13 October 2016

John Pierce
Chairman
Australian Energy Market Commission
PO Box A2449
SYDNEY SOUTH NSW 1235

By online submission

Dear Mr Pierce

System Security Market Frameworks Review

Hydro Tasmania welcomes the opportunity to provide comments on the AEMC's System Security Market Frameworks Review consultation paper.

Hydro Tasmania's submission contains the following three sections:

- an overview of the challenges and solutions Tasmania has developed in relation to the integration of renewables in Tasmania;
- responses to specific questions raised in the AEMC's consultation paper; and
- a Tasmanian case study on managing high penetration of renewables.

If you have any questions in relation to this submission, please contact David Bowker on (03) 6230 5775.

Yours sincerely

D. Bowker.

David Bowker
Regulatory Manager

4 Elizabeth Street Hobart TAS 7000 Australia • GPO Box 355 Hobart TAS 7001 Australia
t 1300 360 441 f +61 3 6230 5363 e contactus@hydro.com.au w www.hydro.com.au
Hydro-Electric Corporation ABN 48 072 377 158

Submission to the AEMC's System Security Market Frameworks Review

Section 1: Overview of renewable energy integration in Tasmania

Energy security has been a key challenge for Tasmania in the last year, and many system integration challenges for the last 10 years. A number of innovative solutions have been developed with TasNetworks and AEMO which demonstrate that there are a number of affordable options to address any issues caused by integrating renewable energy into the NEM. The challenge for the NEM is to introduce the right market or technical mechanism so that these solutions are deployed correctly and efficiently. Our responses are informed by this work.

Success in managing up to 80% non-synchronous generation sources and system security being maintained with a virtually unconstrained network while catering for the instantaneous loss of the interconnector which can be providing up to 50% of the total demand in the region.

The Tasmanian power system has been rapidly evolving over the past 15 years with increasing levels of renewables penetration in conjunction with the commissioning of the Basslink High Voltage Direct Current (HVDC) interconnector that connects Tasmania to the National Electricity Market (NEM). During these advances, Hydro Tasmania, TasNetworks (formerly Transend) and the Australia Energy Market Operator (AEMO) have worked collaboratively to identify key emerging issues and develop innovative and cost effective solutions to allow a largely unconstrained but secure network.

While Tasmania is not the region with the greatest deployment of wind and solar energy, the technical and market challenges tend to demonstrate themselves earlier due to its size, load characteristics and electrical isolation. Tasmanian hydro generation is on one hand the most flexible of all energy sources, but conversely, is subject to seasonal fluctuations, 'must-run' requirements and limitations on its ability to run at low output on a continuous basis. The Basslink HVDC interconnector adds significant additional flexibility to the system but is also a large non-synchronous supply with a number of operational complexities which have driven several innovative but readily achievable technical solutions.

Many challenges experienced in Tasmania are now emerging in South Australia (SA) and are attracting NEM wide attention. The key reasons for Tasmania to have proactively managed emerging issues associated with renewables include, but are not limited to:

- The Basslink HVDC interconnector does not transfer the electrical properties of the Alternating Current (AC) system from Victoria, including inertia and fault level, although it does deliver synthetic inertia[1] and Frequency Control Ancillary Services (FCAS) when not operating at its limits;
- The Tasmanian transmission network is not as heavily meshed as many parts of the mainland;

[1] The term 'synthetic inertia' in this case can be alternatively described as 'Fast Frequency Response (FFR)' given that Basslink is capable of responding to frequency deviations.

- Tasmania has disproportionally large credible contingencies relative to the size of the power system:
  - Loss of Basslink, which can export 630 MW (from Tasmania) and import 478 MW.
  - Loss of the largest generator, being the Combined Cycle Gas Turbine (CCGT) at George Town rated at 208 MW.
  - Loss of the largest single load block, currently up to 230 MW.
- Hydro generators supply relatively limited quantities of fast FCAS (raise and lower); and
- Half of Tasmanian wind is currently non-scheduled (140 MW). A portion of the hydro generation fleet is also operated as non-scheduled in the market and not subject to dispatch constraints.

Solutions have been found for all of these issues to the extent that the existence of the solutions (and the issues) have not generally been recognised by the market, so effective have the solutions been.

All of these issues need to be considered under 'system normal' operating conditions whereas much of the focus for SA is following a second contingency or non-credible contingency event.

Before providing the answers to the specific questions which the Review poses there are three key concepts which Hydro Tasmania believes should be considered, based on the Tasmanian experience. They are :

- Injected Energy as a way of introducing technology neutrality
- The benefits of Reducing Contingency size
- The use of System Protection Schemes

Our experience has shown that there are affordable technical solutions to the issues anda Case Study has been prepared with TasNetworks which summarises these experiences and is shown as Attachment 1.

Injected Energy

This considers the role of inertia and emerging technologies such as batteries, other energy storage devices and fast frequency response (FFR). There is an urgent need to create a level playing field so that the most effective solutions can be deployed. Frequency excursions occur when the supply and demand of energy is imbalanced. The fundamental purpose of these technologies is to inject energy to cater for loss in supply. A rotating generator is able to inject energy due to the energy stored in the rotating mass (inertia), an energy storage device (such as batteries) can inject energy because of its power electronics being able to rapidly respond to disturbances and a wind farm can potentially inject energy with similar principles. If a service were created which required the injection of energy under some profile, all of these technologies could compete. Hydro Tasmania's view is that inertia is too technologically specific despite it being a very good way of managing system frequency and associated Rate of Change of Frequency (RoCoF).

A further consideration is the energy available from rotating synchronous inertia. The energy available is only that which is injected into the system as a proportion of the change in machine speed during the time it is needed, not the total energy stored by its rotating mass.

Reduction in contingency size

One of the key emerging issues as part of a lighter power system due to high penetration of renewables and asynchronous generation sources is the size of frequency deviations for contingency events (credible or non-credible) and RoCoF. A very effective way to reduce the impact of contingency events is by reducing the size of potential events (credible or non-credible). This could include loss of generation, load or interconnectors and is used for various events of this nature in Tasmania. There are two categories of methods which can be used for reducing the contingency size;

- Event based – based on triggers such as circuit breaker status and inter-tripping; and
- Response based – based on measurements and thresholds, for example frequency level and RoCoF.

System Protection Schemes (SPS)

System Protection Schemes (SPS) offer an enhanced way of managing credible and non-credible contingency event and the instantaneous tripping of an interconnector and effectively provides the aforementioned reduction in contingency size. Tasmania has valuable experience with SPS schemes since interconnection to the NEM in 2006. Schemes were created to manage very large contingencies being the credible contingency of the Basslink interconnector tripping on import or export. There has been recent discussion on “protected” events which are essentially non-credible events with a high impact. An SPS is ideally suited to managing the impact of these types of events as they represent a low cost solution which does not impact on the market outcomes under system normal. There has been much discussion of how to manage protected events which have generally involved interference in the market which leads to winners and losers within generators and higher cost for customers.

An SPS is a low cost option which allows the market to function normally until the non-credible contingency occurs. The system will then be secure but some load or generator tripping will occur.

These schemes can work in conjunction with other emergency schemes such as under frequency load shedding (UFLS) and Over frequency generator shedding (OFGS) schemes.

Such an approach does not inhibit the declaration of some non-credible events to be credible in some circumstances, as happens now. It does however allow a more rational approach in the knowledge that a protected event will only cause some load or generator tripping and not a more severe outcome.

It also has the advantage that it can be implemented much quicker than any other solution, especially than building regulated transmission lines and can significantly enhance the performance of existing transmission infrastructure.

Current system impacts and payment mechanisms

Currently in Tasmania much of the potential impact of the increasing levels of non-synchronous energy, (both generation and HVDC interconnector supply) are alleviated by running hydro generators in synchronous condenser mode. However this generator operation to increase inertia, voltage support and fault level is provided by Hydro Tasmania on a voluntary basis and under the existing arrangements AEMO does not procure or dispatch this as a service.

The cost of energy used to operate in this mode, along with the associated operation and maintenance costs, is ignored by the market. By taking this voluntary action, Hydro Tasmania masks the issues which could otherwise result in significantly reduced amounts of renewable energy being supplied into the NEM. Significant operating and capitals costs are borne by Hydro Tasmania for the provision of these services. Hydro Tasmania estimates the direct benefits of these services to the market exceed several million dollars per year. These benefits are calculated on the basis that the increased interconnector capability allows cheaper generation to be dispatched in both Victoria and Tasmania.

Hydro Tasmania believes the existing Network Support and Control Ancillary Services (NSCAS) mechanism provides a framework for these services to be procured by either AEMO or TasNetworks, however the NSCAS Quantity procurement methodology is backward looking. Hydro Tasmania provides system support (NSCAS "type") services which mask these issues in Tasmania. Hydro Tasmania also believes that the mechanism does not consider future issues therefore will not promote investment to manage emerging technical issues. Hydro Tasmania is currently engaging with AEMO to progress this matter.

Assessment Principles

Hydro Tasmania supports the Assessment Principles in section 3.4 and believes it is highly important to have a good framework for assessing options to ensure objectivity is maintained.

Section 2: Responses to specific questions

The following section addresses the specific questions raised in the AEMC's Consultation Paper.

Question 1

Do you consider that the issues outlined above cover the matters that need to be considered going forward in managing changes in system frequency?

Hydro Tasmania agrees that these issues need to be considered in managing changes in system frequency, however there needs to be a very clear distinction as to the applied management and mechanisms of credible and non-credible events despite the technical issues and system security being relevant to both. The work in Tasmania has demonstrated that there are cost effective technical solutions to these issues.

Hydro Tasmania believes that all key variables that influence the outcomes of system frequency need to be considered as options in its management rather than just focusing on inertia and RoCoF. These include current contingency FCAS requirements set by:

- Contingency size;
- System inertia (post contingent);
- Demand (load relief); and
- Energy withdrawn/blocked by power electronic (wind, solar, HVDC) during faults.

All of the above mentioned variables have an influence on RoCoF and magnitude of frequency deviations. RoCoF is at its maximum immediately after the contingency and is currently considered in setting the FCAS requirements in Tasmania. **Error! Reference source not found.** below outlines all variables Hydro Tasmania deems relevant to managing system frequency (and RoCoF) and should be considered when developing system standards, market mechanisms and optimisation for defining and procuring all relevant contributors to managing system frequency. A key new concept is that of 'injected energy' which is more technology neutral than system inertia.

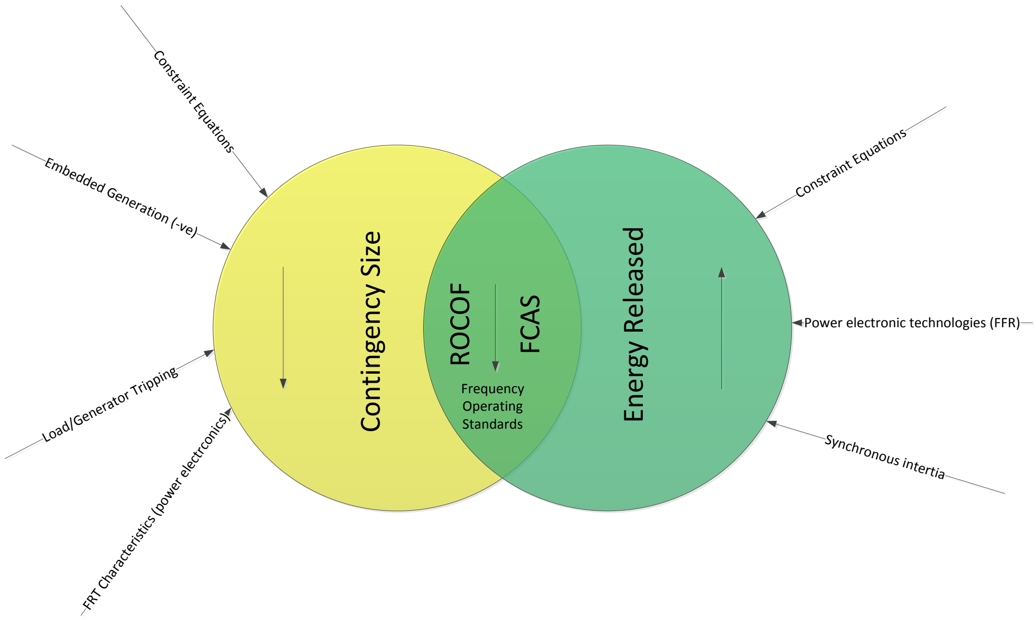

Figure 1 - All variables affecting management of system frequency

Tasmania has strong examples of how adding inertia, injected energy and reducing contingency sizes (with load tripping) can effectively manage system frequency including RoCoF. However there is currently no mechanism for the recovery of investment or operational costs for these additional services. There are also no current market mechanisms for schemes to reduce the contingency size of instantaneous interconnector losses (such as SPS schemes) which often present the biggest risks to the power system. These schemes have an additional benefit of allowing increased interconnector flows and significantly enhancing existing transmission capability, as is current practice in Tasmania.

In terms of meeting FCAS requirements or managing frequency within the Frequency Operating Standards (FOS), only plant that can be registered under Market Ancillary Service Specification is considered to be able to supply FCAS and can therefore recover costs or promote investment. Inertial energy is released during frequency disturbances which is a form of injected energy but is not recognised as a market service. Switching controllers are also recognised as supply but if they are directly offsetting the contingency size and are not offered/dispatched, they are not recognised as a market service. This could present a barrier to investment in relatively low cost schemes such as the SPS in Tasmania which drives cost effective solutions and better market outcomes.

Fast Frequency Response (FFR) or synthetic inertia devices need to be assessed against MASS as to whether the MASS adequately caters for these devices. If these devices satisfy the MASS there is a market mechanism for them to be procured. These devices could include batteries, supercapacitors and HVDC injection. Thyristor controlled loads delivering proportional frequency control should also be considered.

Another consideration should be the time to reach minimum frequency (nadir) which would be different for each region if they are not interconnected via Alternating Current (AC) such as SA under outage scenarios or Tasmania. This would mean that technical solutions and market mechanisms could be adopted as the most effective outcome for each region/scenario in the same way as energy and FCAS markets are currently co-optimised, locally and globally.

To summarise the above, Hydro Tasmania's main points in the consideration in managing system frequency within the Frequency Operating Standards (FOS) are:

- The need for clearly delineating credible and non-credible events; and
- Recognising all variables/inputs into the elements that affect frequency changes.

Frequency changes result from a mismatch between energy supply and demand. In short time frames, all elements that contribute to energy lost and energy supplied (injection) need to be considered and the technical solutions and market mechanisms should recognise this. We appreciate the technical difficulty of multiple co-optimisations, so there may be a pragmatic, simpler approach which achieves the majority of the efficiency.

Nevertheless, there are affordable technical solutions to all of the issues mentioned, as demonstrated by the work done in Tasmania.

Question 2

What do you consider to be the issues associated with low power system strength?

Hydro Tasmania considers the following as the key issues associated with low power system strength (fault level);

- Increasing changes in voltage for changes in reactive power (e.g. switching capacitors and contingency events causing larger voltage changes);
- Short circuit ratios (SCR) falling below design levels of power electronic interfaced equipment such as HVDC, solar PV and wind. The ability of equipment to perform as designed could be compromised. One of the key risks of this is the ability for power electronic interfaced equipment to be able to ride through faults or avoid mode cycling;
- Performance of traditional protection systems may be compromised by being unable to discriminate different scenarios/events or detect faults at all and therefore not operate as designed. This includes emergency control schemes being unable to operate as designed; and
- Quality of power supply such as voltage flicker and harmonics being more prevalent and cause fatigue or damage to equipment.

Some examples in Tasmania of how system strength and fault level have been managed:

- Musselroe wind farm – installation of two local synchronous condensers to boost the SCR to allow the turbines to operate within design parameters;
- Basslink – a minimum fault level constraint exists such that the interconnector flow will be reduced if a certain fault level is not met at the converter station. The constraint forces

synchronous generation online or can be managed by operation of synchronous condensers in the Tasmanian system; and

- Voltage instability – weakening fault levels producing large changes in voltages for capacitor switching which would cycle above and below switching thresholds hence becoming unstable. Control algorithms were modified to widen switching thresholds and additional reactive power from synchronous condensers can alleviate these constraints.

Another consideration is how can power electronic interfaced devices be configured to allow fault level support to increase system strength such as Doubly-Fed Induction Generator (DFIG) wind turbines delivering fault current.

Finally the issue of how fault level and SCR is calculated, measured and applied to power electronics needs to be considered as the technologies move away from traditional methodologies of determining fault levels from synchronous sources.

Question 3

Do you consider it beneficial to set a standard for RoCoF? What format should this standard take and what factors should be taken into account when setting the standard? Who should set it?

Would the establishment of a new standard trigger significant additional costs to comply?

Do you consider there to be a role for maintaining system strength? Who should be responsible for undertaking this role or how should the responsibility be determined?

Setting a Standard for RoCoF

Hydro Tasmania supports a standard for RoCoF. Hydro Tasmania's view is that the maximum ROCOF limit should be based on plant/equipment ability to stay connected during power system disturbances or operate as designed. Frequency for credible events should still always be maintained within the frequency operation standards (FOS) and the FCAS market should address this but the system needs to cater for the potential of a cascading effect from ROCOF being too high.

Another potential impact is emergency schemes may not operate as designed or intended. RoCoF is only likely to be an issue for regions that are not interconnected via AC such as SA under outage scenarios or Tasmania. Therefore a regional standard should apply and a limit/constraint equation could be developed to manage RoCoF to acceptable limits for each region. The TNSP and/or AEMO should define the maximum level of RoCoF in a region based on an evaluation of all equipment in the system that has the potential to materially impact system frequency and RoCoF. This will include generators, loads, transmission infrastructure (including HVDC interconnectors) and associated protection systems. The constraint equation(s) could then be managed by AEMO in central dispatch via NEMDE.

As per the response to Question 1, all variables that affect RoCoF such as contingency size applies to interconnecters, loads and generators, must be considered. An example of how contingency size can significantly reduce the FCAS requirements and RoCoF outcomes is shown below in **Error! Reference source not found.**. The two surfaces (lower surface, lower contingency size) represent a reduction in FCAS requirements due to reduction in contingency size. While this figure represents a credible contingency, the same principles apply to non-credible events.

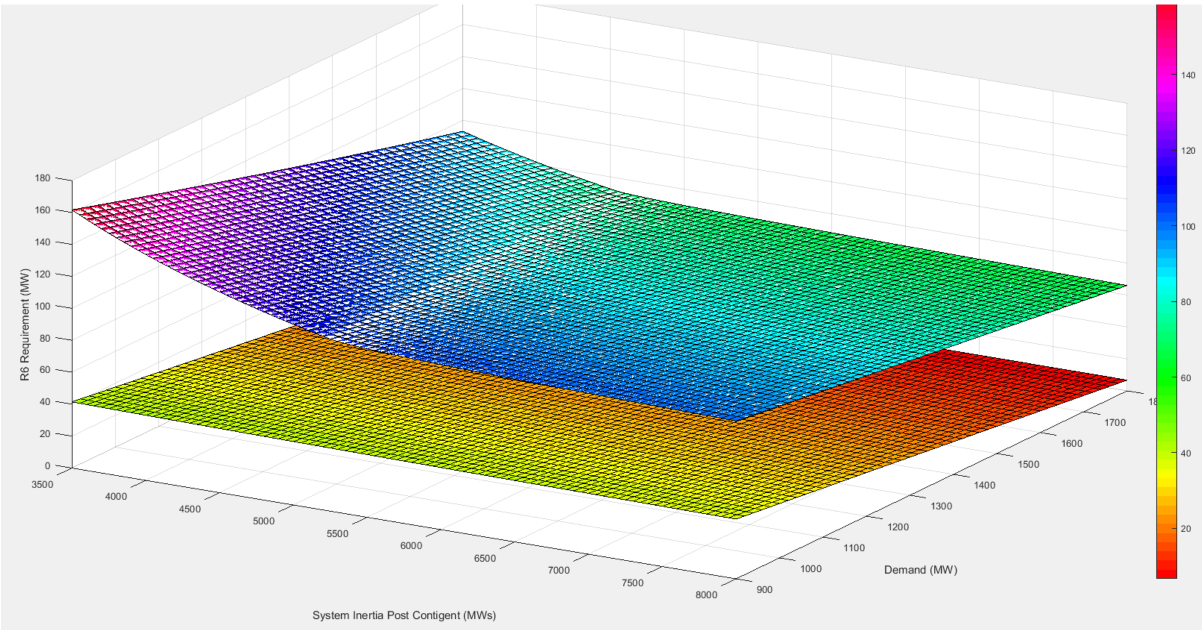

Figure 2 - Changes to FCAS requirements due to reduction contingency size

The TNSP has defined the RoCoF limit in Tasmania of 3Hz/s based on known RoCoF limits based on the following;

- A large wind farm's anti-islanding protection (and risk of a cascading event);
- The HVDC operating design limits; and
- The limit for which the emergency Under Frequency Load Shedding (UFLS) schemes is able to operate as per design.

A final consideration similarly to system strength is a standard methodology for defining and measuring ROCOF.

Cost of a RoCoF Standard

If RoCoF limits are exceeded, the cost of a cascading effect on the system could far outweigh the costs of a RoCoF limit/constraint being applied. A cascading non-credible event may have severe consequences, particularly if associated with an HVDC interconnector. If a limit/constraint is applied, a costs/benefit analysis could easily justify any investment in equipment or infrastructure to limit impacts of such a constraint. Hydro Tasmania's view is that NSCAS could be a valid mechanism to minimise the impact of constraints. The mechanism would need to be a forward looking view on constraint impacts to justify procurement of services or investment in infrastructure prior to there being an impact to the market which it currently does not cater for.

It is important for AEMO to have an objective standard to form the basis for invoking constraints. Putting constraints on the system will have implications for the supply side as there will be winners and losers. Generally constraints will increase the costs to customers. RoCoF could form the basis of an objective standard.

Management of System Strength

As system strength is more of a localised issue, Hydro Tasmania has the view that the TNSP's should manage fault levels (including minimum level) across their networks. The TNSP may need to procure services, invest in infrastructure, develop limits/constraints or a combination of all of these in order to manage system strength. Management of system strength (fault level) should be developed on a 'least cost' approach.

However, if a new connection (generator or load) attempts to connect to a weak connection point of the network which does not meet their design requirements, that customer should be responsible for the system strength to be adequate for their connection. However, TNSP's should guarantee a minimum system strength (fault level) which protects already connected parties. This obligation should be based on either other developments or known retirement of plant in the network such that remaining connected parties can maintain their ability to meet their performance standards.

Question 4

What roles do you consider services such as inertia and fast frequency response should play in maintaining system security in the NEM? How else could RoCoF be managed?

Hydro Tasmania's view is that this relates back to the response to question 1 and managing frequency within the frequency operating standards (FOS). Both inertia and Fast Frequency Response (FFR) are methods of arresting a mismatch in energy as the result of a contingency event resulting in frequency deviations (and associated RoCoF).

To highlight a key consideration again, a reduction in contingency size by load tripping and/or SPS schemes can very effectively manage RoCoF and frequency deviations for both credible and non-credible events.

In Tasmania, there are key examples of adding inertia, FFR (from Basslink) and reducing contingency size to manage RoCoF and these should all be considered in the most cost effective way of managing system security and ROCOF.

A key consideration in using FFR technologies is the FRT characteristics of power electronic interfaced devices and associated energy withdrawn or blocked from the system during faults and potential delays in delivery of energy.

Question 5

Do you consider it beneficial to establish new mechanisms for the procurement of additional systems security services?

What form of mechanism do you consider to be preferable and which services should the mechanism be targeted at?

Hydro Tasmania considers it to be essential that new mechanisms allow for the procurement of services (new and existing) which assist in managing system security due the emerging issues and risks to the power system with the increased amounts of nonsynchronous and variable generation mixes.

In line with Hydro Tasmania's response to question 1, services relating to system frequency for credible contingency events should consider all the variables that affect system frequency as outlined, including the concept of injected energy. Mechanisms need to exist for the cost recovery for all aspects that can manage system frequency (and ROCOF), not just the supply of FCAS in its current form. MASS also needs to be reviewed such that it considers FFR devices and adequately compensates all technologies that benefit the system.

In terms of system strength and fault level, as outlined in Hydro Tasmania's response to question 3, it is believed there needs to be an obligation (proposed to be on the TNSP) to manage minimum fault levels at a 'least cost' approach. If a limit/constraint is applied, a cost/benefit analysis could easily justify any investment and Hydro Tasmania's view is that NSCAS could be a valid mechanism to minimise the impact of constraints provided it allows a forward looking view on constraint impacts to justify procurement of services or investment in infrastructure prior to there being an impact to the market.

Question 6

What form of cost recovery do you consider to be preferable in the design of a mechanism to procure additional system security services?

Should the cost recovery mechanism be designed to create stronger incentives to provide the required services?

Hydro Tasmania believes that the cost recovery of anything related to managing system frequency for credible contingency events could be done through FCAS and/or interrelated and optimised markets. As outlined above however, the current FCAS market only offers recovery for the supply of FCAS in its current form. The reduction in FCAS requirements through reduction in contingency size and addition of inertia (e.g. through operation of synchronous condensers) and injected energy which assist in managing system frequency should be traded off with the availability of FCAS sources and the cost recovery should recognise this.

Limits/constraints can manage fault levels and as previously mentioned Hydro Tasmania believes the TNSP should manage these to be greater than or equal to minimum levels where appropriate with a main focus on critical or very weak connection points. If there is a market benefit, the NSCAS framework could be a valid mechanism to minimise the impact of constraints provided it allows a forward looking view on constraint impacts to justify procurement of services or investment in infrastructure prior to there being an impact to the market.

In terms of emergency schemes for non-credible events, the NER requires the TNSP to operate and manage these schemes and they should be a regulated asset based on a 'least cost' approach. If this is unclear within the Rules, it should be made more transparent. If limits/ constraints exist as a result of these requirements, the same view on NSCAS applies provided it allows a forward looking view on constraint impacts to justify procurement of services or investment in infrastructure prior to there being an impact to the market.

RoCoF limits should be managed by limit/constraint equations and there may be benefit in investing in services or infrastructure to minimise this impact. This can be procured through NSCAS. provided it allows a forward looking view on constraint impacts to justify procurement of services or investment in infrastructure prior to there being an impact to the market.

Summary

The drive for reducing carbon emissions is now well entrenched so the future will encompass high levels of renewable energy. The work in Tasmania has demonstrated that there are technical solutions to the issues involved with high a penetration of renewables. There is no problem in accommodating high levels of renewables and other new technologies. There are existing practical technical solutions and the challenge is to develop a framework which delivers ongoing decarbonisation of the energy system at the lowest cost.

Hydro Tasmania
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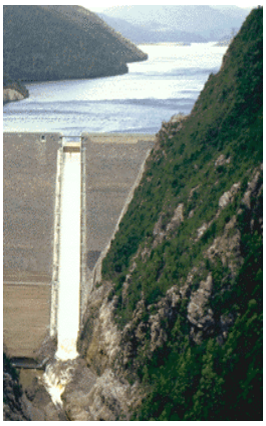
Managing a High Penetration of Renewables– A Tasmanian Case Study



1. Background

The Tasmanian power system has been rapidly evolving over the past 15 years with increasing levels of renewables penetration in conjunction with the commissioning of the Basslink High Voltage Direct Current (HVDC) interconnector that connects Tasmania to the National Electricity Market (NEM). During these advances, Hydro Tasmania, TasNetworks (formerly Transend) and the Australia Energy Market Operator (AEMO) have worked collaboratively to identify key emerging issues and develop innovative and cost effective solutions to allow a largely unconstrained but secure network.

While Tasmania is not the region with the greatest deployment of wind and solar energy, the technical and market challenges tend to demonstrate themselves earlier due to its size and electrical isolation. Tasmanian hydro generation is on one hand the most flexible of all energy sources, but conversely, is subject to seasonal fluctuations, 'must-run' requirements and limitations on its ability to run at low output on a continuous basis. The Basslink HVDC interconnector adds significant additional flexibility to the system but some operational complexities exist which have driven a number of the technical solutions outlined in this paper. A key aspect of this is catering for the instantaneous loss of this interconnector being up to 50% of the total demand in Tasmania at a given time being a credible contingency.

The challenges experienced in Tasmania are now emerging in South Australia (SA) and are attracting NEM wide attention. The key reasons for Tasmania to have proactively managed emerging issues associated with renewables include, but are not limited to:

- The Basslink HVDC interconnector does not transfer the electrical properties of the Alternating Current (AC) system from Victoria, including inertia and fault level, although it does deliver synthetic inertia[1] and Frequency Control Ancillary Services (FCAS) when not operating at its limits;
- The Tasmanian transmission network is not as heavily meshed as many parts of the mainland;
- Tasmania has disproportionally large credible contingencies relative to the size of the power system:
  - Loss of Basslink, which can export 630 MW (from Tasmania) and import 478 MW.
  - Loss of the largest generator, being the Combined Cycle Gas Turbine (CCGT) at George Town rated at 208 MW.
  - Loss of the largest single load block, currently up to 230 MW.
- Hydro generators supply relatively limited quantities of fast FCAS (raise and lower); and
- Half of Tasmanian wind is currently non-scheduled (140 MW). A portion of the hydro generation fleet is also operated as non-scheduled in the market and not subject to dispatch constraints.

[1] The term 'synthetic inertia' in this case can be alternatively described as 'Fast Frequency Response (FFR)' given that Basslink is capable of responding to frequency deviations.

All of these issues need to be considered under 'system normal' operating conditions whereas much of the focus for SA is following a second contingency or non-credible contingency event.

In 2010, the Tasmanian government submitted a paper to the AEMC which canvassed several options for addressing the issues in the Tasmanian system. The paper was developed by an advisory panel called the Electricity Technical Advisory Committee. It stated:

> *Whilst not recommending a mechanism that enables the connection of asynchronous generation without unduly impacting on the operational flexibility of the Tasmanian power system, the following options are proposed for consideration and discussion:*
>
> - *development of minimum access standards; for example, frequency control capability, minimum inertia, and minimum fault level contribution which could then be enforced through the relevant rules, whether national or Tasmanian;*
> - *the application of National Electricity Rules (Rules) clause S5.2.5.12 in relation to intra-regional and inter-regional transfer limitations;*
> - *the introduction of new market ancillary services covering inertia and fault level;*
> - *a review of AEMO's Market Ancillary Service Specification (MASS) to provide for inertia contributions;*
> - *a review of the Tasmanian frequency operating standards for network events;*
> - *the development of new non-market ancillary services, network support and control ancillary service of inertia and fault level;*
> - *clarify the provision of network support and control services; and*
> - *the adequacy of constraint equations to manage the issues in this paper*.

It is interesting to note that these are the same issues that are now being considered in South Australia and that there has been essentially no change to the market to address these issues since 2010 despite the significant growth of renewables across the NEM.

One of the key lessons from this work was the need to consider the inter-related impact of inertia, fault level and voltage when assessing potential changes.

2. The Tasmanian Power System

To provide context, the following is a summary of the key aspects of the Tasmanian Power System:

- Generation (approximate):
  - ➢ 2300 MW hydro (14 hydro units capable of synchronous condenser operation)
  - ➢ 308 MW wind (2 local synchronous condensers installed at Musselroe Wind Farm)
  - ➢ 386 MW gas (3 Open Cycle Gas Turbines (OCGT) units capable of synchronous condenser operation)
  - ➢ ≈ 100 MW solar (as at end of 2016, embedded/behind the meter)
- Interconnector (Basslink, monopole HVDC), 478 MW import, 630 MW export;
- Demand: 900 MW (min, summer), ≈ 1800 MW (max, winter) ;
- Renewable energy production: 10,000 GWh (90% hydro) per annum; and
- Energy storage capacity: 14,000 GWh of hydro

3. Current Position

The current position for Tasmania is that the minimum demand can be as low as 900 MW, Basslink may be importing up to 478 MW and wind can contribute up to 308 MW. Under these conditions, there is little room left for synchronous generation noting that the minimum run of the river ('must run') generation is slightly over 200 MW. Additionally Basslink power transfer during import is limited by a minimum required fault level at George Town (maintained by a limit/constraint equation), a minimum inertia requirement to manage system rate of change of frequency (ROCOF, maintained by a limit/constraint equation) and interrelated availability of FCAS. Consequently, if these minimum system technical requirements cannot be met within the central dispatch process, constraints will limit Basslink flow and/or wind farm output so that more on-island synchronous generation is provided.

These constraints can also be alleviated by dispatching selected hydro generators in synchronous condenser mode. However under the existing rules, AEMO does not have a mechanism to dispatch this service and the service is provided by Hydro Tasmania on a voluntary basis. The cost of energy used to operate in this mode, along with the associated operation and maintenance costs, is ignored by the market. By taking this voluntary action, Hydro Tasmania masks significant dispatch issues which could result in significantly reduced amounts of renewable energy being supplied into the NEM. The capability of some of hydro generators to operate in synchronous condenser mode is a significant difference between the Tasmanian and South Australian systems.

Significant operating and capitals costs are borne by Hydro Tasmania for the provision of these services. Hydro Tasmania estimates the direct benefits of these services to the market exceed several million dollars per year. These benefits are calculated on the basis that the increased interconnector capability allows cheaper generation to be dispatched in both Victoria and Tasmania. Hydro Tasmania believes the existing Network Support and Control Ancillary Services (NSCAS) mechanism provides a framework for these services to be procured by either AEMO or TasNetworks, however the NSCAS Quantity procurement methodology is backward looking. Hydro Tasmania provides system support (NSCAS "type") services which mask these issues in Tasmania. Hydro Tasmania also believes that the mechanism does not consider future issues therefore will not promote investment to manage emerging technical issues. Hydro Tasmania is currently engaging with AEMO to progress this matter.

Frequency Control Ancillary Service (FCAS) requirements have been a function of system inertia for some time in Tasmania. The inclusion of inertia as a calculation variable was necessary to correctly calculate fast (6 second) FCAS requirements when frequency may reach its permissible limits in a shorter time frame (due to high ROCOF conditions). As a result, fast FCAS requirements are non-linear and increase dramatically under low inertia operating conditions as illustrated in Figure 1.

When Basslink is operating on its limits (high import or minimum export) or is transitioning through its 'no-go' zone during power reversals, there is no opportunity to transfer raise services from the mainland. Figure 1 demonstrates that adding inertia can reduce fast FCAS requirements and that reducing the contingency size also has a significant impact. The two surfaces represent a 144 MW contingency (higher requirement) and an 80 MW contingency (lower requirement).

In Tasmania, there are various schemes that have been deployed to reduce the effective contingency size including load inter-tripping following the loss of a large generator. The Tasmanian Frequency Operating Standard (TFOS) has a requirement that generator contingency events must not exceed 144 MW and that load tripping may be used to compensate for contingencies of higher value.

Figure **2** demonstrates a more detailed view of key variables in managing ROCOF and FCAS, as well as their inter-relationship with inertia.

It can be noted that the contributions from generators operating in synchronous condenser mode to inertia and fault level are the same as when generating. It is also noted that increasing system inertia to reduce fast raise and lower requirements is effective only up to a certain level of system inertia, and above this level, fast FCAS requirements are relatively linear.

Figure 1 - Impact of inertia on fast raise requirements

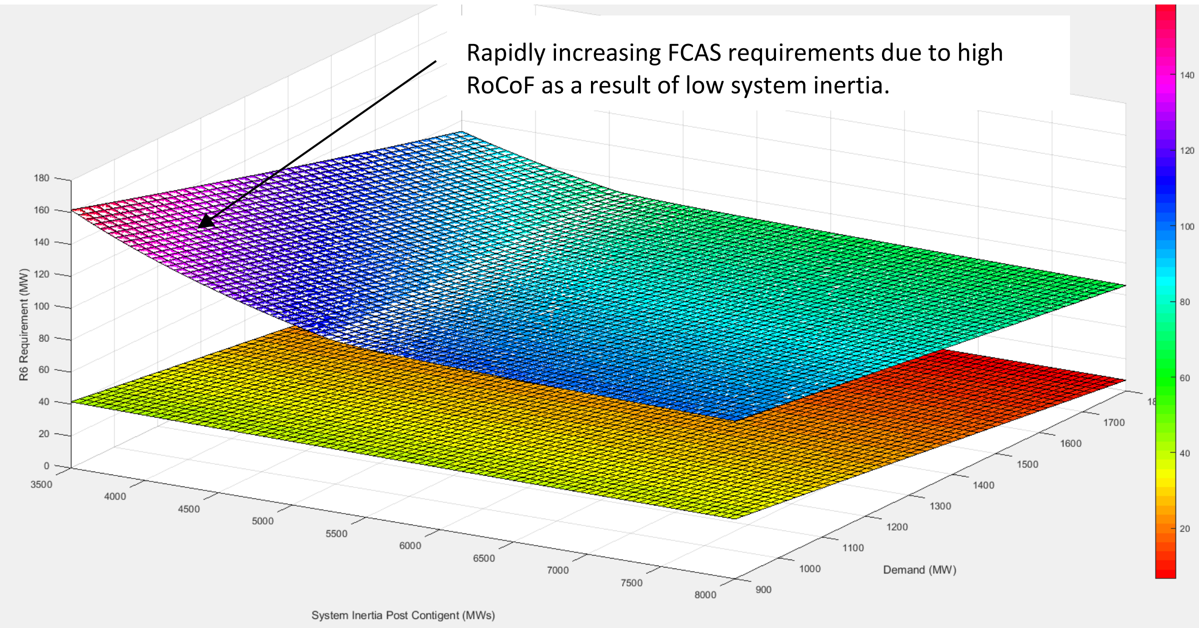
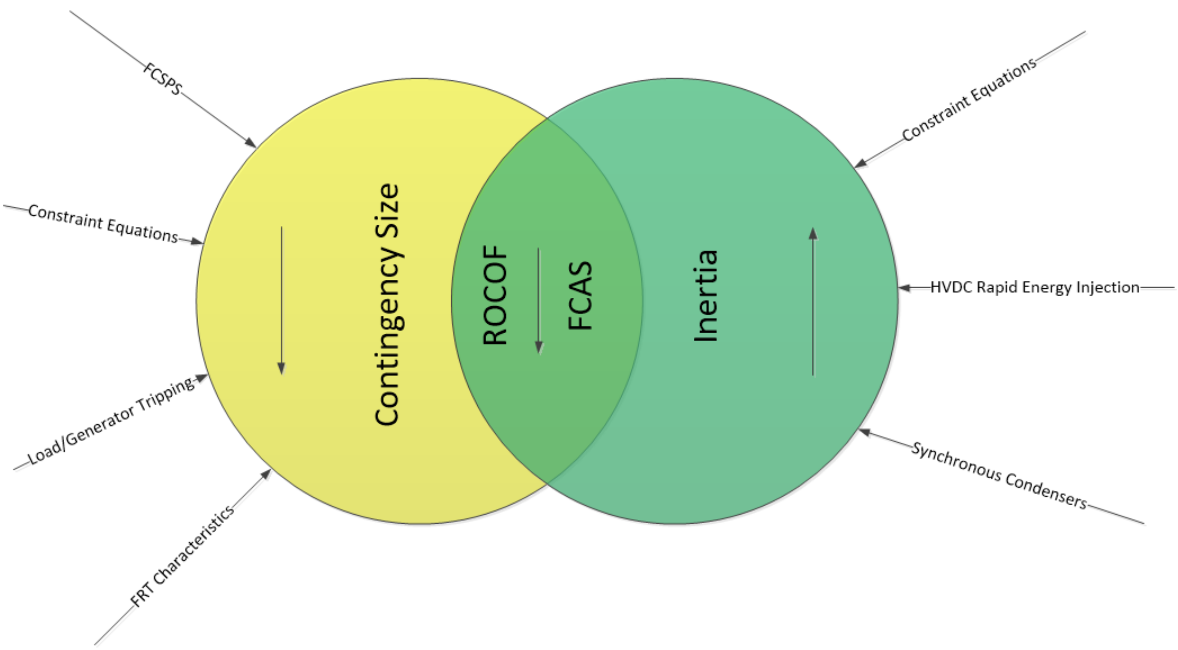


Figure 2 - Relationship between RoCoF, FCAS and Inertia



A key consideration in the future of the NEM is the increased variability of generation sources, particularly wind and solar. The value of fully dispatchable renewable generation from hydropower can play a significant role in supporting a diverse generation mix. As mentioned earlier over 14,000 GWh of energy storage capacity exists within Tasmania and over 2000 MW of capacity can be started within minutes. This also has the potential to provide significant ancillary services support to the mainland in addition to energy/capacity. The key limitation to this is currently the interconnector capability to the mainland of the NEM and should be a key consideration when understanding the future value of a second Bass Strait interconnector.

4. Remedial Actions

Over the last 10 years, Hydro Tasmania, TasNetworks (formerly Transend) and AEMO have undertaken numerous initiatives to assist with managing and maintaining system security and stability. This has included significant capital expenditure to increase the capability of selected hydro and gas generation plant.

An outcome from this work is that a number of technical issues have been successfully addressed In Tasmania and the impacts of these issues on energy market outcomes are, in the most part, manageable. Consequently, there has been little impetus for addressing these issues in a more systematic, 'NEM focused' way until they surfaced as significant considerations for South Australia.

Each of the following initiatives is discussed in more detail below:

- Hydro plant operating in synchronous condenser mode to support inertia and fault level requirements;
- Conversion of open cycle gas turbines (OCGT) to allow both generation and synchronous condenser operation;
- Generator governor modifications;
- Implementation of Frequency Control System Protection Scheme (FCSPS);
- Implementation of Network Control System Protection Scheme (NCSPS);
- Defining 'region appropriate' generator performance standards to maintain critical network capabilities;
- Network constraint formulation and optimisation; and
- Integrating new technologies to help manage high renewable penetration.

4.1. Hydro plant operating synchronous condenser mode to support inertia and fault level

Selected hydro plant can be operated as synchronous condensers. For Francis turbines, this is achieved by 'dewatering' using high pressure air to force the water level below the turbine so that it can spin freely and with minimal hydraulic resistance. This is also referred to as tail water depression mode. For Pelton turbines, synchronous condenser operation is generally easier to achieve, as the turbine is not submerged during normal operation.

It should be noted that not all Tasmanian hydro generators have been designed to operate in this mode, with fourteen units having the capability at present.

Hydro Tasmania has undertaken several upgrade projects in recent times to reinstate the capability of plant to run in synchronous condenser mode[2]. The upgrades required a significant financial and resource commitment to be made and provide a total of 1470 MW.s of synchronous condenser inertia in a system which typically requires at least 3500 to 4000 MW.s post-contingency.

It should be noted that in order to further increase system inertia, Hydro Tasmania has the option to dispatch certain hydro generating units at low output. Such measures are also used to increase Fast Raise FCAS (R6) capability when needed. Such an approach, although effective, may cause additional wear and tear to these units, as hydro machines are typically not designed to operate at low output for long periods. Hydraulic cavitation is a common issue which can cause elevated machine vibration levels as well as mechanical damage to the turbines themselves.

Fault level has been actively managed in Tasmania since Basslink was commissioned in 2006. The requirement to maintain a minimum fault level at George Town is managed by a limit/constraint equation embedded within AEMO's National Electricity Market Dispatch Engine (NEMDE). The constraint considers variables of interconnector flow and online synchronous generation until the minimum technical requirements are satisfied. The impact of the constraint can be assisted by the running of synchronous condensers, or dispatching generating units at low MW output, to boost network fault levels.

At present, neither AEMO nor TasNetworks has a contract for the dispatch of synchronous condensers for such purposes, so their running is determined only by Hydro Tasmania. This solution may not deliver the most efficient overall market outcome as it would be at the discretion of Hydro Tasmania. If synchronous condensers could be committed by Hydro Tasmania as part of a service offering to AEMO and co-optimised with other resources, the objective function of the dispatch is likely to be improved.

4.2. OCGT conversion synchronous condenser mode

Hydro Tasmania has four OCGT peaking plants located at Bell Bay in the state's north. Three units were successfully modified to operate in synchronous condenser mode. They provide a very cost effective source of fault level support for the George Town area when compared to building new synchronous condensers. The units also provide some inertia, although being aero-derivative machines, the inertia contribution is significantly less than would be provided by a hydro unit of similar MVA rating.

4.3. Generator governor modifications [Ref. 1 and 5]

Hydro Tasmania has implemented a number of governor enhancements as part of its core asset management program including:

- Development and implementation of governor boost functions to deliver rapid response FCAS. This allows the governor output to be temporarily saturated to force the fast opening of guide vanes (control gates). When a frequency disturbance occurs, the functions allows for an accelerated opening of the guide vanes to achieve a temporary boost in machine responsiveness; and
- Tail Water Depression (TWD) or synchronous condenser fast raise (SCFR) mode provides fast transition from synchronous condenser to generator mode, delivering fast raise FCAS (R6) in the process. This requires considerable governor and control system modifications,

[2] Where plant had not been used in this mode for a considerable time, efforts were required to ensure that cooling systems and other mechanical aspects of the machine were refurbished to ensure correct operation.

with not all hydro plant being suitable for such conversions due to original design limitations that are impractical to alter.

It can be noted that both of these control actions are activated by high ROCOF conditions and are not triggered for every contingency event. As a result, both modifications have created a new class of FCAS controller that is a combination of 'switching' and 'linear/proportional' controllers.

4.4. Frequency Control System Protection Scheme (FCSPS) [Ref. 2 and 3]

TasNetworks own and operate the FCSPS and were key in its development. This scheme was developed to allow the integration of the Basslink interconnector which has power transfer capability that significantly exceeds the size of the next largest system contingencies (load or generation). System Protection Schemes (SPS) had previously been used elsewhere in the world as a remedial action to manage non-credible contingencies. However in the case of Basslink, the concepts were applied to mitigate the effects of a credible contingency and in doing so, significantly optimised the import and export capability of the interconnector.

The scheme continuously monitors the interconnector flow and Tasmanian system load demand and calculates the required load or generation tripping that is necessary to mitigate the contingent loss of the interconnector. This occurs on a 4-second cycle. Contracted load blocks and generating units that participate in the scheme, are automatically 'armed and disarmed' as necessary to meet the calculated requirements. If Basslink flow is interrupted, the armed loads or generators are tripped in protection clearance time (within hundreds of milliseconds). The scheme allows system frequency to be maintained within the *operational frequency tolerance band* limits as defined by TFOS, even though Basslink could be operating at up to 630 MW export or 478 MW import.

The experience with the operation of this scheme has been very positive. The scheme has operated multiple times and on each occasion, has managed the Tasmanian power system successfully and in accordance with design expectations. The successful implementation of a wide area protection scheme such as the FCSPS has demonstrated what can be achieved with quality engineering design. Consideration should be given elsewhere to the benefits of implementing such countermeasures where system technical capabilities may not support desirable power flows, either within or across NEM regions.

4.5. Network Control System Protection Scheme (NCSPS)

TasNetworks own and operate the NCSPS and were key in its development. It allows dual circuit transmission corridors to increase their 'non-firm' operational capacity from 50% up to 95% of thermal rating. In the case of a transmission line contingency event that results in overloading of surrounding circuits, the NCSPS issues runback or trip commands to selected generators to relieve the overload conditions. The scheme works in unison with the frequency controller on Basslink to maintain system frequency within limits and has a speed of response that grades appropriately with other network protection functions.

While the NCSPS design as implemented in Tasmania is reliant on specific controls and equipment capability, the concept has direct applicability for broader network issues that include:

- The intermittency of renewables where it is perhaps not economic to build transmission capacity to enable traditional 'firm' operation of assets; and
- To mitigate the impacts of credible and/or non-credible contingencies when thermal overloading is the primary concern post contingency. An NCSPS could be used to prevent the cascading loss of transmission assets due to activation of overload protection.

As with the FCSPS, the experience with the operation of the Tasmanian NCSPS has been very positive. The scheme has only been required to operate a small number of times but in each case, reduced the affected transmission circuits to within continuous thermal ratings in accordance with design expectations.

4.6. Defining 'region appropriate' generator performance standards

Given the particular characteristics of the Tasmanian power system, TasNetworks is currently developing connection requirements that will be applicable for future renewable generation developments in the region. The connection requirements are based on Schedule 5.2 of the National Electricity Rules (Rules) and will define the minimum level of performance at which negotiation will be possible. The key objective of this undertaking is to preserve, as far as is reasonable to do so, the future capability of the network.

In doing so, the intent is to not inadvertently impede the connection of future projects by having to enforce performance standards that are overly onerous just to enable successful network integration. If every new connection provides certain capabilities to the network and is able to operate with a defined level of technical performance, then a situation where the 'next project to be considered' has to compensate for past or hidden issues can be avoided. In essence, all generating systems will be expected to contribute to the operability and security of the network rather than being allowed to be heavily reliant on the characteristics of the network to achieve adequate levels of performance.

4.7. Network constraint formulation and optimisation [Ref 4]

New and modified network limits/constraints have been developed as a result of the changing nature of the Tasmanian power system. The identification of new issues is likely to be ongoing as more asynchronous generation is connected over time.

Examples of constraints that have been modified and/or developed in recent times include:

- Management of fault levels at specific connection points;
- Control of maximum ROCOF to ensure that under frequency load shedding (UFLS) and over frequency generator shedding (OFGS) schemes in Tasmania can continue to operate correctly and provide protection against non-credible contingency events; and
- The inclusion of 'energy deficit' contributions into FCAS calculations to account for the fault ride through (FRT) characteristics exhibited by power electronic interfaced energy sources (e.g. wind and HVDC) and the impact that such characteristics have on power system frequency.

It needs to be recognised that the technologies currently being utilised within the renewable energy sector have very different technical characteristics to traditional synchronous generating units. This does not mean that they cannot be successfully integrated into the power system, just that their performance characteristics need to be understood and their impacts on the power system properly assessed. As demonstrated in Tasmania, new types of constraint formulations are likely to be required if the security of the power system is going to be adequately managed going forward.

It should be noted that the availability of quality design documentation and accurate mathematical models are important inputs for achieving this. TasNetworks and Hydro Tasmania have put significant effort into obtaining such information from various equipment suppliers, covering synchronous machines and their control systems, as well as wind turbines and various ancillary equipment associated with wind farms (including STATCOMs). As a result, Tasmania is in a fortunate position of having validated models for the vast majority of equipment connected to the transmission network. This is viewed as a key enabler for future developments within the state.

4.8. Integrating new technologies to help manage high renewable penetration.

In a quest to reduce the cost of supply on King Island over the past 10 years, Hydro Tasmania has developed significant intellectual property that is applicable to the development and operation of low inertia power systems. The key initiatives on King Island have been:

- Managing any excess of renewable energy by converting it to FCAS through the development of a resistor based frequency controller. Energy is dissipated in a resistor supplied through a power electronic interface that provides frequency regulation capability;
- Management of voltage, reactive power and rotating inertia through the use of heavy flywheel technology fitted to a diesel Uninterruptable Power Supply (UPS). The flywheel unit is capable of providing energy to the system following the largest contingencies until the diesel engine can be started and connected to the synchronous compensator via a dynamic clutch;
- Use of a dynamic clutch allowing mechanical synchronisation of the diesel UPS in an islanded system;
- Control of a power system without any synchronous generation in service, with all inertia and fault level support provided by the synchronous compensator;
- Parallel operation of light and high inertia generators; and
- Advanced control strategies for battery storage systems.

While not all of these developments can be directly scaled for use in larger power systems, the learnings obtained are directly applicable to other opportunities including control of embedded battery storage systems to provide frequency control and application of advanced power electronic technologies like Siemens SVC Plus with Frequency Stabilisation.

Hydro Tasmania and TasNetworks will continue to work together to identify opportunities to apply advanced technologies to enhance the operability and capability of the Tasmanian power system.

5. Implications for other NEM regions

Some of the solutions that have been developed in Tasmania will have direct applicability to other NEM regions as their level of renewable generation increases. With competing generators and a more complex environment, there will need to be market mechanisms which deliver the right incentives for participants. The underlying technical solutions, however, remain the same.

6. Conclusion

Tasmania’s experience over the last 15 years has shown that there are many and varied technical solutions that can be applied to overcome the challenges created by the increasing penetration of renewables (asynchronous energy sources more generally). Some solutions implemented in Tasmania have been relatively low cost and without the need for significant capital investment. Tasmania has been leading the field in the development of innovative solutions which reduce the costs of the technical solutions significantly.

Hydro Tasmania, TasNetworks and AEMO have implemented many successful initiatives that help to manage and maintain the security of a power system that has a high penetration of asynchronous energy sources. Initiatives of note include, but are not limited to the following:

- Inclusion of Fault Ride Through characteristics in FCAS requirement calculations;
- Actively managing ROCOF and minimum system fault level requirements via limit/constraint equations;
- Improving the delivery of fast FCAS from hydro generators through modifications to hydro governor designs and introduction of new operating modes allowing automatic transfer from synchronous condenser to generation to provide fast raise FCAS;
- Optimisation of hydro machine synchronous condenser capability to manage network limits/constratins;
- Modification of existing OCGT generators to allow synchronous condenser operation;
- Implementing centralised control and protection schemes like the FCSPS and NCSPS to extend the capability of existing assets and maximise power system utilisation (without compromise to system security);
- Reducing the largest generator contingency size by introducing load inter-tripping schemes that manage FCAS requirements;
- Development of switching control based FCAS delivery mechanisms for fast raise and lower services; and
- Commencement of a process to define Tasmanian specific performance standards that will be applicable to future renewable energy developments which will ensure that the capability of the future network is proactively managed.

A key consideration in the future of the NEM is the increased variability of generation sources, particularly wind and solar. The value of fully dispatchable renewable generation from hydropower can play a significant role in supporting a diverse generation mix. As mentioned earlier over 14,000 GWh of energy storage capacity exists within Tasmania and over 2000 MW of capacity can be started within minutes. This also has the potential to provide significant ancillary services support to the mainland in addition to energy/capacity. The key limitation to this is currently the interconnector capability to the mainland of the NEM and should be a key consideration when understanding the future value of a second Bass Strait interconnector.

Hydro Tasmania believes the existing Network Support and Control Ancillary Services (NSCAS) mechanism provides a framework for these services to be procured by either AEMO or TasNetworks, however the NSCAS Quantity procurement methodology is backward looking. Hydro Tasmania provides system support (NSCAS “type”) services which mask these issues in Tasmania. Hydro Tasmania also believes that the mechanism does not consider future issues therefore will not promote investment to manage emerging technical issues. Hydro Tasmania is currently engaging with AEMO to progress this matter.

It can be noted that many of these initiatives address issues that are now being considered in South Australia and that there has been essentially no change to the market to address such challenges despite the significant growth of renewables across the NEM.

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