DEMONSTRATION OF FLEXIBLE AND ROBUST USE OF LARGE SCALE BATTERY STORAGE IN LOW VOLTAGE DISTRIBUTION NETWORK WITH HIGH PENETRATION OF DISTRIBUTED GENERATION

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ABSTRACT

Rapid emergence of distributed energy resources (DER), installed mainly in low voltage networks, poses new challenges to distribution system operators (DSO). Besides regular voltage quality provision, load balancing solutions are becoming one of the most important future DSO operational concepts.

Rapidly developing storage technologies are without no doubt one of the future balancing solutions and already paving its way into distribution low voltage networks. Elektro Gorenjska d.d. (EG) is an active partner of STORY H2020 project titled "Added value of STORage in distribution sYstem" and strongly contributed to demonstration of a flexible and robust use of a large-scale battery energy storage system (BESS). The storage is currently installed in residential type of low voltage network with high penetration of distributed generation.

During the project, different storage functionalities will be implemented and tested, compared and evaluated for future large-scale storage implementation. Article summarises different demonstration outcomes and shares the lessons learned.

INTRODUCTION

EG significantly contributed to demonstration of large scale Li-Ion storage, as being defined within the scope of the EU H2020 STORY project. Two types of low voltage networks with specific load diagrams were chosen for demonstration, first a residential and second an industrial low voltage type of a grid.

Low voltage residential network with a high penetration of photovoltaics (PV) has been chosen as a first demonstration site. The operation of high number of photovoltaic power plants during sunny days results in a mid-day production load peak of up to 180 kW, being almost equal to consumption peak during mornings and evenings. The storage was connected directly to 400 kVA busbar of distribution transformer with OLTC in order to compensate transformer peak loads. To enable the storage demonstration, a number of interesting network subsystems were implemented. Besides BESS, real time monitoring system for enhanced network observability, local demo SCADA system for network control and up to date ICT system based on WiMAX broadband radio were some of them.
As the result of STORY project activities, five different demonstration functionalities were implemented.

DEMONSTRATION POYLGON

Demonstration location

Suha village low voltage network, located near Kranj, represents the first demonstration site. It is an example of a 0,4 kV rural cable network with 7 photovoltaic power plants installed. There is a peak load in the morning and evening hours andthe peak PV power production during the day, resulting in high production peaks, feeding energy into MV grid during sunny days. Figure 1. depicts typical transformer and PV production daily diagram.

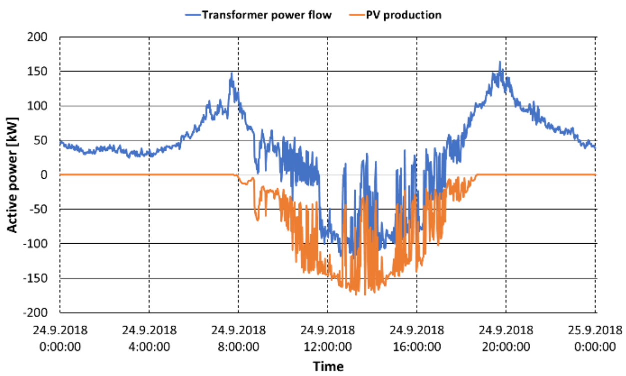

Figure 1: Distribution transformer power flow and PV production diagrams.

Battery energy storage system specification

Dedicated BESS has been designed and produced by ABB project partner with the following salient features, depicted in Table 1.:

Installed Power (kW)	170 kW @400 Vac
Range of Power Factor	Fully inductive to fully capacitive 100% P(kW) or Q(kvar)
Total Installed Energy (kWh)	552 kWh @ BoL – Beginning of life
Total Usable Energy BOL - 4wires	450 kWh @ BoL (discharge 1 C)
Efficiency (BOL) measured	87 %

The storage outdoor solution comprises the battery compartment, inverters, control cubicles and heating, ventilation and air conditioning system. The BESS was placed adjacent to Suha transformer station and directly connected to transformer low voltage busbars. The demonstration site depicts Figure 2.

Figure 2: Demonstration site.

Demonstration setup

Storage demonstration follows a thee layer concept. Primary, local layer, consist of a storage device as a physical entity, and in order to minimise energy losses, situated besides transformer station. The storage low voltage output is directly connected to transformer low voltage busbars via point of common coupling cabinet, which serves as intermediate point for network protection and visual separation in case of maintenance of the system.

On the secondary level, demo system control and data acquisition (SCADA) system with remote main controller unit (MCU) provides a platform for complete system control and surveillance. MCU, as the front-end processor, executes the algorithm and controls BESS programmable logic controller (PLC) and is installed in the transformer station as well. MCU and BESS PLC are directly connected with network cable in order to ensure maximum communication reliability. SCADA serves as a data collection and remote-control support. It collects and processes all demo signals for later analysis and enables complete remote control of MCU and BESS itself. Remote control with different levels of authorisation enables complete system insight. SCADA additionally collects sun radiation forecast retrieved from Slovenian Environmental Agency and provides communication with tertiary layer.

Following project definitions, BASeN project data server on tertiary layer, provides complete data back up and computational platform for demonstration key performance calculations.
Communication and protocol scheme is depicted on Figure 3.

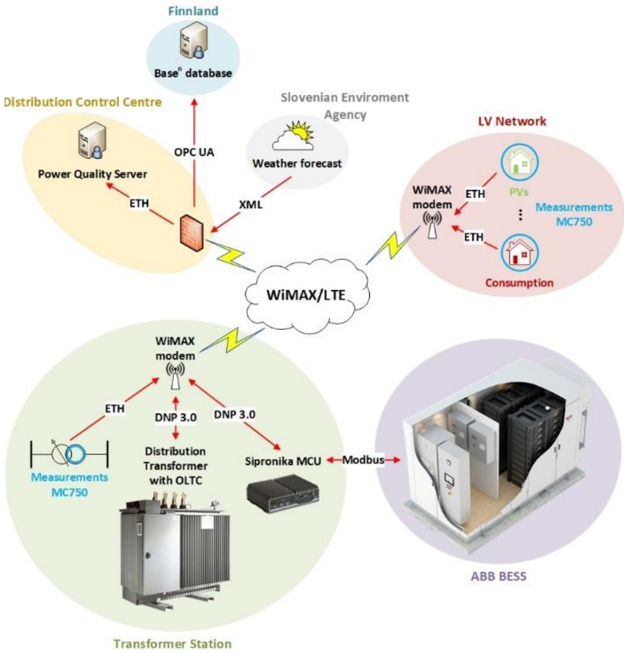

Figure 3: Protocol and communication scheme.

Integration of a variety of EG technological subsystems and ABB storage as well required the utilization of three different standardised protocol. Modbus for communication between MCU and BESS PLC, DNP3.0 for SCADA to MCU and OPC UA for the communication between SCADA and tertiary layer.
EG private WiMAX broad band network provided the basic communication platform for the dispersed device locations.

BESS functionalities

According to project definitions, EG demo will provide the following functionalities:

- Transformer load management (peak shaving and shifting),
- Reactive power compensation,
- Tertiary reserve,
- Harmonic compensation,
- Zero load provison.

Transformer load management

Peak load shaving represents the main BESS functionality, also providing the major impact. Within the STORY project, the peak shaving control algorithm was developed by Faculty of Electrical Engineering, University of Ljubljana. According to high PV penetration and the unpredictable impact of local production, the utilization of sun radiation forecast was mandatory. The 36 hours ahead sun radiation forecast is provided by Slovenian Environmental Agency every six hours.

Based on the past three year transformer load measurements and past three year solar radiation data, the 360 reference daily load/sun radiation related diagrams were defined.

The real-time control algorithm, receiving updated sun radiation forecast every six hours, firstly determines the reference transformer load diagram choosing out of 360 predefined for the next 24 hours. On that reference, and taking the state of the charge (SoC) of the BESS into account, algorithm calculates and determines the peak shaving maximum and minimum allowed values. By comparing real time transformer loads and predefined max/min values, the set points for BESS activation are send from MCU to BESS PLC on one minute interval.

The peak shaving algorithm on Figure 5. and real-time control measurements on Figure 4. represent BESS 24 hour operation far a sunny day, when the BESS is charged only during mid-day. It is evident, that a real-time diagrams on Figure 4. perfectly match the calculated reference diagrams shown on Figure 5..

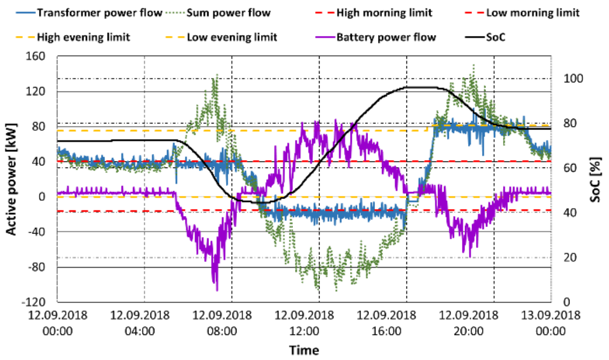

Figure 4 : Real-time diagram for a sunny day.

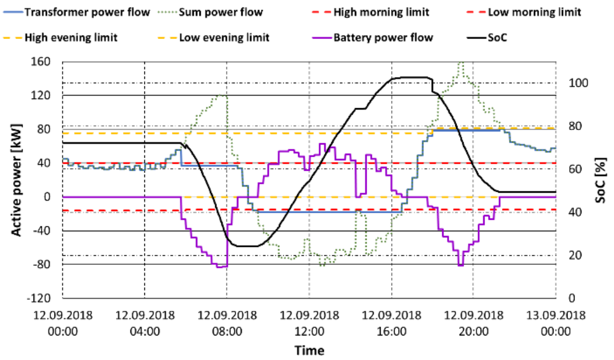

Figure 5: Reference (calculated) diagram for a sunny day.

Figure 6. and Figure 7. represent BESS operation on a foggy day, which is the case, when BESS recharges during night low energy tariff.

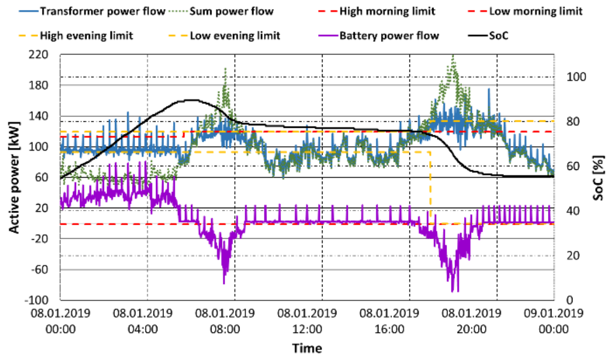

Figure 6: Real-time diagram for a foggy day.

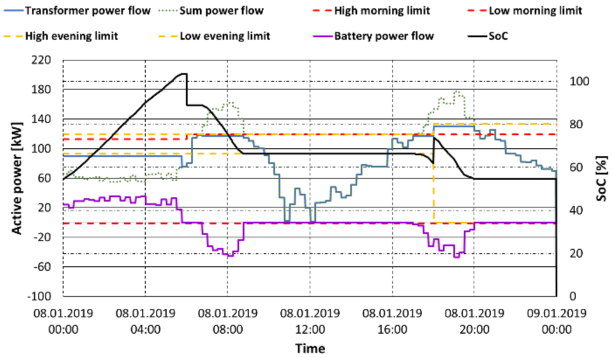

Figure 7: Reference (calculated) diagram for a foggy day.

Reactive power compensation

BESS can provide fully inductive to fully capacitive load, what will be exploited for transformer reactive power compensation. By defining maximum and minimum allowed transformer reactive load, MCU automatically calculates and sends related set points to BESS PLC, based on the real-time load measurements.

Zero load provision

According to STORY project specification, no off-grid (islanding) operation is foreseen, even BESS itself could support that kind of operation. In order to support the idea of self-sufficiency, a zero load provision functionality is additionally introduced. Zero load algorithm, based on the real-time measurements of transformer load and SoC of the battery, will establish the zero transformer load as long as the battery capacity would allow that kind of operation.

Tertiary reserve

Tertiary reserve represents an important TSO mechanism for frequency support. By accumulating and preserving the predefined level of storage capacity, that amount of energy can be deployed on TSO tertiary reserve request. Even the injected tertiary power, related to time of deployment and capacity available is relatively small, will prove the utilization of storages in case of large scale of future storage utilization.

Harmonic compensation

One of the important BESS inverter functionalities represents current harmonic compensation. Based on transformer current THD measurements, the set points for maximum level of 20 single harmonics can be determined. The current harmonic compensation functionality has been tested and proved during site acceptance tests, but during the demo, the influence of current compensation on voltage THD will be tested as well.

LESSONS LEARNED

A lot of interesting lessons have been learned during the first six months of storage operation. The shown experience relates only to the most important and newly installed technology system related to demo, far from ignoring the importance of other technical subsystems involved.

Battery energy storage system

Demo BESS is the ABB company first product of a family of storages intended mainly for operation in distribution networks. The system was designed on the explicit transformer load requirements and as an outdoor solution, additionally with complex HVAC unit.

Due to the complexity of the BESS subsystems, a number of initial faults occurred during first months of operation. Some are as follows:

- the overload of BESS processor,
- HVAC tripping due to false temperature settings and filter problems,
- Battery management system upgrade,
- High frequency noise generation,
- Inverter controller failures.

During the operation, an online direct VPN access to BESS main controller has been established for ABB, what significantly simplified system surveillance. Local support, provided by distribution skilled personnel, proved to be a major advantage in supporting the producer.

Demo SCADA system

A dedicated SCADA system was implemented exclusively for demo purposes. With different protocols implemented, it proved to be a stable and reliable platform for primary and the tertiary control system level support. Due to the huge number of signals and high frequency reading and data storing, only minor upgrades were required.

CONCLUSION

The installation of a demo storage is still the first of a kind in Elektro Gorenjska and even in Slovenian transmission or distribution networks. From this point of view, the demonstration challenges and expectations were really high.

The BESS itself had been designed practically from the scratch and according to ABB business plan, the first example of a new storage family, intended for installation in distribution networks. Therefore, the initial operating issues were reasonably expected. Active collaboration of knowledgeable partners, high attention, problem sensitivity and thorough surveillance resulted in fast problems mitigation, which led to achieving the acceptable reliability of the system.

The active design phase, with network data collection, including transformer station measurements and especially knowing PV production profiles, enabled the preparation of quality and efficient control algorithm. Decision, to implement a sun radiation forecast as well, proved to be crucial for the algorithm optimisation. Nevertheless, the algorithm has been additionally updated during operations to even optimize the storage capacity utilization.

After six months, the BESS operation reliability has been stabilised, what will enable thorough analyses and key performance indicator calculation.

BESS will definitely bring a new quality of operation into distribution low voltage networks with high penetration of distributed resources. Based on lessons learned and rising challenges in low voltage networks. Elektro Gorenjska already started a new demonstration project, trying to analyse the impact of small scale storage connected at the far end of low voltage feeder.

REFERENCES

[1] http://horizon2020-story.eu/