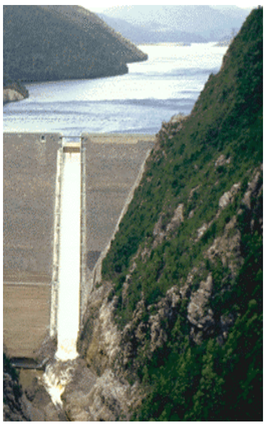
Managing a High Penetration of Renewables– A Tasmanian Case Study



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

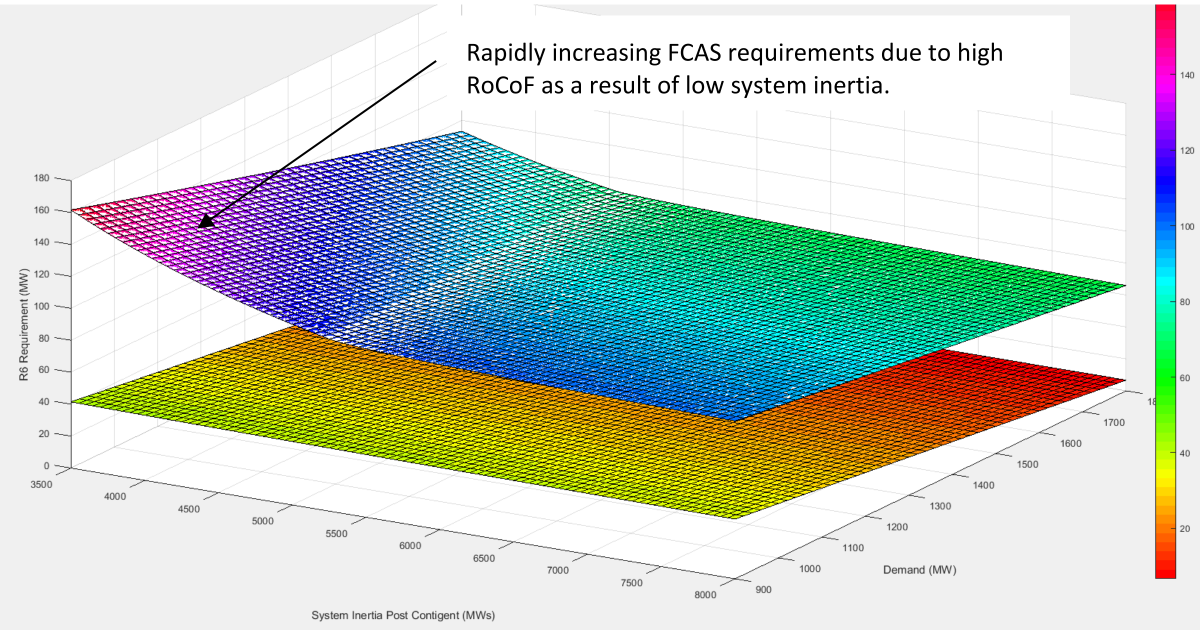
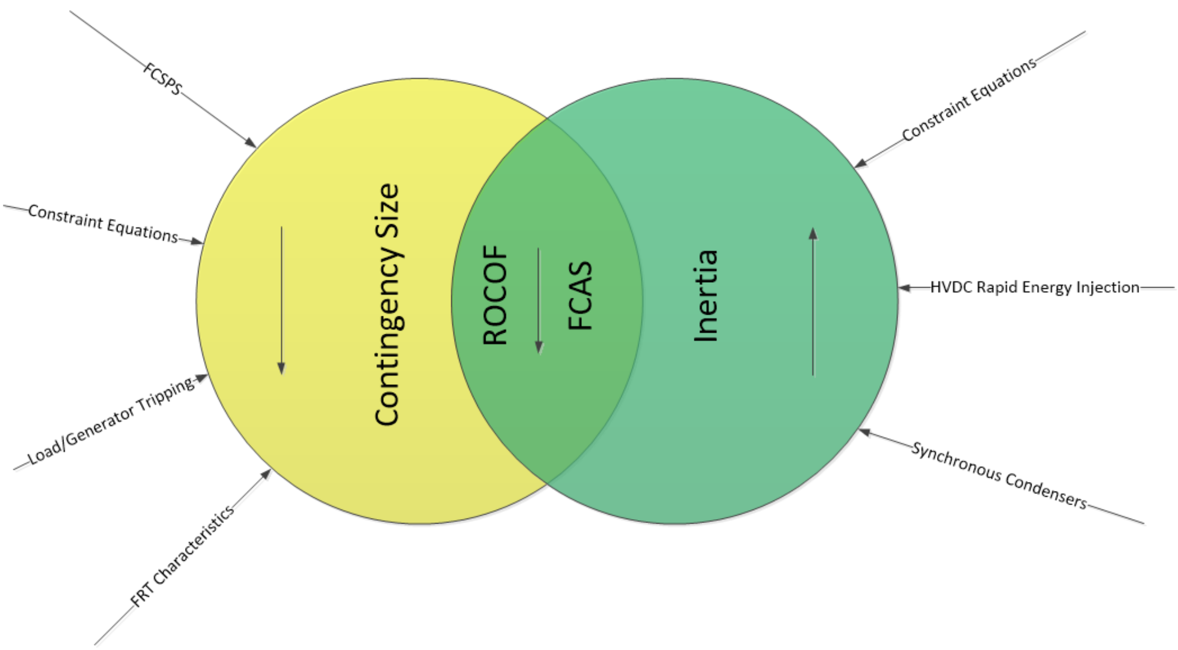


Figure 2 - Relationship between RoCoF, FCAS and Inertia



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.

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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.

7. References

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