DSO Microgrid in Southern Sweden

Control, operation and management of power quality within a zero interia microgrid

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***Abstract*— In December 2017, E.ON commissioned a microgrid in Simris, in the south of Sweden. The first full week of islanding was successfully completed on the 16th of March 2018. The microgrid is embedded in the existing distribution grid where a complete bay of a primary substation with 150 customers is being islanded during specific test weeks. The generation sources in the microgrid consists of solar, wind and a combustion engine generator which runs on renewable fuel and is only intended as a back-up source. In addition, a Battery Energy Storage System (BESS) is included in the system and is responsible for power balancing in island operation. Results have shown that the system is capable of seamless transition from grid connected to island operation and vice versa. It has also been shown that the system is fully capable of maintaining frequency, voltage and Total Harmonic Distortion (THD) well within limits. The microgrid is, when running without the generator, a zero-inertia system and results have shown that the BESS is fully capable of handling load steps such as losing the largest generator asset in the system. The long-term stability of the system has been verified when the full first test week was successfully completed.**

Keywords – Battery, Energy Management System, zero-inertia microgrid, THD, seamless transition.

I. INTRODUCTION

The power system is changing, from being a one-directional system where loads where supplied from centralized generation resources, to a bi-directional network where the share of Renewable Energy Systems (RES) are increasing rapidly which have led to new challenges and opportunities for distribution networks. The fact that generation is distributed gives the network owner more options in terms of solving issues, caused by the RES, locally. Often in traditional power networks, a fault or issue in one part of the network affects the rest of the network as well, sometimes leading to cascade trips. With modern inverters and Battery Systems, it is possible to perform active and reactive power regulation and hence local balancing both in grid-connected and in full island-mode with seamless transition. The versatility of the microgrid makes it possible to provide ancillary services to the main network. All of which will be demonstrated in the project.

II. SIMRIS MICROGRID

The microgrid in Simris comprises 5 km of medium Voltage (10kV) cables, supplying 150 customers across five secondary substations (10/0,4 kV), with 11 km of low voltage cables. In addition, a wind turbine generator and a PV-plant are connected to the medium voltage through their own secondary substations. The microgrid is part of an open ring network so has a single point of connection to the primary substation, as shown in Figure 2. The load profile of the microgrid point of network connection is shown in Figure 1. On an annual energy basis, the load and generation are approximately equal.

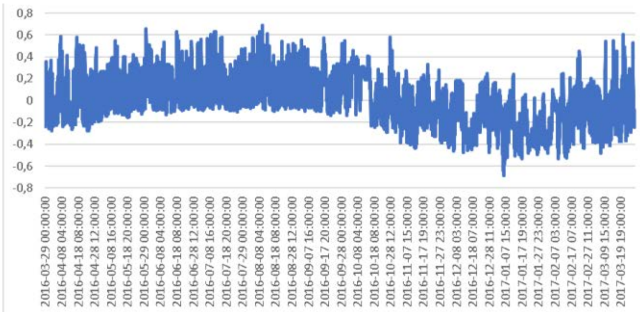

Figure 1 Active power exchange at PCC March 2016-March 2017

The PV plant was commissioned in 2012 and has rated capacity of 442 kW. It consists of several SMA Sunny Tripower 17000TL inverters, connected in parallel to a dedicated transformer. To allow monitoring and control of all inverters, an SMA cluster controller is utilized.

The second power source is an Enercon E40 wind turbine, rated at 500 kW. It is approximately 20 years old and connected to the grid through three inverters operating in parallel and its own transformer.

A combustion engine generator, running on renewable fuel, has been installed in addition to the renewables to allow prolonged operation islanded from the grid. The engine is rated at 480 kW.

While the generation and load are approximately equal over a year, these vary significantly on an intraday and seasonal basis, where the BESS proved the energy buffer, absorbing or delivering the imbalance load and generation while performing managing the voltage when the system is islanded. The BESS consists of Lithium Ion batteries with a capacity of 330 kWh and a power converter rated at 1 MVA, with its own transformer to the medium voltage network.

To connect the assets, a new substation was deployed. The substation contains four bays and all the necessary equipment for control of the microgrid, such as elements of the Energy Management System (EMS), Remote Terminal Unit (RTU), Protective relays (which operate against different setting when grid connected and islanded), and communication interfaces. In Figure 2, the substation is illustrated as the green box.

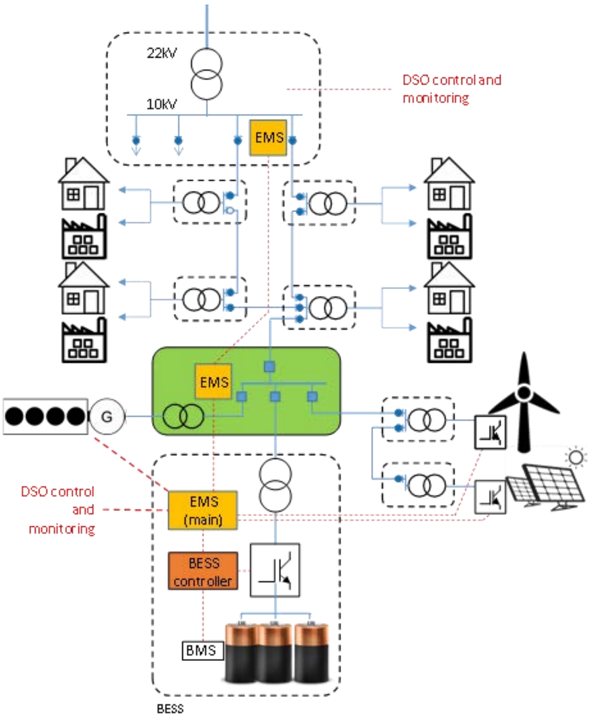

Figure 2 – Schematic over microgrid in Simris

III. FREQURNCY- AND VOLTAGE CONTROL

When grid-connected, the BESS system operates as a grid-following inverter, where the EMS sets the real and reactive power delivered to the grid. On operational mode is “virtual island”, where the BESS power is controlled such that the real and reactive power at the point of network connection are near zero. To enable the transition to island the BESS is set as a voltage source with droop for both power as a function of frequency and VARs as a function of voltage. This mode allows operation both when grid connected and when islanded. The transition from grid-connection to islanded is managed by the EMS controlling the voltage and frequency targets such that the real and reactive power across the PCC is near zero by tracking the grid frequency and voltage. Once within predefined limits, the EMS opens the circuit breaker and islands the system.

When islanded, the droop control within the battery inverters allows the frequency and voltage to vary as a function of real and reactive power changes within the microgrid, with the EMS updating the target voltage and frequency targets for the BESS to maintain the nominal 50Hz / 10.7kV. Changing the droop percentage would allow power sharing between other generation sources if they were also in droop control. At the test site, all the other generation sources are controlled to operate at a constant power - the renewables at their maximum available power and the backup generator at a constant power, so the droop is not actually required when islanded. A viable alternative approach to control would be for the EMS to update the droop percentage when islanded to zero, in which case the BESS would be a stiff voltage source, supplying exactly 50Hz, 10.7kV to the medium voltage network. The droop would need to be re-enabled during re-synchronization to avoid the BESS tripping immediately after reconnection.

Another alternative control approach when islanded would be to maintain constant frequency and voltage targets and a relatively tight droop percentage. In this case the frequency would reflect the charge / discharge power of the battery when islanded and the voltage would reflect the reactive power from the BESS.

Each of the control approaches have their relative merits in the control and operation of the microgrid. Leaving the BESS in droop control while updating the target frequency and voltages targets has been selected as the best compromise between power quality and offering future demand-side response assets visibility of power imbalance through the frequency variation. As frequency variation can be measured in milliseconds, this allows other assets to respond without the need to expensive high-speed communication systems.

IV. RESULTS

The microgrid hardware was commissioned during 2017. After installing the major components, there were several months of testing and parameter tuning for the BESS and EMS operating in parallel with the wind turbine, solar generation and backup generator only, isolated from all customers. A load bank was used to replicate the customer load and to test the effect of large load steps.

Testing also demonstrated that the battery system can deal with a fault on any LV circuit by creating several short circuits with 63A fuses.

In December, the circuit breaker at the PCC was opened and customers were taken off-grid for the first time, with their supply being provided by the local renewable generation and battery system only, with zero inertia in the local power system.

When operating in island mode, frequency, voltage and currents and all measured and if there are any issues with the power quality the EMS will immediately attempt to resynchronise with the network. If this is not possible for any reason, the BESS is shut down and the network connection point is restored.

A. Power quality when operating as an island

When operating as an island, the BESS is responsible for managing the power quality within the network to be within the required Voltage, frequency and THD limits. As the BESS operates in droop for both voltage and power, the EMS continually trims the target voltage and frequency values to the BESS such that system nominally operates at 50Hz, 10.7kV

Results of the commissioning tests 13th December are shown below. The system was islanded several times across the day, and resynchronised to the network, with the power delivered to customers being within the required limits 100% of the time. Figure 3 and Figure 4 show the frequency and power when operating as an island 11:06 – 11:15. During this time, the BESS state of charge reduced to the threshold at which the backup generator started, synchronised and ramped to 350kW nominal power to charge the battery. During the generator on-loading the frequency increased to 50.16Hz while the EMS was reducing the target frequency for the battery to target 50Hz.
At 11:11:30, the wind turbine tripped from delivering full power of 500kW and the BESS allowed the frequency to reduce by around 225mHz, subsequently recovering. The inertial contribution from the Backup generator was up to an additional 30kW for around 5 seconds, returning to nominal power once the BESS had stabilised the frequency. The EMS subsequently trimmed the frequency back to 50Hz. The customer load remained relatively constant at 500kW across this test period. The droop and control parameters have subsequently been further tuned so that for similar future events the frequency variation will not exceed 150mHz.

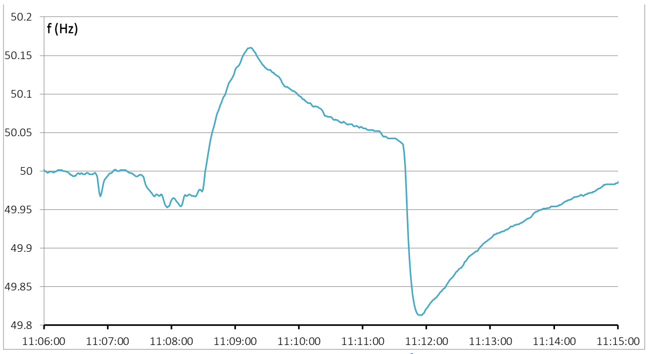

Figure 3 frequency from islanding test 13th December 2017

Figure 4 Power from islanding test 13th December 2017

The THD across the three line-line voltages is shown in Figure 4. When the BESS was connected to the network, the THD reduced from 1.5% to 1.3%, attributable to the BESS filter capacitance offering low impedance to harmonics. When Islanded, the THD was slightly higher than when grid-connected, at up to 1.9%, still well below the 8% requirement imposed by national standards. The THD is also seen to vary inversely with wind turbine power, which could be attributable to the hysteresis current controller in the wind turbine power electronics delivering lower frequency current harmonics at lower powers. The Voltage during the same period is shown in Figure 5, which shows the voltage being more tightly controlled when islanded than when grid-connected.

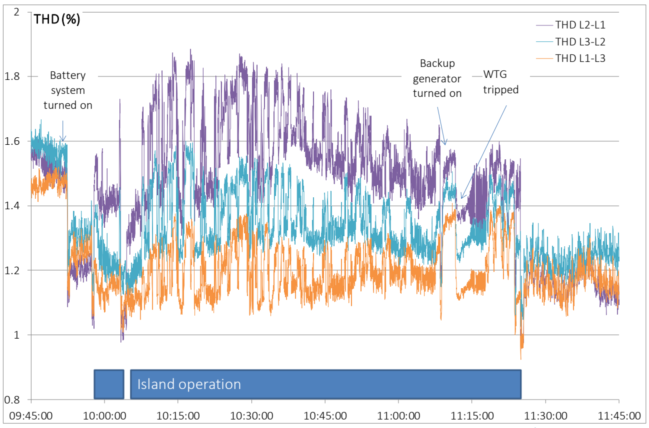

Figure 4– THD when islanded and grid connected 13th Dec 2017

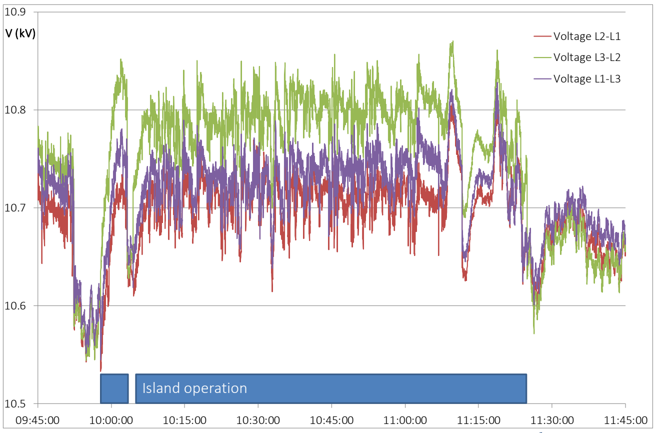

Figure 5 Voltage when islanded and grid connected 13th Dec 2017

During the commissioning in December, customers in Simris were transitioned to island over 20 times, and parameters for the BESS and EMS were optimised for the best compromise between performance, smooth transitions, voltage and frequency variation when islanded and speed of reconnection.

B. Electrical protection and fuse operation when islanded

Fault clearance is a critical issue and a concern for protection within a microgrid where the potential fault current is both significantly lower than when grid-connected and has different characteristics, where the BESS fault current is limited to a fixed value regardless of fault location as oppose to a conventional synchronous generator being a voltage source where the fault current reduces with impedance between the generator and the fault.

To account for the difference in fault current contribution, the substation connecting the generation sources to the network has relay protection on each circuit breaker, each with two setting groups, changing between the settings based on the status of the network connection.

A critical protection requirement is that the microgrid can clear a fault within 500ms and restore the voltage. During system commissioning, several faults were created on the LV side of a substation, protected by 63A fuses. The tests included single-phase and three-phase faults, and were repeated for all possible generation combinations. In all cases the fault was cleared within 100ms and the voltage transiently reduced by no more than 15%.

To mitigate the risk that the BESS is unable to provide sufficient fault current to clear a fault, the BESS fault current contribution is limited to 1s after which the BESS will trip. If the BESS does not trip and continues to deliver fault current, after 2s the protection in the substation will trip. This multiple-layered approach to microgrid protection results in the microgrid operating safely regardless of the grid conditions.

C. Extended testing and integration of DSR

The microgrid is controlled to operate as an island for as many hours as possible for one week in every five. The time between the tests allows data processing and any further tuning and system optimisation before the next run.
The state of charge for the BESS during of the test days on the 6th March is shown in Figure 6. For this day, the renewable generation was low and the consumption high, so the backup generator was operating almost half the time. Figure 6 shows the BESS cycling between the setpoints for starting- and stopping of the generator.

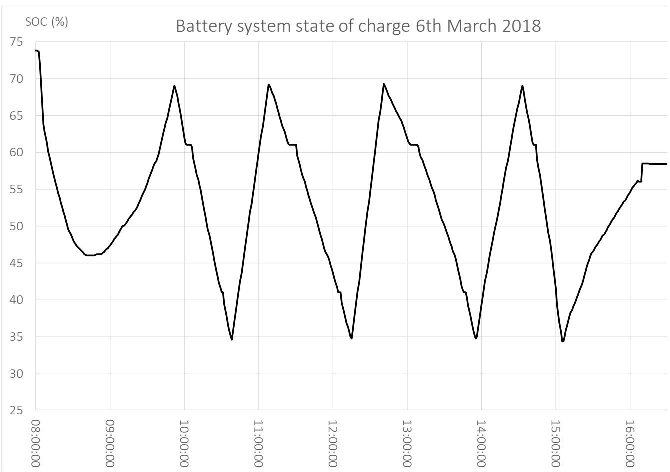

Figure 6 BESS SoC 6th March when the system was islanded 08:00 – 16:00

As part of the EU Horizon 2020-funded Interflex programme[1], some customers in Simris are taking part in a trial to test the efficacy of allowing flexible power generation and load to prolong island operation by matching consumption against generation. Interflex has part-funded the installation of residential batteries, heat pumps and control devices for residential hot water heaters, and an additional control system is being developed to make best use of these flexible resources without compromising comfort within the houses. These flexible assets will come online throughout 2018 and the five-weekly testing will show how effective demand side response can be in supporting the microgrid.

V. Summary

Tests have shown that it is fully possible to island a village with roughly 150 customers and around 750 kW peak load with only renewable generation and a BESS, with zero inertia. The microgrid can maintain frequency and voltage well within imposed limits and handle big load steps such as onloading of the combustion generator engine and the intermittent power variation of the renewables, including tripping from full power.

In addition, tests have confirmed that seamless transition is possible and since commissioning, the village has been islanded 25-30 times with no reduction in the integrity of customer supply.

The total harmonic distortion, which was a big concern in the system design phase since the two renewable sources were connected through power electronics, stayed well below the regulatory limits, although it was slightly higher in island-mode compared to normal operations.

The limitation of the system to island for prolonged periods without on renewables only is the limited energy of the BESS, making it necessary for onloading of the combustion engine generator to support and extend the time in island mode. The size of the BESS, being the most expensive asset, was a conscious design choice to keep the project costs manageable while demonstrating all the required functions and transitions since Simris does not have issues with the traditional supply of electricity. The goal of the microgrid in Simris is to validate the functional capability of all systems and not to be able to run in island mode always, which would require a battery with several hundred times the capacity.

Tests have shown that the system can manage big load steps, with the combination of the EMS and BESS controllers managing the frequency and voltage. For a 500kW load step due to the wind turbine tripping presented in Figure 4, the inertial contribution from the synchronous generator was around 30 kW. Testing of the load step without customers connected showed that the BESS can manage the 500kW load step and the test will be repeated with customers connected with no synchronous generation, where the results are expected to be full compliance with all required power quality during the load step with zero inertia in the system.

[1] http://interflex-h2020.com/