THE SMART GRID REAL LAB OF EWZ: FINDINGS FROM A LARGE-SCALE DEMONSTRATION PROJECT

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ABSTRACT

ewz, the distribution system operator (DSO) of the city of Zurich, has been operating since June 2015 in a residential area in the suburbs of the city the Smart Grid Real Lab (SGRL), a test field in the low voltage grid for the demonstration of smart grid solutions. The purpose of SGRL is to gain practical know-how for the design of future distribution grids, where new technologies will help the DSOs face the challenges that the energy transition poses. During the one-year SGRL operation phase, the interplay between various systems and components was investigated. In this paper, we present and evaluate the main findings of the large-scale demonstration project from a DSO's perspective in terms of operating a smart grid in practice. The success of the Smart Grid Real Lab serves as a basis for concretising our smart grid architecture of tomorrow.

INTRODUCTION

Motivation

The citizens of Zurich decided in 2008 to set ambitious decarbonisation goals by aiming for a reduction of the CO_2 emissions to 1t per person per year. In this context, the distributed generation (DG) and battery storage shares as well as the electrification rate of the heat and transportation sector are expected to rise with a growing pace over the next years. This will require the adoption of new approaches in the planning and operation of distribution grids. To ensure the reliable and undisturbed operation of distribution grids in a cost-efficient way, new grid solutions will have to be increasingly integrated into the existing infrastructure. The challenge for the DSOs lie in successfully managing the bidirectional load flows, dealing with voltage deviations and achieving a better information and control of the distribution grid state.

Related Work

In the past, several studies at ewz addressed the issue of the increasing distributed generation penetration, investigated the resulting problems and suggested potential countermeasures. In [3] a full PV penetration in a residential area of Zurich is assumed and potential PV integration measures are subsequently compared on a technical and economic basis. The authors of [4] suggest a battery placement and sizing optimization tool and explore synergies between PV generation, battery storage, PV curtailment and electric mobility. The concept and functionalities behind GridBox, an open platform for monitoring and active control of distribution grids, were presented in [5]. The first test results of the SGRL are given in [6], where the effect of two different technologies, a battery system and a line voltage regulator, are investigated.
The idea of developing technologies to monitor, control and manage the distribution grids is gaining recently a lot of interest. In French-speaking Switzerland, the company DEPSys has launched the system GridEye [7], a network optimization platform. The German SAG group presents the iNES system, an extensive, modular smart grid platform [8].

Goals

In order to be ready for the challenges that the energy transition poses, ewz aims at testing and implementing new grid solutions, as well as at familiarizing with their functionalities. The main high-level goals that were defined regarding the SGRL were:

- The low voltage (LV) grid state (Voltage magnitude and phase, current magnitude and phase as well as the real and reactive power flows) should be measurable or observable.
- The analysis of the distribution grid state should allow the localisation of system failures as well as the identification of potential overloaded grid elements.
- Potential grid overloads or voltage rises should be able to be resolved by use of the controllable grid elements (producers, loads, battery storage).

PILOT GRID

A LV grid in a residential area in the periphery of Zurich was selected to host the SGRL. The topology of the pilot area, along with the main SGRL elements, is illustrated in Figure 1.
In order to test potential critical grid states, the robustness of the investigated LV grid had to be intentionally worsened by means of a weaker topology configuration. Apart from the existing meshed grid structure, another two long lines were integrated into the pilot grid. After the topology reconfiguration, the whole test area is fed from two 1 MVA transformers supplying about 700 customers. On the generation side, a total of 200 kWp installed PV capacity feeds into the reconfigured pilot grid. Additionally, a diesel generator together with a frequency converter was installed at the end of a long feeder to simulate a remote PV unit for a test period of one week.
As illustrated in Figure 1, the SGRL comprises the following elements:
A) GridBox
B) Battery Energy Storage System (BESS)
C) Low Voltage Line Regulator (LVLR)
The characteristics and the role of these elements are presented in this chapter.

GridBox system

The SGRL served as a test area for GridBox (A in Figure 1), a worldwide unique open platform for monitoring and active control of distribution grids [5]. The GridBox system has been developed within a 3-years research project in cooperation with the project partners BKW (DSO in the Swiss cantons of Bern and Jura), Supercomputing systems (development service provider), Bacher Energie (consulting and project support) and co-funded by the Swiss Federal Office of Energy.
The GridBox concept comprises real-time measurement devices synchronized by GPS. These devices are able to measure voltage and current synchrophasors and communicate the measurement data to hierarchically layered masters, which enable the centralized monitoring and control of the distribution grid. The state estimation completes and adjusts the inaccurate or completely missing measurements, while the optimizer determines a set of control signals with respect to a certain objective. The GridBox master sends subsequently the appropriate control signals to the grid components actuators. Such controllable grid components are PV inverters, water boilers and Battery Energy Storage Systems (BESS). The architecture of the GridBox system and its interplay with the grid actors is depicted in Figure 2.
In context of the pilot project, we aimed at a complete coverage of all nodes in the network area with GridBox modules. In this sense, a total of 50 devices was installed at transformer stations, distribution cabins, PV plants and house connections of the SGRL pilot grid.
Extensive details about the GridBox pilot project can be found in the BFE Report (German) [9].

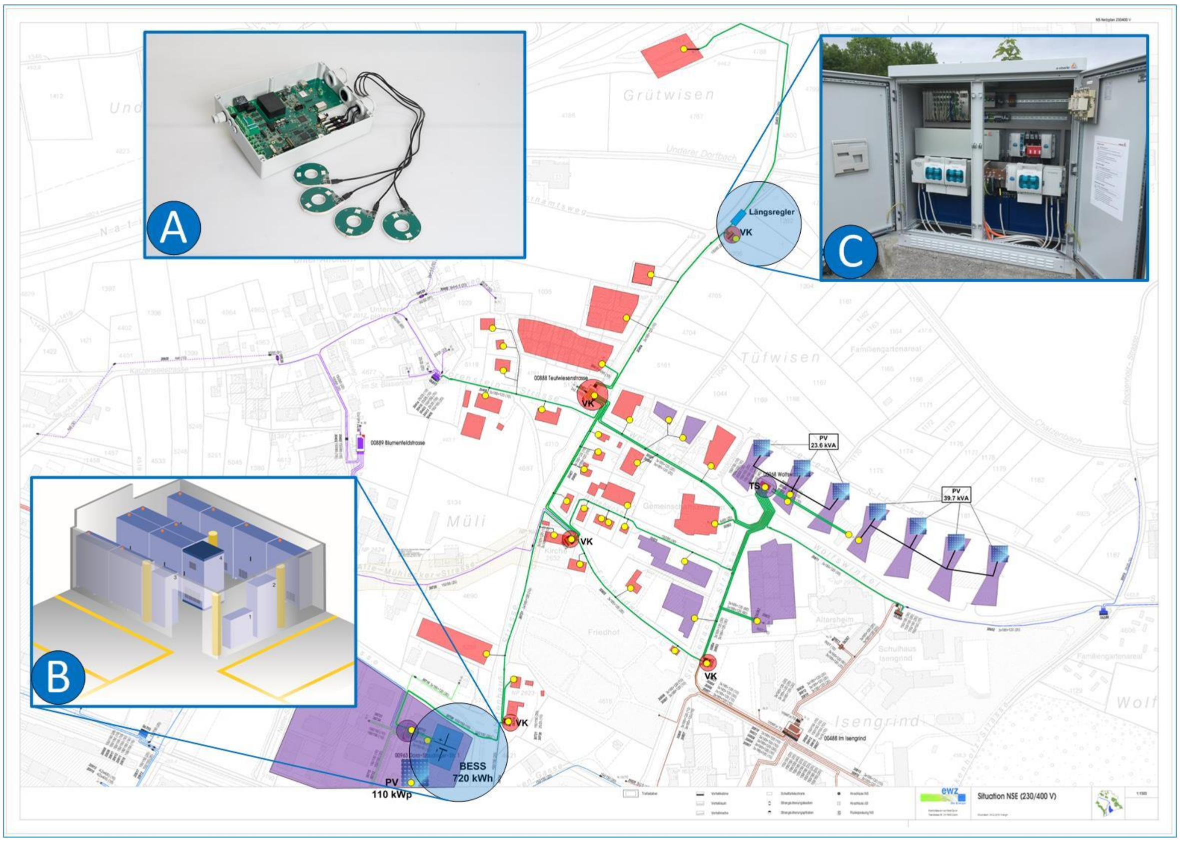

Figure 1 The Smart Grid Real Lab in the city of Zurich: A) GridBox, B) BESS, C) LVLR.

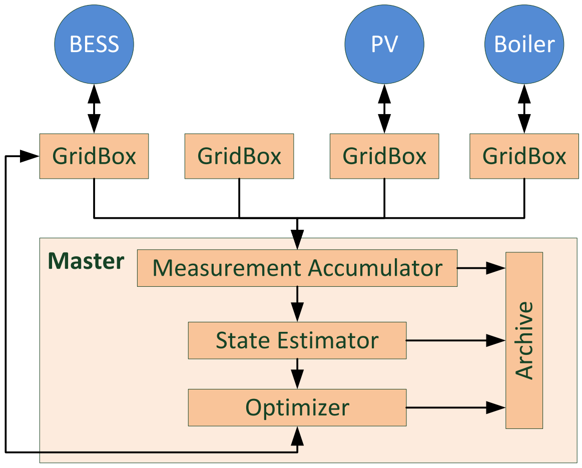

Figure 2 The architecture of the GridBox system

Battery Energy Storage System (BESS)

Since 2014, ewz has been operating in the SGRL a 120 kW Li-Ion battery system at the end of a long feeder (B in Figure 1). With a storage capacity of 720 kWh it is the battery with the biggest capacity in Switzerland. The BESS is installed at the end of one of the two long lines of the reconfigured grid in the underground parking lot of a block of flats. The dynamic control of the BESS by GridBox is achieved through Modbus protocol while its main function during the pilot project was the voltage support during high loading times.

Low voltage line regulation (LVLR)

A low voltage regulation system by A-Eberle, LVRSys™, is also installed in the Smart Grid Real Lab (C in Figure 1). The goal of this installation was to test the effectiveness of this technology in regulating the voltage on a long cable. Although the control of the LVRSys™ through GridBox over a Modbus would be possible, a predefined voltage tolerance band was chosen in the context of this project.
In order to examine how the regulator deals with overvoltage problems in case of a photovoltaic unit at the end of a long feeder, ewz performed a week-long test, simulating a PV unit using a diesel generator and a frequency converter.
More details as well as extensive results regarding the tests with the LVLR in context of the SGRL can be found in [6].

METHODS AND RESULTS

During the one-year operation phase of the demonstration project, various campaigns were carried out in order to examine the SGRL functionalities in three different areas: data communication quality, state estimator performance and optimizer. The most important findings from the large-scale demonstration project are being presented in this chapter. Extensive results and technical details in regard with the GridBox project in both pilot grids of ewz and BKW can be found in [10].

Data communication quality

A crucial component of the GridBox system and the SGRL is the communication network. Due to the potentially different grid locations (urban, rural) and the consequent possible technology unavailability, three different communication types (optical fiber, power-line communication and 3G+) were put into test and compared in terms of latency, bandwidth, packet loss and reliability (Table 1).
The best performance in all assessment categories is clearly shown by optical fibres. It is however a technology not yet widely available, especially in rural areas.
Broadband power-line would be a very suitable technology for a smart grid test field, since the needed infrastructure exists already and belongs to the DSO. Nonetheless, various problems, mainly related to the power-line modems and their signal strength, arose during the test phase. A very high packet loss in case of a weak signal could be noticed. In conclusion, power-line communication has a good potential for future smart grid applications, but is still quite power-hungry and is restricted by law to grids consisting only of underground cables.
Finally, the first experiences with the mobile 3G+ technology have shown a poor performance in the categories bandwidth and reliability. On the other hand, and in case of a sufficient antenna capacity, the technology presents a very good latency with a very low packet loss rate. However, as a technology with very high costs when it comes to handling of big data volumes, it would be an attractive solution only in case of unavailability of the other two technologies.

Table 1 Comparison of the tested communication technologies.

Technology	Latency	Bandwidth	Packet loss	Reliability
optical fiber	very good	very good	very low	very good
power-line	average	average	high	average
mobile 3G+	good	poor	low	poor

State estimator performance

One of the main high-level goals that were defined in regard with this project was the full observability of the LV grid state, even when a direct measurement would not be available. This task is carried out by the state estimator.
The developed, in context of the GridBox pilot project, three-phase state estimator, is capable of detecting and treating bad data as well as of handling missing data.
Besides the goal for grid observability, the second motivation behind the development of a state estimator was more of an economical nature: the goal of a DSO

would be to deploy only as many measurement devices in the network as necessary. A robust state estimator would allow the sparser deployment of measurement devices, while maintaining the same grid observability. In the context of the pilot project, in order to evaluate the confidence metrics of the state estimator by deliberately considering only subsets of the available measurement points, all accessible nodes were equipped with a GridBox device.
As it is not possible to assess the true state of the grid, there is no way to quantify the accuracy of estimation by itself. Therefore, the state estimator performance is evaluated by comparing the absolute values of the estimated voltage and current magnitudes to their corresponding measurements. An estimation passes this absolute error test, if it lies within the sensor uncertainty range. If this is not the case, then either the sensor uncertainty is higher than documented or the estimator is intrinsically not completely precise (or both).
Table 2 gives an overview of the median absolute error, the accuracy achieved with a 75% confidence interval as well as the sensor uncertainty per measurement group. As it can be seen, the current magnitude errors lie clearly within the sensor uncertainty limits. On the other hand, the majority of the voltage measurements clearly exceed the sensor uncertainty levels.

Table 2 Absolute error and sensor uncertainty per measurement group.

Measurement group	Median absolute error	Absolute error 75% confidence interval	Sensor uncertainty
Voltage magnitude	0.42 V_{rms}	0-0.9 V_{rms}	0.23 V_{rms}
Voltage angle	0.08°	0-0.14°	0.02°
Current magnitude	1.55 A_{rms}	0-1 A_{rms}	4 A_{rms}
Current angle	1.3°	0-6°	1°

Optimizer

The optimizer's main function was to avoid voltage and loading violations in a cost-efficient way through the activation of controllable actors. In this sense, the optimizer can control PV plants by curtailing active power as well as manage active and reactive charge and discharge of the BESS. For this purpose, a three-phase optimal power flow application with objectives like voltage stability or reducing line or transformer loading at multiple locations in the grid was developed.
Figure 3 shows the voltage profile at BESS during one evening when the optimizer was inactive. The voltage level of the phase S drops during the peak load time below 207V and thus the -10% limit of the norm EN50160 [11] is being violated. It should be noted that this specific voltage profile refers to the intentionally weaker network configuration to serve the pilot needs.
The effect of the optimizer on the voltage profile of the same node can be seen in Figure 4. In this case, the voltage in all 3 phases stays within the EN50160 limits. Plotted are both the voltages of the state estimator (SE) as well as those calculated with Newton Raphson (NR) by the optimizer. The fact that estimation and prediction don't present big deviations means that the grid state can be assumed as stationary over the optimizer control lag of few seconds.
The voltage profile histogram of phase 2, with and without GridBox control, is depicted in Figure 5. Specifically, two weeks, one with and one without optimization, at one grid node close to the BESS are compared. As it can be seen, the optimizer intervenes and resolves the various voltage drops. The lower mean voltage value in case of "Optimizer:on" occurs due to seasonal changes in electricity demand.
A side effect of the voltage stabilization, carried out by the optimizer, is the increased long time flicker values due to the consequent frequent charging and discharging of the BESS (Figure 6). Although there were no EN50160 violations recorded in our case, attention to the issue by DSOs that are operating such systems in their network should nevertheless be given. A counter-measure could be the introduction of a soft ramping of battery charging and discharging power.

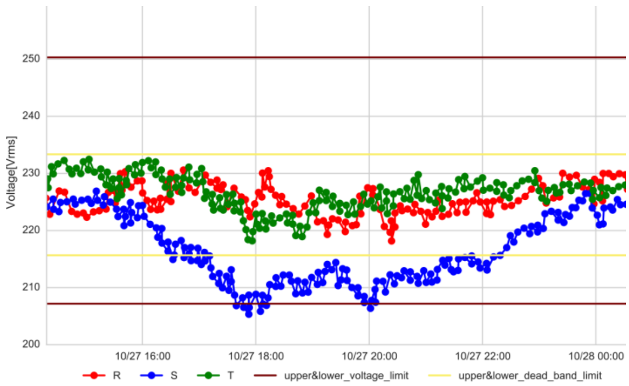

Figure 3 Voltage profile at BESS – optimizer inactive

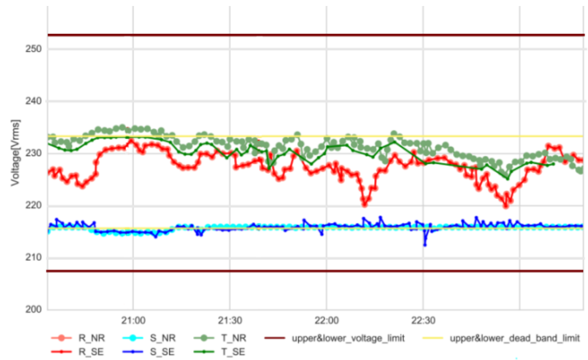

Figure 4 Voltage profile at BESS – optimizer active

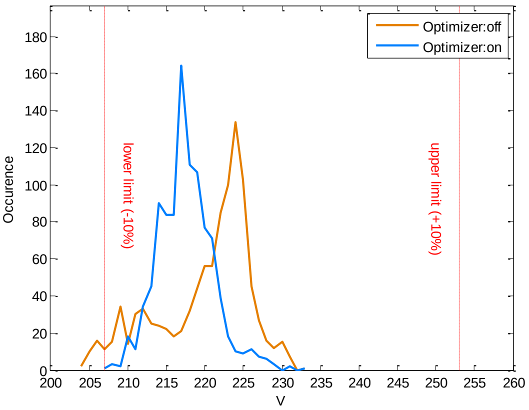

Figure 5 Voltage profile histogram with and without optimization over two different weeks.

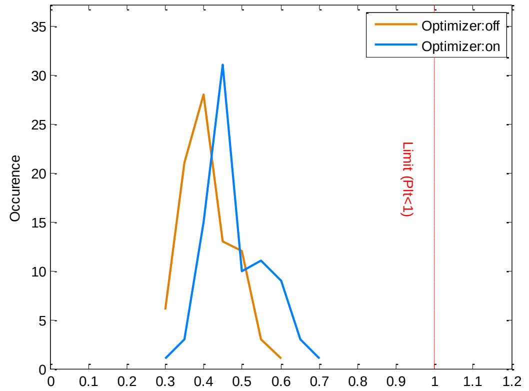

Figure 6 Long-time flicker histogram with and without optimization over two different weeks.

CONCLUSIONS AND OUTLOOK

Through the Smart Grid Real Lab ewz was able to operate a smart grid and demonstrate its technical feasibility in practice. Additionally, the large scale demonstration project helped generate valuable know-how and familiarize with new technologies and concepts. However, the scale and the difficulties of such a project should not be underestimated. The implementation and operation of new applications requires a mix of conventional grid and IT knowhow, which in our demonstrator was achieved through the collaboration of partners with different skills.

In terms of data communication, the optical fibre was proven to be the ideal solution, with cost and availability acting however as limiting factors. Despite the difficulties, the development and use of a state estimator application in similar test fields would be highly advisable, since it could drastically reduce the number of necessary smart grid devices deployed in a grid. Moreover, the developed optimizer proved in practice that it can successfully avoid voltage norm violations through the grid-optimized BESS operation.

The results of the Smart Grid Real Lab prove very valuable for the definition of the ewz smart grid architecture of the medium- and low-voltage level. The project showed the importance of transformer stations as key components of this architecture. They will serve as decentralized, intelligent hubs for the monitoring and control of the grid state. In the project it became also clear that DSOs must have access to the flexibility provided by components in buildings (e.g. battery storage or PV inverters). In order to allow for this in an efficient way in the future, the definition of a standardized interface between DSOs' smart grid systems and building energy management systems is crucial.

Given the overall success of the GridBox demonstration project, the project partners decided to commercialize the GridBox system under the name smartbox through the company smart grid solutions AG [12].

REFERENCES

[1] 2016, "Gemeindeordnung der Stadt Zürich", status June 2016.

[2] http://www.2000watt.ch/ (accessed January 2017).

[3] V. Poulios et al: Challenges with PV grid integration in urban distribution systems: A case study in the city of Zurich. CIRED 2014. Rome, June 2014

[4] V. Poulios et al: Optimal placement and sizing of battery storage to increase the PV hosting capacity of low voltage grids. ETG Congress 2015. Bonn, November 2015

[5] M. Mangani et al.: GridBox – An open platform for monitoring and active control of distribution grids. CIRED 2015. Lyon, June 2015

[6] E. Kaffe et al: New grid solutions in practice: Voltage regulation in a low voltage grid in Zurich. CIRED 2016. Helsinki, June 2016

[7] http://www.depsys.ch/products/ (accessed January 2017).

[8] http://www.sag.de/de/leistungen-produkte/smarte-technologien/smart-grids.php (accessed January 2017).

[9] BFE: GridBox; Netzbasierte Echtzeit-Erfassung des Verteilnetzzustandes und erste Praxistests – Schlussbericht (Publikation 291129). March 2016

[10] A. Brenzikofer et al: GridBox pilot project – A platform for monitoring and active control of distribution grids. Computer Science Research + Development. July 2016

[11] CENELEC: EN 50160: Voltage characterictics of electricity supplied by public distribution systems, 2010

[12] http://www.smartgridsolutions.ch/ (accessed January 2017).