Grid forming energy storage with microgrid controls provides green hydrogen, enhanced reliability, reduced site costs and lower emissions. ATCO Clean Energy Innovation Hub (A Case Study)

S. Sproul[1], S. Cherevatskiy[1], S. L. Mohan[2]*

[1]Grid Edge Solutions, Hitachi ABB Power Grids, Brisbane, Australia
[2] Innovation Projects, ATCO Gas, Perth, Australia
**stephen.sproul@hitachi-powergrids.com*

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Abstract

As the number of distributed energy resources on the power system grows, there are fewer opportunities to realise value from delivering energy alone. However, within the broader clean energy transition, there are new opportunities to both support the power system and extract site benefits to improve industrial site operations, through behind-the-meter microgrids. At ATCO's Clean Energy Innovation Hub, a grid-forming battery energy storage system (BESS) with microgrid control is implemented to extract a broad array of benefits for the site. These include maximising renewable hosting capacity, realising tariff benefits, enhancing site reliability and running 100% green processes – creating green hydrogen. The site consists of a 300 kVA/500 kWh grid-forming BESS, 300 kW of rooftop solar photovoltaics, 260 kVA hydrogen electrolyser and 200 kVA gas generator. A distributed, real-time control system orchestrates these assets, underpinned by the grid-forming converter, to achieve all the functions required by the site. The microgrid provides back-up supply to the site's mission critical control centre, seamlessly islands and re-synchronises with the grid, and also creates green hydrogen based on the site's local PV generation. ATCO's Clean Energy Innovation Hub demonstrates how a grid-forming BESS with microgrid control can integrate renewables, create green hydrogen and deliver both site and distribution system benefits.

1 Introduction

ATCO's Clean Energy Innovation Hub (CEIH) primarily investigates the role hydrogen can play in the future energy mix. The project developed an Australian first research facility that integrated renewable hydrogen production with a renewable energy stand-alone power-system in a "living lab" microgrid setup [1]. Renewable energy from the 300 kW roof-top solar system is stored within the onsite 500 kWh battery energy storage system (BESS) to firstly provide back-up supply to the site, which is ATCO Gas' mission critical Jandakot Operations Centre, and provide peak demand shaving for reduced grid supply demand charges. Excess renewable energy generated from the 300 kW of rooftop solar photovoltaics (PV) that could not be stored is used to produce renewable hydrogen from a 260 kVA electrolyser. The 100% green hydrogen is stored in a 30-bar, high-pressure storage vessel where it is either distributed within the microgrid as a blended fuel for normal consumption or used as a direct fuel for appliance testing.

The CEIH microgrid not only demonstrates the integration of these technologies and their control, but also evaluates the commercial viability of microgrids with and without green hydrogen. The project tests the reticulated natural gas network as a peaking back-up system to a commercial scale microgrid, self-consumption electrical solution and providing peaking generation ancillary services to the electrical grid [1].

The project demonstrates how a commercial-scale microgrid integrating solar PV, BESS and gas generation can address availability and variability issues inherent with intermittent renewable energy technologies by working synergistically with other components within the microgrid [2].

The key enabler was the real-time, microgrid control, both at the primary grid-forming converter level and secondary power management level to orchestrate and balance the behind-the-meter assets when isolated as a stand-alone power system and when connected to the Western Power distribution network [1]. The system was designed to seamlessly transition between these two states, disconnecting from the distribution network during a network outage and seamlessly reconnecting on return of a healthy grid, satisfy all the requirements of the grid connection agreement when operating in parallel with the utility and support existing site operations and processes.

2 Site Configuration

The ATCO CEIH is a behind-the-meter microgrid that performs various functions in both on-grid and off-grid configurations. The control system utilises the controllable assets within the microgrid to achieve the objectives of enhancing reliability, reducing energy supply costs and creating green hydrogen. To this end, the real-time control system manages:

- 300 kVA/500 kWh grid forming BESS;
- 300 kW of rooftop PV;
- 180 kW/260 kVA hydrogen electrolyser;
- 200 kVA gas generator; and
- Metering, grid monitoring, status and synchronisation at the site grid connection.

Fig. 1 presents the 300 kVA/500 kWh grid-forming BESS and Fig. 2 shows the 260 kVA hydrogen electrolyser and 30-bar high-pressure hydrogen storage vessel.

Fig. 1. Indoor energy storage system, electrical and control cabinets (rear) hosting 300 kVA grid-forming converters and 500 kWh li-ion battery racks (right).

Fig. 2. 260 kVA controllable hydrogen electrolyser (front left) and 30-bar high-pressure hydrogen storage vessel (centre) [3].

The control system in place to manage these assets and deliver the functions discussed in Section 3 are the primary control, which is the Virtual Synchronous Machine (VSM) hosted on the grid-forming converter, which enables the 0-50msec foundational power system functions such as seamless back-up, stand-alone operation (islanded) and black start. A secondary, distributed, real-time control system then manages power flows in the 50-250msec time scale to orchestrate, schedule and dispatch assets to achieve the microgrid objectives. The secondary control is a distributed control architecture, with a controller located at each field device (solar PV inverters, gas genset, BESS and grid connection) to monitor and control the resource in the context of the microgrid. Communicating across a peer-to-peer ethernet network provides redundancy and scalability for the microgrid as there is no single master controller.

3 Functions

The primary function of the control system whilst grid connected is to perform peak lopping to maintain imports from the main grid below a certain agreed value (Contract Maximum Demand) for the purpose of reduced demand charges. In addition, this function is managed in reverse to prevent export of excess power above the agreed export level produced by the distributed generation sources within the CEIH microgrid – as agreed with the distribution service provider (at the time of writing the CEIH is a zero-export system). This is an important feature to host higher levels of behind-the-meter renewable generation than would otherwise be approved to operate by the utility. This is managed firstly by charging the battery, then operating loads – the hydrogen electrolyser and then finally curtailment of on-site PV generation. Contribution from solar PV is continuously maximised and prioritised over grid imports. With respect to reactive power, the four quadrant BESS converters and PV inverters are manged by the control system to provide power factor correction at the grid connection point.

The operator can request a disconnection of the microgrid from the utility where the control system is able to unload the grid connection and seamlessly transfer the microgrid into islanded operation. Once disconnected from the main grid, through controlled opening of the grid breaker, the BESS operates islanded in isochronous frequency and voltage control mode. This is achieved through the VSM primary control implemented on the BESS converter. The BESS functions as a voltage and a frequency source that the solar PV inverters synchronise to. Through a scheduler, the system can start and synchronise a gas genset in case of insufficient spinning reserve or low battery state-of-charge (SOC). The gas genset is only utilised in islanded operation but never grid parallel. The genset's frequency and voltage setpoints cannot be altered, therefore when the genset is called upon, the BESS starts following the genset's nominal frequency and voltage[1] in order to enable an in-sync closure of the genset's circuit breaker onto the microgrid formed by the BESS. While the gas genset is operating, the control system provides load-sharing between all generating sources and monitors the genset's power output and takes appropriate actions to maintain both the minimum and maximum loading on the

[1] Genset's nominal voltage is 400V, while the whole system normally runs at 415V, including when grid-parallel.

genset. The VSM software layer plays an important role to allow the grid-forming converter to operate in parallel with other voltage sources such as the gas genset and the grid.

In addition to planned islanding, the CEIH microgrid is equipped with a grid monitoring protection relay that is configured to utilise several passive islanding detection methods in line with [4] and serves the purpose of detecting disturbances on the main grid and pre-emptively separating the microgrid from the main grid supply in a quick transition, from grid connected to islanded operation. This is done to safeguard continuous supply to the critical site and its loads. Automatic or operator-initiated resynchronisation to the main grid is co-ordinated by the microgrid. During the resynchronisation process, the synchronising device provides voltage and frequency lower/raise pulses to the control system which in turn coordinates operation of the isochronous BESS (since the genset is not certified to operate grid parallel, it needs to be brought offline prior to grid resynchronisation) to align frequency slip, voltage and phase angle across the grid connection point through active synchronisation so the circuit breaker can be safely closed.

Should the islanded microgrid experiences an outage, the system can black start the site utilising the grid (if available), BESS and/or the gas genset. The BESS can ramp it's voltage output from 0 to 1pu over 1 second to avoid transformer in-rush current which could otherwise overload the BESS. While operating the microgrid in islanded mode, the BESS converters, possibly being the only voltage/frequency source on the power system, provide up to 2 per unit of their nominal current for up to 2 seconds for clearing faults within the microgrid. The BESS converters maintain the capability to feed in fault currents while operating in parallel to the grid.

Finally, the microgrid regulates the creation of hydrogen to match the on-site solar generation. Solar is first stored in the BESS to allow evening peak lopping and maximise available energy in the batteries should a grid outage occur. Once this condition is met, the electrolyser is controlled to follow the on-site solar generation profile to create 100% green hydrogen.

In summary, the microgrid's functions can be categorized under each of the following, and demonstrates the broad array of services extracted by the control system:

1. Seamless back-up
2. Stand-alone operation (Islanded)
3. Resynchronisation
4. Black start
5. Peak demand management
6. Renewable integration/maximisation
7. Power factor correction
8. Green hydrogen creation
9. Ancillary grid services

4 Results

The following section presents field data and results with respect to how the primary and secondary control work in concert to deliver the functions described in Section 3.

Fig. 3 illustrates two days of BESS operation, where the BESS charges in the morning to prevent export, keep reserves high throughout the day for the back-up function and have capacity to provide evening peak lopping. As the generation from solar PV drops below the load in the microgrid, either during cloud events or at the end of the day, approximately 18:00 in the evening in Fig. 3, the BESS discharges the energy previously acquired from solar PV – this is geared at maximising the renewable energy portion in the site supply. The first day in the figure exhibits variability in solar PV caused by passing clouds, while the second day has largely a clear sky. The solar variability is reflected in the BESS power which is varied in response to compensate for variability of PV in the site supply and ensure the zero-export condition is met.

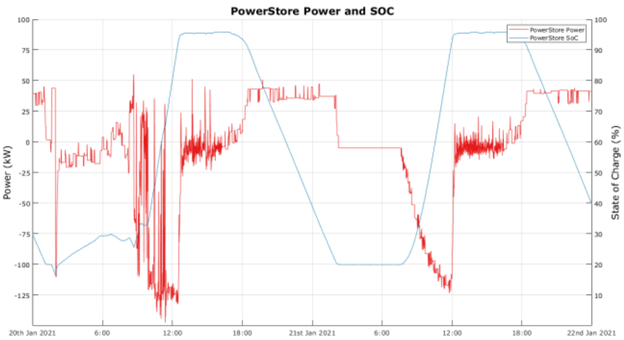

Fig. 3. Two days of BESS operation, cloudy day followed by clear day (red trend – BESS power; blue trend – BESS SOC)

Fig. 4 now shows the electrolyser power consumption on the same two days. The electrolyser is regulated to match the solar generating profile in the afternoon, once the BESS SOC is full. As discussed previously, the electrolyser is only fed from solar PV and supplemented by energy from the BESS (previously charged from solar PV) such that the hydrogen is created from green energy only.

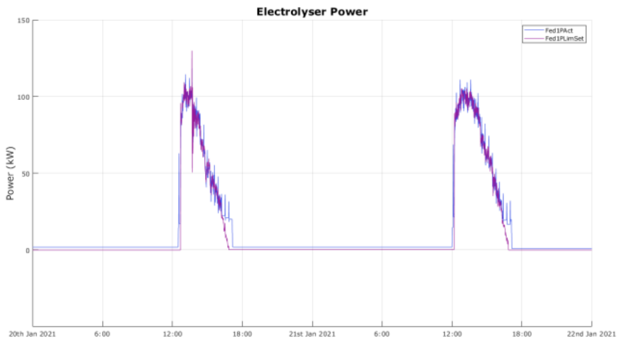

Fig. 4. Electrolyser power supply for two days (blue trend – actual electrolyser consumption; purple trend – electrolyser setpoint)

The various controllable assets on the same two days can be seen below in Fig. 5 where the orchestration conducted by the real-time microgrid control system can be seen.

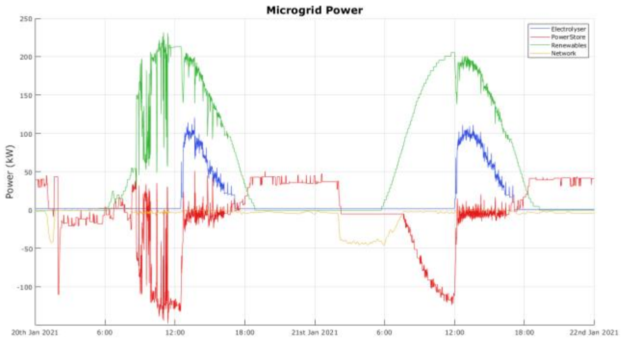

Fig. 5. Hydrogen electrolyser (blue), solar PV (green), grid supply (yellow) and BESS (red) output over two-day period.

Fig. 5 demonstrates the typical behaviour of the microgrid – the BESS is charged in the morning, electrolyser is brought online once the batteries are full and commences with the production of hydrogen from excess PV power. In the late afternoon, the PV output drops such that the electrolyser is stopped, and the BESS discharges its stored energy (approximately 18:00 to 01:30 in Fig. 5) into the microgrid loads, and only then is power imported (01:30 to 07:00 in Fig. 5) from the network to cover the site loads. While each individual asset offers a service, the ability to co-ordinate the site with the microgrid control system ensures all the competing prioritise can be met and the assets are maximised.

On both days, the BESS can be seen to play a critical role in buffering imbalances and ensuring the zero-export requirement at the point of common coupling is met. The 20th of January has a large amount of solar intermittency as shown in Fig. 5 by the solar output (green trend) and the BESS mirrors this (red trend) to compensate. On the 21st, where the solar is less intermittent, the BESS output still varies as it balances the power flows to maintain the overall requirements of the microgrid. In the CEIH microgrid, the BESS is always operated as a voltage source (grid-forming) when grid connected and islanded, which results in the BESS current output being load dependant rather than following or responding to the load and generations. As a voltage source it acts as the slack bus in the system which ensures power flows are balanced at all times with a very fast current response. This behaviour is captured in Fig. 6 which is an example from a large-scale BESS project that utilises the same grid-forming converters and control approach. High resolution voltage and current waveforms are not available for the CEIH microgrid, but the converter is operated with the same control philosophy and approach as shown in Fig. 6. Fig. 6 illustrates the performance during a seamless transition and speed of current response. The top of Fig. 6 shows the voltage waveform supplied by the grid-forming BESS, where at the vertical red line there is a network fault, at which point the current output, which is load/fault dependant, can be seen to respond instantly. Given it is a voltage source converter the system feeds the fault for approximately 70msec upon such time the local protection opens to form a stand-alone grid. It is noticeable in the top of Fig. 7 that the voltage supplied to the loads on site experience no notching or distortion throughout switch from grid connected to islanded operation. It is important during this sequence that the protection operates fast enough to disconnect the microgrid and not overload the converter. In the case of the CEIH microgrid the converter can supply 2pu current for 2 seconds and as such the protection should open within this timeframe to avoid overloading the converter. Finally, the current response in the bottom of Fig. 7 highlights the speed of current response. Again, this is due to the load or fault drawing the required current from the voltage source BESS rather than the BESS trying to measure, detect and respond to an event.

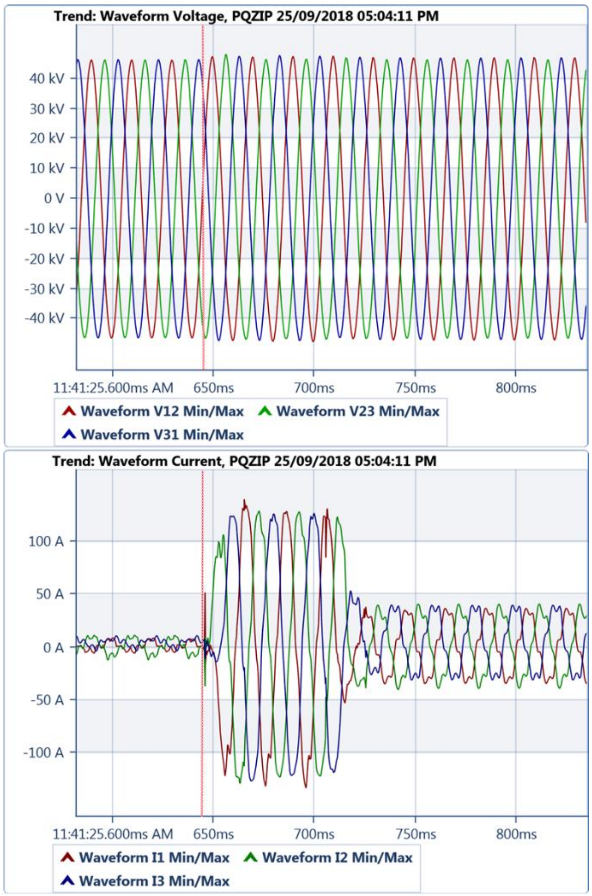

Fig. 6. Voltage (top) and current (bottom) waveforms of the BESS before and after the islanding instant marked by the red vertical line [5].

During the on-grid to off-grid transition process the converter always remains in grid-forming mode, however in the case of CEIH microgrid the grid breaker is monitored to control switching in and out of the governor and automatic voltage regulator (AVR) control loops as seen in Fig. 7. When grid connected the governor and AVR are switched out to operate in (P/Q) mode, to allow compliance with local grid codes, particularly active anti-islanding in line with [4] and provides power factor correction at the grid connection point. Once the grid breaker opens the governor and AVR control loops are switched in to achieve (f/V) control and isochronous frequency and voltage control to sustain the now stand-alone grid. It is important to highlight the converter is always in voltage source mode and does not switch between current and voltage source mode, resulting in the uninterrupted transition seen in Fig. 6. The inertial response is always active and supports the transition and the VSM layer seen in Fig. 7 allows tuning and switching of control circuits to meet various competing requirements through implementing 'blended' control configurations.

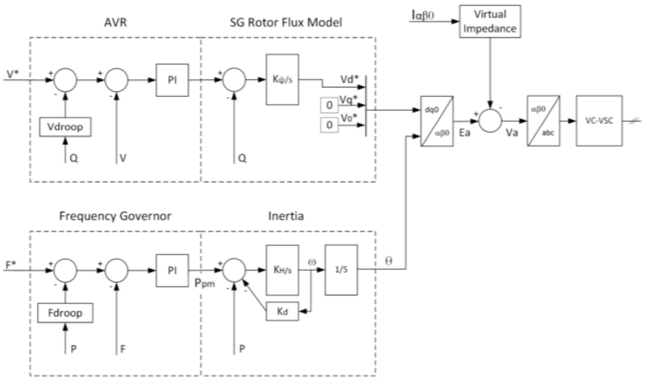

Fig. 7. Five-part Virtual Synchronous Machine control diagram, the primary control on the BESS grid-forming converter [6].

It is important grid codes around the world not only ensure safe and stable interactions with the grid but also enable new and advanced operation of converter technology that can offer superior performance and grid services such as those discussed here. Performance based standards rather than prescriptive standards will be critical for innovative solutions.

4 Conclusion

The ATCO Clean Energy Innovation Hub was commissioned in July 2019 and has operated to improve site reliability, maximise renewable hosting capacity, extract tariff benefits and above all, create green hydrogen from excess on-site solar generation. The project successful demonstrated the seamless integration of hydrogen production and renewable electricity generation [1] as well as the broad array of services a behind-the-meter microgrid can deliver. This was achieved through combination of a grid-forming BESS and a real-time microgrid control system to support an industrial facility in achieving lower energy costs, lower greenhouse emissions and improved reliability. This paper presents how the various assets within the microgrid are controlled to deliver these services.

In the pursuit of green hydrogen to further decarbonise energy systems around the world, the CEIH microgrid highlights the importance of the microgrid control system to ensure all energy used to generate hydrogen is from a renewable source, that these renewables are maximised and the microgrid is managed in a way that meets existing site operation requirements and distribution utility rules. The ability to ensure hydrogen generation can follow renewable generation will become an ever more important feature as more and more un-dispatchable renewable generation is added to the power system. While there continues to be a large focus on lower battery and technology costs to enable commercially viable BESS and microgrids projects, the CEIH microgrid shows that sophisticated control can deliver value to a commercial and industrial site, and local distribution system by stacking a variety of services and value streams to maximise the investment.

ATCO Gas are currently considering further enhancements to the CEIH microgrid which include engaging in demand response programs, to absorb excess solar generation on the local distribution network by increasing load and charging the BESS at certain times. This would be enabled by adjusting the existing microgrid control system. Finally, ATCO Gas are investigating the addition of a hydrogen re-fuelling station for hybrid vehicles to reduce greenhouse gas emissions in the transport sector by supplying them with 100% green hydrogen.

5 Acknowledgements

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6 References

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