PROGRESS REPORT

FUTURE POWER SYSTEM SECURITY PROGRAM

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AEMO
AUSTRALIAN ENERGY MARKET OPERATOR

IMPORTANT NOTICE

Purpose

AEMO is responsible for overseeing the vital system operations and security of the National Electricity Market (NEM) power system across Queensland, New South Wales, the Australian Capital Territory, Victoria, Tasmania, and South Australia. From July 2016, that responsibility has extended to the South West interconnected system (SWIS) in Western Australia. This means operating the power systems within safe and technical limits to manage the secure and reliable transmission of power through the electricity supply chain from generators to consumers.

AEMO has prepared this document to provide information about the Future Power System Security (FPSS) program, as at the date of publication.

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Version control

Version	Release date	Changes
1	31 January 2017	

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1. INTRODUCTION

This report provides a consolidated update of AEMO's Future Power System Security (FPSS) work program, which aims to ensure power system security is maintained in the National Electricity Market (NEM) in the face of a changing generation mix and demand patterns.

This report does not discuss the events of 28 September 2016, which saw South Australia disconnect from the rest of the NEM power system resulting in a state-wide power outage. A series of reports have been published analysing this event and the fourth and final report is expected to be published in March.[1] As the technical analysis of this 'black system' event progresses, recommendations, learnings and issues raised will be incorporated and prioritised accordingly within the FPSS program.

It is important for the FPSS work to continue as a broad analysis to underpin the development and implementation of efficient and adaptable solutions for the long-term security of the NEM.

AEMO's process for identifying emerging technical challenges and prioritising focus areas was established in the FPSS program progress report published in August 2016.[2] The intent of this and future progress reports is to provide high level information and updates about key work packages.

Identified high priority areas

AEMO enlisted the expertise of a technical advisory group, with representatives from all industry sectors, regulatory and government agencies, and consumers, to inform its qualitative challenge identification and definition. Four areas were immediately progressed following this consultation:

- Frequency control.
- Management of extreme power system conditions.
- Visibility of the power system (information, data, and models).
- System strength.

This report outlines the analysis completed to further understand and address challenges within these areas since August 2016, and outlines AEMO's key focus areas for the next six months.

Collaboration

AEMO continues to leverage industry expertise through collaborations with:

- The Australian Energy Market Commission (AEMC), which was formalised on 14 July 2016. Through its own review on power system security, the AEMC is addressing the related regulatory and market framework challenges that will arise, with technical input from the FPSS program.
- Energy Networks Association (ENA), based on the synergies between the FPSS program and ENA's Electricity Network Transformation Roadmap.

Stakeholder engagement

Over the last six months, stakeholders have been invited to contribute to the FPSS program through:

- **Submissions to the FPSS progress report in August 2016** – following an open submission process, key industry stakeholders submitted feedback on the technical challenges identified for further analysis.
- **FPSS program roadshows** – presentations in Adelaide, Hobart, Melbourne, Canberra, Sydney, and Brisbane attracted government, industry, and consumer advocacy attendees. These provided

[1] All preliminary incident reports into the event published to date are available on the AEMO website at: http://aemo.com.au/Electricity/National-Electricity-Market-NEM/Market-notices-and-events/Power-System-Operating-Incident-Reports.

[2] AEMO. *Future Power System Security Program Progress Report*, August 2016. Available at: http://aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FPSS---Progress-Report-August-2016.pdf.

an opportunity for the energy industry to come together to discuss the opportunities and challenges in system security and possible solutions, and for AEMO to engage in valuable two-way conversations with stakeholders across the NEM.

- **Updates at AEMO-hosted forums** – regular updates of work under the FPSS program were provided at forums, such as the NEM Wholesale Consultative Forum.

Since September 2016, AEMO has sought feedback on its FPSS work and the related Rule changes under consideration by the AEMC through the AEMC's power system security technical working group, which included representation from key stakeholder groups.[3,4]

AEMO has also provided updates and presented outcomes of the FPSS program at industry events.

[3] AEMC. *System Security Market Frameworks Review – Terms of Reference.* Available at: http://www.aemc.gov.au/getattachment/b1f8c1e1-dcbe-4585-aa45-9152104fdcf2/Terms-of-reference.aspx.
[4] AEMC. *Technical Working Group on Power System Security.* Key stakeholder group list available at: http://www.aemc.gov.au/News-Center/What-s-New/Announcements/First-meeting-of-the-technical-working-group-held.

2. FREQUENCY CONTROL

Two challenges related to frequency control have been a focus:

1. High rates of change of frequency (RoCoF); and
2. Insufficient amount of available frequency control ancillary services (FCAS).

These are discussed in the following sections.

2.1 High rates of change of frequency

Challenge:

- Supply-demand imbalances due to any disturbance will cause larger and more rapid frequency deviations that will be increasingly hard to manage.

Where challenge might arise:

- Managing RoCoF is not expected to be a global NEM challenge in the near term, as the NEM as a whole is anticipated to have sufficient inertia from online synchronous generation.
- It is likely to first become a challenge in South Australia and Tasmania as these regions can experience periods of low synchronous inertia.

2.1.1 Objective for further analysis

AEMO is seeking to understand the underlying RoCoF limits of the power system. This analysis will provide an indication of when and where challenges are likely to arise and also the probability of their occurrence, and hence the level of exposure to risk emerging in each NEM region. This will inform the reach required by any potential technical solutions.

Historically, RoCoF has been maintained within manageable limits through the presence of synchronous generators that have an inherent inertia. AEMO's analysis will explore ways of managing RoCoF in the future by assessing the potential value of inertia and Fast Frequency Response (FFR) services in the NEM, as well as other potential technical solutions.

2.1.2 Work completed since August 2016

International review of frequency control adaptation

AEMO engaged DGA Consulting to undertake an international review of frequency control adaptation. Published in October 2016, the report explores international experiences in the adaptation of frequency control measures to non-synchronous and variable technologies, and draws out key insights for the NEM.[5]

This review highlighted that most international power systems with large penetrations of non-synchronous generation are not experiencing the same challenges as the NEM because of their comparatively larger size, and strong interconnections with other regions. This provides access to a comparatively larger quantity of inertia, limiting RoCoF challenges.

The report, however, identifies several important exceptions, where relevant work has progressed. These included Ireland (EirGrid/SONI), the United Kingdom (National Grid), and Texas (ERCOT).

[5] DGA Consulting. *International Review of Frequency Control Adaptation*, October 2016. Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/FPSS---International-Review-of-Frequency-Control.pdf.

The report outlines international experience and analysis, drawing out relevant insights for the NEM in the following areas:

- Experiences with high RoCoF (including possible failure mechanisms and other power systems' findings with respect to their secure technical envelope[6]).
- Using FFR to mitigate high RoCoF.
- Storage technologies for frequency control.
- Demand response for fast frequency control.
- Emulated inertia from wind turbines.[7]
- The design of new FCAS.
- Other aspects of frequency control.

This work has informed the development of other analysis of frequency control.

Identifying underlying RoCoF limits of the power system

AEMO currently has two studies underway to understand the RoCoF limits of the power system:

- GE Consulting has been engaged to provide a high level assessment of the components of the South Australian power system that are most likely to be sensitive to high RoCoF, and the possible RoCoF failure mechanisms. The work aims to provide a quantitative indication of the likely RoCoF range that is secure, and potential areas of uncertainty that should be the focus of future analysis. This work is close to completion, with a report expected to be published in early 2017.
- AEMO has also engaged Entura to model the RoCoF withstand capabilities of individual synchronous generators in South Australia. This modelling quantifies the RoCoF levels at which a subset of potential RoCoF challenges can occur, such as pole slipping[8], or the operation of various systems designed to protect plant from damage. Entura's analysis uses a range of scenarios with respect to the nature of the impact of the event (such as association with a voltage depression) and the operation of the unit (such as operation with a leading or lagging power factor, and the unit loading) to explore potential impacts on the SA generation fleet's RoCoF withstand capabilities. This work has included a significant amount of benchmarking and exploratory analysis, including various sensitivity studies, to ensure the results are correctly interpreted.

Projecting RoCoF exposure

AEMO's 2016 *National Transmission Network Development Plan* (NTNDP)[9] includes analysis that projects the future exposure to high RoCoF due to various plausible non-credible contingency events in South Australia and Queensland as potential islanded regions, and on the NEM mainland as a whole (as Tasmania is not connected synchronously). This provides an important context for the timing of potential challenges related to non-credible contingency events, and indicates when appropriate mitigation measures for these extreme events might be necessary to avoid system collapse.

Changes to the National Electricity Rules (Rules) are required to clarify the roles and responsibilities in mitigating the (potentially more extreme) consequences of non-credible contingency events due to

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[6] The *technical envelope* is defined in the NER Clause 4.2.5, available at: http://aemc.gov.au/getattachment/c443cb93-bf9a-40dc-a1a8-05bb1f33db63/National-Electricity-Rules-Version-88.aspx.

[7] Emulated inertia can also be provided by other inverter-connected technologies, such as photovoltaics (PV), but is relatively less mature, and therefore there was less international experience to draw upon for this review.

[8] Synchronous generators consist of a stable non-rotating stator and a rotating part called a rotor which sits inside and rotates around the generator shaft. Magnetic fields from the stator and rotor are linked or in step during normal operation. Pole slipping occurs when the magnetic link is broken and the rotor loses synchronism.

[9] AEMO. *National Transmission Network Development Plan*, December 2016. Available at: http://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/National-Transmission-Network-Development-Plan.

higher RoCoF. This is being considered by the AEMC at present, and is discussed further in Section 3.1.2.[10]

Fast Frequency Response specification

AEMO engaged GE Consulting to assess the potential value of FFR services in the NEM to help mitigate high RoCoF, and to determine the degree to which FFR could substitute for synchronous inertia. The study included advice on the capabilities of emerging technologies to provide FFR, and conceptual modelling of South Australia to investigate the operation of such a service in the power system.

The analysis of technical capabilities confirms that:

- FFR is distinct from instantaneous inertia, as there will always be a delay in the measurement and identification of the frequency change.
- For now, some minimum amount of synchronous inertia is required to manage frequency control in the NEM, but FFR may provide a benefit by reducing the amount of synchronous inertia required. In the future, FFR might be able to replace synchronous inertia with equivalent instantaneous services from inverter-connected plant, but this is not possible at present. Significant development will be required by equipment manufacturers and researchers before this becomes possible.
- FFR is not symmetrical, with different costs and implications for delivery of raise and lower services from different technologies.

The study provided detailed information that can be used to inform the specification of an FFR service that facilitates broad participation while meeting future power system security needs. The report is currently being finalised for publication.

2.1.3 Key focus for January – June 2017

Indicative timeframes for all work underway are set out in Chapter 6.

Collaboration with the AEMC

AEMO is collaborating with the AEMC to analyse potential mechanisms for implementing procurement mechanisms for FFR and inertia in the NEM. This will take into account the findings from the studies above.

Given the interactions between different elements of system security, any assessment of the pros and cons of different technical solutions is likely to be complex. The technical issues are likely to change over time as the power system continues to evolve. In this context, the regulatory framework should be designed in a way that retains the flexibility to adopt the most efficient technical solution under a range of unknown future scenarios.

AEMO is developing a strawman proposal for the potential specification of an FFR service in parallel with the AEMC's review, noting that there is still much technical analysis to be performed.

Further analysis on RoCoF limits

Upon completion of these RoCoF studies, AEMO will assess the need for further analysis to determine more accurate and robust secure operational limits for RoCoF in the NEM. As existing synchronous generators were not designed with specific RoCoF settings or protection, significant uncertainties are likely to remain. Further work will focus on reducing this uncertainty to ensure the power system can be operated securely, and as efficiently as possible. This could include further modelling studies, or various kinds of testing of power system elements.

[10] AEMC. Emergency frequency control schemes rule change. Available at: http://www.aemc.gov.au/Rule-Changes/Emergency-frequency-control-schemes-for-excess-gen.

Projecting RoCoF exposure

The work completed in the 2016 NTNDP is being expanded to project exposure to high RoCoF due to a range of credible contingency events. This would allow AEMO to assess when the existing FCAS may no longer be sufficient to maintain frequency within the Frequency Operating Standards (FOS). This would imply that a re-design of the existing FCAS framework or additional mechanisms (such as an FFR or inertia procurement mechanism) are required.

Developing and validating models for high RoCoF in power systems with reduced system strength

AEMO is developing electromagnetic transient-type models of the South Australian power system that will enable studies for high RoCoF response, particularly under reduced system strength conditions, as this is difficult to model accurately with conventional power system modelling tools. Accurate models are essential for facilitating the secure operation of the power system and the effective implementation of any new mitigation measures.

2.2 Insufficient amount of available FCAS

Challenge:

- The market has historically attracted regulation and contingency FCAS from synchronous generation. If this synchronous generation is displaced (either permanently or temporarily), the level of FCAS it provided will have to be procured from other sources, which the market has not attracted to date.
- Additionally, the increasing variability of supply and demand is likely to be met with increased frequency control requirements from the market.

Where challenge might arise:

- Similar to the challenges of high RoCoF, AEMO does not expect a system-wide shortfall of either regulation or contingency FCAS in the near term.
- This challenge is likely to be restricted to regions of the power system that could become islanded, as FCAS would need to be enabled locally within those regions during islanding.

2.2.1 Objective for further analysis

AEMO seeks to:

- Identify the technical capability of technology to provide frequency control services, and assess whether there are any technical or regulatory barriers to their participation in FCAS markets.
- Estimate future requirements for regulation[11] and contingency[12] FCAS on the basis of changing variability and uncertainty of supply and demand, and determine whether a shortfall in FCAS is likely to occur, particularly in areas susceptible to islanding.
- Determine whether adjustments to the FCAS framework would allow frequency control to be managed more efficiently in the future, in light of the changing generation mix.

[11] Regulation FCAS refers to the market service which is centrally controlled by AEMO to manage minor deviations within the five-minute dispatch interval.

[12] Contingency FCAS refers to the market service which is enabled to correct relatively material frequency deviations that might arise from larger supply-demand imbalances.

2.2.2 Work completed since August 2016

Projecting FCAS requirements

A review of international renewable integration studies revealed that contingency FCAS requirements generally remain unaffected by growth in renewable generation, or decrease due to a reduction in unit sizes. For this reason, the primary focus of this work has been on requirements for regulation FCAS related to growing proportions of variable technologies (wind, utility-scale photovoltaics (PV), and rooftop PV).

AEMO has completed a detailed analysis on future regulation FCAS requirements associated with these technologies. To achieve this, AEMO developed a methodology to project future regulation needs informed by international renewable integration studies. This methodology was applied to project regulation FCAS requirements based on future installed capacities of each technology as forecast in the 2016 NTNDP.

Additional to the projection of needs, AEMO explored potential mechanisms for minimising future regulation FCAS requirements, such as the:

- Application of dynamic requirements, which would be adjusted as a function of the real-time operating level of wind, or the “cloudiness” of the day for PV.
- Potential efficacy of ramp rate constraints.

High level results were published in the 2016 NTNDP, while a comprehensive technical report will be published in early 2017.

Review of technical barriers to participation in FCAS

In late 2016, AEMO commenced work to identify technical barriers to the participation of emerging technologies in FCAS markets. This work has included interviews with a range of manufacturers of wind and PV technologies to understand the capabilities of these technologies to provide both existing and potentially new FCAS services and any potential barriers to their participation. Findings from these interviews will inform a range of other review activities looking to update and augment the FCAS regulatory framework, as discussed in Section 2.2.3.

2.2.3 Key focus for January – June 2017

Indicative timeframes for all work underway are set out in Chapter 6.

Projection of FCAS requirements

The analysis on future regulation FCAS requirements and potential mitigation mechanisms will continue in early 2017. Following publication of a preliminary report, further analysis and implementation activities for promising approaches will be considered.

Review and adaptation of FCAS frameworks

AEMO is currently scoping a broad work program on FCAS frameworks, comprising multiple work packages to be completed in 2017. The immediate focus of this FCAS program is to review the frameworks that support the operation of FCAS markets in the NEM, in the context of ongoing changes to the generation mix as considered in the FPSS program and implementation of the Demand Response Mechanism and Ancillary Services Unbundling Rule.[13]

In aggregate, this series of work packages will consider the following:

[13] AEMC. Final Rule Determination, 24 November 2016. Available at: http://www.aemc.gov.au/getattachment/68cb8114-113d-4d96-91dc-5cb4b0f9e0ae/Final-determination.aspx.

- Technical issues relating to frequency control and the need for further adaptation of FCAS frameworks (including a potential FFR service, as described in Section 2.1.2), based on an assessment of the ability of current markets to continue to meet the technical requirements of the power system. AEMO expects that findings from this work would inform future work by the AEMC.
- Alternative approaches using forecasting and information systems to mitigate the frequency impacts of unusual power system events, such as high speed cut-out of wind farms under extreme wind conditions, or the potential simultaneous intermittency of utility-scale PV during solar events (such as a solar eclipse).

Examples of the reviews within the broader work program on FCAS frameworks include:

- Review of the regulation FCAS 'causer pays' mechanism. AEMO released an *Issues Paper*[14] in December 2016, with submissions due mid-February 2017. The focus of this review is to consider potential amendments to the calculation mechanism for 'Market Participation Factors',[15] which are used as the basis for recovering costs associated with procuring regulation FCAS. Consultation on this mechanism is being undertaken in accordance with clause 3.15.6A(k) of the Rules.
- Review of the Market Ancillary Services Specification (MASS), which seeks to identify and address barriers to participation by emerging technologies. AEMO released an *Issues Paper* on 25 January 2017.[16] This review focuses on amendments to the MASS required to support implementation of the Demand Response Mechanism and Ancillary Services Unbundling Rule. Consultation on the MASS will be undertaken in accordance with clause 3.11.2(b) of the Rules.
- Review of current Essential Service Commission of South Australia (ESCOSA) generator licensing conditions, including consideration of any potential adjustments (or additions) to licence conditions. ESCOSA released an *Issues Paper*[17] seeking comment from interested parties by 30 January 2017. The current timetable of ESCOSA's review extends to August 2017. AEMO's role in the review includes the provision of advice on the basis for existing and new entrant generators to provide a broader range of capabilities, including frequency control services.

Operation of South Australia as an island

In conjunction with ElectraNet and South Australian Power Networks (SAPN), AEMO is exploring options to adjust system parameters to manage system security of an islanded South Australian region. Actions in progress include:

- Efforts to minimise rapid changes in the supply-demand balance resulting from the 11:30 pm hot water demand peak. AEMO continues to work with SAPN to evaluate the effectiveness of SAPN's 2016 program to adjust and randomise the timeclocks controlling hot water heaters. AEMO proposes to assess any residual system security risks from the 11:30 pm hot water peak once the program has concluded. Recommendations for further work will be made if required.
- Assessment of operating the region as an island, including the potential of the resulting weak system to affect the functionality of protection schemes designed to handle faults (see Chapter 5).
- Analysis of levels of both regulation and contingency FCAS necessary for islanded operation.
- Investigations to determine levels of expected RoCoF in South Australia following separation from the rest of the NEM.
- Developing electromagnetic transient-type models of the South Australian power system (see Section 2.1.3 and Section 5.1.2).

[14] AEMO. *Causer Pays Procedure Consultation – Issues Paper*, December 2016. Available at: http://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2016/Causer-Pays-Procedures-Issues-Paper-Dec-16.pdf.

[15] Further information on Market Participation Factors is available at: https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Security-and-reliability/Ancillary-services/Ancillary-services-causer-pays-contribution-factors.

[16] AEMO. *Market Ancillary Service Specification – Issues Paper*, January 2017. Available at: http://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2017/MASS/MASS-stage-one-consultation-issues-paper.pdf

[17] Further information on ESCOSA's review, including an Issues Paper, available at: http://www.escosa.sa.gov.au/projects-and-publications/projects/inquiries/inquiry-into-licensing-arrangements-for-inverter-connected-generators.

3. MANAGING EXTREME POWER SYSTEM CONDITIONS

3.1 Emergency under frequency control schemes

Challenge:

- The performance assumptions of under-frequency load shedding (UFLS) schemes are being challenged by the high RoCoF that could result under contingency conditions involving the loss of interconnection of NEM regions susceptible to islanding.
- The efficacy of these schemes is also being impacted by increased penetration of distributed energy resources (DER), which:
  - Can reduce the load available to be shed at times when distributed generation (such as rooftop PV) is generating in the parts of the network that are shed.
  - Can mean, in areas of high DER penetration, that at certain times of the day part of the distribution network could be operating in reverse, so generation is shed instead of load. The current schemes and technologies that shed load using pre-set relays are not designed to adapt to changing system conditions such as the reversal of power flows.

Where challenge might arise:

- In regions that separate from the rest of the NEM resulting in high RoCoF, UFLS schemes might not react fast enough to arrest the fall in frequency and prevent cascading generation failure.
- The effectiveness of UFLS could be reduced in regions that have high penetrations of DER when they separate from the rest of the power system. The primary focus is on South Australia, Tasmania, and Queensland.

3.1.1 Objective for further analysis

Following publication of the 2016 AEMO/ElectraNet Report *Update to Renewable Energy Integration in South Australia*[18], the focus of further work in this area has been to consider options for amending the settings and equipment used in the South Australian UFLS scheme for it to be as effective as possible under the current range of expected conditions.

AEMO has completed a review of options to improve the UFLS scheme, in conjunction with Network Service Providers (NSPs), and identified operational improvements. These improvements have now been implemented by SAPN.

AEMO will continue to assess whether these schemes will retain their effectiveness under expected RoCoF, and the increasing prevalence and potential for reversing power flows due to DER. AEMO expects it will be necessary to consider whether more fundamental changes (other than UFLS settings) are required to make the scheme dynamic and adaptive to maintain frequency within required levels.

[18] AEMO/ElectraNet. *Update to Renewable Energy Integration in South Australia*, February 2016. Available at: http://aemo.com.au/-/media/Files/PDF/Joint-AEMO-ElectraNet-Report_19-February-2016.pdf

3.1.2 Work completed since August 2016

UFLS review

In light of the changing dynamics of the power system, AEMO, with SAPN and ElectraNet, completed a review of the UFLS scheme in South Australia in December 2016.

The basic design premise of the scheme is that any frequency drop in response to credible and non-credible contingency events[19] should be limited to 47 hertz (Hz) by the controlled disconnection of load.

The review analysed the performance of the existing under-frequency relay-based design, and considered a number of options to increase the effectiveness of the scheme.

Two redesign options to improve the effectiveness of UFLS were investigated:

- Continued use of frequency-sensing relays that trip only following the detection of specific frequency set points.
- Utilising a hybrid design involving relays that measure RoCoF and disconnect load when it is clear a significant under-frequency event is in progress, in conjunction with the more traditional relays that trip on an absolute pre-set value of frequency.

The hybrid design using a mixture of RoCoF based and conventional relays was found to operate at a much higher level of performance. SAPN has agreed to implement the recommended changes to this scheme using the new mixture of relays.

The proposed design will require 15% of the load available to the UFLS scheme to be tripped based on RoCoF. These relays are tripped if the RoCoF is ≥ 1.5 Hz/s and the absolute frequency is ≤ 49.4 Hz. The benefits of this scheme include:

- Since 15% of the load is shed sooner, this option effectively presents a smaller contingency with lower residual RoCoF to the remaining blocks of UFLS.
- For a NEM-wide under-frequency event, this option will not affect the existing equitable load shedding arrangements.

AEMO understands this design is now operational.

Frameworks for UFLS and ‘protected events’

In parallel with the review of existing UFLS settings, AEMO has been considering amendments to those parts of the Rules that relate to the roles and responsibilities for AEMO and NSPs in the design, implementation, and ongoing maintenance of control schemes designed to mitigate the impacts of under-frequency events.

AEMO supports the need for broader amendments to frameworks for under/over frequency load shedding as raised in Rule change proposals submitted in July 2016 by the South Australia Minister for Resources and Energy.[20]

AEMO also considers that there is likely to be merit in the introduction of a new category of events in the Rules – notionally ‘*protected events’* – as suggested by these Rule change proposals. The introduction of a *protected events* category would allow the impacts of specific non-credible contingency events to be managed, following a market consultation process, with a least-cost mixture of emergency control schemes, alternative network investment, and ex-ante action by AEMO where there existed a clear cost/benefit case for action.

[19] As discussed on page 13 of *Update to Renewable Energy Integration in South Australia*, February 2016, the SA region had adapted a frequency band of 47–52 Hz for credible separation events. A consequence of this is that UFLS can operate in SA for credible as well as non-credible contingency events. This is not the case for other NEM regions.

[20] Submission available at: http://www.aemc.gov.au/getattachment/6c2140e8-36d5-4178-8640-e6d9a046929d/Emergency-underfrequency-control-schemes.aspx.

Development and refinement of this framework will continue until the AEMC's Rule change process concludes in Q2 2017.

Work in progress or completed in this area includes:

- Providing advice as part of the AEMC – AEMO *Collaboration on Framework for System Security in the NEM* to support improvements to the Rules framework for UFLS schemes.
- Lodging a submission[21] to the AEMC's Consultation Paper on under/over frequency control schemes in October 2016.

The AEMC published a Draft Determination[22] on these Rule change proposals on 22 December 2016.

3.1.3 Key focus for January – June 2017

Indicative timeframes for all work underway are given in Chapter 6.

Promoting Rule changes

Analysis conducted in the review of the UFLS scheme supports the need to look at a combination of mitigation measures for managing extreme power system conditions in the future. The review found, not only that UFLS will not work for all possible system conditions, but also that the underlying assumptions need to be tested, in particular those related to generators remaining online and no voltage reductions occurring.

To be effective in containing the effects of high RoCoF events, AEMO considers there is value in establishing a clear basis in the Rules to support the use of *adaptive* UFLS schemes, which can respond much more rapidly to high RoCoF events. Such schemes would use high speed communication and detection systems, in conjunction with sophisticated supervisory control, to allow sufficient load to be shed in much shorter timeframes than is possible under current schemes.

Changes to the existing UFLS infrastructure will need to be supported by clear responsibilities in the Rules for design, investment, and funding. AEMO will continue to provide robust advice and submissions on these issues in 2017, including amendments to the framework proposed in the AEMC's December 2016 Draft Determination.

3.2 Emergency over frequency emergency control schemes

Challenge:

- Over-frequency emergency control schemes (also referred to as over frequency generator shedding schemes or OFGS schemes) could be useful to coordinate tripping of generation to manage contingencies resulting in an excess of generation. To be effective, these schemes also need to manage other technical matters, such as RoCoF and system strength, and avoid tripping generation that supports managing these technical matters.

Where challenge might arise:

- Similar to under-frequency control schemes, the challenges associated with over-frequency controls will emerge first in regions that can be separated from the rest of the NEM (South Australia, Tasmania, and Queensland).

[21] AEMO's submission is available at: http://www.aemc.gov.au/getattachment/c33bc3ad-9df3-4821-ad64-e65037b3029b/AEMO.aspx.

[22] AEMC. Draft Rule Determination – National Electricity Amendment (Emergency frequency control schemes) Rule 2016, 22 December 2016. Available at: http://www.aemc.gov.au/getattachment/a4fddcd6-2dda-4f9e-b041-a99be095be78/Draft-Rule-Determination,-Emergency-Frequency-Cont.aspx.

3.2.1 Objective for further analysis

AEMO's immediate focus in the second half of 2016 has been to support the design and implementation of an OFGS scheme in South Australia. Consideration of the need for OFGS schemes in other NEM regions will follow as AEMO continues to monitor the impacts of further changes to the generation mix.

3.2.2 Work completed since August 2016

Design of OFGS for South Australia

AEMO, with ElectraNet, has designed an OFGS to limit the frequency rise in South Australia to 52 Hz in line with the FOS. The objective of the scheme is to coordinate the tripping of generation in a pre-determined manner, tripping low inertia generators first, to maximise the inertia online. This seeks to minimise the impacts of exacerbated RoCoF that would result from disconnecting synchronous generators that provide system inertia during an extreme frequency event. Actual operation of the scheme is expected to be rare.

The scheme would only operate for frequency excursions above the upper limit of the "operational frequency tolerance band" of 51 Hz. Generation to be tripped is split into eight blocks, each with around 150 megawatts (MW) of wind generation, set to trip between 51 Hz and 52 Hz.

Due diligence on OFGS scheme settings has been completed by ElectraNet, which is targeting the end of Q1 2017 for implementation of the scheme. AEMO will assist ElectraNet in this process.

3.2.3 Key focus for January – June 2017

Indicative timeframes for all work underway are set out in Chapter 6.

Promoting Rule changes

The Rule change proposals, as lodged by the SA Minister for Resources and Energy and discussed in Section 3.1.2, also explore the need to establish a formal framework for the implementation of OFGS schemes. Clear guidance in the Rules on the roles and responsibilities for AEMO, NSPs, and market participants in the development and implementation of OFGS schemes would be of significant benefit in reducing the perceived risk associated with, and expediting implementation of, an OFGS for South Australia, and in other regions if the need emerges.

AEMO will continue to work with the AEMC, NSPs, and other industry stakeholders during 2017 to ensure a functional and fit-for-purpose framework is in place to allow efficient and cost-effective management of over-frequency events.

4. VISIBILITY OF THE POWER SYSTEM – INFORMATION, DATA, AND MODELS

4.1 Visibility of distributed energy resources

Challenge:

- The customer-driven trend for DER and technologies that can integrate the control of devices to manage load is not directly visible to AEMO. In aggregate, these can have a material impact on the power system, and a lack of visibility affects AEMO's ability to accurately assess the operational limits of the power system.

Where challenge might arise:

- The challenge will arise in all NEM regions as their relative penetration of DER grows.

4.1.1 Objective for further analysis

The objective of work in this area is to develop a set of justified requirements in relation to standing and real-time data about DER, and explore avenues for obtaining access to this data. AEMO will work with NSPs and other stakeholders on their needs and ability to access this information.

AEMO seeks to inform the relevant bodies on the need to establish mechanisms to ensure sufficient information is collected, stored in a consistent and accessible form, and provided to the appropriate bodies such as AEMO and NSPs.

Such frameworks would provide AEMO with visibility and confidence in the performance of DER, so it can plan for any aggregate outcomes, and manage the reduction in generation that can be centrally-controlled at times when DER constitutes large proportions of online generation.

4.1.2 Work completed since August 2016

Data needs analysis

AEMO has assessed its operational processes and the data considered critical to the future operational management of the power system. The data can be divided into:

- Static data, such as capacity and location – static or standing data needs cannot be aggregated for a combination of installations, as the technical characteristics of each individual installation are potentially unique.
- Dynamic data, such as generation output – dynamic data can be aggregated at the transmission connection point level, providing efficiencies in its management.

There are gaps in the current mechanisms by which AEMO can access data, namely there is no mandate for entities to collect information about DER located behind the meter. Without access to this data, AEMO may need to determine operational limits and operate the power system on a more conservative basis to account for uncertainties when keeping the power system within its technical limits at all times. Operating more conservatively comes at a cost because it risks asset under-utilisation and inefficient investment, which ultimately flows through as increased costs to consumers.

The data requirements are specific to each technology. Given the potential for the fast development of new technologies, any data collection framework would need to be sufficiently flexible to accommodate future needs without lengthy regulatory processes.

AEMO has published a report on the need for visibility of DER for efficient and secure power system operations.[23]

Demand side participation information guidelines

AEMO is currently undertaking a consultation to formulate its requirements for electricity demand forecasting through the development of demand side participation (DSP) guidelines which will enable AEMO to obtain information on DSP from registered participants in the NEM.[24] Submissions to the draft issues paper closed 19 January 2017.

Energy Market Transformation Project Team – battery registry

The Energy Market Transformation Project Team (EMTPT), a working group of the Senior Committee of Officials of the COAG Energy Council, has been consulting on energy storage registration. Consultation has focused on the need to establish a battery storage registry for, among other purposes, power system operations and planning. AEMO's submission encouraged the EMTPT to consider a broader registry that would cater for a wide range of technologies.

4.1.3 Key focus for January – June 2017

Indicative timeframes for all work underway are set out in Chapter 6.

Developing an appropriate DER data collection mechanism

Any regulation to make data on DER available to AEMO is contingent on the frameworks that facilitate the collection and registration of this information. There are several potential technical and regulatory options to enable data collection, each needing to be explored to unpack their relative merits and costs.

AEMO will be looking to consult with industry about these options. AEMO is also conscious of the activity of the EMTPT and will look to collaborate, where possible, to leverage mutual opportunities and avoid any duplication.

4.2 Tools and capabilities

Challenge:

- Unless progressively revised, models of physical plant and modelling tools might not be capable of providing accurate system state information to underpin real-time and operational forecasts, and to support decision-making by system operators and planners.

Where challenge might arise:

- AEMO is obliged under clause S5.5.7 of the Rules to develop and publish Generating System Model Guidelines (GSM Guidelines) and associated documentation in accordance with the Rules consultation procedures. The current GSM Guidelines were published in February 2008, and focus on accurately modelling synchronous generation for power system simulation.

  Since the first release of the GSM Guidelines, the proliferation of new generation technologies and experience gained from past connection projects has triggered a need to review them to ensure they remain relevant and effective. With increased penetration of inverter-connected generation, failure to adequately cater for new and emerging technologies can have a material impact on the secure operation of the power system.

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[23] AEMO. *Visibility of Distributed Energy Resources.* Available at: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO-FPSS-program----Visibility-of-DER.pdf.

[24] Information, consultation timeline, and documents available at: https://aemo.com.au/Stakeholder-Consultation/Consultations/NEM-Demand-Side-Participation-Information-Guidelines-Consultation.

4.2.1 Objective for further analysis

AEMO's role as system operator requires the continual review of its models and technical modelling tools, and implementation of additional developments where required. This is an ongoing process necessary to support the secure and economic operation of the power system within the bounds of the technical envelope as set out in the Rules.

4.2.2 Work completed since August 2016

Generating System Model Guidelines

AEMO lodged a Rule change proposal in November 2016 with the AEMC to support updating and broadening the scope of GSM Guidelines, and is set to undertake a subsequent review of the GSM Guidelines in recognition of the growing importance of aspects of the power system, such as embedded generation, voltage support equipment/control, and protection systems, on AEMO's role as system operator.[25] AEMO considers that these are not adequately addressed by the current GSM Guidelines.

The key objectives of this Rule change request are to allow for:

- Broadening the Guidelines and datasheets to include non-generating system power system elements.
- More detailed and accurate modelling and simulation of the power system to manage power system security with rapidly changing power system dynamics and generation technologies.
- More efficient procurement of ancillary services, and more accurate understanding of the technical capability of plant for the provision of new ancillary services.

4.2.3 Key focus for January – June 2017

AEMO's key focus for the first half of 2017 is to support development of the GSM Guidelines Rule change proposal in consultation with the AEMC, and to continue to evaluate ongoing needs for development of modelling capability.

4.3 Representation of distributed energy resources

Challenge:

- As DER increases, demand (as seen by the power system operator) will become more intermittent and dynamic, displaying new characteristics. Dynamic load behaviour is not effectively represented in power system models and system security studies.

Where challenge might arise:

- The challenge will arise in areas with large penetrations of DER. If the representation of DER in load models is inaccurate:
  - There will be greater uncertainty in operational demand forecasts, so it will be more difficult to match supply and demand through the dispatch process, increasing the reliance on FCAS.
  - AEMO's power system models will not be able to accurately determine the system security limitations without accurate representations of the behaviour of loads under voltage and frequency variations.

[25] Information and documents available at: http://www.aemc.gov.au/Rule-Changes/Generating-System-Model-Guidelines.

4.3.1 Objective for further analysis

The objective of work in this area is to determine the required representation of DER for AEMO's studies. This includes verifying whether current levels of aggregation will remain appropriate as the proportion of DER increases, or whether they no longer accurately reflect the behaviour of net load.

Similarly, for system stability studies, AEMO seeks to develop more accurate load models that will reflect the system dynamics and enable effective management of power system security.

4.3.2 Work completed since August 2016

AEMO has commenced a joint project with several NEM NSPs to revise the dynamic representation of customer load models. These load models are used in both planning and operation of the electrical network.

It is proposed that measurement data collected will be used as part of a longer-term project to assess and revise dynamic load models based on empirical methods.

To date, AEMO has:

- Obtained on loan a number of high-speed monitoring devices suitable to capture the required disturbance recording.
- Signed agreements with project partners to install the available high-speed monitoring devices, and subsequently installed these on radial feeders within a distribution network.
- Commenced gathering data to determine the dynamic response of various types of customer load, including connections with known high rooftop solar PV penetration.
- Commenced development of a methodology for data analysis and development of revised composite load models.

4.3.3 Key focus for January – June 2017

AEMO will continue to collect high-speed data of load behaviour and assess the need to collect further data. Concurrently, AEMO will develop the necessary numerical methods for load data analysis, and verify the analysis process on sample data sets.

Assessment of requirements for load models

AEMO is assessing the adequacy of currently available load models, and will seek to determine an appropriate representation of load responses and DER for operation and planning of the electrical power system.

5. SYSTEM STRENGTH

Challenge:

- Adequate fault currents are essential for correct operation of protection systems, voltage stability, and the stable operation of non-synchronous generation. Substantial fault currents are presently only provided by synchronous generation and could, therefore, reduce in future as the amount of synchronous generation declines. Furthermore, standard power system models cannot accurately capture weak[26] system behaviour.

Where challenge might arise:

- At present, challenges related to reduced system strength have been observed predominantly in isolated locations (electrically remote from synchronous generation), particularly where a comparatively large quantity of non-synchronous generation has connected (or sought to connect).
- Where system-wide operational impacts have been identified (such as in South Australia), additional operational measures have been introduced (requiring a minimum combination of synchronous units to remain online). However, because of its complexity in how it may impact system security, it is important to deepen our understanding of any potential challenges.

5.1.1 Objective for further analysis

The work program on system strength should fulfil the following objectives:

- Clarify the nature of the challenges that arise as system strength reduces.
- Identify a range of potential technical solutions, and the limitations and applicability of each. Many may be most suitably implemented by generators and network service providers.
- Review international experiences with reduced system strength, and draw out any important lessons for the NEM.
- Identify where and when challenges with reduced system strength are likely to require further intervention in the NEM.
- Clarify the manner in which regulatory frameworks, the Rules, the system standards, and the generator access standards may need to vary to mitigate system strength challenges in future.
- Develop and benchmark improved system models for reduced system strength analysis.

5.1.2 Work completed since August 2016

Defining the challenges and technical solutions

AEMO has drafted a report to clarify the nature of the challenges that arise as system strength reduces. This summarises the nature of the many challenges that can arise in an accessible framework.

The report also identifies the range of potential technical solutions that could be utilised to address these challenges, and the limitations and applicability of the options considered. The report is being finalised at present, with anticipated release in early 2017.

Projecting emerging system strength challenges

Changes in system strength were projected in the 2016 NTNDP in a high-level assessment to locate areas where system strength is an existing or emerging challenge. Overall, system strength is expected

[26] AEMO. "Fact sheet: System strength". Available at: http://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/AEMO-Fact-Sheet-System-Strength-Final-20.pdf.

to decline, given the increase in inverter-connected generation coupled with synchronous generation withdrawals, with challenges first appearing in much of South Australia, western Victoria, north Queensland, and Tasmania.

The NTNDP also found that increased interconnection provides a marginal benefit, with local network and non-network options also needed to maintain a reliable and secure supply. For example, synchronous condensers, or similar technologies, can provide local system strength and resilience to frequency changes.

A key analysis of the challenges of system strength was the propagation of voltage dips through the network. In a network of reduced system strength, voltage dips are deeper, more widespread, and can last longer than in a strong network. The transient voltage dip resulting from a short circuit event will be more severe, more widespread, and slower to recover in a weak system.

Model development for reduced system strength

AEMO has an ongoing work program to develop and benchmark improved system models for reduced system strength analysis. This is essential to ensure the power system can be accurately represented as system strength reduces.

Generating System Model Guidelines

The GSM Guidelines are discussed in Section 4.2.2.

5.1.3 Key focus for January – June 2017

International review

AEMO is reviewing international experiences with reduced system strength, including system operators that have produced significant reports and analysis, such as National Grid (the United Kingdom), ERCOT (Texas), EirGrid/SONI (Ireland), various systems in the USA, and islanded or semi-islanded power systems (where analysis is available). The aim of this review is to ensure that AEMO (and AEMO's stakeholders) are well informed on international experiences, and to develop and draw on any important lessons and insights for the NEM.

Modelling of the location and timing of emerging challenges

Further modelling will be conducted (extending analysis included in the 2016 NTNDP) to identify where and when challenges with reduced system strength are likely to arise in the NEM, and the factors that influence the emergence of these challenges. This modelling will also consider the manner in which various technical solutions could be implemented, and the degree to which they mitigate the issues that arise (for example, quantifying the number and location of synchronous machines that may be required to address system strength issues).

Regulatory frameworks

Analysis will clarify the manner in which regulatory frameworks might need amendment to address system strength challenges in future. This will include consideration of the Rules, especially the system standards and the generator access standards. Clarification around the roles and responsibilities for monitoring and maintaining system strength via various approaches will be a particular area of focus. Outcomes from this work will feed into the AEMC's System Security Market Framework Review.

Model development for reduced system strength

Development and benchmarking of improved system models for reduced system strength analysis will continue.

6. SUMMARY OF WORK SINCE DECEMBER 2015

Action No.	Action	Timeframe	Progress
General reporting			
R.01	*Update to renewable energy integration in South Australia – joint AEMO and ElectraNet report*	February 2016	Completed
R.02	FPSS Progress Report	August 2016	Completed
Power Systems Implications Technical Advisory Group (PSI TAG)			
PT.01	PSI TAG meeting	16 December 2015	Completed
PT.02	PSI TAG meeting	5 February 2016	Completed
PT.03	PSI TAG meeting	17 March 2016	Completed
PT.04	Communication brief of PSI TAG published	8 April 2016	Completed
PT.05	PSI TAG meeting	16 May 2016	Completed
PT.06	Communication brief of PSI TAG published	1 June 2016	Completed
Frequency control			
FC.01	Factsheet – *Frequency control*	August 2016	Completed
FC.02	*International Review of Frequency Control Adaptation*	October 2016	Completed
FC.03	Potential for fast frequency response	Early 2017	In progress
FC.04	Independent expert advice on managing high RoCoF	Early 2017	In progress
FC.05	RoCoF withstand capability of South Australian generation	Early 2017	In progress
FC.06	Projection of FCAS requirements	Early 2017	In progress
FC.07	Technical capabilities to provide FCAS and technical barriers to participation	2017	In progress
FC.08	Operation of South Australia as an island	Ongoing	In progress
FC.09	Capability and limitations of HVDC interconnectors to provide FCAS	2017	In progress
FC.10	Projecting RoCoF exposure for non-credible contingency events	Early 2017	In progress
FC.11	Input into AEMC rule change on FFR and inertia	June 2017	In progress
FC.12	Projecting RoCoF exposure for credible contingency events	Early 2017	In progress
Managing extreme power system conditions			
MEC.01	Assessment of exposure risk to high RoCoF in South Australia	July 2016	Completed
MEC.02	UFLS review for South Australia	December 2016	Completed
MEC.03	Design of OFGS for South Australia	December 2016	Completed
MEC.04	*Submission to the AEMC on UFLS and OFGS Rule changes*	October 2016	Completed
MEC.05	Input to the AEMC rules change process on protected events and emergency control schemes.	2017	In progress
Visibility of the Power System – information, models and tools			
IMT.01	*Response of existing rooftop PV inverters to frequency disturbances*	February 2016	Completed
IMT.02	Factsheet – *Visibility of the power system*	August 2016	Completed
IMT.03	Consultation with government on data needs	2016	In progress
IMT.04	Collaboration with ENA	July 2016	In progress
IMT.05	Data needs analysis	December 2016	Completed
IMT.06	Rule change request – Generating System Model Guidelines	1 November 2016	Completed

Action No.	Action	Timeframe	Progress
IMT.07	Review of modelling capability needs	Ongoing	In progress
IMT.08	Assessment of requirements for load modelling	Ongoing	In progress
IMT.09	*Submission to the Energy Storage Registration Consultation Paper*	September 2016	Completed
IMT.10	Report – *Visibility of Distributed Energy Resources*	January 2017	Completed
IMT.11	Demand side participation guidelines – initial consultation	January 2017	Completed
IMT.12	Scoping potential DER data collection mechanisms	2017	In progress
System strength			
SS.01	Factsheet – *System strength*	August 2016	Completed
SS.02	Develop modelling capability for weak system conditions	Ongoing	In progress
SS.03	Defining the system strength challenge, and identifying potential technical solutions	2017	In progress
SS.04	*Projecting emerging system strength challenges*	December 2017	Completed
SS.05	Input into AEMC rule change on system strength	June 2017	In progress
Stakeholder engagement			
SE.01	Wind Industry Forum	17 March 2016	Completed
SE.02	COAG Energy Council report	July 2016	Completed
SE.03	Collaborative agreement with AEMC	14 July 2016	Completed
SE.04	Presentation – Clean Energy Summit	27 July 2016	Completed
SE.05	Presentation – ENA Regulation Summit	3 August 2016	Completed
SE.06	*FPSS Roadshows*	15-24 August 2016	Completed
SE.07	*Submissions to FPSS Progress Report received*	19 September 2016	Completed
SE.08	Presentation – Australian Institute of Energy Symposium	10 October 2016	Completed
SE.09	COAG Energy Council report	14 December 2016	Completed
General submissions			
SUB.01	*Queensland Renewable Energy Expert Panel – Issues Paper*	10 June 2016	Completed
SUB.02	Queensland Renewable Energy Expert Panel – Industry Forum	20 June 2016	Completed
SUB.03	*Victorian Renewable Energy Target*	31 August 2016	Completed
SUB.04	*Queensland Renewable Energy Expert Panel – Draft Report*	2 November 2016	Completed
SUB.05	Queensland Renewable Energy Expert Panel – Industry Forum	24 October 2016	Completed