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added value of STORage in distribution sYstems

Deliverable 5.6
Report Chapter on Medium Scale Storage: Residential Zone in Slovenia

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Authors:

Marjan Jerele	EG
Camilla Neumann	JR
Andrej Gubina, Jernej Zupančič	UL

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1 Publishable executive summary

This report covers the experience of the medium-scale battery energy storage system (BESS) in two related demo sites: Elektro Gorenjska (EG) Suha and EG Headquarters (HQ). The medium-scale BESS for the demo case EG Suha was connected to 20/0,4 kV MV/LV transformer station supplying the Suha village residential LV grid in the vicinity of the Kranj city. Suha village LVN is an example of a 0,4 kV rural cable network without overhead lines and with high penetration of PV generation.

The second pilot site location in Slovenia is EG Headquarters, an industrial type of end consumer, located in an urban area. The BESS was to be connected within the internal LV network of the building, and its control strategy was to optimize the BESS operation with the active distributed RES generation devices and flexible consumption devices currently existing in the grid. Two 630 kVA MV/LV transformers serve as a connection of the local LV grid to the MV grid and supply the loads in the industrial compound. The EG headquarters consist of an office building with its consumption, a 35 kWp rooftop PV installation and a 27 kW CHP plant. The CHP plant serves as a heating source for colder months of the year and in the warm months of the year, the ice bank is responsible for cooling the offices. The aim of the EG Headquarters simulations was to present the economic potential of BESS for an industrial user with peak demand control. Since the BESS has not been deployed to the EG Headquarters, we only present simulation results.

Overall experience and major lessons learned in EG Suha demo site are summarised as follows. Generally, all BESS predefined functionalities were successfully tested and confirmed in the demonstration, including:

- Successful transformer load peak shaving.
- Successful grid consumption reduction.
- Implementation of efficient BESS control algorithm
- Reliable operation of EG broadband radio (WiMax)
- Reliable operation of EG control and monitoring systems

The most important, load management functions, based on a properly developed and optimized algorithm, proved to be efficient and well suited for future distribution network operations.

On the other hand, BESS operation revealed a lack of maturity and technical inadequacy comparing to existent distribution technology solutions. Unacceptable low reliability, high system losses and consequently high operational costs, system complexity and unexpectedly short lifetime are still major disadvantages, limiting large scale distribution exploitation. Drawbacks include also unexpected high-frequency noise generation, high system complexity and the fact that the batteries are not available to the extent that it is marketed.

The EG HQ BESS implementation aimed to utilize the BESS flexibility as a load shifting mechanism for the daily load profile which benefits from price differences of a two-tariff price system of an industrial user. The main assumption was that the profit is generated by price arbitrage between the two price levels. With the assumed realistic price levels of the two tariffs in

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Slovenia, BESS could be generating very small profit this way. The profits could be increased either if the BESS system achieved higher round-trip efficiency rates or if the electricity market conditions became more favourable with a higher price difference between high and low tariffs. An already existing alternative would also be an operation on other markets where energy stored in BESS could be sold at a better price, e.g. ancillary services – especially secondary and tertiary reserve market, where annual income of the owner increases, as already presented in the economic analysis of Suha demo.

BESS installation and nearly two years operation enabled us a detailed and priceless insight into so-called future smart grid installations. Lessons learned will enable better and matured decisions, needed for the future distribution network operations. A major lesson learned in this demonstrator is that when a combination of technologies is considered, good knowledge of different technical systems and their limits is crucial. This can be obtained by involving an experienced "technology integrator/aggregator" that knows how to integrate various BESS components and assist the owner/investor with any issues that may arise during operation. Also, it is important to develop a control system that appropriately considers the operating limits of various components to guarantee the safety of operation and to avoid costly technical problems and long downtimes.

2 Medium Scale Storage: Residential Zone in Slovenia and EG headquarters

The rapid emergence of distributed energy resources (DER), installed mainly in low voltage (LV) networks, poses new challenges to distribution system operators (DSO). Besides regular voltage quality provision, new load balancing solutions are becoming one of the most important future DSO operational concepts to address those challenges. Rapidly developing storage technologies are with no doubt among the tools to provide the future load balancing measures and already paving its way into distribution LV networks. The BESS is currently installed in a residential-type of LV network with high penetration of distributed generation.

2.1.1 Objectives

The main goal of the Slovenian field tests is the demonstration of flexible and robust use of medium-scale BESS connected in residential and industrial distribution LV network types. The demos aimed to demonstrate the ease of BESS integration in the existing infrastructure (including interoperability), controlling and managing the BESS and its cooperation with the devices in the system (in this case the MV/LV transformer and the PV units in the LV feeders), a high degree of self-sufficiency of the LV grid connected to the MV/LV transformer station, ensuring maximum economic efficiency (return on investment) of BESS application in decentralised energy production, the potential in supporting the regime of the PV production, a high degree of self-sufficiency of BESS in combination with PV production, peak demand control within the LV system within the daily load diagram and reduction of line congestion.

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The first chapter summarises the demonstration of a BESS connected in Suha, in a residential LV distribution grid. The second pilot site location in Slovenia is EG Headquarters, an industrial type of end consumer, located in an urban area. The BESS was to be connected within the internal LV network of the building, and its control strategy was to optimize the BESS operation with the active distributed RES generation devices and flexible consumption devices currently existing in the grid.

2.1.2 Partners engaged

EG delivered the installation and supplied measured values for both EG Suha and EG HQ demo sites, and the evaluation and lessons learned for the EG Suha demo site. UL has advised on BESS dimensioning and designed the control algorithm for BESS, and defined the BESS model to be used in the EG HQ simulations. UL has also designed the test case scenarios and performed the KPI calculations based on the measured data. Data was stored at EG premises as well as the platform hosted by BASN. UL and EG monitor the data and calculate the Key Performance Indicators (KPIs) (as part of WP6). ABB provided the BESS to the Suha site, corrected the initial faults and supported EG in the restart when the COVID-19 pandemic restricted ABB from travelling to the site to realise the restart.

2.1.3 Booklet chapters

The chapters are added as Appendix 1.

3 Acronyms and terms

BESS	Battery Energy Storage System
DER	Distributed Energy Resources
DSO	Distribution System Operator
GECC	Grid Energy Consumption
LV	Low Voltage
MCU	Main Controller Unit
MV	Medium Voltage
PCC	Point of Common Coupling
PDATR	Peak to Average Demand Ratio
PLC	Programmable Logic Controller
PPC	Peak Power Change
PV	Photovoltaic
RTU	Remote Terminal Unit
SCADA	System Control and Data Acquisition

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4 Appendices

Apendix 1: Report chapters on Medium Scale Storage: Residential Zone in Slovenia and EG Headquarters

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Report Chapter on Medium Scale Storage: Residential Zone in Slovenia

Authors: Marjan Jerele (EG)

Reviewed by: Andrej Gubina (UL)

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1. Introduction

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

Rapidly developing storage technologies are with no doubt among the tools to provide the future load balancing measures and already paving its way into distribution LV networks. Elektro Gorenjska d.d. (EG) is an active partner of STORY H2020 project entitled "Added value of STORage in distribution sYstem" and leads the demonstration of a flexible and robust use of a medium-scale battery energy storage system (BESS). The BESS is currently installed in a residential-type of LV network with high penetration of distributed generation.

2. The concept

The main goal of the Slovenian field tests is the demonstration of flexible and robust use of medium-scale BESS connected in residential and industrial distribution LV network types. The demos aim to demonstrate the ease of BESS integration in the existing infrastructure (including interoperability), controlling and managing the BESS and its cooperation with the devices in the system (in this case the MV/LV transformer and the PV units in the LV feeders), a high degree of self-sufficiency of the LV grid connected to the MV/LV transformer station, ensuring maximum economic efficiency (return on investment) of BESS application in decentralised energy production, the potential in supporting the regime of the PV production, a high degree of self-sufficiency of BESS in combination with PV production, peak demand control within the LV system within the daily load diagram and reduction of line congestion.

This chapter summarises the demonstration of a BESS connected in Suha, in a residential LV distribution grid.

3. The installation

3.1. Demo site topology

The medium-scale BESS for the demo case was connected to 20/0,4 kV MV/LV transformer station supplying the Suha village residential LV grid in the vicinity of the Kranj city.

Suha village LVN is an example of a 0,4 kV rural cable network without overhead lines and with high penetration of PV generation. The cable network topology, the locations of PV units and 20/0,4 kV MV/LV transformer station is depicted in Figure 1.

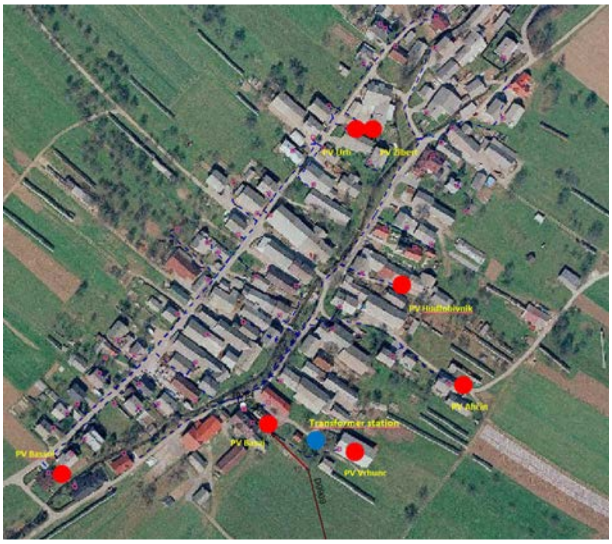

Figure 1. LVN SUHA topology, PV and transformer locations.

Several power network analysers are already installed within the network for the on-line monitoring and control purposes, with the data registration time interval of one-minute. Due to expected STORY project requirements, additional power network analysers were installed on the two remaining PV locations

Power plants' nominal power data are shown in Table 1.

Table 1. PV data

Photovoltaic power plant	**Active power**
PV Basaj	29 kW
PV Ahčin	22 kW
PV Bassol	15 kW
PV Žibert	22 kW
PV Vrhunc	50 kW
PV Urh	22 kW
PV Hudobivnik	50 kW
Total nominal power	**210 kW**

3.2. Transformer station 20/0,4 kV

T0248 Suha transformer station (TS) is a typical standardised EG 20/0.4 kV transformer station. As shown in Figure 2, the TS comprises:

- Transformer concrete casing TSN TPR-C type
- 20/0.4 kV, 400 kVA OLTC transformer (Schneider - Minera SGrid)
- 20 kV Siemens ring main unit 8DJH with motor
- 0.4 kV switchboard
- TS remote control system.

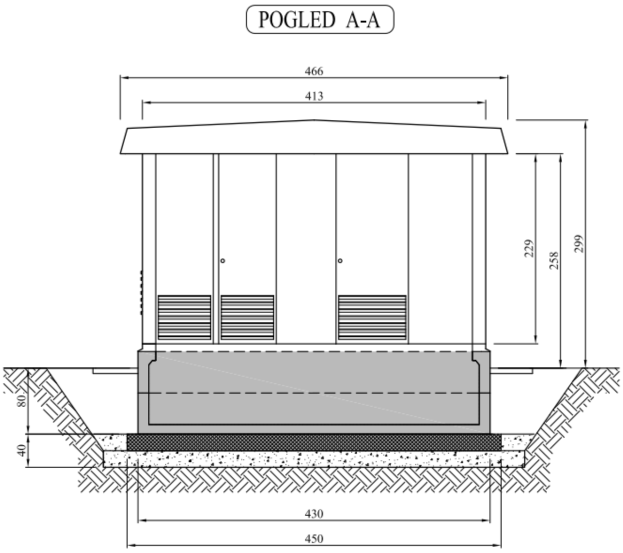

Figure 2. TS casing

The BESS unit is connected to one of the spare LV feeder connections via Point of Common Coupling (PCC) cabinet. PCC consists of a main circuit breaker with network protection relay, remote control terminal unit and main system process controller.

3.3. BESS description

The BESS is designed to provide nominal power of 170 kW and an gross installed energy capacity of 552 kWh (net storage capacity of 450 kWh), and it is ready for outdoor installation.

3.3.1. BESS functionalities

The BESS system main functionalities are shown in Table 2:

Table 2. BESS functionalities

Functionality
Peak Shaving (Main functionality)
Islanding (not applied in Suha demo)
Black Start (not applied in Suha demo)
Reactive power compensation*

Functionality
Harmonic Compensation* - specific for 5th Harmonic
Load Balancing*
Tertiary Reserve

* - Reactive power compensation, harmonic compensation and load balancing functionalities require current measurement signals from the distribution transformer.

3.3.2. System Layout

BESS construction is modular, single elements as indicated in Table 3.

Table 3. Elements composing the BESS

Item	Apparatus	Technical Data
Electrical elements	Converter	Power Converter System (PCS)
	Battery	Battery Racks
	AC / Control Panel	Including control systems and AC protections
	DC Cabinet	Including DC protections
	Container	MECB-type
Control Elements	MCU	Master Control Unit
	EMS	Energy Management System
	BBMS	Bank Battery Management System
	Rack BMS	Rack Battery Management System
	Module BMS	Module Battery Management System
	PCS Control	ESI Manager

A simplified BESS connection scheme is presented in Figure 3.

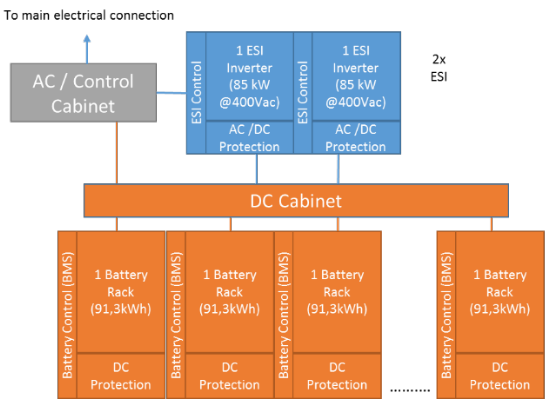

Figure 3 . BESS System Overview

The salient features of the BESS are described in Table 4.

Table 4 . BESS System salient features

System parameter	Value
Total Installed Power (kW)	170 kW @400 Vac
Power per ESI unit (kW)	85 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
Installed Energy per Rack (kWh)	91,3 KWh
Total Usable Energy @BoL - 4 wires	58% of Total Installed Energy @ BoL (discharge 1 C)
Inverter Parasitic Loads	2.5% of Losses @ Rated Power
Battery Parasitic Loads	2% of Losses @ Rated Energy
Auxiliaries Parasitic Loads (LV)	1.5% of Losses @ Rated Power / Energy
Typical round trip efficiency	>85% for 1 Full cycle at 1 CP
Max Temperature for Battery (°C)	25°C – Ambient Temperature
Max Temperature for PCS (°C)	40°C – Ambient Temperature
Max C Rate	1 CP Charge/discharge
Communication EMS/MCU	Via Modbus protocol**
Communication EMS/PCS	Via Modbus protocol
Communication EMS/BBMS	Via Modbus protocol

The total installed energy comprises of 6 LG Chem battery racks, with salient features described in Table 5.

Table 5. Battery rack data

System parameter	Value
Manufacturer	LG Chem
Module Type	JH3-2P (M48126P3B)
Module energy	6.52kWh
Rack type	JH3-2P R800
Elements included in rack	Modules (14), Battery Protection Unit (1), Rack BMS (1)
Number of modules per rack	14
Rack energy	91.3 kWh
Rack voltage nominal (Vdc)	725
Rack Voltage maximum (Vdc)	823.2
Rack voltage minimum (Vdc) – 3 Wires	588.0
Rack voltage minimum (Vdc) – 3 Wires	650.0
Maximum C-rate	1CP
Self-discharge (% per year based on cell)	<6% * based on cell
Operating ambient temperature	21° C ± 4°C
Maximum ambient operating humidity	<80% with none condensation

System parameter	Value
Indoor installation	Up to 1000 m above sea level
Rack protection degree	IP20
Rack cooling	Air-cooling front to rear
Rack dimension	W x D x H: 520 x 670 x 1800 mm (unpacked)
Weight	710kg
DC cable connection	Top
DC protection	Main contactor and fuses
Compliant with standards:	IEC 62133, UL 1642, UN 38.3, KBIA 10104-01, SBA S1101

An illustrative picture of the BESS layout is represented in Figure 4.

Figure 4. BESS system layout

3.3.3. BESS connection

BESS power output is connected to a distribution transformer LV cabinet feeder via PCC cabinet, as depicted in Figure 5. The main goal of the PCC cabinet is the network protection comprising voltage, current and frequency protection relays and to visually disconnect BESS during its maintenance.

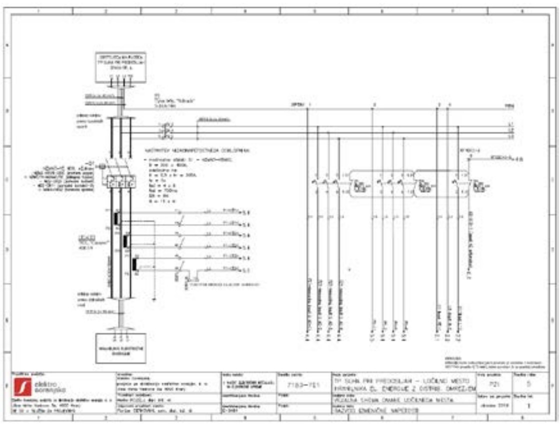

Figure 5. BESS system power connection

The main controller unit (MCU), with an implemented control algorithm, is also installed in PCC in order to bring system calculations and process control as close to BESS as possible. MCU and BESS programmable logic control unit (PLC) are directly connected via network cable to minimise connection failure risks during operation. PCC is remotely controlled by a remote terminal unit (RTU).

3.4. Communication and control

3.4.1. General

The BESS is completely integrated into Elektro Gorenjska remote control system. All the demo parameters are logged and collected in a controlled way by EG development system control and data acquisition (SCADA) system based on Unifusion professional data acquisition and control system. Besides system remote control, SCADA also enables communication with third-party partners.

3.4.2. System description

BESS demonstration control strategy follows a three-layer control concept.

Primary control layer, also referred to as a local layer, consist of numerous devices (as physical entities) installed on site. Besides BESS and PCC cabinet, various information and communication technologies, network monitoring and metering data systems and RTUs represent the vital and most utilized demo subsystems.

On the secondary control level, remote demo SCADA system with a 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 the BESS programmable logic controller (PLC) and is installed in the PCC cabinet in the transformer station itself. MCU and BESS PLC are directly connected with a network cable 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 and exchanges data with different third-party data systems as follows:

- connection to Slovenian Environmental Agency, providing sun radiation forecast required for BESS control optimisation.
- Connection to the main project data server, located in Finland and supported by STORY partner BaseN, providing complete data back up and computational platform for demonstration and key performance calculations.

The demo communication and protocol scheme is depicted in Figure 6.

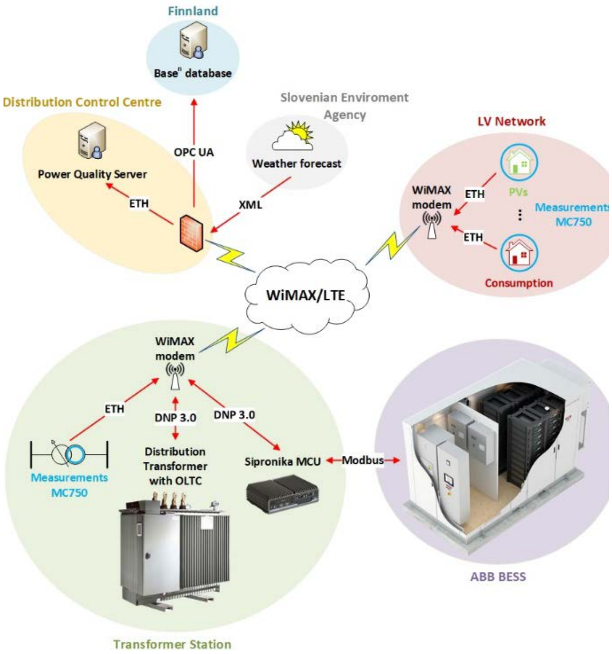

Figure 6.Protocol and communication scheme

The integration of a variety of EG technological subsystems and ABB storage as well, requires the utilization of three different standardised protocols. Modbus, enabling communication between MCU and BESS PLC, DNP3.0 for SCADA to MCU communication and OPC UA for data exchange between SCADA and servers on the tertiary control layer.

EG private WiMAX and LTE broadband radio network provides two basic communication platforms, which enable communication among dispersed device locations.

4. Monitoring

4.1. Monitoring process

Monitoring and metering of all system parameters are of key importance for overall evaluation and key performance indicators calculation.

The measurement system, depicted in Figure 7 consists of the following devices:

- BESS (ABB power analyser), metering all storage parameters
- MV/LV transformer (MC power analyser), measuring all transformer parameters on the LV side
- PV POWER PLANTS (MC power analysers) metering all individual PV power plant parameters

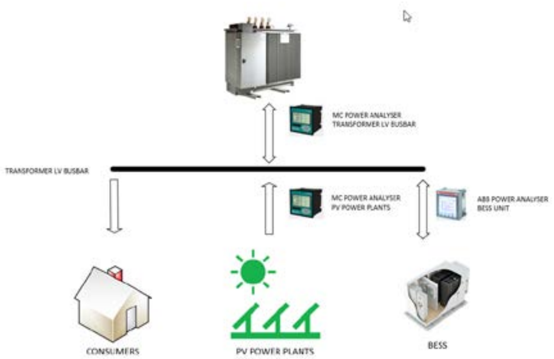

Figure 7. Suha demo measurement system

Time resolution of power analyser measurement and storage for all parameters is 1 minute.

4.2. Monitoring results

This chapter describes the most interesting results of the BESS operation.

4.2.1. Change of peak to average demand ratio/relative peak power change

The change of peak to average demand ratio (PDATR) is defined as the ratio between the peak value of the demand profile and its average value, shown in Figure 8. It is measured in both directions and designated as PDATR+ and PDATR-. The transformer profile in the use case (blue) is flattened compared to the base case (orange) on the first of June.

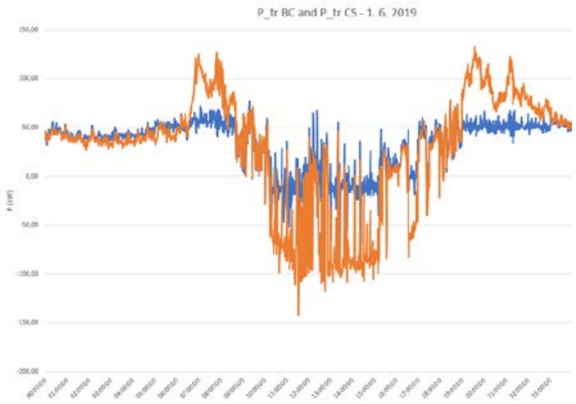

Figure 8. Transformer BC (orange) and CS (blue) daily profiles

Weekly PTADR+ and PTADR- data is presented in Table 6.

Table 6. Weekly PTADR+ and PTADR- comparison

	PTADR+	PTADR-
24. - 30. 1. 2019	8,01%	83,43%
24. - 30. 6. 2019	54,81%	55,05

A similar result is shown regarding the relative peak power change (PPC). Relative peak power change is defined as the change of peak power flows in the network, before and after storage implementation, compared to peak power levels before the storage technology implementation, and measured in both directions, Table 7.

Table 7. Weekly PPC+ and PPC- comparison.

	PPC +	PPC -
24. - 30. 1. 2019	2,66%	82,47%
24. - 30. 6. 2019	40,43%	40,74%

Winter to summer peak load data comparison shows considerable differences in levels of both indicators. Indicators are significantly lower for the winter period, revealing a much lower peak to average demand ratio change and relative peak power change compared to the summer. The obvious reason for that is almost negligible PV winter production, BESS night charging and consequently relatively low consumer peak reduction. On the contrary, BESS operates much more efficiently in the summer period, reaching much higher indicator levels and in that way fulfilling its role much better.

4.2.2. Grid energy consumption change

The grid energy consumption (GECC) change KPI compares the grid-injected energy before and after storage implementation. June 2019 daily grid consumption change values are shown in Figure 9.

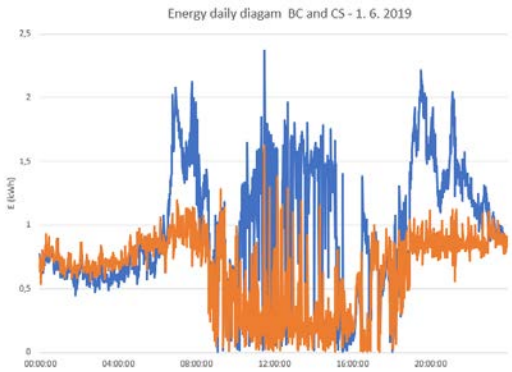

Figure 9. Transformer daily load diagram – BC (blue) and CS (orange)

Weekly GECC data is presented in Table 8.

Table 8. Weekly grid consumption change comparison

	E BC (kWh)	E CS (kWh)	GECC
24. - 30. 1. 2019	13798,59	14538,00	+5,36%
24. - 30. 6. 2019	8849,93	5706,20	-35,52%

Winter daily grid energy consumption change is positive, meaning more energy is consumed from the grid. Low relative values at the same time mean insignificant volumes change in kWh. As expected, mostly sunny summer week with high PV generation results in negative grid consumption change, which is not only relatively higher but significant also in overall energy volume.

4.2.3. BESS operation

The reliability of the devices operating and providing any kind of services also needs to be monitored. **Device availability** is defined as a comparison of time, or the number of availability checks when the device is available for operation and duration of the monitored interval. The fallout duration is determined by measuring the time between the availability checks. BESS operating time totals 7113 hours, which means **81.2%** in one-year analysed period. BESS should support the distribution everyday operations, but the device availability is not even close to the distribution reliability standards of supply. In order to support 24/7 operations, BESS would have to significantly improve its reliability, as e.g. the reliability of supply of 5h/year in Slovenia translates to 99,9999% reliability.

The full cycle equivalent (FCE) depends on BESS discharged energy compared to the nominal net storage capacity of 450 kWh. **Winter** FCE ranges from **16 % to 59 %** with moderate average value. Minimal FCE values are experienced on cloudy days with no PV production, while values are higher even on a cloudy day with at least some PV production. **Summer** FCE values are higher than winter ones, but even on the most PV productive day, FCE does not exceed much more than **52 %.** The average winter to summer FCE difference is unexpectedly not so high as it is between a cloudy day with no PV production compared to sunny or even a cloudy with at least some PV production.

Storage efficiency is defined as the overall system efficiency, comparing the amount of injected and discharged from the device at the PCC back to the network. **Winter** efficiency ranges **42 % to 74 % with an average value of 57 %.** During winter days, measurements reveal constant BESS auxiliary consumption in an average of 3 kW (most probably battery compartment heaters). Surprisingly, summer SE indicators are comparable to the winter ones. The obvious reason for not being better refers to BESS auxiliary load (HVAC unit) for system temperature conditioning.

Operating efficiency is relatively low compared to the system beginning of life efficiency being 87%, measured during site acceptance test procedures. BESS efficiency is strongly related to the operating conditions influenced by the BESS load level, storage capacity factor, environmental temperature and the consumption of auxiliary subsystems. BESS heating, ventilation and air conditioning (HVAC) unit with up to 13 kW consumption (cooling and ventilation) significantly contribute to relatively low overall system efficiency. In June 2019 efficiency losses total 4.67 MWh and at an average energy price of 50 Euro/MWh, which means 233 Euro of BESS operational costs for this period.

5. Conclusions and lessons learned

Overall experience and major lessons learned are summarised as follows:

Table 9. BESS overview

Advantages	Disadvantages
All BESS functionalities were successfully confirmed.	Unreliable operation, unacceptably high number of different BESS faults during the complete demonstration
Successful transformer load peak shaving.	BESS maintenance and operational problems
Successful grid consumption reduction.	High BESS investment costs.
Implementation of efficient BESS control algorithm	Low system efficiency.
Reliable operation of EG broadband radio (WiMax)	Unexpected high-frequency noise generation
Reliable operation of EG control and monitoring systems	High system complexity

	Batteries are not available to the extent that it is marketed.

Generally, all BESS predefined functionalities were successfully tested and confirmed in the demonstration. The most important, load management functions, based on a properly developed and optimized algorithm, proved to be efficient and well suited for future distribution network operations. On the other hand, BESS operation revealed a lack of maturity and technical inadequacy comparing to existent distribution technology solutions. Unacceptable low reliability, high system losses and consequently high operational costs, system complexity and unexpectedly short lifetime are still major disadvantages, limiting large scale distribution exploitation.

BESS installation and nearly two years operation enabled us a detailed and priceless insight into so-called future smart grid installations. Lessons learned will enable better and matured decisions, needed for the future distribution network operations.

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Report Chapter on Medium Scale Storage: EG headquaters

Authors: Jernej Zupancic, Andrej Gubina (UL)

Reviewed by Camilla Neumann (JR)

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6. Introduction

The second pilot site location in Slovenia is EG Headquarters, an industrial type of end consumer, located in an urban area. The BESS was to be connected within the internal LV network of the building, and its control strategy was to optimize the BESS operation with the active distributed RES generation devices and flexible consumption devices currently existing in the grid.

7. The concept

The aim was to show local LV network peak demand control of an industrial user (EG headquarters) through the installation of a BESS system. By storing the energy withdrawn from the grid and reinjecting it later, BESS shifts the load from high tariff time intervals into the intervals with low energy cost and flattens the overall consumption profile. High tariff time interval consumption, which is present during the weekdays is reduced with the energy - provided by the BESS, which charges during the night and during weekends. With this measure, high-tariff time interval energy consumption of the industrial consumer gets partially covered by the stored energy in BESS, stored during the low-tariff time interval, thus lowering the energy costs of the industrial end consumer.

8. The installation

Two 630 kVA MV/LV transformers serve as a connection of the local LV grid to the MV grid and supply the loads in the industrial compound. The EG headquarters consist of an office building with its consumption, a 35 kWp rooftop PV installation and a 27 kW CHP plant. The CHP plant serves as a heating source for colder months of the year and in the warm months of the year, the ice bank is responsible for cooling the offices. The aim of the EG Headquarters simulations was to present the economic potential of BESS for an industrial user with peak demand control. Since the BESS has not been deployed to the EG Headquarters, we only present simulation results.

8.1. Simulation input

A 12-month period simulation was performed for the technical simulations of the two pilot sites, Suha LV network and EG HQ LV network. Voltage, current, active-and reactive power measurements of both transformers were available and were used to provide load and generation profiles, to calibrate the models and to run the simulations. All the PV locations in the networks are also available, which was utilized in the scenario application process. Power flow simulations were run for an entire simulation interval, in 15 min timestep resolution. The BESS reacts based on the local measurement of active power flows, measured at the MV/LV transformer substation. Based on the grid topology, power consumption and production profiles and BESS response, the technical results are calculated in the simulation platform. Through technical parameters, BESS impact can be seen on the chosen key grid parameters, such as voltage levels, loading of the elements and losses in the network. Energy consumption shifts are seen through the transformer power flow profiles. In addition to the data for the simulations, 3 key algorithm functions were included for the technical simulations of the EG industrial pilot site:

- **BESS Peak demand control algorithm**, which is installed in the Suha LV network, through which BESS is preventing reverse power flows of active power to the main grid and shifting/reducing peak demand values.

- **BESS two-tariff economic control with peak consumption reduction,** which was used to control BESS in the EG HQ setting.
- **PV unit droop control algorithm,** which curtails PV production based on the droop control function instead of in an on/off fashion. If the PV unit causes voltage rise above certain threshold, the BESS output is decreased to maintain the voltage values within the allowed boundaries. This functionality was implemented for simulations in Suha village PV inverters.

8.2. Algorithm update

The existing peak demand control algorithm, which was designed for the control of the BESS unit for the installation in Suha village, has been updated and tailored to the EG HQ location. The algorithm still uses same logic behind the calculations. The EG HQ utilizes BESS to a more economic goal of shifting the high-tariff time interval consumption to the low-tariff time interval. High demand intervals occur in office hours during the weekdays, and the low tariff is present during the night and weekends. BESS now reacts upon received demand forecast for both price time intervals. Based on available capacity, BESS charges during low price time interval, withdrawing energy from the local LV grid and injects energy back during the high tariff interval. Figure 10 shows the weekly transformer profile of active power flows, (blue = low tariff power profile, orange = high tariff power profile). BESS is scheduled to charge (yellow charging threshold) and discharge (purple = discharging threshold) accordingly to the price-related time intervals.

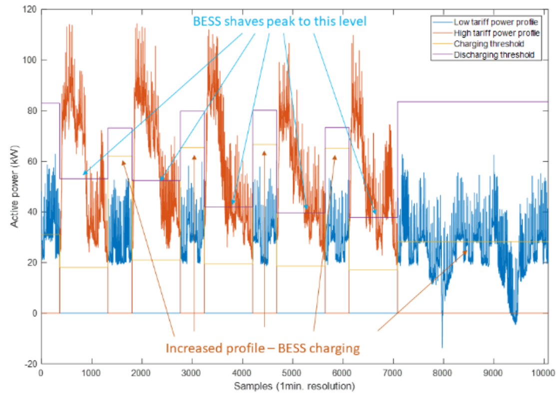

Figure 10. BESS algorithm threshold calculation

After the calculation, the threshold values are stored in the algorithm and utilized in real time part of the control, where transformer power flows are monitored, and BESS response is calculated afterwards.

8.3. Simulations

The simulation platform was designed in OpenDSS and Matlab, including the EG HQ model. Yearly simulations with the 15-min time resolution were performed for BESS evaluation. The BESS model parameters were defined in Matlab code, together with the transformer yearly input profile and the BESS control threshold levels. These inputs were sent to OpenDSS, where BESS was connected to the LV side of the MV/LV transformer and the rest of the EG HQ LV grid. Afterwards, the power flows were calculated in OpenDSS and exported to Matlab for storage and analysis.

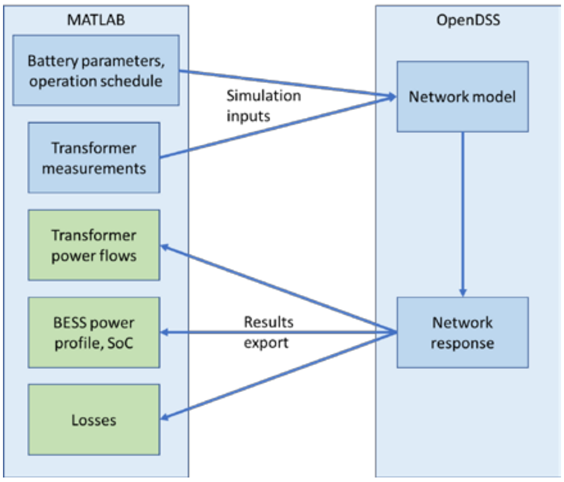

Figure 11. Simulation flowchart

The BESS parameters used in simulations are presented in Table 10.

Table 10.BESS model parameters

Capacity	320 kWh
Rated power	170 kW
Efficiency (for charging and discharging)	94.12% (88.58% round trip eff.)
Auxiliary power consumption	4 kW
Minimum SoC level	18 %
Maximum SoC level	98 %
Lowest discharging power flow	20 kW
Highest charging power flow	120 kW

With the last two parameters we ensure that BESS operation does not increase power flows above 120 kW with charging and it does not decrease the power flows below 20 kW. With this definition we have two hard limits within the algorithm as an additional measure in the algorithm to further enforce the BESS limitations and operation boundaries.

In Figure 12 below we see weekly operation of BESS in spring. In the higher part of the graph, the comparison of active power flows through the transformer is presented, in the lower part, the BESS profile and the SoC levels are visualized.

In the summer interval, the compressor is providing cooling for the office building via an ice bank and it operates mostly during the low-price time interval or when depleted in high tariff time interval. On Figure 13 and Figure 14 we see the impact of the ice bank operation. It mostly operates during the low-price time interval and limits the BESS potential to feed the system load.

As seen on the Figure 14, BESS charging is limited due to the ice bank operation and algorithm limit, where we allow BESS only to charge to power flows up to 120 kW in the network.

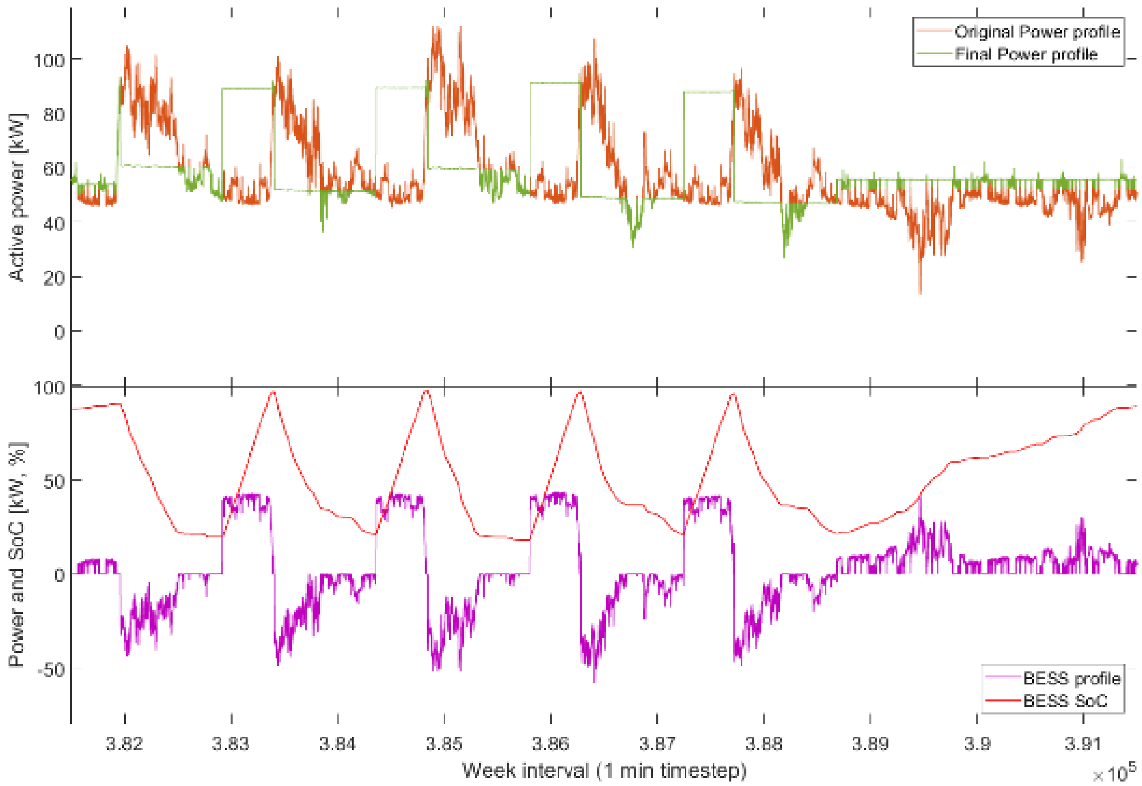

Figure 12. Spring transformer active power profile (higher part) and BESS operation (lower part)

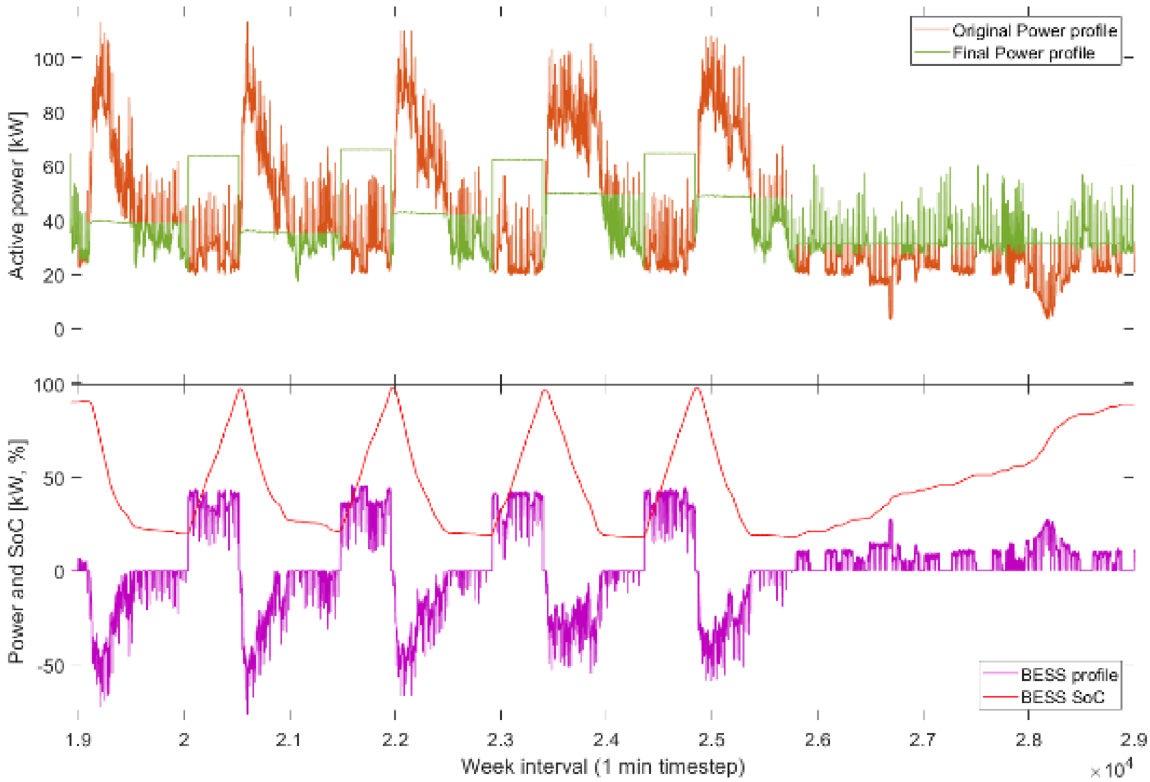

Figure 13. Transformer and BESS active power flow profiles, summer week without ice bank operation

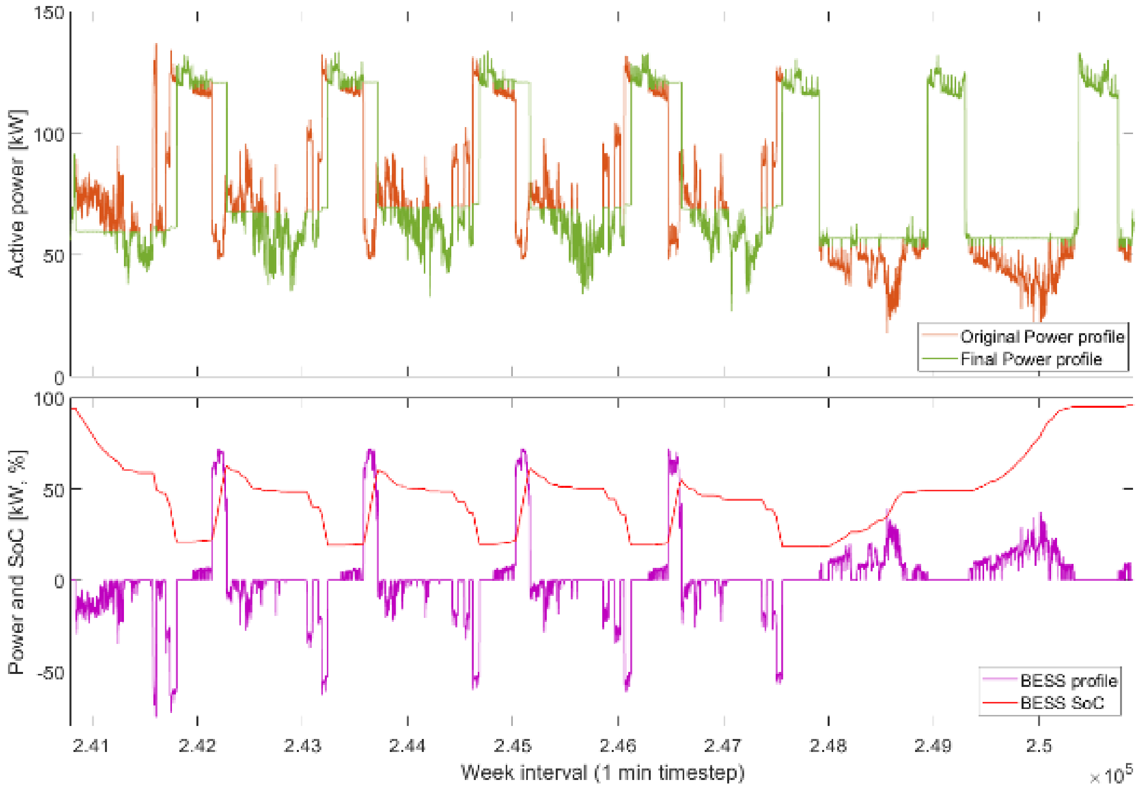

Figure 14. Ice bank impact on the transformer active power flow profile

8.4. Scenarios

For the EG HQ, three different PV settings and two different use cases were investigated:

- **Base case setting**, a 35 kWp PV unit is installed
  - UC1: no BESS installed
  - UC2: BESS installed
- **+100% PV setting,** a 70 kWp PV unit is installed
  - UC1: No BESS installed
  - UC2: BESS installed
- **+200 PV setting,** 105 kWp PV unit is installed
  - UC1: No BESS installed
  - UC2: BESS installed

For the EG headquarters, the PV curtailment option was not applied due to several reasons. Even a 200 % increase of the existing PV installation (105 kWp total) wouldn't pose operational problems at the demo site location as no surplus of PV production would occur. Additionally, 2 x 630 kVA transformers present a very strong connection point, obscuring the impact of BESS on the network beyond the MV/LV transformer station, so it is more interesting to look into the impact of BESS operation alone, instead of the including PV curtailment option as well.

9. Monitoring and key results

The focus of the technical analysis results is the energy consumption of the EG HQ demo site. The aim of use cases investigated was to shift consumption from the high tariff time interval into the low tariff time interval and thus lower the energy consumption cost. Additionally, the overall consumption profile was flattened and peaks were reduced.

In Table 11, the energy consumption of the EG HQ is presented. With the BESS implementation, high tariff time interval consumption is decreased by 50 MWh per year, while low tariff time interval consumption is increased for 70 MWh per year, due to increased consumption of BESS (auxiliary energy consumption and round-trip efficiency losses).

Table 11. Energy consumption comparison (MWh/year)

Scenario	**Low RES**		**100% RES increase**		**200% RES increase**	
Interval	**Original**	**BESS**	**Original**	**BESS**	**Original**	**BESS**
Low Tariff	208,0	279,5	198,3	265,6	188,6	253,5
High Tariff	230,1	181,6	205,5	158,5	181,1	135,0
Total	438,0	461,1	403,8	424,1	369,7	388,4

On Figure 15 and Figure 16 the BESS impact on the transformer loading levels for each tariff time interval is presented. In the low tariff interval, the loading levels increase due to BESS charging, a 120 kW threshold of charging is clearly seen on the graph. Similarly, in high tariff instances, the lowest discharging point is 20 kW, where a spike in the number of samples occurs as well. In high tariff time interval consumption we see a reverse trend, where consumption values are lowered compared to the original power flow.

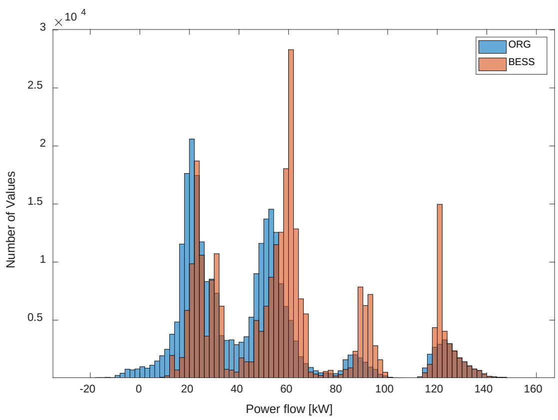

Figure 15. Impact of BESS on low tariff power flows

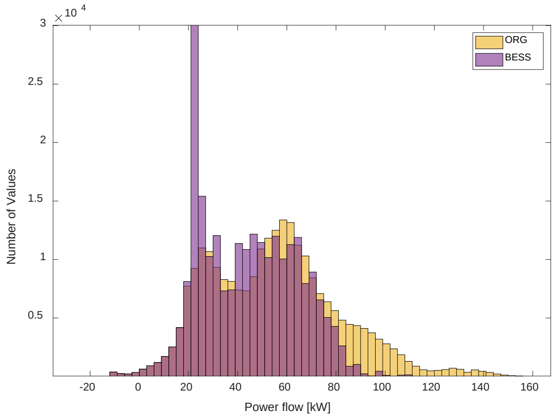

Figure 16. Impact of BESS on high tariff power flows

For the economic evaluation, the energy shift was evaluated with the Slovenian high and low industrial tariff energy prices. The assumed high tariff energy price was 0.08534 €/kWh and the low tariff price was 0.05606 €/kWh, which results in 0,02928 €/kWh price difference between the intervals.

As the results in Table 12 show, the BESS impact on the annual energy cost is very small.

Table 12. BESS impact on energy consumption cost

Scenario	Low RES		100% RES increase		200%RES increase	
Costs [€]	Orig.	BESS	Orig.	BESS	Orig.	BESS
Low tariff	11,658	15,667	11,114	14,888	10,572	14,210
High tariff	19.634	15498	17540	13524	15453	11517
Total costs	31,292	31165	28654	28413	26025	25727
Profit [€/year]	127		242		298	

This is a result of several factors, both technical and economic. BESS efficiency factors are highly impacted by the auxiliary power consumption of the unit for the needs of an HVAC system. In addition to charging and discharging round-trip efficiencies, auxiliary consumption was also considered in the technical simulations. If BESS could achieve a higher overall efficiency ratio, the energy difference between high and low tariff time intervals would increase together with the economic profit of the operation. The second option, which would enhance the BESS impact on the overall economic situation is market-specific, namely the price difference.

Figure 17 presents sensitivity analysis results. The increased price difference of only 0.015 €/kWh from existing prices would result in 1000 €/year energy cost reduction.

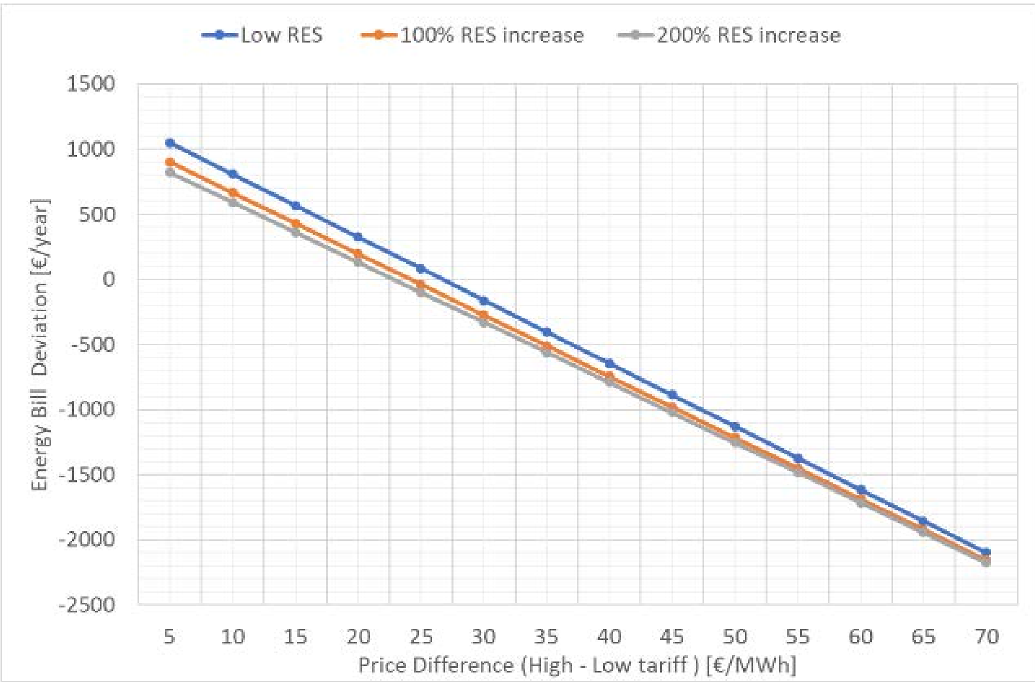

Figure 17. Energy cost deviation due to BESS load shift and price difference

10. Conclusions and lessons learned

The EG HQ BESS implementation aimed to utilize the BESS flexibility as a load shifting mechanism for the daily load profile which benefits from price differences of a two-tariff price system of an industrial user. The main assumption was that the profit is generated by price arbitrage between the two price levels. With the assumed realistic price levels of the two tariffs in Slovenia, BESS could be generating very small profit this way. The profits could be increased either if the BESS system achieved higher round-trip efficiency rates or if the electricity market conditions became more favourable with a higher price difference between high and low tariffs. An already existing alternative would also be an operation on other markets where energy stored in BESS could be sold at a better price, e.g. ancillary services – especially secondary and tertiary reserve market, where annual income of the owner increases, as already presented in the economic analysis of Suha demo.

A major lesson learned in this demonstrator is that when a combination of technologies is considered, good knowledge of different technical systems and their limits is crucial. This can be obtained by involving an experienced "technology integrator/aggregator" that knows how to integrate various BESS components and assist the owner/investor with any issues that may arise during operation. Also, it is important to develop a control system that appropriately considers the operating limits of various components to guarantee the safety of operation and to avoid costly technical problems and long downtimes.

11. References

[1] https://contest.techbriefs.com/2016/entries/sustainable-technologies/6990