FIELD TEST ON A DSO MICROGRID IN SOUTHERN SWEDEN – DESIGN AND CONTROL ASPECTS

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ABSTRACT

In autumn 2017 E.ON has launched a microgrid in Simris in the south east of Sweden. The microgrid covers a part of the existing distribution grid with roughly 150 costumers. As generation sources a PV plant and a wind turbine generator are available as well as a combustion engine driven generator for backup purpose. Power balance is achieved by a battery energy storage system. The main goal of the field trial is to demonstrate the possibility of running a microgrid in island mode without any spinning resources and seamless transition from grid connected to island operation and vice versa.

INTRODUCTION

With an increasing amount of photovoltaics and wind power, i.e. a higher share of Distributed Energy Resources (DER), distribution networks have been facing new challenges during the past years. From being purely passive grids with unidirectional power flow they have evolved to active grids with possibly bidirectional power flows. Thus, when the share of power supply from large units with synchronous generators decreases, ancillary services have to be provided by other sources. Further on the requirements regarding the reliability of electricity supply have been increasing as well.

Microgrids are aggregating production, consumption and storage units in a small area to cope with the challenges of future distribution systems but also permit customers to be active participants. Design and control of the microgrid are the main challenges to be faced.

The Local Energy System in Simris was designed to test and verify the following:

- Battery Energy Storage Systems (BESS) acting as grid forming units fully capable of maintaining frequency and voltage control within limits imposed by the operator.
- BESS able to provide ancillary services to the main grid (mainly voltage control through reactive power injection/consumption in Simris case).
- Renewable Energy Resources (RES) can be connected and operated alongside a BESS system.
- The Local Energy System (LES) can run autonomously in island mode with seamless transition from grid connected to island mode and vice versa.
- The LES can provide adequate system stability although it is a system completely without classic inertia.
- The LES can provide enough fault current to ensure relay and fuse operation and thus safe conditions for being around the system.
- The power quality in island mode and during transition is fully compliant with relevant standards and requirements.
- By adding Demand Side Responses (DSR) in a second phase, the total time in island mode can be prolonged without increasing the size of the BESS.

The decision to create the LES in Simris was based on the favourable conditions in that location with existing RES connected to the grid and a load which on an annual energy basis was nearly equivalent to the RES generation. It is important to highlight that Simris does not have issues with the traditional supply of electricity, which is why the decision was made to have a smaller BESS energy wise but to make sure that the BESS could run entire Simris power wise. The goal of the LES in Simris is to validate the before mentioned use-cases and not to be able to run in island mode at all times.

MICROGRID SIMRIS

E.ON has built up and put in operation a microgrid in the South of Sweden during 2017. The microgrid described below is located in Simris, a small village close to the east coast.

System Design

The area of the microgrid Simris includes eight secondary substations from 10 kV to 0.4 kV and includes in total roughly 5 km of medium voltage cables at 10 kV and about 11 km of low voltage cables at 0.4 kV where the customers are connected.

On the load side the microgrid consist of around 150 mainly residual electricity customer connections which are distributed along five secondary substations located in or close to the village Simris. In the initial phase of the project the customer load is not controllable.

The PV power plant is ground mounted and has a rated capacity of 440 kW. The PV power plant is built up of several strings with dedicated inverters which are interconnected on the AC-side at the 0.4 kV level. All converters together are controlled by a PV plant controller which amongst others allows limiting the active power output of the PV plan. Grid connection of the PV power plant is realized by its own 10/0.4 kV secondary substation.

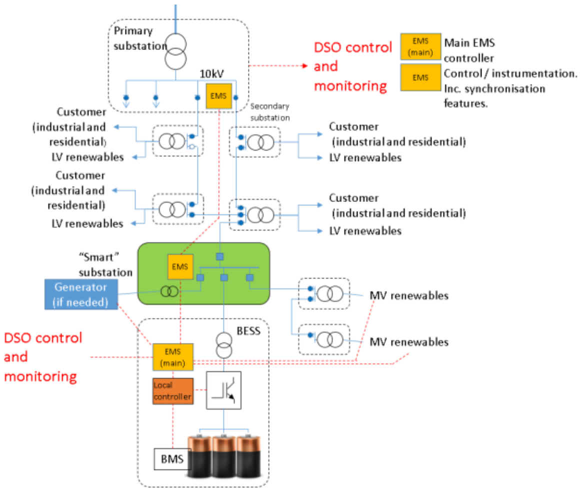

Figure 1 Overview over microgrid Simris.

The wind turbine generator has a rated capacity of 500 kW and is connected to the grid by a full-scale back-to-back converter. Thus, both active and reactive power output from the wind turbine can be controlled very flexible. However, in the microgrid Simris only active power control is used. The wind turbine generator is connected to the medium voltage grid at the 10 kV level via its own secondary substation.

The third power source in the microgrid is the combustion engine driven generator with a rated capacity of 440 kW. Power conversion from mechanical to electrical power is provided by a synchronous generator. Therefore, active and reactive power output from the generator could be controlled quite widely. The generator is connected to the microgrid on the low voltage level at 0.4 kV and sharing a secondary substation with other assets.

To balance between load and generation as well as for voltage and frequency control in island operation, the microgrid is equipped with a BESS. The BESS contains a stack of lithium ion batteries with a capacity of 330 kWh and a power converter at 750 kVA.

In grid connected mode the microgrid Simris corresponds to one feeder of the feeding substation. Thus, the PCC of the microgrid is the bay in the feeding substation.
In island operation during most of the time the combustion engine driven generator is not in operation and therefore the system is purely fed by devices that are grid connected by power electronics and without rotating mass and traditional inertia.

Challenges

When operating parts of a traditional distribution system as a microgrid some challenges will arise. These challenges are mainly issues that are normally solved on a higher level of the interconnected power system.
In distribution networks, which are a part of the interconnected power system for example, power balance is normally not an issue as the necessary power at every moment is provided from the upstream network. However, in a microgrid operated in island mode the power must be provided locally and balance between consumption and production must be reached. Especially in systems with a high share of intermittent sources, where not only load but also generation varies a lot, a balancing unit is needed. The power exchange at the PCC of the microgrid Simris during the year 2017 is shown in Figure 2.

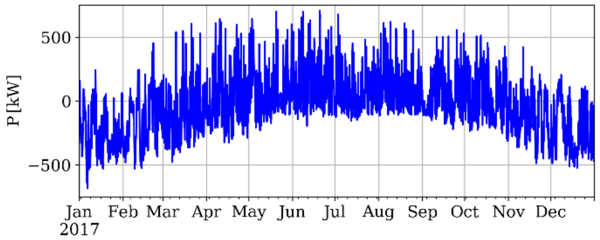

Figure 2 Active power exchange at PCC during 2017.

The power system frequency is usually assumed to be determined by the upstream power system, usually the TSO. In a microgrid disconnected from the external grid, this assumption is no longer valid and frequency needs to be maintained locally. Thus, the operator of the microgrid, e.g. the DSO, becomes responsible for frequency control during island operation.

While large power systems often have numerous synchronous generators contributing with rotating mass and inertia and accordingly provide a stable power system, this is not the case in a small microgrid where all sources are connected by power converters. Therefore, power balance and frequency control are specifically sensible.

CONTROL STRATEGY

Controlling the different assets of a microgrid is one of the most challenging tasks when operating a microgrid.

Control System Overview

There are multiple levels of advanced control systems for the BESS and for the microgrid, these can be divided into the following subcategories:

- Battery Management System (BMS)
- BESS local controller (BLC)
- Energy Management System (EMS)

For an overview of different components and their interconnection see Figure 1.

BMS

The BMS monitors each of the 1344 cells and calculates both SoC and charge and discharge limits, both of which are communicated to the BESS Local Controller. The BMS will isolate the battery if these limits are exceeded.

BESS Local Controller

The BESS local controller interfaces towards the BMS system and towards the EMS. In the Simris application the BLC has only protection automation enabled, meaning that it communicates and receives information from the BMS controller and can shut down the system in case of any issues. There are no microgrid functionalities, only trivial grid connected control functions implemented meaning that it is possible to set set-points for active and reactive power.

Energy Management System

The energy management system serves as the main controller in the microgrid control system. It consists of industrial hardware located in the BESS shelter, DER-substation and in Simris primary substation. In each location, the EMS has access to relevant information, such as measurements from current and voltage transformers, indication of status from power breakers and disconnectors. In addition, the EMS has direct control over the power breaker at the point of common coupling so that it can command island mode by switching of the breaker when certain requirements are fulfilled.

The RES generation is also controlled by the EMS which can demand the RES to be curtailed if the BESS State of Charge (SoC) reaches certain levels. During times of high demand and low generation, the EMS can demand the combustion engine driven generator to be activated and extend the time in island mode.

The high-level control sequence can shortly be described in the following way:

1. Operator demands the EMS to initialize island mode which includes the BESS operating as a voltage source.
2. The EMS controls the BESS power such that the power over the PCC is near zero (virtual island).
3. When the power over the PCC is within acceptable limits, the EMS demands the power breaker at the PCC to be opened.
4. The EMS utilizes droop control for frequency and voltage regulation. The frequency and voltage targets for the BESS are set such that 50 Hz and 10,7 kV are achieved nominally.
5. If enabled, the EMS will demand the generator to be synchronized to the microgrid at low BESS SoC and to go offline when the BESS has reached a sufficiently high SoC.
6. At high SoC, the EMS will demand the RES to be curtailed. The curtailment logic is illustrated in Figure 1.

The Operator can at any time initialize resynchronization to the grid. The EMS will set appropriate voltage and frequency targets for the BESS and demand the breaker at the PCC to be closed once the following conditions are fulfilled:

- Voltage difference across PCC < 150 V
- Frequency difference < 0,05 Hz
- Voltage angle difference < 8 degrees

Operation

The operation strategy for the microgrid is quite simple and has been partly integrated into the ordinary SCADA of the DSO. From the SCADA, the operator has visibility of:

- P,Q,U,I in each of the bays of the DER substation and at the PCC.
- Frequency from voltage transformer in bay 3 in DER.
- BESS SoC and generator fuel tank level.

In addition, it is possible to switch on and off all power breakers in the DER substation and at the PCC as well as emergency stop the EMS in case of severe malfunction. The microgrid control and modification of settings is done through the EMS-HMI and is not a part of the DSO SCADA.

RESULTS

Fault clearance and fault ride through

One important functionality of the microgrid is the potential of fault clearance and fault ride through.
In traditional power systems large generators with inertia are available and can provide major currents in case of short circuits or earth faults. Units connected via power electronics normally have a lower fault current contribution, limited by the design of their power converters.
However, achieving a fault current which is sufficient for fault clearance is essential also in microgrids.
In the microgrid in Simris fault protection in the low and medium voltage network is implemented by fuses. Thus, the ability of operating fuses with the fault current provided by the BESS is of great importance. The results from such a short circuit test are shown in Figure 3.

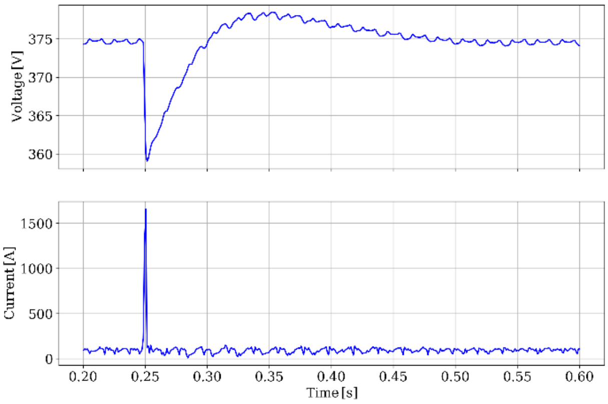

Figure 3 Voltage and current at LV side of the BESS during a single phase short circuit.

Voltage and Frequency Control

As previously mentioned, droop control is used for frequency and voltage regulation. In Figure 4, the frequency during the first full-scale islanding test during commissioning is illustrated. The system was stressed by tripping the WTG, being the largest generator asset in the system. For the EMS/BESS that is a 500 kW instant step change in load. The generator was also synchronized to the micro grid during the test. The three-phase voltages are illustrated for the same test in Figure 5.

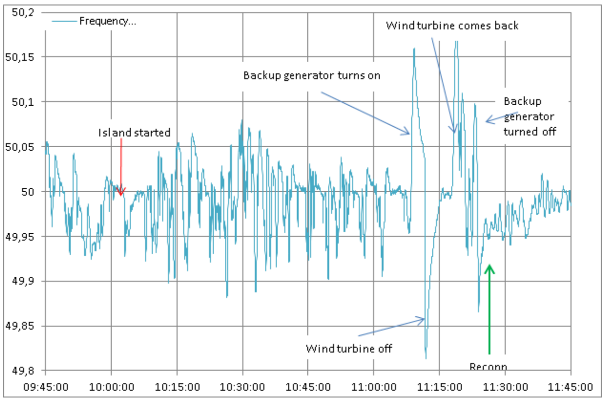

Figure 4 Frequency during transition from grid connected to island mode.

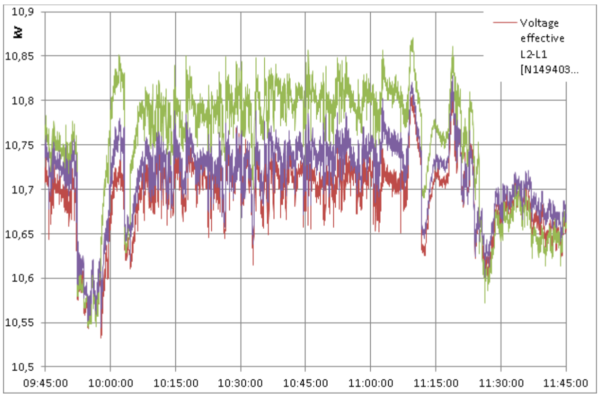

Figure 5 Voltage during transition from grid connected to island mode.

The 6th of March was the second day of the first full test week where Simris was islanded every day. The blue line in Figure 6 illustrates the frequency and the red line the active power exchange with the grid before and after islanding. The frequency spikes during the day are caused by the generator being synchronized to support the active power need of the system and the generator going offline when sufficient SoC was reached. The three-phase voltages during the day are illustrated in Figure 7.

SUMMARY

So far, in the field test it has been shown that it is possible to design a microgrid based on an existing distribution network and operate a grid purely based on sources connected by power electronics.

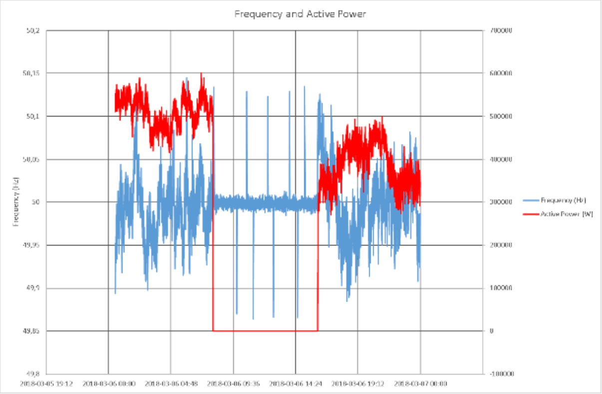

Figure 6 Frequency and active power exchange at PCC during one day of island operation including transition phases.

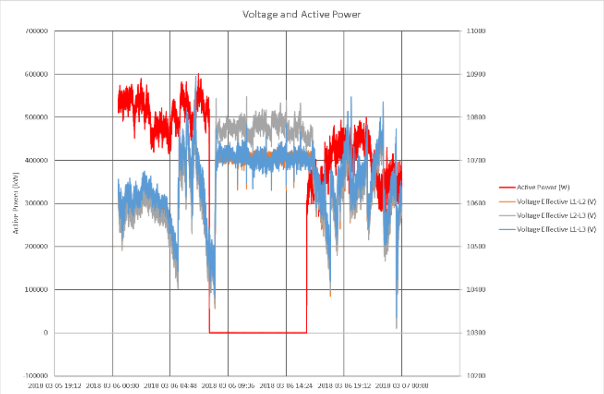

Figure 7 Voltage and active power exchange at PCC during one day of island operation including transition phases.

Another challenge that has been solved is the seamless transition from grid connected to island operation. In grid connected operation the microgrid can support the overlaying distribution network with ancillary services. The recent implementation of the control system allows controlling the active and reactive power at the PCC. However, by upgrading the energy management system this could be turned into voltage and frequency support. But also other use cases as peak shaving and congestions management are possible. In island operation, the system can supply the customers even though there is an outage on the upper part of the grid and thus increase the reliability of the supply of electricity.

However, as expected it is not possible to run the microgrid autonomously in island operation over longer time periods under all conditions. The power production from the PV plant and the wind turbine generator is too little compared to the load especially during winter time with high load and low output from the PV plant. The storage capacity of the BESS is not sized to supply the system during longer periods of power shortage.

REFERENCES

[1] EN50160, 1999, Voltage Characteristics of Electricity Supplied by Public Distribution Systems, IEC standard voltages, Belgium.