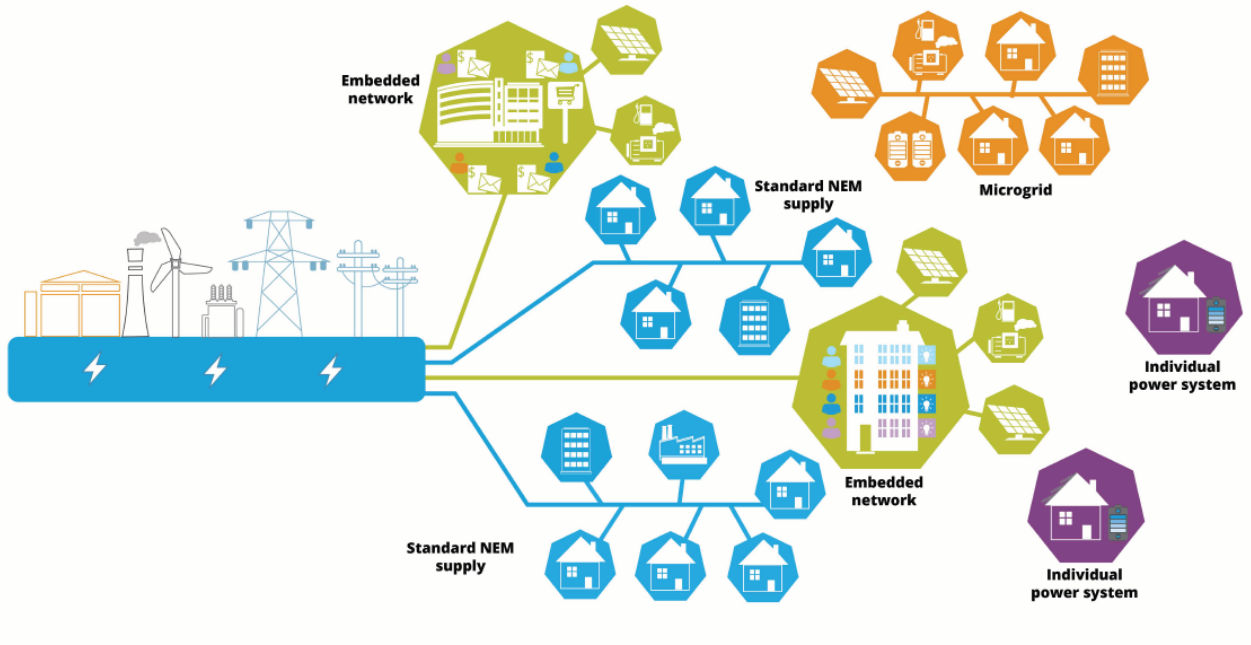
This report provides an assessment of the applicability of the technical schedules included in Australian National Electricity Rules (NER) and other jurisdictional technical codes for effectively and safely managing stand-alone power systems (SAPS), which includes both microgrids and individual power systems (IPS).

The review identified the salient technical issues relevant to the development and operation of SAPS, and the report recommends an approach for revision of the NER to include technical schedules relevant to SAPS.

1.1 Stand-alone power systems

A SAPS is an electricity supply arrangement that is not physically connected to the national grid. The AEMC uses the term to encompass both micro-grids, which supply electricity to multiple customers, and individual power systems, which relate only to single customers. The AEMC's definitions are shown in Figure 1 as 'microgrid' and 'individual power system' below.

Figure 1: Models of electricity supply



Source: AEMC, *Draft Report: Updating the Regulatory Frameworks for Distributor-led Stand-alone Power Systems,* December 2019, Figure 1.1, p. 4.

The concept of small isolated power systems is not new. Systems utilising diesel generators have been used to supply small islands and isolated communities for a long time.

The availability of new power generation technologies, such as solar photovoltaic (PV) (both distributed and centralised), as well as energy storage technologies such as battery energy storage systems (BESS), is making SAPS more viable and economical than traditional alternatives such as extending the distribution network to remote communities and customers. In the future, the technologies presently in development,

which cannot be considered as matured, such as power generation using hydrogen fuel cells and electrolysers for producing hydrogen could become integral parts of SAPS.

The technical concepts associated with electricity generation and transmission (including the technical schedules in the NER) have been developed focusing on the power system performance parameters that are relevant and important for systems dominated by rotating synchronous machines. However, with the transition to variable renewable electricity generation, these concepts may not continue to apply in the same form. For example, SAPS may comprise of only power electronics coupled[1] generating units and may not include any synchronous generators. In these setups, the system-wide control and performance characteristics such as frequency control are significantly different from an interconnected power system with a large proportion of rotating synchronous generation.

In reviewing the technical performance standards, GHD has taken into consideration that the technologies employed within SAPS may continue to develop rapidly, and the standards framework in the NER should be robust enough to accommodate expected changes.

1.2 AEMC review of regulatory arrangements for SAPS

In August 2018, the COAG Energy Council asked the AEMC to undertake a review of regulatory arrangements for SAPS under the national energy laws and the NER. The terms of reference for the review set out two priority areas of work:

- Priority 1 focussed on the development of a national framework for customers that move from grid-connected supply to SAPS provided by distribution network service providers (DNSPs).
- Priority 2 focussed on the development of a national framework to support the supply of electricity from SAPS provided by parties other than DNSPs.

The AEMC published a final report on 'Review of Regulatory Frameworks for Stand-Alone Power Systems – Priority 1' in May 2019. A final report on the priority 2 review was published on 31 December 2019.

On 19 December 2019, the AEMC published a draft report, "Updating the regulatory frameworks for distribution led stand-alone power systems". That report presents draft recommendations for a package of proposed revisions to the NER to implement a new regulatory framework for SAPS provided by DNSPs in the National Electricity Market (NEM). The AEMC invited written submissions on the draft report, specifying a due date of 13 February 2020.

The proposed changes to the NER envisage that the customers transitioned to SAPS would be no-worse-off than had they remained on standard grid-connected supply arrangements. The framework, therefore, allows for SAPS customers to retain access to the competitive retail market, and to receive the same (or better) levels of reliability, safety and quality of supply following the transition to SAPS. To this end, the AEMC included some recommendations in the draft report regarding the application of the technical performance standards defined in the NER to SAPS.

1.2.1 AEMC draft report – SAPS technical performance standards

In the AEMC's draft report, the AEMC recommended an approach whereby the existing technical and performance standards applicable in the NEM should apply to SAPS where they are necessary to ensure the maintenance of equivalent power quality outcomes for DNSP-led SAPS. The AEMC also proposed several

[1] Power electronics coupled generation systems are also often referred to as "power conversion systems (PCS) coupled" or "inverter connected" or "inverter coupled" generating systems.

changes to power quality obligations set out in schedules 5.1a to 5.3a of the NER, to clarify which standards would apply, or would not apply, in the context of SAPS. Finally, the AEMC indicated its intention to consider further the potential for certain power quality requirements for SAPS to be relaxed, either uniformly or on a case-by-case basis, compared to those outlined in schedules 5.1a to 5.3a of the NER.

In their draft report, the AEMC identified updates to the regulatory frameworks for distributor-led SAPS and proposed that the technical schedules in chapter 5 are reviewed and revised appropriately to accommodate the inherent technical characteristics of SAPS.

The AEMC's position as presented in the draft report for the schedules relevant to GHD's scope are summarised in the following table.

Table 1: AEMC's proposed revisions to the technical schedules (Chapter 5 of the NER)

Rule reference	Explanatory notes and comments
Schedule 5.1a (the system standards)	The schedule is intended to apply in relation to a regulated SAPS as follows: • **S5.1a.1 Purpose**: The general principles apply. • **S5.1a.2 Frequency**: National grid frequency performance will be the responsibility of AEMO. In a regulated SAPS, it is the responsibility of the relevant DNSP. • **S5.1a.3 System stability**: This provision applies in relation to the power system, which does not include a regulated SAPS. • **S5.1a.4 Power frequency voltage**: The power frequency voltage limits apply in relation to a regulated SAPS, including the provision for power factor and reactive power flow at the connection point. The "contingency event" triggers will not be determined for regulated SAPS and those parts of the clause are not relevant in a regulated SAPS. • **S5.1a.5 Voltage fluctuations**: The clause applies in relation to a regulated SAPS. • **S5.1a.6 Voltage waveform distortion**: Continues to apply. No changes needed if the SAPS is regulated under jurisdictional DNSP network licensing. • **S5.1a.7 Voltage unbalance**: The clause applies in relation to a regulated SAPS. • **S5.1a.8 Fault clearance times**: This provision is not intended to apply in relation to a regulated SAPS.
Schedule 5.1	Amendments to the schedule are intended to achieve the following: • **S5.1.1 Introduction**: The general principles apply. • **S5.1.2.1 Credible contingency events**: Does not apply. • **S5.1.2.2 Network service within a region**: Applies in relation to a regulated SAPS. • **S5.1.2.3 Network service between regions**: Not relevant to a regulated SAPS. • **S5.1.3 Frequency variations**: Applies in relation to a regulated SAPS. • **S5.1.4 Magnitude of power frequency voltage**: The first part of the clause only applies in relation to transmission network service providers (TNSPs). The final paragraph applies to DNSPs, including regulated SAPSs. • **S5.1.5 Voltage fluctuations**: Applies in relation to a regulated SAPS. • **S5.1.6 Voltage harmonic and voltage notching distortion**: Applies in relation to a regulated SAPS. • **S5.1.7 Voltage unbalance**: Applies in relation to a regulated SAPS. • **S5.1.8 Stability**: Does not apply in relation to a regulated SAPS.

Rule reference	Explanatory notes and comments
	• **S5.1.9 Protection systems and clearance times**: Applies in relation to a regulated SAPS. • **S5.1.10 Load, generation and network control facilities**: Applies in relation to a regulated SAPS. • **S5.1.11 Automatic reclosure of transmission or distribution lines:** Applies in relation to a regulated SAPS. • **S5.1.12 ratings of transmission lines and equipment**: No change – assumes a request for information will not be made. • **S5.1.13 Information to be provided**: Will not apply, as rule 5.3 does not apply to a connection to a regulated SAPS.
Schedule 5.2	It is intended that new clause 5.1.3 has effect, such that this schedule does not apply to generation connections in a regulated SAPS.
Schedule 5.3	New S5.3.1a(f) specifies that the schedule does not apply in relation to a Network Service Provider or a Network User in relation to a connection to a regulated SAPS.
Schedule 5.3a	It is intended that new clause 5.1.3 has effect such that this schedule does not apply in relation to Market Network Service Provider connections to a SAPS.

Source: AEMC, *Draft Report: Updating the Regulatory Frameworks for Distributor-led Stand-alone Power Systems,* December 2019, Table D.1, pp. 99-100.

To assist the AEMC development the final report for the review, GHD has sought to critically evaluate these draft findings from a technical and implementation standpoint.

1.2.2 Submissions to the AEMC's draft report

The AEMC received 17 submissions (including five late submissions) in response to the draft report on updating the regulatory frameworks for DNSP-lead SAPS review.

In developing our recommendations, GHD has considered stakeholder feedback focussing on matters concerning the technical and performance requirements of SAPS. Table 2 (below) briefly summarises the feedback received in response to the draft report relevant to our review.

Table 2: Submission to AEMC's Draft Rule determination

Stakeholder	Relevance to technical standards
TasNetworks	Nothing relevant
AER	Nothing relevant
Energy Queensland	Ergon Energy is concerned that the requirement to maintain a secure SAPS is not adequately defined as the system security provisions of chapter 4 of the NER do not apply for a *regulated SAPS.* To manage system stability due to the intermittency of customer connected renewables and the risk of excessive DER, Ergon Energy is installing a DER co-ordination system. This requires close and centralised coordination due to a range of technical challenges.
AusNet Services	Nothing relevant

Stakeholder	Relevance to technical standards
Essential Energy	Nothing relevant
Energy Networks Australia	In principle, customers should be able to install their own solar or batteries (i.e. DER), in addition to those are already provided as part of the DNSP-led SAPS. These systems' inverters would need to be DNSP controlled or set up to not conflict with the SAPS inverters to ensure safe operation of the SAPS within technical limits.
Firm Power	The technical requirements must be clear and transparent. The technical rules are complicated. Engineering solutions will initially need to be customised before proprietary systems can be developed. The application of NEM-wide standards to SAPS generation services is impractical and would not necessarily lead to a beneficial outcome for customers. Although the same principles apply to small, isolated SAPS projects, the application of controls should be sympathetic to the size and type of technologies used (e.g. non-synchronous inverter-based technologies).
Ausgrid	Nothing relevant
Spark Infrastructure	Nothing relevant
Lumo	Nothing relevant
Endeavour Energy	Nothing relevant
Public Interest Advocacy Centre	Nothing relevant
Mondo Power - received 17/02/20	Nothing relevant
AEMO - received 18/02/20	There are design elements that must be considered for the system, but do not apply in principle and are unnecessary in practice for SAPS. These include the establishment of operating standards for generating systems (requirements critical to support reliability and security of supply in the System, which are not relevant to SAPS).
Department Energy and Mining, SA - received 21/02/20	Nothing relevant
SA Power Networks - received 17/02/20	Nothing relevant
Clean Energy Council - received 19/02/20	Nothing relevant

1.3 Scope and areas of focus

GHD was engaged by the AEMC to provide guidance on technical and performance standards applicable in the NEM to SAPS. The scope of work required GHD to identify and assess instances where the level of the existing technical and performance standards set out in the NER and relevant jurisdictional instruments could be relaxed for SAPS without risking a material impact on a SAPS customers' power quality experience relative to a grid-connected customer.

In preparing analysis and this report, GHD has been guided by the AEMC's objective of ensuring that customers transitioned from the grid to SAPS supply are 'no-worse off' in terms of the power quality outcomes they experience relative to customers connected to the national grid.

In conducting our assessment, we have considered:

- The suitability of applying technical standards set out in schedules 5.1a to 5.3a of the NER and other relevant national and jurisdictional instruments (e.g. the frequency operating standard) to DNSP-led SAPS.
- The extent to which SAPS require different power system performance and technical requirements.
- Appropriate alternative technical and performance standards that consider SAPS specific technical limitations while maintaining customer power quality objectives.

To inform our analysis, GHD has drawn on our experience designing SAPS (both microgrids and IPS) and considered technical standards applicable in other jurisdictions (mainly Western Australia). We also reviewed relevant guidelines published by industry bodies (e.g. DER guidelines by the Electricity Networks Association).

GHD understands that the AEMC may elect to publish this report to inform its review of changes to the NER required to accommodate development of regulated-SAPS within the NEM.

1.4 Limitations

This report has been prepared by GHD for Australian Energy Market Commission and may only be used and relied on by Australian Energy Market Commission for the purpose agreed between GHD and the Australian Energy Market Commission as set out in Chapter 1 of this report.

GHD otherwise disclaims responsibility to any person other than Australian Energy Market Commission arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

2. Assessment of technical codes and standards

The AEMC considers power quality outcomes for DNSP-led SAPS customers should remain equivalent to those of customers connected to the grid. That is, customers should be no worse-off following a transition to a DNSP-led SAPS compared to staying connected to the interconnected power system.

This means the technical standards need to be designed so as to not disadvantage any customer, and to provide sufficient power quality similar to that which a customer would have received if connected to the grid. For an example, any relaxation to the system standard should not cause the customers connected to SAPS to need to procure equipment made for a different specification (for meeting a relaxed technical standard) and thereby incurring a higher cost.

The technical standards for DNSP-led SAPS must strike a balance between relaxing the typical standards used for power systems that create barriers to the efficient development of SAPS and ensuring standards are sufficient that operations of the customers connecting to SAPS are not adversely affected by the changed standards.

Further, while there is a possibility that some flexibility to be left in the standards for negotiations on a case-by-case basis, the framework should ensure the negotiations between SAPS providers (i.e. DNSPs) and customers can take place on a fair and reasonable basis. Rigid application of the technical standards might not be necessary for all SAPS customers. While the AEMC could consider a framework where the standards are able to be relaxed on a case-by-case basis, it is a concern that the fairness of the negotiations between DNSPs and small customers may be impacted by a “negotiation power” bias and may lead to consumer protection issues.

2.1 Technical parameters

The technical standards in NER, as well as other jurisdictional instruments, mainly focus on the following areas:

- Reliability
- Frequency
- Voltage
- Quality (i.e. distortions)
- Stability
- Safety

These aspects are addressed by specifying the obligations of service providers (e.g. DNSPs) and the customers, in some cases explicitly (for example, in the NER) and in other instances implicitly (for example, in jurisdictional technical codes).

The following sections discuss the need and potential for meeting these requirements in SAPS, and where beneficial a comparison is made between meeting the requirements via a SAPS and when customers are supplied via interconnected networks.

2.1.1 Reliability

The reliability of electricity supply to customers typically considers the following two characteristics:

- Adequacy of the energy supply
- Network reliability

The adequacy of energy supply in the NEM is managed by setting the NEM reliability standard and monitoring the reliability of the NEM (as a whole) against this standard as outlined clause 3.9.3 of the NER.

The need to reduce the supply interruptions as a result of the unavailability of the network are addressed via placing obligations on the network service providers (NSPs) to plan and provide adequate redundancy in the supply networks. The obligations are described in S5.1.2 of the NER. DNSPs are required to meet a given level of supply network reliability under their jurisdictional licence requirements and are incentivised to deliver network reliability reflecting customer expectations through the Service Target Performance Incentive Scheme (STPIS) available in the NEM.

Usually, the economic justification for transitioning from electricity supplied through a network connection to a SAPS stems from the inefficiencies and difficulties associated in maintaining the network connection with an adequate level of network reliability. In this regard, the experience to date indicates that the supply reliability to the customers has increased by several folds, after transitioning to SAPS.

Irrespective of the positive customer experience of improved reliability once connected to a SAPS, the AEMC may consider the need for some form of obligations to be placed on DNSPs for DNSP-led SAPS to ensure that the reliability of these SAPS does not deteriorate below a set minimum value. The set minimum value may be derived from the reliability statistics of the same network such as “average reliability of long rural feeder” supplied by the DNSP for the same year.[2]

S5.1.2 of the NER specifies various factors NSPs should consider when planning their network to deliver network reliability. S5.1.2.1 defines various contingency events that NSPs should consider. However, the specific requirements in this clause apply for voltage levels of 66 kV and higher. As the majority of SAPS are likely to operate below 66 kV, the provisions in S5.1.2 are unlikely to have any direct application to these systems.

[2] As an example, the average reliability duration standards of AusGrid for 2019 are shown in the following table:

Average reliability duration standards				
	CBD	**Urban**	**Rural**	**Long Rural**
SAIDI	45	80	300	700
SAIFI	0.30	1.20	3.20	6.00

Source: Ausgrid, *Distribution and Transmission Annual Planning Report*, December 2019, p. 133.

2.1.2 Frequency

For interconnected networks, a very tightly managed system frequency standard is maintained that reflects:

- The inability of frequency sensitive generation units (e.g. combined cycle gas turbines (CCGTs)) to operate over a wide frequency operating band.
- Use of frequency as a mechanism of reference for controlling the speed of motor-driven processors (e.g. production lines).
- Use of frequency as a reference of time (e.g. synchronous clocks). This need has significantly diminished in recent times due to the availability of other mechanisms for providing independent time references to clocks.

As specified in NER S5.1a.2, the frequency operating standard for the NEM (commonly referred to as the NEM FOS) is determined by the Reliability Panel and published by the AEMC. Various provisions in the NER require AEMO, NSPs, generators and loads to take action to control frequency to within the limits specified in the NEM FOS. Furthermore, the NER place an obligation on NSPs, loads and generators to ensure their facilities can ride through frequency variations consistent with the NEM FOS.

The above requirements for maintaining the frequency of the interconnected networks are, however, not as pertinent to SAPS due to less sensitive generation units being connected in a SAPS (i.e. no CCGTs). Additionally, there are inherent technical and operating characteristics of generating units typically connected to a SAPS (such as low capacity and low inertia diesel reciprocating engine generators) that are unable to achieve such tight frequency bands without a disproportionately high and potentially prohibitory investment costs.

Therefore, the AEMC could consider relaxing of the frequency variation management bands as specified in the technical standards for interconnected networks when applying to SAPS.

2.1.3 Voltage

The power system voltage for the interconnected networks is usually controlled within tight bands under normal operation because the prolonged operation of the power system outside these limits may:

- Damage the connected equipment and pose a safety risk to the consumers.
- Reduce system stability and may even lead to system collapse.
- Affect the performance and efficiency of the connected devices, e.g. motors.

It is expected that as contingencies in the electricity networks occur, the supply voltage could momentarily vary over a wider range than normal, for short periods.

NER Figure S5.1a.1 outlines the acceptable voltage variations above the nominal operating voltage, momentarily for a given period of time. This specification directly translates to the overvoltage variations that can be tolerated by the connected equipment. This technical requirement is, therefore, driven by the design capability of the connected customer equipment and therefore is applicable for interconnected networks as well as SAPS.

It should be noted that SAPS typically have lower system strength[3] due to higher impedance compared to interconnected systems such as the NEM. This results in the voltage fluctuations being more widespread for

[3] System strength is an inherent characteristic of any power system – it is a measure of the stability of a power system under all reasonably possible operating conditions. System strength is important as it can materially impact the way a power system operates.

system disturbances. Notwithstanding this, power electronics coupled generating units can have fast voltage control schemes that should be capable of achieving current NER voltage limits. As such, there is no apparent technical or performance barrier with requiring SAPS to comply with the limits set out in Figure S5.1a.1 of the NER.

2.1.4 Quality

The frequency and voltage quality attributes of electricity supply systems are discussed in above subsections 2.1.2 and 2.1.3. The quality associated with the distortion to the supply waveforms is considered in this section.

Customers expect a steady-state voltage waveform that is relatively free from distortions. This is reflected in standards that seek to maintain a sinusoidal (or sine waveform) supply voltage that is free of waveform distortion. In addition, three-phase supplies must be adequately balanced, which requires that the voltage in each phase has the same magnitude and a relative constant phase displacement. Any deviations from these ideal conditions represent a distortion and reduction in the supplied power quality.

Not maintaining a power supply of adequate quality may lead to:

- Mal-operation or damage of the connected equipment.
- Inefficiencies and underperformance in operation of connected equipment (usually three phase equipment).

The system standards in the NER place obligations on the NSPs for ensuring the following will not impact on the operation of the customer connected equipment or their experiences:

- Voltage fluctuations (i.e. flicker)
- Voltage waveform distortions (i.e. harmonics, dips and swells)
- Voltage unbalance

For the NEM, the system standards corresponding to the above requirements appear in clauses S5.1a.5 to S5.1a.7 of the NER, while the obligations on NSPs to meet those standards are defined in clauses S5.1.5 to S5.1.7 of the NER. The minimum level of quality specified in these technical standards is governed by the designs of connected equipment and the perceptions of consumers. For example, flicker requirements are specified such that, among other factors, customers do not notice any visible flicker of electric lighting. Industry peak bodies such as Standards Australia, the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) publish power supply quality withstand capabilities of electrical equipment.

These technical standards impact customers in the same manner irrespective if they are supplied via a network or a SAPS.

It is recognised that power electronics coupled generating units can emit higher levels of harmonics than rotating synchronous machines but provided the plant is designed and tested to the relevant Australian and international technical standards, SAPS can achieve NER limits. Relaxing voltage quality standards in SAPS would potentially expose connected customers to higher costs as they may need to procure devices that can accommodate wider power quality variations. GHD therefore recommends that SAPS are required to meet the quality of supply standards in clauses S5.1a.5 to S5.1a.7 of the NER.

2.1.5 Stability

Clause S5.1a.3 of the NER focuses on three types of power system stability that are normally observed in rotating synchronous machine dominated interconnected networks:

- Transient stability,
- Oscillatory stability, and
- Voltage stability.

Stability characteristics can impose limits on the ability to transmit a significant amount of power over long distances across transmission networks linking a large number of generators and load centres.

In contrast to interconnected networks like the NEM, SAPS may contain a smaller number of small generating units, either in one location or connected via very short lines. In a SAPS connected with rotating synchronous generators, the generators are likely to perform in unison as one large generator (i.e. isochronous load sharing) and therefore, unlikely to manifest transient or oscillatory instability. Further, as the length of the network from generators to the loads in a SAPS is short, it is unlikely to subject to voltage instability.

Within SAPS, power electronics coupled generating units (including BESS) often use the concept of frequency and voltage droop control whereby they dynamically adjust their real and reactive output based on the system frequency and voltage respectively. If these settings are incorrectly implemented across multiple connected power electronics coupled generating units, oscillatory instability could be present in a SAPS.

Additionally, settings associated with ensuring stable operation of power electronics coupled generation, such as fault ride-through settings, need careful consideration to minimise the risk of instability which would in turn result in cascaded tripping of online generating units. While this is a potential risk for generating units both connected to high voltage interconnected networks as well as those connected to SAPS, current settings as called for under relevant Australian technical standards (such as AS4777) are not appropriate for SAPS for the reasons outlined below and in section 2.1.6.

The power electronics coupled generating systems, when subjected to close in faults, may fail to ride-through faults if settings are based on current standards (including AS4777). The post fault behaviour is dependent on the time required to clear the fault and the inverter connected generation may either trip or will take a long time to recover from the fault. Given the small number of generating units connected to a SAPS and small size of the network within it, it is likely that some load or generation will also be tripped when the faulted line in the network is isolated.

Although the system strength[4] (i.e. ability to maintain the power system voltage magnitude and phase angle when subjected to network disturbances) is reduced in a SAPS, existing and emerging inverter control techniques (including grid forming) can provide these stabilising characteristics. However, there is presently a mismatch between the prescribed requirements for addressing the relevant stability phenomena (e.g. anti-islanding settings versus fault-ride through requirements).

Inverter connected generation has very fast-acting controllers, which operate within milliseconds, compared to slow-acting controllers associated with rotating synchronous generation. Any adverse interaction of controllers could result in oscillation in the power system, making the power system unstable.

[4] Note: fault level is a proxy measure to describe the system strength. Minimum fault level describes the minimum system strength required for a generator to stably and continuously operate without an interruption following a network disturbance.

In the light of the changes in generating mix from rotating synchronous machines (e.g. diesel generating sets) to inverter connected renewable generation in power systems generally, while the concept of power system stability is still relevant, stability modes that may be observed will be different.

New forms of instabilities that may be observed in SAPS include:

- Negative interactions of the controllers (e.g. oscillations due to interactions of the controllers embedded in grid coupling inverters).
- Oscillations caused by poorly implemented controller settings (e.g. ineffective voltage droops associated with generating units).

The AEMC may consider expanding existing compliance obligations or creating a new obligations that mitigate instability concerns.

2.1.6 Safety

The safety of the connected equipment and personnel is assured through:

- Maintaining sufficient clearances and isolating environments as appropriate for the operating voltages.
- Isolating any faulted equipment sufficiently fast that faulted equipment will not impact on the safe operation of the rest of the network.
- Maintaining stable operation of the power system

Maintaining sufficient clearances and isolation is covered in the applicable Australian electricity design standards (including but not limited to AS3000, AS2067 and AS61439). As described in the previous section, the stability of power systems (interconnected power systems or SAPS) are also significantly influenced by the time required for clearing and isolating the faults.

The NER and other jurisdictional technical codes specify the maximum time allowed for clearing faults in the electricity networks. The fault clearance process consists of the following steps:

- identification of the fault,
- discrimination of the faulted equipment, and
- isolation of the fault by opening a circuit breaker.

SAPS will typically include small rotating synchronous generating units, or inverter connected renewable generation making the fault current variations in the network smaller than that found in interconnected networks. The smaller variations (sometimes comparable to the load current) make it challenging to identify and discriminate the source of the faults; therefore, it may take a longer time to clear the faults.

While clause S5.1a.8 in the NER places obligations on NSPs to ensure faults are cleared within a given maximum time, the rule only provides specific times for voltage levels above 100 kV. The requirement for voltage levels below 100 kV is “as necessary to prevent plant damage and meet stability requirements”. As SAPS are likely to operate below 100 kV, applying clause S5.1a.8 of the NER would require fault clearing times be set as necessary to prevent plant damage and meet stability requirements, which NSPs can do in accordance with this clause.

Jurisdictional technical standards, in particular those associated with the distribution networks, specify maximum fault clearance times for lower voltages. Some standards (e.g. Technical Standards published by Horizon Power) have recognised the need for more extended periods for clearing faults in SAPS.

Anti-islanding protection detects and isolates a generator when it is disconnected from a network and stops it operating as an islanded system by itself or more often as a generator connected to a part of the network. Allowing generation to continue to operate when islanded may pose significant safety hazard and quality of supply risk particularly if the generator is not capable of controlling voltage and frequency within the island.

Islanding detection relies on detecting a variation of the frequency and voltage following a disturbance. Because of the wider band of variations to be expected in SAPS voltage and frequency, the anti-islanding protection in SAPS needs to be set to anticipate these wider variations (compared to interconnected networks) to avoid spurious operation. Currently, AS4777 does not permit or contemplate wider settings, but network service providers, such as Horizon Power, have specified their own.

2.2 National Electricity Rules

Schedule 5 of the NER sets the technical standards appropriate for planning, design, and operation of the networks:

For DNSP-led SAPS, the pertinent schedules and those that GHD has reviewed are:

- Schedule 5.1a System standards
- Schedule 5.1 Network Performance Requirements to be Provided or Coordinated by Network Service Providers
- Schedule 5.2 Conditions for Connection of Generators
- Schedule 5.3 Conditions for Connection of Customers
- Schedule 5.3a Conditions for connection of Market Network Services

The present version of the NER (at the time of preparation of this report, the relevant version is v134) does not explicitly address technical requirements for SAPS. As a part of the proposed rule change, the AEMC has consulted on the applicability of S5.1a to S5.3a of the NER and proposed amendments. The proposed amendments are repeated in this report as Table 1 (on page 3 of this report) for brevity.

GHD has reviewed the present NER technical standards and their applicability to SAPS considering the technologies that are likely to be included in SAPS and their operation (as outlined in previous section 2). The analysis that supports our findings is provided in Appendix B.

We found that the proposed amendments to NER, in particular for technical schedules 5.1a and 5.1, are technically sound, but for the following:

- S5.1a.8: Sufficiently fast fault clearance ensures system stability and safety. In this regards, it is important that DNSPs have an obligation to:
    a) plan and set standards for clearing faults sufficiently fast to achieve the above objectives, and
    b) publish those set standards and coordinate the fault clearance times with customers connecting to SAPS.
- S5.1.8: Instability can manifest when more than one generating units are connected, irrespective of their technology or interconnectedness with a large network. It is recommended that the AEMC considers imposing obligations on DNSPs to ensure stable power supply to customers in SAPS.

We also found that further consideration and revision of the current NER provisions is warranted in adopting the following standards for SAPS:

- S5.1a.2: Frequency standards for SAPS need to be specified. At present, in clause S5.1a.2, only the frequency operating standard for the interconnected NEM is considered and cannot be directly applied to SAPS.
- S5.1a.3: The stability requirements specified in clause S5.1a.3 currently address the stability concerns of NEM, which is mainly supplied by rotating synchronous machines. The requirements need to be revised to capture the instability phenomenon expected in SAPS that may have fewer or no rotating synchronous machines.
- S5.1.2: This clause (and its subclauses S5.1.2.1 to S5.1.2.3) as presently drafted cannot apply to SAPSs because a SAPS may not have redundancy in generation or transmission built into it. The concepts associated with the management of supply security of interconnected power systems also cannot be directly transferred to the operation of SAPS. GHD considers that, in place of defining explicit redundancy requirements, supply reliability targets for SAPS should be established that achieve the same objectives as clause S5.1.2 of the NER.
- S5.1.3: This clause needs to be revised to reflect the frequency variations that are expected within SAPS and the ride-through capabilities of the connected equipment. A wider frequency band for steady state operation, i.e. 49.5 to 50.5Hz, and contingencies, i.e. 45 to 55Hz may be considered, without adversely impacting on the quality of supply expected by the connected customers and improving the economic efficiency of the associated investment.

GHD agrees with the AEMCs assessment that if a registered generator or market customer seeks to connect to a DNSP led SAPS, the existing provisions under Chapter 5A of the NER allow DNSPs sufficient flexibility to negotiate connection applications. GHD is of the view that the obligations outlined in S5.2 Conditions for Connection of Generators are too onerous for connection of generators to SAPS that are likely to be of very small in size (i.e. less than 1 MVA) compared to those connected to interconnected networks.

The National Distributed Energy Resources Grid Connection Guidelines published by the Electricity Network Association (ENA) (refer to section 2.4 below for further information) provide a comprehensive and adequate framework for coordinating the generators connecting a SAPS, supplementing DNSP's ability to consistently meet the obligations set under NER Chapter 5A.

2.3 Distribution technical codes

DNSPs are increasingly considering SAPS as a way for improving the utilisation of assets and maximizing investment efficiency. Several DNSPs has been trialling SAPS as pilot projects. In Australia, the uptake in the SAPS is higher on the west coast compared to the east coast.

There are two network service providers in Western Australia from which insights on SAPS could be drawn. Western Power operates the South West Interconnected System in the south-west of the state and services the majority of the states' customers. Horizon Power serves all other areas of the state, including managing the North West Interconnected System in the Pilbara and many microgrids and standalone power systems that services remote and regional communities.

The Western Power Technical Rules do not currently differentiate between interconnected power systems and SAPS. Western Power is currently developing a range of revisions to it's Technical Rules, and one of the topics being considered is the need to introduce specific system standards for SAPS.

In contrast, Horizon Power's Technical Rules provide for and distinguish separate standards for microgrids and standalone power systems.

GHD has reviewed Horizon Power's Technical Rules[5] in relation to the treatment of SAPS within them and their suitability for application to SAPS. Our review is included in Appendix C.

In the review of Horizon Power's Technical Rules, the application of rules for SAPS and to the Pilbara Grid are compared, and observed gaps are highlighted.

The summary findings from the review are as follows:

- Horizon Power has considered SAPS as a distribution system and applied the same standards (unless otherwise specified) for SAPS.
- A larger frequency variation band is specified for SAPS compared to interconnected networks, recognising the inherent difficulties in managing the frequency of SAPS with only a small number of small-sized generators (in particular synchronous generators). As a comparison, following a contingency event, frequency variation within the range of 48 Hz to 52 Hz is allowed for interconnected networks, whereas variations of 45 Hz to 55 Hz are allowed for a SAPS.
- While specific under frequency load shedding blocks and under frequency islanding schemes are specified for interconnected networks, flexibility is allowed in specifying the same for SAPS.
- While maximum total fault clearance times are specified for both interconnected networks and SAPS, no differentiation in fault clearance times for local and remote ends is made for SAPS. The maximum allowed fault clearance times are increased for SAPS when compared to the connected networks, recognising the smaller fault currents and slower fault clearing times in SAPS.
- In relation to generator connections, frequency excursion withstand capability is requested only from the generating units connecting to interconnected networks and not from the generators connecting to SAPS.

2.4 Industry guidelines

GHD reviewed the following National Distributed Energy Resources Grid Connection Guidelines published by Electricity Network Association (ENA):

- Technical Guidelines for Medium Voltage and High Voltage EG Connections (ENA DOC 041-2019), 2019
- Technical Guidelines for Low Voltage EG Connections (ENA DOC 040-2019)

The National DER Connection Guidelines set out the framework, principles, approach and consideration of technical settings for Australian DNSPs to adopt in the development and application of their technical requirements for grid connection of DER.

The guidelines are intended to be consistent with and complement existing legislation, regulation and industry codes.

The guidelines provide a nationally consistent approach for providing and obtaining information from the generators who wish to connect to DNSPs and complements the requirements outline in NER chapter 5A.

[5] Horizon Power, Technical Rules, Standard Number: HPC-9DJ-01-0001-2012

3. Experience to date

GHD has gathered significant experience in the development of SAPS with Horizon Power in Western Australia. The lessons learnt through these experiences are general and may be applied to the development and operation of SAPS irrespective of their geographical location.

This section summarises the practical experiences from the planning, operation and design of existing SAPS owned and operated by Horizon Power.

3.1 Form and configuration of SAPS

SAPSs (referred to as microgrids in the Horizon Power Technical Rules) are extensively used throughout Western Australia, with Horizon Power owning and operating 37 individual microgrids (as of 2018). Depending on their location and requirements, microgrids can have grid interconnection, be embedded, or entirely remote and standalone from the main grid.

The isolated networks that are owned and operated by Horizon Power in Western Australia include:

- East Kimberley (Kalumburu, Wyndham, Kununurra, Lake Argyle, Warmun and Halls Creek),
- West Kimberley (Derby, Camballin/Looma, Fitzroy Crossing, Yungngora, Bidyadanga, Broome, Beagle Bay, Djarindjin/Lombadina and Ardyaloon),
- East Pilbara (Marble Bar and Nullagine),
- West Pilbara (Onslow),
- Gascoyne/Midwest (Exmouth, Coral bay, Carnarvon, Denham, Gascoyne Junction, Meekatharra, Cue, Mt Magnet, Yalgoo, Wiluna, Sandstone, Laverton, Leonora and Menzies), and
- Esperance (Esperance, Norseman and Hopetoun).

3.2 Technical standards

3.2.1 Frequency control and frequency performance

Horizon Power's Technical Rules (section 2.2.1) recognises inherent difficulties associated with frequency control of SAPS, which are normally constituted of a small number of small generators. The rules dictate that SAPS operate with more relaxed frequency band under normal operation, between 49 and 51 Hz, but under any kind of contingency, requirements are even more relaxed, between 45 and 55 Hz.

To contrast, frequency on the main Pilbara grid, under normal operating conditions is restricted to the band of 49.75 to 50.25 Hz, and under multiple contingencies only permitted to move between 48 and 52 Hz.

3.2.2 Voltage control performance

Horizon Power does not specify separate requirements for SAPS in its Technical Rules with regards to voltage control either during steady-state conditions or under contingencies. Horizon Power is expected to be able to control voltage and be able to adhere to the same voltage standards for distribution voltage assets on the larger Pilbara grid and SAPS.

It is expected that controlling voltage at SAPS connected loads will be easier compared to controlling the voltage at network-connected loads, in particular if the loads are a significant distance away from the

generators. In SAPS, loads and generators are often situated electrically close to each other and connected via short lines.

3.2.3 Protection and Safety

Horizon Power makes some allowances for inherent microgrid characteristics in its Technical Rules with regards to protection (section 2.6.4). The maximum allowed fault clearance times are increased when compared to the Pilbara grid, with 33 kV and below assets allowed 200 ms to clear faults, compared to 105 ms on the Pilbara grid. This reflects the lower fault levels on microgrids compared to the distribution system, which often do not facilitate traditional methods of overcurrent protection used on conventional synchronised grids.

The Horizon Power Technical Rules also do not discriminate between local and remote end faults for microgrids, likely due to the relatively small geographical distances covered by microgrids. This specification is more common at higher voltages (>33 kV) covering longer distances.

3.2.4 Stability and technical schedules defining stability

Horizon Power's Technical Rules regarding stability remain focused on conventional synchronous plant that supplies the majority of the Pilbara grid (as is the case for the majority of conventional power systems). There is likely scope for increased specification within Technical Rules to define the roles and limits of inverter connected generation and BESS systems for standalone power systems, with regards to frequency, transient and voltage stability.

Currently, separate fault ride-through requirements are not specifically defined in Horizon Power's Technical Rules or performance standards for generators connecting to SAPS or interconnected networks. The ability to ride through concurrent faults has a significant impact on system stability and is likely to be more of an issue for SAPS due to the abundance of inverter connected generation and likelihood of higher voltage and frequency variations following faults. Technically, inverter connected generation can be more effective at riding through faults than synchronous generation without sustaining damage. However clearly specified rules optimised for SAPS is preferred, due to the higher impact the disconnection of these generators can have on smaller grids.

3.2.5 Specification of supply reliability

Horizon Power set a System Average Interruption Frequency Index (SAIFI) performance target across all of its systems for 6.6 interruptions per year, and an average System Average Interruption Duration Index (SAIDI) performance target of 290 minutes per year.

In the 2018/19 regulatory year, the overall SAIDI and SAIFI targets were met, with an average interruption length of 178 minutes, and an average number of interruptions of 1.7 per customer. However, only 29 of the 38 power systems that Horizon Power operates met these targets. Although SAPS may result in an overall improvement to customer's reliability in rural networks, it is unlikely they will achieve the same reliability of large synchronous grids when compared as an average.

3.2.6 Expansion of SAPS and provision for expansion

Due to Western Australia's vast geography, abundant solar resources, and relatively large numbers of remote communities, SAPS are becoming preferred sources of energy supply for many remote communities in the state. SAPS with integrated solar generation allow remote communities to significantly decarbonise their electricity supplies while reducing risk to supplies from disruption on rural networks. The characteristics

that make Western Australia suitable for SAPS also apply across other states in Australia. It is likely that the role of SAPS in helping meet Australia's electricity requirements will increase significantly in the near future.

3.2.7 Technical standard gaps as experienced in practice

Horizon Power's Technical Rules have addressed the majority of the standard technical gaps that can be expected due to the inherent characteristics of microgrids. Lower inertia due to low levels of synchronous generation leads to significant deviations in frequency compared to larger synchronised grids. Protection of microgrids is also more complex, due to lower fault levels often disallowing traditional protection scheme implementation. However, the voltage quality supplied by the microgrid is expected to be able to meet the same standards of the distribution network.

4. Conclusions and recommendations

GHD's review of the proposed revisions to the NER has identified gaps which may lead to some of the key technical requirements for SAPS either undefined or poorly defined:

- S5.1a.2: Frequency standards for SAPS need to be specified. As at present, in S5.1a.2, the frequency operating standard specifically for the interconnected NEM is considered and cannot be directly applied to SAPS.
- S5.1a.3: Presently the stability requirements specified in S5.1a.3 address the stability concerns of the NEM, which is mainly supplied by rotating synchronous machines. The requirements need to be revised to capture the instability phenomenon expected in SAPS.
- S5.1a.8: The proposed draft revisions suggest that the fault clearing times as specified in S5.1a.8 do not apply to SAPS. GHD considers that fault clearance times are a major consideration which could lead to operating issues in multiple fronts and should be specified
- S5.1.2: The rule clause as at present in NER does not apply to SAPS. GHD considers that supply reliability targets for SAPS should be defined elsewhere
- S5.1.2.1: While this clause is not applicable to SAPS, the design of SAPS should cater for contingencies such as the loss of a single generating unit.
- S5.1.3 to S5.1.3: These clauses need to be revised to reflect the frequency variations SAPS equipment should ride through.
- S5.1.8: The proposed draft revisions suggest that the stability requirements as specified in S5.1.8 do not apply to SAPS. GHD considers that it is important to specify the stability requirements for SAPS

  Appendix B considers each technical characteristic covered by the technical schedules in the NER and identifies appropriate revisions for application to a SAPS.

GHD's review has also found that some of the gaps identified above were recognised in the drafting of specific SAPS requirements in the Horizon Power technical standards. The review found that the key pertinent learnings from the experience of Horizon Power are:

- Larger frequency variation band is specified for SAPS compared to interconnected networks, recognising the inherent difficulties in managing the frequency of SAPS with only a small number of small-sized generators (in particular synchronous generators).
- The maximum allowed fault clearance times are increased for SAPS when compared to the connected networks, recognising the smaller fault currents and slower fault clearing times in SAPS.

GHD considers that there are a variety of ways the AEMC may choose to develop technical requirements applicable for SAPS:

(a) Revisions to the existing system standards and NEM frequency operating standards to make them applicable to SAPS. This is not recommended because it would be difficult to ensure and maintain the appropriate balance of robustness for consumer protection and flexibility given the technology involved.

(b) Creation of a new and specific technical schedule in the NER for specifying technical requirements for SAPS. This approach will potentially inhibit innovation that might arise if DNSPs are free to publish their own SAPS technical standards

(c) Setting a requirement in the NER clarifying that the present system standards in Chapter 5 do not apply to SAPS, but that each DNSP proposing to develop a regulated-SAPS must publish applicable technical standards. The published standards must address the technical requirements covered by the NER technical schedules and deviations are allowed from those in the NEM only where there is no additional material impact on customers but the deviation allows more efficient development of the SAPS.

On balance, GHD recommends the AEMC adopt the approach set out in option c). This option makes it clear that the NER standards, which are not currently fit-for-purpose where SAPS are concerned, do not apply to a regulated-SAPS. It also provides DNSPs with the appropriate flexibility to develop standards that can cater for a range of technically feasible options for these systems, while ensuring essential system standards that dictate the performance experienced by customers is maintained.

Appendix D provides amendments, for consideration by the AEMC, that reflect our recommended option.

GHD Advisory

Appendices

Appendix A Acronyms and abbreviations

The following acronyms, terms and abbreviations have been used in this report.

Acronym / term / abbreviation	Meaning
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
BESS	Battery energy storage systems
CCGTs	Combined cycle gas turbines
COAG	Council of Australian Governments
DER	Distributed energy resources
DNSP	Distribution network service provider
ENA	Electricity Networks Association
FOS	Frequency operating standards
FRT	Fault ride through
Hz	Hertz
IEC	International Electrotechnical Commission
IEE	Institute of Electrical and Electronics Engineers
IPS	Individual power systems
kV	Kilovolt
LVRT	Low voltage ride through
ms	Millisecond
MW	Megawatt
MWh	Megawatt hour
NEM	National Electricity Market
NER	National Electricity Rules
NSP	Network service provider
PSC	Power conversion systems
PV	Photovoltaic
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SAPS	Stand-alone power systems
STPIS	Service Target Performance Incentive Scheme

Acronym / term / abbreviation	Meaning
TNSP	Transmission network service provider

Appendix B GHD clause by clause analysis

Out analysis of specific NER clauses with consideration to the applicability for SAPS is outlined in Table 2 below.

Table 3: GHD's analysis of specific rule clauses

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
S5.1a.1	Purpose	The general principles apply.	General principles continue to apply.
S5.1a.2	Frequency	National grid frequency performance will be the responsibility of AEMO. In a regulated SAPS, it is the responsibility of the relevant DNSP.	Frequency is a supply quality parameter. Appropriate frequency standards must be specified for a SAPS. S5.1a.2 specifies that the NEM FOS is published by the Reliability Panel. The NEM FOS defines the frequency standards applicable in NEM power systems. The proposed change to the definition of power system will specifically exclude regulated SAPS. Hence the NEM FOS will not apply for SAPS. The interconnectedness of the NEM enables the operating frequencies to be set in a very tight band, and some of the equipment commonly connected to the network require very tightly controlled frequency for their safe and reliable operation (e.g. combined cycle gas turbines). A well-controlled frequency is a common quality that all the customers connected to a SAPS will expect and still some consumer equipment will require a supply frequency in a given band for them to effectively and efficiently operate. The frequency standards applicable for a SAPS should allow for wider frequency variations than the NEM FOS.

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
S5.1a.3	System Stability	This provision applies in relation to the power system, which does not include a regulated SAPS.	S5.1a.3 considers three types of stability phenomenon: (a) transient stability (b) oscillatory stability (c) voltage stability In relation to a SAPS, while above (a) and (c) are less likely to be material in determining the system stability, oscillatory stability may become an issue when more than one power generating facilities are connected to a SAPS. The generating facilities could be central PV systems, wind turbines, battery storage system, diesel generating sets etc. Careful control and coordination of these devices are required for a reliable operation of a SAPS and uncoordinated designs may result in oscillatory instabilities, mainly due to the interactions of the controllers within different generating equipment. The presently defined obligations for mitigating oscillatory instability do not capture the “control interaction instabilities” that may be experienced in inverter coupled power systems. The AEMC may consider including a new obligation or expanding the existing oscillatory stability obligations to cover control interaction instabilities.
S5.1a.4	Power frequency voltage	The power frequency voltage limits apply in relation to a regulated SAPS, including the provision for power factor and reactive power flow at the connection point. The “contingency event" triggers will not be determined for regulated SAPS and those parts of the clause are not relevant in a regulated SAPS.	Will equally apply for SAPS. S5.1a.4 specifies the requirement of voltage as a common quality factor defining the supply voltage. The effective and safe operation of the consumer devices are reliant on the voltage levels and set time limits for potential exceedance of the voltage above the nominal value. S5.1a.4 in its entire form may apply to SAPS. However reference to the contingency events as referred to in this clause will require revision to reflect the types of events that could be an issue for SAPS. In addition to what is considered in NER, consideration of compatibility and

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			coordination between fault ride through and anti-islanding settings may be useful
S5.1a.5	Voltage fluctuations	The clause applies in relation to a regulated SAPS.	S5.1a.5 – S5.1a.7 specify the common qualities expected of the supply voltage. The many consumer equipment (e.g. induction motors) rely on distortion free voltage supply for their efficient and safe operation. For S5.1a.5 and S5.1a.6, the SAPS developer may set the planning standards sufficiently below the relevant compatibility levels specified in Australian Standard AS/NZS 61000.3.6:2001 and AS/NZS 61000.3.6:2001. The level may be set in anticipation of any future generator or load connections to the SAPS which may impact the voltage fluctuations and waveform distortion. The schedule S5.1a.7 may be used for SAPS. However reference to the contingency events as referred to in this clause will require revision. As an alternative, DNSP's may wish to simplify and create a fit-for-purpose obligations of these requirement.
S5.1a.6	Voltage waveform distortion	Continues to apply. No changes needed if the SAPS is regulated under jurisdictional DNSP network licensing.	
S5.1a.7	Voltage unbalance	The clause applies in relation to a regulated SAPS.	
S5.1a.8	Fault clearance times	This provision is not intended to apply in relation to a regulated SAPS.	Table S5.1a.2 places an obligation on the NSPs for systems less than or equal to 100 kV (which is likely to be all SAPS), to clear faults "as necessary to prevent plant damage and meet stability requirements" Although the concept of specifying reasonable and adequate fault clearance times is still applicable, S5.1a.8 requires a significant revision.

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			This is because: (a) SAPS are likely to operate at significantly lower voltage levels compared to those of the focus of the schedule (b) Modern inverter based power generation system are inherently associated with low fault current and therefore will require significantly longer time for fault identification and discrimination.
S5.1.1	Introduction	The general principles apply.	Applies in principle, but needs significant clarification prior to applying to SAPS. It allows "To the extent that this schedule 5.1 does not contain criteria which are relevant to the description of a particular network service, the Network Service Provider must describe the network service in terms which are fair and reasonable". In this regard, the SAPS developer may define the services pertinent to SAPS, while in general following the guiding principles included in the schedule.
S5.1.2	Network reliability	Does not apply.	Definition of the reliability of the supply from SAPS by using some appropriate measure (e.g. SAIFI, SAIDI) will ensure that the SAPS customers will receive a similar level of reliability as network connected customers. This clause (and its subclauses S5.1.2.1 – S5.1.2.3) as presently drafted cannot apply to SAPS because SAPS may not have redundancy in generation or transmission built into it. Therefore, the concepts associated with management of supply security of interconnected power systems also cannot be directly transferred to the operation of SAPS. GHD considers that, in place of defining explicit redundancy requirements, supply

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			reliability targets for SAPS should be defined to achieve the same objectives as S5.1.2. Further, the AEMC could consider explicitly expanding planning obligations of DNSPs to ensure supply reliability: • DNSPs to plan SAPS to stay below a predefined expected load not served (similar to reliability obligations by the reliability panel) • DNSPs to plan to stay below a predefined expected reliability targets(e.g. SAIDI, SAIFI) • DNSPs to report reliability provided to SAPS as an another category when claiming network incentives (STIPS)
S5.1.2.1	Credible contingency events:	Does not apply	Current definitions unlikely to be relevant in the context of SAPS. This is generally associated with defining the network redundancy to ensure transmission network reliability but also covers generating unit's failure. SAPS are likely to have mostly radial networks, at most ring connected. Therefore, detailed definition of the credible contingency events for networks may be excessive, if directly adopted for SAPS. A single generating unit is a reasonable credible contingency event for a SAPS. SAPS should be designed to adequately cater for such a contingency where reasonable (for example, this contingency does not reasonably apply where there is a single generator). However, it is noted that in an interconnected network a single generation reserve is maintained and provided for a contingency of any generating unit connected, and therefor reduces the cost of providing for generation redundancy. In contrast, in SAPS providing redundancy for generation could be expensive and inefficient.

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
S5.1.2.2	Network service within a region	Applies in relation to a regulated SAPS.	Continue to apply in the context of SAPS This schedule specifies the level of services provided to connection points in a region connected to the NEM. Therefore, in the context of SAPS, the definition and quantification of the services provided to the customers in SAPS, continues to apply, the schedule needs significant revision for adopting to SAPS.
S5.1.2.3	Network service between regions	Not relevant to a regulated SAPS.	Does not apply in the context of SAPS. This schedule specifies the level of transmission services to be provided between the regions of NEM. By definition SAPS are isolated and not interconnected; therefore, this schedule does not apply for SAPS.
S5.1.3	Frequency variations	Applies in relation to a regulated SAPS.	The rule focuses on maintaining the frequency of the interconnected NEM, and recognises the operational oversight of AEMO for management of NEM power system security. AEMO would have no such role for a regulated -SAPS. Notwithstanding the above, S5.1.3 continues to apply meaning that SAPS equipment remains in service for frequency within the extreme frequency excursion tolerance limits. Further consideration should be given to the frequency variations which SAPS equipment should withstand. The band of the frequency variations may be wider, compared to those specified in the NEM FOS.
S5.1.4	Magnitude of power frequency voltage	The first part of the clause only applies in relation to TNSPs. The final paragraph applies to DNSPs including in relation to a regulated SAPS.	S5.1.4 continues to apply in principle. The schedule needs to be significantly revised in its application to SAPS. The rule assumes that the network is interconnected and AEMO has security obligations. The terms within the rule, such as “satisfactory operating state”, “protected

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			events" are defined but are not directly reverent to SAPS In order to ensure the efficiency of development of SAPS and provide a fit for purpose service, some concepts may be relaxed. Examples are: • Target voltage - it may not be possible to operate SAPS to provide a tight target voltage for the connections, but wider variations, within +/- 5% have to be expected. • The "nominal voltage" can be used in place of "normal voltage" or "target voltage". Due to the small size of SAPS, no significant variations in the voltage across the network is expected. • The continuous uninterrupted operation may be too hard (given the higher fault clearance times). The voltage variation could be more than 10%, because of the relaxed supply voltage requirements. As an alternative, in conjunction with S5.1a.3, the SAPS developer may define the supply voltage and voltage operating band.
S5.1.5	Voltage fluctuations	Applies in relation to a regulated SAPS.	S5.1.5 – S5.1.7 place obligations on the NSPs to plan, design, operate and coordinate the connection activities to ensure the quality of the power supply to its customers are adequate. For S5.1.5 and S5.1.6, the SAPS developer may set the planning standards sufficiently below the relevant compatibility levels specified in Australian Standard AS/NZS 61000.3.6:2001. The level may be set in anticipation of any future generator or load connections to the SAPS which may impact the voltage fluctuations and waveform distortion.
S5.1.6	Voltage harmonic and voltage notching distortion	Applies in relation to a regulated SAPS.	
S5.1.7	Voltage unbalance	Applies in relation to a regulated SAPS.	

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			S5.1.5 to S5.1.7 may be used for SAPS without revision but for the revisions required for references associated with operation of inter connected networks such as references to access standards pertinent to S5.2 or market service providers.
S5.1.8	Stability	Does not apply in relation to a regulated SAPS.	The obligations on NSPs in relation to power system stability assume the availability of an interconnected network with sufficient redundancy built in. Therefore, following system disturbances, although the faulted component of the network is isolated, the system stability can be maintained and supply can be continued without a long interruption. In a SAPS, with the generation available locally, some stability concerns should be alleviated to some extent compared to an interconnected network, in particular if the customers connected to the network are supplied over long transmission feeders. In a SAPS while the stability phenomenon of concern are not mainly synchronous or voltage stability, maintaining a stable power supply during normal operation and to a lesser extent maintaining stability following a system disturbance is important. In particular, SAPS may experience control interaction instabilities, due to the interaction of inverter controllers or poorly set and coordinated voltage drops. The AEMC may consider placing an obligation on SAPS developers to maintain stability, at least in high level. It may also consider placing planning and operating obligations on DNSPs to: • Anticipate and plan for different types of generation that may connect to SAPS

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			• Coordinate that generation will work stably over the expected range of generation mix and variations • Request testing and obtaining measuring information from the generators, if it considers there is a need for ensuring stability • Request generator and load controller parameter resetting if needed for ensuring stability
S5.1.9	Protection systems and clearance times	Applies in relation to a regulated SAPS.	S5.1.9 places an obligation on the NSPs for systems less than or equal to 100 kV (which is likely to be all SAPS), to coordinate the protection systems and clearance times to ensure stable operation of the network and safety of its operation. Uncoordinated or poorly set protection settings may result in harm to connected equipment, personnel, and may lead to cascaded collapse of the power system. Therefore, the same obligations as in S5.1.9 should still apply for the operators of the SAPS.

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
S5.1.10	Load, generation and network control facilities	Applies in relation to a regulated SAPS.	Load and generation control (e.g. load shedding or generation tripping/runbacks) are utilised for managing the supply reliability and system stability, in interconnected networks, following transmission outages, if there is built in transmission redundancy. Given the headroom available in the dispatched generation and scheduled spinning reserve, such control facilities are rarely called into operation. In SAPS, given the limited generation capacity, the maintaining supply reliability and system stability may place an increased reliance on operator's ability to control and manage generation and load. Such control systems may be activated more often compared to those interconnected networks. Therefore planning, design and maintaining such systems are particular important in SAPS and schedule S5.1.10.1 and S5.1.10.2 will continue to apply. S5.1.10.1a places an obligation for NSPs to coordinate with AEMO on the design and operation of interconnected NEM frequency emergency control schemes and therefore is not relevant to SAPS. S5.1.10.3 is associated with TNSP coordinating with DNSPs for testing of load shedding and emergency frequency control facilities. This schedule is not relevant to SAPS.
S5.1.11	Automatic reclosure of transmission or distribution lines	Applies in relation to a regulated SAPS.	This schedule ensures safe and stable operation of power systems with transmission lines consisting of auto-reclose facilities. If unchecked, auto-reclosing of a line connecting two generators out of synchronism could lead to significant damage of the equipment. S5.1.11 continues to apply for SAPS, because there is a possibility that auto-reclose may attempt to connect two

NER clause	Rule name	Initial AEMC Priority 1 draft position	GHD comment on applicability for SAPS
			generators in SAPS which are not in synchronism.
S5.1.12	Rating of transmission lines and equipment	No change – assumes a request for information will not be made.	This schedule places an obligation on NSPs to provide AEMO with ratings of transmission lines and equipment, so that the transmission assets can be more efficiently utilised under different operating conditions. While this schedule does not apply in verbatim for SAPS, in principal the AEMC may consider placing an obligation on DNSPs to achieve the same objective: i.e. use the transmission asset ratings to maximize their utilisation and reduce the investment required. For an example use of day and night ratings, and seasonal ratings may reduce the investment required on the network within SAPS.
S5.1.13	Information to be provided	Will not apply, as rule 5.3 does not apply to a connection to a regulated SAPS.	Does not apply.

Appendix C Insights drawn from review of Horizon Power Technical Rules

Table 4 provides definitions for various terms used in the Horizon Power Technical Rules that are relevant when seeking to understand the difference between requirements placed on SAPS and the interconnected Pilbara grid. Table 5 compares the technical requirements in the Horizon Power Technical Rules applicable to SAPS with the technical requirements in the NER.

Table 4: Horizon Power definitions

Description	Definition
Distribution System	Any apparatus, equipment, plant or buildings used, or to be used, for, or in connection with, the transportation of electricity at nominal voltages of less than 66 kV and which form part of the Pilbara Grid or Microgrids owned and/or operated by the Regional Electricity Networks Corporation (trading as Horizon Power),
Microgrids	The isolated networks in East Kimberley (Kalumburu, Wyndham, Kununurra, Lake Argyle, Warmun and Halls Creek), West Kimberley (Derby, Camballin/Looma, Fitzroy Crossing, Yungngora, Bidyadanga, Broome, Beagle Bay, Djarindjin/Lombadina and Ardyaloon), East Pilbara (Marble Bar and Nullagine), West Pilbara (Onslow) Gascoyne/Midwest (Exmouth, Coral bay, Carnarvon, Denham, Gascoyne Junction, Meekatharra, Cue, Mt Magnet, Yalgoo, Wiluna, Sandstone, Laverton, Leonora and Menzies) and Esperance (Esperance, Norseman and Hopetoun).
Pilbara Grid	The interconnected network located in the Pilbara region of the state of Western Australia.
Power System	The electric power system constituted by the Pilbara Grid and its connected generation and loads, operated as an integrated system and Microgrid distribution systems owned and operated by the Regional Corporation trading as Horizon Power.
Transmission System	Any apparatus, equipment, plant or buildings used, or to be used, for, or in connection with, the transportation of electricity at nominal voltages of 66 kV or higher, and which forms part of the Pilbara Grid. For the avoidance of doubt the transmission system includes equipment such as static reactive power compensators, which is operated at voltages below 66 kV, provided that the primary purpose of this equipment is to support the transportation of electricity at voltages of 66 kV or higher.

Table 5: Comparison of NER and Horizon Power technical requirements

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
2.2.1 Frequency Variations	**S5.1a.2** (Defers to the Frequency Operating Standards published by the AEMC)	Normal operation frequency band is between 49.75 and 50.25 Hz. Expands to 48 to 52 Hz in case of multiple contingency events. Target recovery is return to normal frequency band within 25 minutes.	Normal operation frequency band is between 49.75 and 50.25 Hz. Frequency band following disturbance is 45 to 55 Hz. Less than 5 seconds continuously outside this range permitted.	Pilbara Grid has a specified accumulated synchronous time error which is missing for the Microgrids. Both Pilbara Grid and the Microgrids have increased frequency bands in cases of contingency events/disturbances. It is not specified whether there is a target recovery time for the Microgrids to return to 'normal operation mode' from the 'following disturbance operation mode'. In comparison, Pilbara Grid has a target recovery time of 25 minutes following contingency events.
2.2.2 Steady State Power Frequency Voltage	**S5.1a.4**	Acceptable voltage limits have been provided.	Acceptable voltage limits have been provided.	There are no gaps in information for the Microgrids.
2.2.3 Flicker	**S5.1a.5** (Defers to Table 1 of Australian Standard AS/NZS 61000.3.7:2001)	Planning levels for the flicker severity caused by voltage fluctuations have been provided for distribution system and transmission system.	Planning levels for the flicker severity caused by voltage fluctuations have been provided for distribution system and transmission system.	There are no gaps in information for the Microgrids.
2.2.4 Harmonics	**S5.1a.6** (Defers to Table 1 of Australian Standard AS/NZS 61000.3.7:2001)	Planning levels for harmonic voltage in networks with system voltage less than or equal to 35 kV have been provided for distribution and	Planning levels for harmonic voltage in networks with system voltage less than or equal to 35 kV have been provided for distribution and	There are no gaps in information for the Microgrids.

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
		transmission systems.	transmission systems.	
2.2.5 Negative Phase Sequence Voltage	**S5.1a.7**	Limits for negative phase sequence component of voltage have been provided.	Limits for negative phase sequence component of voltage have been provided.	There are no gaps in information for the Microgrids.
2.2.6 Electromagnetic Interference	**N/A**	Reference made to Australian Standard AS 2344 (1997) for both the transmission and distribution system.	Reference made to Australian Standard AS 2344 (1997) for both the transmission and distribution system.	There are no gaps in information for the Microgrids.
2.2.7 Transient Rotor Angle Stability	**S.5.1a.3**	States that all generating units must remain in synchronism following contingency event.	States that all generating units must remain in synchronism following contingency event.	There are no gaps in information for the Microgrids.
2.2.8 Oscillatory Rotor Angle Stability	**S.5.1a.3**	Refers to a small disturbance rotor angle stability criteria which must be adhered to and that the power system must return to a stable operating state following a disturbance.	Refers to a small disturbance rotor angle stability criteria which must be adhered to and that the power system must return to a stable operating state following a disturbance.	There are no gaps in information for the Microgrids.
2.2.9 Short Term Voltage Stability	**S.5.1a.3**	Short term voltage stability is concerned with the power system surviving an initial disturbance and reaching a satisfactory new steady state.	Short term voltage stability is concerned with the power system surviving an initial disturbance and reaching a satisfactory new steady state.	There are no gaps in information for the Microgrids.
2.2.10 Temporary Over-Voltages	**S5.1a.4**	Percentage overvoltage envelope	Percentage overvoltage envelope	There are no gaps in information for the Microgrids.

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
		provided for the power system.	provided for the power system.	
2.2.11 Long Term Voltage Stability	**S5.1.8 and 4.5.1**	Makes reference to voltage stability of entire power system.	Makes reference to voltage stability of entire power system.	There are no gaps in information for the Microgrids.
2.3.1 Frequency Control	**4.4** (defers to AEMO)	Reference to Frequency Variations table provided.	Reference to Frequency Variations table provided.	There are no gaps in information for the Microgrids.
2.3.2 Load to be Available for Disconnection	**4.3.2** (defers to AEMO)	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.3 Flicker	**S5.1.5**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.4 Harmonics	**S5.1.6**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.5 Negative Phase Sequence Voltage	**S5.1.7**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.6 Electromagnetic Interference	**N/A**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.7 Power system Stability and Dynamic Performance	**S5.1.8**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.3.8 Determination of Power Transfer limits	**N.A**	All provided information is relevant to	All provided information is relevant to	There are no gaps in information for the Microgrids.

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
		Pilbara Grid and the Microgrids.	Pilbara Grid and the Microgrids.	
2.3.9 Assessment of Power System Performance	**N/A**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.4.1 Settings of Under-Frequency Load shedding Schemes for Pilbara Grid	**S5.1a.2** (Defers to the Frequency Operating Standards published by the AEMC)	Under-frequency load shedding scheme settings are provided.	No information provided	There is no information provided regarding the under-frequency load shedding scheme settings for the Microgrids. The information provided for Pilbara Grid includes frequency, time delay, load shed percentage and capacitor shed percentage for each stage.
2.4.2 Existing Settings of Under-Frequency Islanding Schemes	**S5.1a.2** (Defers to the Frequency Operating Standards published by the AEMC)	Information provided regarding islanding scheme and load areas.	No information provided	There is no information provided regarding the islanding scheme and load areas for the Microgrids.
2.4.3 Under Frequency Load Shedding Schemes for Microgrids	**N/A**	N/A	Frequency load shedding schemes must meet power system performance standards specified in **2.2.1 Frequency Variations.**	There are no gaps in information for the Microgrids.
2.6.1 General Requirements	**4.6** (Defers to AEMO) & **S5.1.9**	Requirements stated regarding protection systems for transmission and distribution system.	Requirements stated regarding protection systems for transmission and distribution system.	There are no gaps in information for the Microgrids.

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
2.6.2 Duplication of Protection	**S5.1.9**	Protection schemes provided for both transmission and distribution system.	Protection schemes provided for both transmission and distribution system.	There are no gaps in information for the Microgrids.
2.6.3 Availability of Protection Systems	**N/A**	Information is provided for both transmission and distribution system.	Information is provided for both transmission and distribution system.	There are no gaps in information for the Microgrids.
2.6.4 Maximum Total Fault Clearance Times	**S5.1a.8**	Maximum total fault clearance times provided for local end and remote and of all voltage levels. Alternative maximum total fault clearance times are also provided for 2 of the 4 voltage levels.	Maximum total fault clearance time provided for local end of single voltage level.	The Microgrids is missing 'remote end' maximum fault clearance time for its relevant voltage level. Alternative maximum total fault clearance times are not provided.
2.6.5 Critical Fault Clearance Times	**S5.1a.8**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.6.6 Protection Sensitivity	**N/A**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.6.7 Trip Supply Supervision Requirements	**S5.2.5.8** (Defers to AEMO/NSP)	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
2.6.8 Trip Circuit Supervision Requirements	**S5.2.5.8** (Defers to AEMO/NSP)	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.

HP Clause	Equivalent NER Clause	Pilbara Grid	Microgrids	Microgrids and Pilbara Grid Gap Assessment
2.6.9 Protection Flagging and Indication	**N/A**	All provided information is relevant to Pilbara Grid and the Microgrids.	All provided information is relevant to Pilbara Grid and the Microgrids.	There are no gaps in information for the Microgrids.
3.1 Introduction	**N/A**	N/A	N/A	N/A
3.2 Requirements for All Users	**N/A**	N/A	N/A	N/A
3.3.3.1 Reactive Power Capability	**S5.2.5.1**	Unsure	Unsure	Unsure
3.3.3.2 Generating Unit Performance Standard	**S5.2.5.2**	N/A	N/A	N/A
3.3.3.3 Generating Unit Response to Disturbances in the Power System	**S5.2.5.3 & S5.2.5.4 & S5.2.5.5**	Information provided regarding immunity to frequency excursions.	No information provided	There is no information provided regarding immunity to frequency excursions for the Microgrids. Information provided for the Pilbara Grid includes requirements of generating units when responding to disturbances in power system.

Appendix D Recommended revised rules

GHD recommends that the AEMC considers the revisions outlined in Table 6 below.

These revisions are meant to provide the context of the revision required and should not be considered as an accurate redrafting of the rules.

Table 6: Suggested revisions to the rules

Rule	Suggested revision
S5.1a.1Purpose	Other than the purpose expressed in S5.1a.1, the rule S5.1a does not apply to SAPS.
S5.1	The introduction of S5.1.1 is pertinent to SAPS. An additional rule clause under this rule (e.g. S5.1.14) to be created, placing an obligation on DNSPs to develop and publish technical standards for SAPS. With the exception of this introduction and clause S5.1.14, this schedule does not apply in relation to a regulated SAPS.
S5.1.14 (new clause)	**S5.1.14 System Standards and Network Performance Requirements to be coordinated by regulated SAPS** A *Network Service Provider* must prepare and publish a *system standard* for *regulated SAPS* that it owns, operates or controls or intends to own, operate or control. The *system standard for regulated SAPS* prepared and published by the *Network Service Provider* in relation to a *regulated SAPS* must satisfy the purposes of clause S5.1a.1. The *system standard for regulated SAPS* may refer to S5.1a in its entirety or parts of it, as they are applicable. In preparing the *system standard for regulated SAPS,* the *Network Service Provider* must provide justification for deviating from the technical requirements set out in S5.1a and S5.1.9. The *system standard for regulated SAPS* must specify the standards the *regulated SAPS* will adopt in providing the electricity supply to customers connected to the *regulated SAPS,* and must include the standards for the following: • Frequency • System stability • Power frequency voltage • Voltage fluctuations • Voltage waveform distortion • Voltage unbalance • Fault clearance times • Reliability In the preparation of the *system standard* for *regulated SAPS*, the *Network Service Provider* should consider the inherent technical capabilities and limitations of the connected equipment. The *system standard* for *regulated SAPS* developed under this clause must ensure customers connected to the *regulated SAPS* do not experience a reduced quality of supply or lower reliability of supply than if they maintained a connection to the *national grid*.

Rule	Suggested revision
10. Glossary	System Standard: Recognise that, a standard for the performance of the power system refers to is set out in schedule 5.1a or those developed by DNSPs as per rule S5.1.14 in relation to a regulated SAPS.

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GHD Advisory

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