A 30MW Grid Forming BESS Boosting Reliability in South Australia and Providing Market Services on the National Electricity Market

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***Abstract*—The Australian National Electricity Market (NEM) has experienced a dramatic transformation due to the rapid uptake of both small and large-scale renewable energy generation, along with the closure of multiple coal power plants. The Australian state, South Australia, epitomises this transformation as the share of renewable energy generation in the state grew from 14% in 2009 to 47% in 2018, dominated by wind power. Combined with limited interstate transmission capacity, the state's power system has experienced instantaneous penetration from wind generation in excess of 120% - the highest for any major power system in the world. This high presence of non-synchronous generation reduces the system strength that has traditionally been provided by synchronous generators. The ESCRI-SA 30MW Battery Energy Storage System (BESS) installed on the lower Yorke Peninsula in 2018, near the end of a long 132kV single-circuit radial feeder, is a Grid Forming BESS built on ABB's Virtual Synchronous Generator platform, which strengthens the grid by providing inertia, high fault current and fast power injection, as well as competitive market services on the NEM. It is also capable of seamlessly transitioning into islanded operation when faults occur on the upstream feeder, thus ensuring continuity of supply to local customers by operating an islanded power system with the nearby 91 MW Wattle Point Wind Farm and distributed solar PV. ESCRI-SA addresses an array of challenges, and reinforces how BESS with Virtual Synchronous Generator technology, can provide multiple value streams to utilities, consumers and the broader electricity market, as well as enabling large scale power systems to operate at 100% renewable energy.**

Keywords*—*Virtual Synchronous Generator; Grid forming inverters; Battery Energy Storage Systems; wind energy; microgrid; renewable energy; ancillary services;

I. Introduction

The Australian National Electricity Market (NEM) has experienced a dramatic transformation due to rapid uptake of both small and large-scale renewable energy generation and the closure of multiple coal power plants. The Australian state of South Australia epitomises this transformation as the contribution of renewable energy generation in the state grew from 14% in 2009 to 47% in 2018 [2], dominated by wind power. Combined with limited interstate transmission capacity, the state's power system has experienced instantaneous penetration from wind generation in excess of 120-140%, – the highest for any major power system in the world [3]. The high penetration of non-synchronous generation reduces both the fault current available and the system strength. In response to these issues, the Australian Renewable Energy Agency (ARENA), a body established by the federal government to fund renewable projects and enhance their competitiveness, and ElectraNet, South Australia's principle Transmission Network Service Provider (TNSP) sought a solution to the technical challenges faced by the state, that also offered a commercial return.

Battery Energy Storage Systems (BESS) with grid forming inverters (GFI) and high power capability, can complement and replace services provided by synchronous generators, to make the grid stronger, safer, and more reliable. This technology was sought by ARENA and ElectraNet for the ESCRI-SA BESS. AGL, who operate Australia's largest electricity generation portfolio and is the largest investor in Australia's renewable energy field, were also are a key participant as commercial operator of the BESS.

The Lower Yorke Peninsula, a 33 kV medium voltage network at the end of a long radial 132 kV feeder, was selected as the host site for the multiple value streams it presented. The long radial 132 kV line connects the 91 MW Wattle Point Wind Farm to the NEM and also serves local towns in the area. The region is exposed to outages when lightning strikes interrupt the single supply line. The site allowed regulated benefits to be harnessed by providing back up to towns in area, by seamlessly transitioning to an island with the wind farm when upstream outages occur, reducing unserved energy for ElectraNet's customers. While this network is interconnected with the NEM, in non-islanded operation, the system can provide both inertia and fast active power injection to enhance the reliability of South Australia and support power system operation with the high penetrations of wind in the state. The site, being within South

Australia, also allowed for management of the loading on interstate interconnectors to further assist the stability and reliability of the state's power. Along with these technical benefits, commercial value would be extracted by having access to the national electricity wholesale and frequency control ancillary services (FCAS) markets. Fig. 1 shows the location of the BESS, also known as Dalrymple BESS, on the Yorke Peninsula, at the end of the 132 kV line with the 91 MW Wattle Point wind farm to the south.

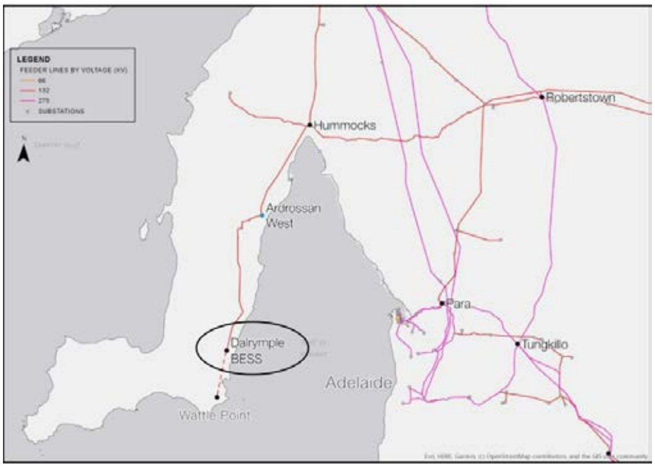

Fig. 1. ESCRI-SA BESS connection point relative to existing transmission assets and the Wattle Point Wind Farm at the tip of the peninsula [4]

After a competitive bidding process, Consolidated Power Projects (CPP), an Adelaide-based engineering, procurement and construction (EPC) firm, partnered with ABB, the provider of the high power, grid forming converters and microgrid control technology, along with modelling and technical expertise, were selected to deliver the ESCRI-SA: 30 MW Grid Forming BESS solution. Samsung SDI provided the lithium-ion batteries.

This paper begins by presenting the business case, including the market context, innovative ownership structure, and actual and estimated revenues. It then explores the considerations for the Virtual Synchronous Generator BESS design, the role of simulation models and highlights the key technical benefits the ESCRI-SA BESS offers. Finally, the paper concludes with key validated performance results based on commissioning data and the first months of operation.

II. Business Case Set-up

A. South Australian market context

The South Australian grid, like most of the large Australian electrical systems, is deregulated. The TNSP ElectraNet is a private company that provides regulated transmission services for the grid. Generators in South Australia compete to provide electricity and energy services in the NEM, while retailers compete to connect and manage energy sales to residential and commercial customers. Most electricity customers in South Australia connect to the transmission network via a distribution network operated by the sole, regulated electricity distributor, SA Power Networks, a privately held company.

In 2018 the Australian Energy Market Operator, (AEMO), the independent system operator in Australia, reported that within South Australia, "coal-fired generation assets have withdrawn while wind generation, behind-the-meter rooftop photovoltaics (PV) generation, and battery storage have grown rapidly [6]." In the 2017-18 fiscal year, almost half of the energy generated in the South Australian system came from renewable sources. South Australia hosts 930 MW of rooftop PV and 1809 MW of wind with respect to a peak demand of 3244 MW in the summer of 2018/19. AEMO noted that with this system evolution, additional fast-start and rapid-response technologies were necessary [6]. The challenges are further increased due to limited power support from neighbouring states; the South Australian network at present has only one AC interconnection to the rest of the NEM, the Heywood Interconnector [7].

The operation of the NEM is managed by AEMO, while the Australian Energy Market Commission (AEMC) develops its rules. Regulations and rules are enforced by the Australian Energy Regulator (AER) [8]. AEMO operates the wholesale energy market as a physical spot trading market and in addition, procures various ancillary services, through market and non-market mechanisms. In addition to the trading through the NEM, there are a number of additional financial products traded to reduce risk and hedge against high prices in the NEM market [9].

The ESCRI-SA BESS provides regulated and market services to fulfill needs of customers both in its local sub-network on the lower Yorke Peninsula and the broader NEM.

B. Ownership and commercial structure

The key challenge during the ownership negotiation process was to agree on risk allocation, annual lease payments and associated availability guarantees.

The BESS is owned and maintained by ElectraNet, with the operation of the BESS leased to AGL for twelve years. ElectraNet has set up a corresponding agreement with CPP, the primary EPC contractor for maintenance of the BESS for the twelve-year period with an availability guarantee. The ownership and operation model of the ESCRI-SA BESS project is shown in Fig. 2. As shown, grants from ARENA provided partial funding for the project. ElectraNet gains regulated services from the ownership of ESCRI-SA BESS while AGL operates in competitive markets with the BESS through the lease arrangement. The payments are shown with red arrows and the benefits are illustrated with green arrows.

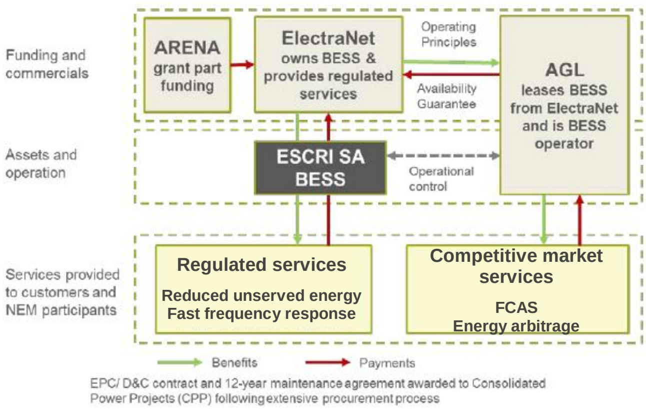

Fig. 2. Ownership and operation model of ESCRI-SA project [10]

C. Revenue streams

The revenue streams for the ESCRI-SA BESS project are from fast frequency response (FFR), reduction of Unserved Energy, FCAS markets and energy arbitrage.

- The supply of FFR reduces constraints on the Heywood interconnector, improving utilization of the single interstate AC interconnection. This is achieved through a contribution of 200 MWs equivalent of synchronous inertia provided by the synthetic inertia of the BESS into the South Australian power system [4].
- Reduction of Unserved Energy to the Dalrymple region following loss of supply, involving islanding of the BESS with the local load, while keeping the Wattle Point Wind Farm and local rooftop PV in service at reduced output, until connection to the NEM is restored. In the first six months of operation the BESS has reduced the loss of supply from approximately 8 hours to 30 minutes [4].
- Market trading of electricity in the NEM through the provision of FCAS services and energy arbitrage. In the first six months of operation the BESS had earnt AU$1.13 million from FCAS markets [4].

The estimated costs and benefits to regulated customers are summarised in TABLE I. with approximate figures using direct attribution methodology. The capital cost allocation for the project is shown in TABLE II. with grant funding from ARENA, and other factors for regulated financial components. The capital cost offsets are related to in-kind contributions and R&D tax credits. The non-regulated component is related to battery operator lease [10].

TABLE I. ESTIMATED COSTS AND BENEFITS TO REGULATED CUSTOMERS [10]

Estimated costs and benefits to regulated customers	*Present Value (PV) (AU$M)*
Prescribed costs of project (including operating costs)	(6.3)
Benefits of reduced unserved energy	5.3
Benefits of reduced interconnector constraints	8.2
Net benefits to customers	7.2

TABLE II. CAPITAL COST ALLOCATIONS [10]

Capital cost allocation	*Cost allocation (AU$M)*
Total Capital cost	30.0
ARENA grant funding	12.0
Capital cost offsets	1.6
Non-regulated component	10.6
Prescribed componenet	5.8

Fig. 3 shows a relative breakdown of construction and maintenance cost. Less than half of the project costs were for the BESS (ABB Virtual Synchronous Generator converters and Samsung SDI batteries) while the remainder comprised of switchgear, civil costs, studies and other related costs.

Over the first six months of operation, the majority of revenue, AU$1.13 million came from FCAS, as mentioned, supplemented with AU$0.12 million from energy arbitrage. The high FCAS revenue is approximately double that anticipated under revenue estimation during project development [4].

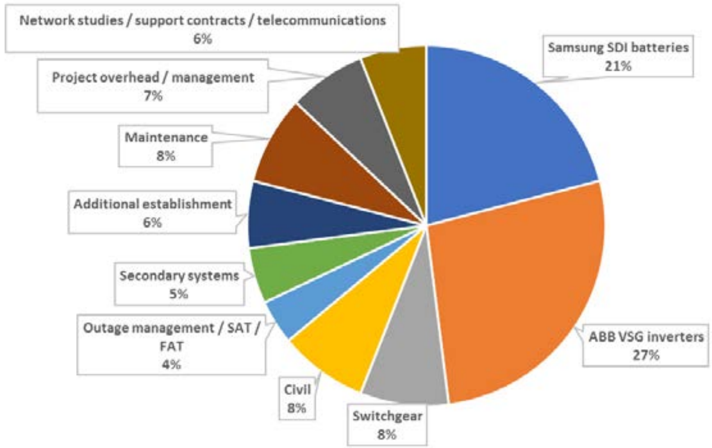

Fig. 3. Construction and maintenance cost [10]

III. BESS DESIGN

A. Strategic planning and basic engineering

At the time of the project feasibility study, Australia had little experience with non-hydro energy storage within its interconnected systems, and the technologies involved were just emerging into the mainstream internationally. This meant that the work had to concentrate on a range of issues across a broad spectrum, including:

- The regulatory environment in which such an asset would operate
- What services it would provide, and how would these be monetised
- Where the asset would be sited
- What energy storage technology was available, its maturity and both supply and operational risks
- Issues around project progression, including planning and environmental approvals
- Procurement of the asset, specifications and contracting terms
- Commercial framework under which the asset would be owned, and outputs traded
- The business case in terms of BESS commercial return, risks and sensitivities

The work was found to be highly iterative, with many combinations and permutations of technology, siting, services and prices. All of these had to fit within the regulatory bounds and commercial constructs that existed.

Business cases were explored for a wide range of BESS sizes at various locations in the current South Australian region of the market.

At the feasibility study stage, it was found that no project could be made Net Present Value (NPV) positive and a decision was made to choose the best performing variation, initially a 10 MW, 20 MWh system sited at the Dalrymple substation on the Yorke Peninsula, as the basis for the detailed business case. The Dalrymple substation on the Yorke Peninsula was chosen as project site as it has significant local renewable energy generation (Wattle Point Wind Farm) and appeared to have the most suitable characteristics to leverage value from such BESS sizing. A Lithium-Ion battery was used as the basis of the business case as this showed the best overall metrics.

An important aspect of the Dalrymple option was the revenue sources that could be leveraged, which included market-based products but also significant regulated value, one of which involved the BESS supporting islanded operation together with the Wattle Point Wind Farm following a 132 kV fault on the incoming radial transmission line. Such islanding meant that reduced unserved energy could provide additional benefit to the project with the BESS and wind farm serving the load until transmission service was restored.

While the Project ultimately evolved into a 30 MW, 8 MWh (end of life) system to align closer to the particular services needed within the South Australian power system, the basic concepts involving siting at Dalrymple and the BESS technology remained and became the backbone of the final solution.

The Dalrymple ESCRI-SA BESS showcases the widest range of services provided by a grid connected BESS in the NEM covering both energy and system security services, as detailed in section III.B.

Further innovations of this project that contribute to the advancement of the application of battery storage technologies include:

- a first-of-its-kind commercial model to support the provision of regulated reliability and security services by a Network Service Provider (ElectraNet) alongside competitive market services (AGL), challenging perceived limitations to network ownership of battery energy storage technologies;
- navigating the market registration, licencing and connection processes for the first time paving the way for others to follow;
- largest autonomous regional microgrid developed to date co-optimised for both grid-connected and islanded operation with 100% renewables allowing seamless transition between the two operating states (for both planned and unplanned islanding).

Additionally, the ESCRI-SA BESS is the largest-known indoor and climate-controlled BESS installation (30 MW), with the advantages of quicker installation and lower cost compared to containerised battery solutions. The photograph of the structure is shown in Fig. 4.

Fig. 4. Aerial photograph of ESCRI-SA BESS and the Dalrymple substation [4]

B. Key services and functionality

All of the ESCRI-SA BESS functionality is enabled by the ABB PowerStore™ high power, Grid Forming BESS platform, and its control system consisting of two levels: primary and secondary. The primary control is implemented on the inverters while the secondary control is housed in ABB's overarching and distributed e-mesh™ controllers.

At the heart of the primary control is the ABB Virtual Synchronous Generator (VSG) – a high power, grid forming inverter combining synthetic inertia, synthetic impedance, frequency governor, synchronous generator rotor flux model and an automatic voltage regulator (AVR). Its control diagram is shown in Fig. 5.

These control components work in concert to make the VSG behave closely to a synchronous generator during both steady-state and transient conditions [11] and enable advanced performance in stand-alone operation, when paralleling with other voltage and/or current sources or grid connected. The inverter always operates as a voltage source which enables seamless transition into and out of islanded operation.

The secondary control, the overarching and distributed e-mesh™ control, is integrated on top of the primary control and houses the majority of the project specific automation and functional logic.

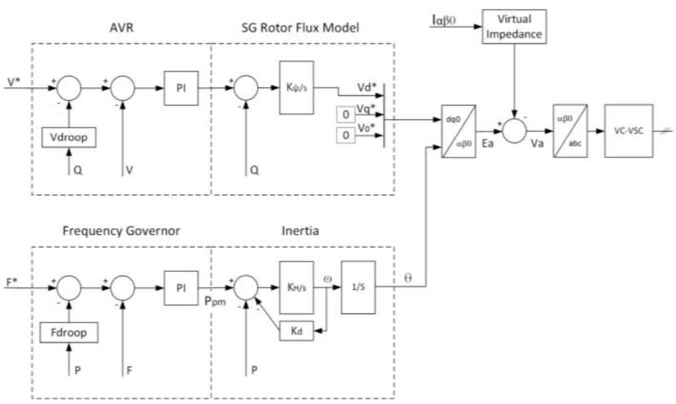

Fig. 5. ABB Virtual Synchronous Generator primary control model [11]

Together, both control layers provide the following key functionality and innovative features relative to other generation and energy storage installations:

- inverters with **grid forming** capability and the ability to operate at very low Short Circuit Ratios (<<1.5), significantly beyond what existing electronic converter-based generation can perform;
- seamless planned and unplanned **transition into islanded operation** and subsequent **live-live resynchronisation** to the power grid;
- **synthetic inertia** responding to rate of change of frequency (RoCoF) on the grid and stabilising frequency in islanded operation with unprecedented response speed and bandwidth for grid-parallel converters. This function is also referred to as Fast Frequency Response (FFR) in the project context although authors note that the synthetic inertia provided by the ESCRI-SA BESS is governed by the fundamental power transfer between two voltage sources proportional to the voltage angle between those sources and requires no external measurement, detection and processing pertinent to most FFR mechanisms and therefore closely resembles the inertial response of a traditional synchronous generator through a similarly inherent response;
- non-synchronous **fault level/system strength support** capability via short-term fault current overload (up to 2.0 p.u. inverter rating);
- **islanded grid master control** including wind farm generation MW dispatch/curtailment facilitating supply to the local island indefinitely under reasonable wind conditions;
- **black start capability** with soft transformer energisation for the local island with a peak demand of 8 MW;
- pre-emptive emergency response as part of the South Australian **System Integrity Protection Scheme** (SIPS), providing **fast active power injection** into the network following a significant loss of generation. The BESS can be operating at full capacity and providing meaningful network support within 250ms of receiving a command of a network event being detected about 400 km away in the South East of South Australia;
- participation in the National Electricity Market for **Energy Arbitrage** and **Contingency Frequency Control Ancillary Service** (FCAS);
- **voltage, power factor, reactive power regulation** and external set-point control;
- integration with ElectraNet's transmission-system level topology-based **Islanding Detection Scheme**;
- **control of distributed energy resources (DER)**: ESCRI-SA BESS can adjust the islanded system frequency to invoke curtailment of behind-the-meter DER when required, to manage power flows and avoid over generation conditions due to these un-controlled local generators (e.g. Customer rooftop solar PV).

C. Modelling and simulation of dynamic behaviour

As discussed in section III.B, the control architecture of the BESS consists of two layers: the fast primary control implemented as Virtual Synchronous Generator on the inverter, and the slower secondary control located on a number of distributed controllers. The logic on both levels is initially developed in the Matlab® Simulink® platform and, following code generation, used in power system simulation tools and embedded into the hardware.

1) Matlab® Simulink® development space and source code

The primary control system logic on the VSG exists as Matlab® Simulink® models and Dynamic Link Libraries (DLLs) are created through code generation from Simulink® for use in Electro-Magnetic Transient (EMT) based simulation tools. Secondary control functionality is initially developed (designed, implemented, unit tested) in the Simulink® environment and also compiled into DLLs which can be utilized in a range of simulation platforms. ABB in collaboration with Mathworks developed toolboxes that can generate DLLs for different targets including DIgSILENT PowerFactory (C++ based), PSS®E and PSCAD™ (Fortran based). This allows a sustainable model maintenance stream, as any changes in the source code get propagated into all models simultaneously, and the models always remain up to date.

This flexibility in design helps with the development of the control algorithms as the generated DLLs can be utilized for simulation of the interaction with the power system. ABB is using a test harness in DIgSILENT PowerFactory in order to test the secondary control functions. Hardware in the loop (HIL) and Software in the loop (SIL) are the other level of testing and debugging that occurs in conjunction with the microgrid test harness. The Simulink® source codes get compiled and downloaded onto the actual controllers and the functions are tested thoroughly through HIL/SIL or in the actual test facility in combination with physical units in order to close the development loop.

2) DIgSILENT PowerFactory

DIgSILENT PowerFactory has two time-based domains for simulations – RMS and EMT. For the EMT domain, DLLs compiled directly from Simulink® models are used both for the primary and the secondary control levels, whereas for the RMS domain DLLs are applied only for the secondary control level. An RMS representation of the primary control on the VSG was developed as a native DSL control block in the PowerFactory environment. This VSG DSL block accepts setpoints from secondary control DLLs. The simulation tool was used by ABB as a testing environment to validate and benchmark secondary control functionality.

3) PSS®E models

AEMO as the network operator in Australia, requires PSS®E and PSCAD™ models for generation plants connecting to the NEM to be submitted for assessing the performance of the plant in the context of the Australian power grid. Additionally, significant network studies were undertaken by ElectraNet as the responsible TNSP in determining the effects of the BESS on the local network, wind farm and the transmission system. ABB provided both a PSS®E and a PSCAD™ model of the BESS for those studies.

Initially, an R1 PSS®E model package is submitted pre-connection which may be used to establish the Generator Performance standards (GPS) setting the agreed performance level for the plant. The GPS are developed against the clauses mandated by the National Electricity Rules (NER). Following system commissioning, the model is validated against site measurements and together with the plant's compliance with the GPS, constitutes the R2 post-connection data.

During commissioning, a staged approach is taken in that AEMO impose successive hold points (generation limits) for the plant while the plant's performance is assessed against that predicted by the model and once considered safe with regards to its impact on the power system security, grants approval to proceed to the subsequent higher hold point. At the time of writing, the ESCRI-SA BESS plant has undergone GPS compliance site testing while the R2 PSS®E models are currently undergoing validation.

4) PSCAD™ models

Since July 2018 EMT-type simulation models are required to be supplied for existing and new plant. Use and application of those models enables an accurate assessment of unbalanced/balanced events, power system security, weak system connections, and control and dynamic (stable/unstable) interactions between a generating system and its surrounding network [12]. Those models have been gaining importance in the light of the number of connection applications from non-synchronous generation sources.

The ABB PSCAD™ model is delivered with the control library modules compiled into DLLs directly from the Simulink® source code. Those DLLs are interfaced with the other plant and grid components for assessment of dynamic behavior as part of system studies. The DLLs encompass both the primary (VSG) and secondary (e-mesh™ Control) control layers and can be scaled from a single inverter module to a multi-MW BESS system. Additionally, the model includes a control library for dispatch/curtailment instructions for the wind farm.

D. Factory Acceptance Testing

ABB carried out Factory Acceptance Testing (FAT) of the key control functionality and plant automation in their test facility in Darwin, Australia during the final stage of the detailed design process. The test facility offers flexibility to be configured to represent the ESCRI-SA BESS project assets on a small scale. This allows the project stakeholders to witness the functionality and performance provided by the BESS and its interaction with the grid, wind farm and loads, before the actual plant is built and commissioned.

IV. Technical Performance

The performance of the ESCRI-SA BESS has been proven during system commissioning in 2018 and in the first six months since entering commercial operation in December 2018 [4]. In this chapter we present some of the results collected by ABB at commissioning time.

A. Seamless islanding

As discussed in section III.A, one of the key regulated services provided by the ESCRI-SA BESS is reduction of the amount of unserved energy in the area, which effectively means prevention of an outage upon disconnection of the Dalrymple substation from the upstream bulk power system during a fault or contingency event. The system can be islanded on command (planned islanding) or become islanded unexpectedly (unplanned islanding). The latter is more onerous than the former as pre-emptive steps cannot be taken to prepare for a smoother transition, such as reducing the active and reactive power flow across the point of connection to zero and reducing the output of the wind farm to an appropriate level.

A challenge encountered during the control and protection system design is presented by the relative rating of the wind farm (91 MW) to that of the BESS (30 MW). If the wind farm were producing at its full capacity at the instant of unplanned islanding, the BESS may have had to absorb power significantly above its rating until 4 out of 5 wind turbine collectors groups are switched out by the protection relays to reconfigure the wind farm for islanded operation, some 80-100 msec after islanding. Such a large power spike can be demanding for the batteries.

This problem is overcome owing to the synthetic inertia of the grid forming BESS, which immediately responds by raising the frequency. This reduces the slip in the induction generators of the wind turbines, instantaneously dropping their power output with the result that the power peak the BESS has to absorb does not exceed 27 MW and therefore remains within the steady-state rating of the batteries. This behaviour is shown in Fig. 6, captured by a high-speed data recorder during the real-life test. The wind farm was unable to ride through the event due to its tight overfrequency protection settings which will be raised by the operator over the coming months.

Fig. 6. Islanding instant during high wind farm production of 79 MW prior to islanding. Shown here are frequency (top) and BESS active power (bottom)

However, the BESS remained online and maintained supply throughout the transition and thereafter.

A noteworthy remark is that the PSCAD™ model provided with the BESS was able to accurately replicate this frequency behaviour in the system studies [4].

A closer look at the voltage and current waveforms in Fig. 7 recorded during another unplanned islanding test reveals that the grid forming BESS creates its own continuous voltage waveform such that no voltage sag occurs during the transition, and thus there is no supply interruption to loads. Islanding is followed by increased current injection from the BESS drawn by the upstream 132 kV line for 70 msec until the line is isolated at the Dalrymple substation.

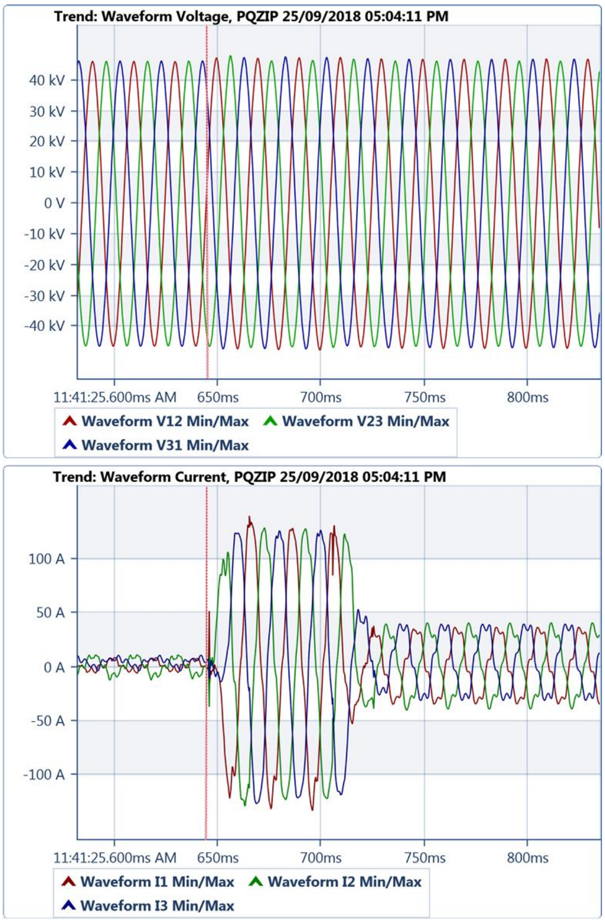

Fig. 7. Voltage (top) and current (bottom) waveforms recorded at the 33 kV connection point of the BESS before and after the islanding instant marked by the red vertical line

When islanded, the BESS regulates the frequency in the microgrid by means of the Virtual Synchronous Generator, consisting of synthetic inertia, a frequency governor operating in droop mode on the primary control level and an isochronous frequency controller with a small deadband on the secondary level. Fig. 8 presents the frequency profile observed while operating in parallel with the bulk power system (NEM) and in comparison, the frequency regulated solely by the BESS while islanded. It can be seen during the islanded period the frequency is controlled within a tighter band due to the Virtual Synchronous Generator control.

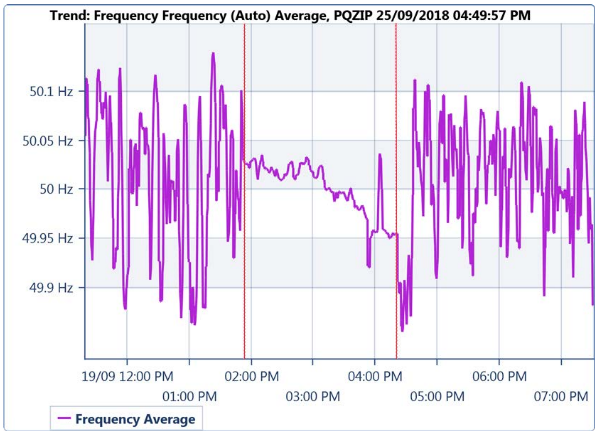

Fig. 8. Frequency regulation by the BESS in the islanded microgrid between the two red vertical lines. Outside of the lines is the frequency profile on the bulk power system (NEM)

B. Fast active power injection (SIPS)

The System Integrity Protection Scheme (SIPS) was devised by ElectraNet following the South Australia system black event in September 2016 to achieve a coordinated fast active power injection from BESS systems in response to the loss of a significant amount of generation within South Australia [13]. The SIPS scheme takes over detection of such a contingency situation and presents the BESS with a binary trigger signal to which it is required to respond with a pre-defined power output (typically maximum available). The design requirement for the ESCRI-SA BESS is to provide 30 MW within 250 msec which was successfully demonstrated in the field. Fig. 9 illustrates the recorded current waveforms injected by the BESS in response to receipt of the SIPS trigger. For clarity, the difference between the response shown in Fig. 7 and the response to the SIPS trigger in Fig. 9 is that the latter is a command response (to a setpoint) whereas the former is load current drawn by all loads within the now islanded grid, from the grid forming BESS, as it is the only source (the slack bus) within the islanded microgrid, and is effectively instantaneous.

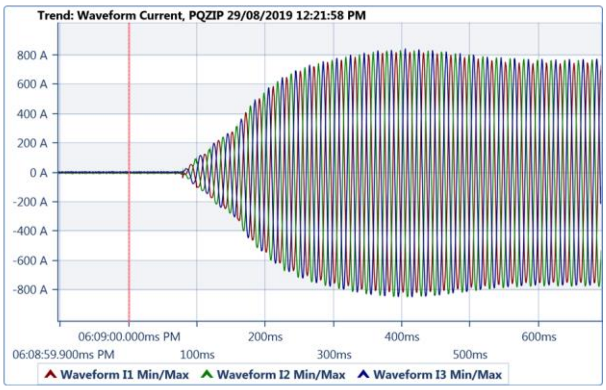

Fig. 9. ESCRI-SA BESS fast active power injection in response to the SIPS trigger; the trigger reception instant is marked by the red vertical line

C. Black start

Another key function provided by the ESCRI-SA BESS is black start of the local 33 kV distribution network. This is achieved through a soft energization of the BESS coupling transformers (6 x 6 MVA) and one of the substation transformers (25 MVA) with the subsequent energization of the two 33 kV distribution feeders. The transformer energization instant is illustrated in Fig. 10 as voltage and current waveforms. While the voltage is ramped up over one second, the currents are so insignificant that they remain below the pick-up threshold of the high-speed recorder. This method eliminates transformer and cable inrush completely.

The active and reactive power profile of the 33 kV feeders during this consecutive load feeder pick-up by the BESS are shown in Fig. 11.

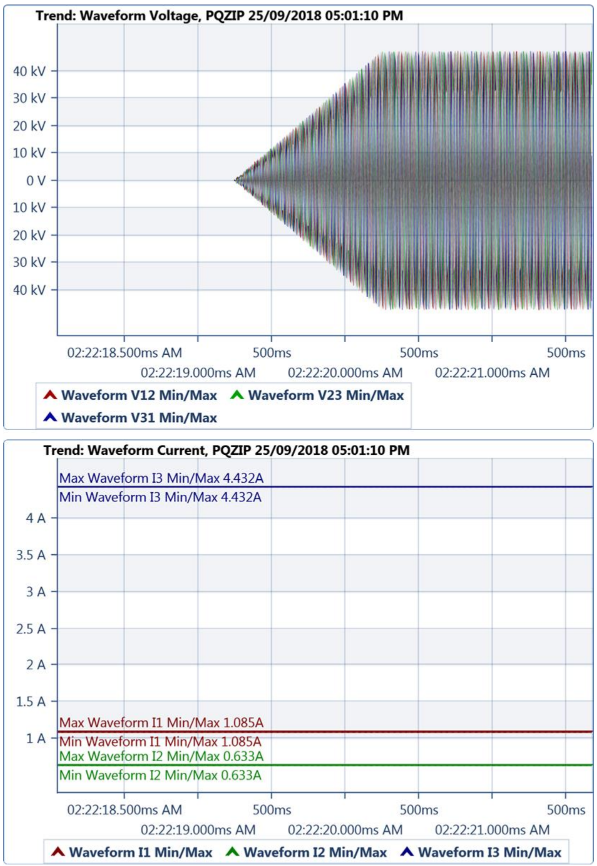

Fig. 10. Ramp-up of voltage (top) by the BESS to soft energise transformers in the local nework. Resulting currents (bottom) are so small that they were not captured by the high-speed recorder

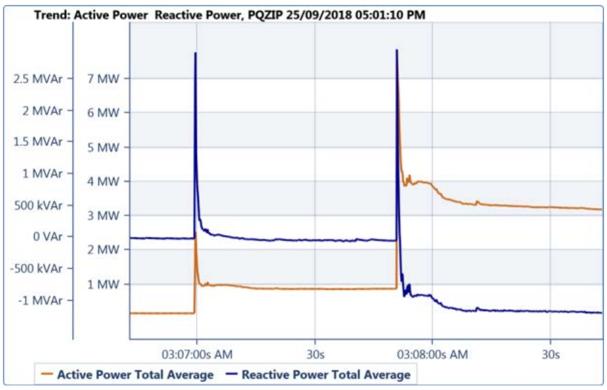

Fig. 11. BESS active and reactive power profiles for consecutive energization of two 33 kV distribution load feeders

V. Conclusions

The ESCRI-SA 30 MW BESS project has shown how Grid Forming BESS can provide a range of advanced technical services, critical in supporting the operation of high penetration renewable energy power systems. ABB's high power, Virtual Synchronous Generator platform, and advanced automation at ESCRI-SA has enabled the largest autonomous regional microgrid developed to date, to operate grid-connected and islanded, with seamless transition between these two states. This unlocked a first-of-its-kind commercial model, the provision of regulated reliability and security services by a Network Service Provider, in addition to competitive market services for an energy generator and retailer. When NEM connected, with the presence of high wind generation in the state of South Australia, ESCRI-SA BESS has provided a range of power system stability and support services as outlined in this paper. Further development of high power, Grid Forming Inverter and Virtual Synchronous Generator technology, building on the features demonstrated by ESCRI-SA BESS, will provide important reinforcement to future power systems, by replacing services traditionally provided by synchronous generation. This will facilitate both increased interconnection of non-synchronous renewable generation and enable high penetration renewable energy power systems to operate reliably.

References

[1] Online website ESCRI-SA www.escri-sa.com.au, last accessed August 2019

[2] Department of the Environment and Energy, Australian Energy Statistics, Table O, March 2019

[3] Australian Energy Market Operator, "South Australian Renewable Energy Report", p.3, November 2017

[4] ElectraNet report, "ESCRI-SA Battery Energy Storage Project Operational Report #1. First six months (14/12/2018 – 14/06/2019). July 2019

[5] Australian Energy Regulator, Seasonal peak demand, accessed in August 2018 online at https://www.aer.gov.au/wholesale-markets/wholesale-statistics/seasonal-peak-demand-region

[6] Australian Energy Market Operator, "South Australian Electricity Report", p.3, November 2018

[7] Australian Energy Market Operator, "South Australia System Strength Assessment", September 2017

[8] Deparment of the Environment and Energy, National Electricity Market (NEM), available online at https://www.energy.gov.au/government-priorities/energy-markets/national-electricity-market-nem. Last accessed August 2019.

[9] ASX Corporate overview. Available online at: https://www.asx.com.au/about/corporate-overview.htm. Last accessed August 2019.

[10] ElectraNet report, "ESCRI-SA PROJECT SUMMARY REPORT, The Journey to Financial Close" May 2018. Available online at https://www.escri-sa.com.au/globalassets/reports/escri---sa---project-summary-report---the-journey-to-financial-close---may-2018.pdf. Last accessed August 2019.

[11] Tuckey, A., Round, S., "Practical application of a complete virtual synchronous generator control method for microgrid and grid-edge applications", 2018 IEEE 19th Workshop on Control and Modeling for Power Electronics

[12] Australian Energy Market Operator – Network Development, "Access Standard Assessment Guide", January 2019

[13] ElectraNet report, "SA ENERGY TRANSFORMATION RIT-T. Special Protection Scheme", 22 May 2019