NEW GRID SOLUTIONS IN PRACTICE: VOLTAGE REGULATION IN A LOW VOLTAGE GRID IN ZURICH

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ABSTRACT

In order to deal with voltage problems which are expected to arise in the low voltage grid due to high penetration of renewable energy sources, ewz, the electrical utility of the city of Zurich, investigates the effect of two new technologies, a battery system and a line voltage regulator. Both technologies are installed and tested in the low voltage grid of ewz. The results of these tests have shown that they can both be solutions for keeping the voltage within acceptable limits and they represent complementary alternatives to traditional grid reinforcement. The final choice of the most appropriate technology depends on the specific requirements of the particular case.

INTRODUCTION

In 2008, 76% of the citizens of Zurich voted in favor of the implementation of the “2000-Watt society” concept, an environmental vision introduced by ETH Zurich [1]. The 2000-Watt society concept refers both to the reduction of the overall continuous energy usage to no more than 2000 Watts per person, and to the reduction of the carbon footprint to no more than 1 ton CO2 equivalent per person by 2050 [2].
Therefore, the penetration of renewable energy sources and new loads is expected to grow significantly in low voltage (LV) distribution grids. Large shares of such units pose new challenges to distribution system operators (DSOs) which may need to confront line/transformer over-loadings and voltage violations. In this work, the main focus lies on the voltage problems.
Apart from the traditional grid reinforcements like new cables and new transformer stations, the problems arising from a high penetration of renewables can be solved by the usage of new “smart” technologies.
In this paper, we compare two technologies, namely a low voltage line regulator (LVLR) and a battery energy storage system (BESS), regarding their capability of dealing with voltage problems resulting from the high penetration of photovoltaics. The results of two respective field tests for active voltage management in a suburban area in Zurich are presented.

VOLTAGE-RELATED STANDARDS

It is more likely to observe voltage deviations, which could damage the equipment of the customers or some grid components, on long feeders. This likelihood rises significantly if a distributed generation unit is installed at the end of a long feeder, e.g. a remote farm with a low load and a photovoltaic plant on the roof. For low voltage grids, the European standard EN50160 allows a voltage deviation of ±10% of the nominal voltage. In order to avoid violations of EN50160, a DSO can resort to traditional grid reinforcement. Alternative solutions can be the installation of a LVLR or a BESS.

SMART GRID REAL LAB

ewz, the electrical utility of the city of Zurich, has developed a Smart Grid Real Lab in a residential area in the suburbs of the city. The purpose of this test field is to develop the practical know-how for the design of future distribution grids where smart technologies will help DSOs manage the high penetration of distributed generation, storage and new loads like heat pumps and electric vehicles. The grid area of the Smart Grid Real Lab includes photovoltaic panels on the roofs of several buildings, a battery storage system and a low voltage line regulation system on a long feeder. It is also the test area of the ewz pilot project Gridbox [3], which is an open platform for monitoring and active control of distribution grids.

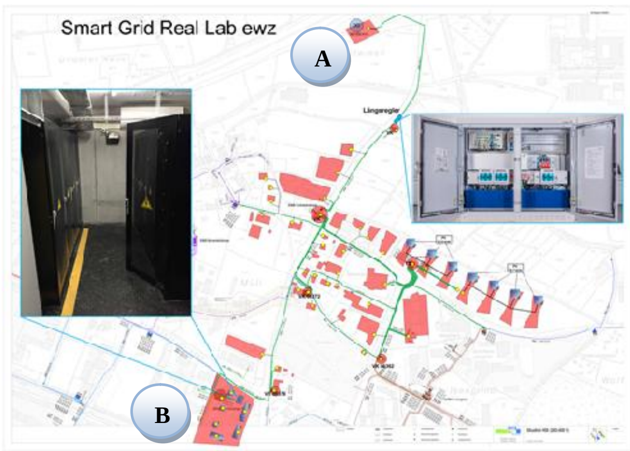

Figure 1. Test field of ewz with smart grid technologies.

LVLR

In order to simulate the aforementioned generation unit at the end of a long feeder, ewz has used a diesel generator at a motorway service area with minimal load (see location [A] in Figure 1) in combination with a frequency converter during a one-week test to feed-in a specific daily profile, based on a real PV unit in the area. A LVLR by A-Eberle (LVRSys 175 kVA) is installed in the middle of the long feeder leading to the service area. It offers independent regulation of the three-phase voltages improving the grid voltage balance and thus dealing with possible asymmetries. It regulates in both directions and measures among others voltage and current. A nominal value for the voltage can be defined as well as a tolerance band in both directions as acceptable range of voltage variation.

BESS

Regarding the second alternative, ewz has already installed a building integrated BESS [4] at the end of another long feeder of the grid, a housing complex with a photovoltaic installation of 110kWp on the roof (see location [B] in Figure 1). The BESS is situated in the underground car park of the building. An area of 30m^2 is used for the installation of the energy storage system with 120kW and 720kWh installed power and energy respectively. The BESS plays a different role in the test grid depending on the situation. During the day, if the PV production is higher than the consumption of the building, the surplus production is stored in the BESS. In the evening, when the consumption is higher, the long feeder causes high voltage deviations and the BESS has to inject energy to the grid to keep the voltage in the allowed band of ±10% of the nominal voltage.

TEST ENVIRONMENT

The voltages on the two feeders during high generation infeed are registered and analyzed. In this first approach the LVLR functions independently keeping the voltage in the grid within the allowed limits. The LVLR was installed in May 2015 and the nominal value and tolerance band were defined at 230V ± 5V. It is keeping the voltages in limits at all three phases for normal power flows, from the transformer station to the house connection at the service area. In January 2016, a diesel generator (DG) was temporary installed and put in operation in the service area creating reverse power flows from the house connection to the transformer station in order to simulate a PV unit. To be able to feed-in a specific profile corresponding to a real PV profile, a frequency converter (FC) was used to connect the diesel generator to the grid. The test lasted 7 days and several profiles were fed-in (Figure 2) in order to test both constantly sunny days and days with alternating sunshine.

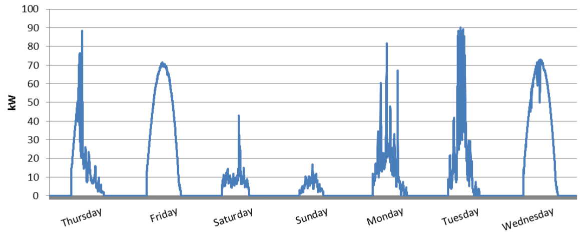

Figure 2. PV profiles used as input for the DG test.

The GridBox system monitors the whole low voltage grid and can avoid problems by controlling variable loads, one of them being the BESS.

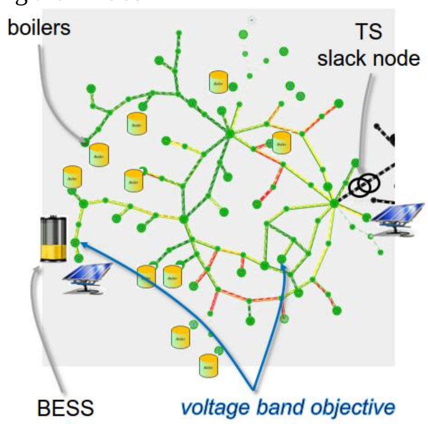

Figure 3. GridBox System in Smart Grid Real Lab

With a configuration of the grid specifically adapted for the field test, voltage problems (Figure 5) arise at the connection point of the building in the evening.

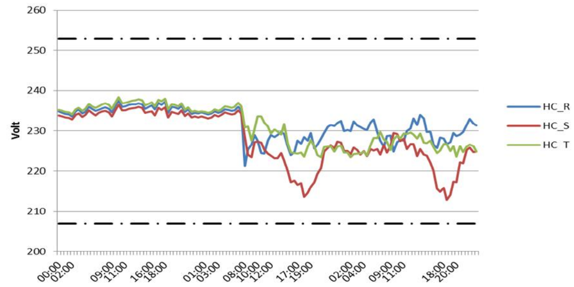

Figure 4. Initial voltages at the house connection as monitored by GridBox.

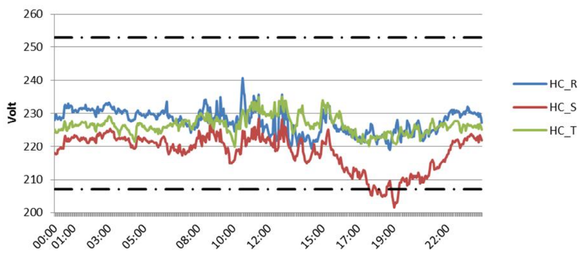

Figure 5. Voltage problems at the house connection as monitored by GridBox with the adapted configuration.

During the GridBox project several campaigns with different settings were planned and tested. In the following chapter some results of the BESS campaign are presented.

RESULTS

In this chapter the results of each test are presented.

LVLR

In the following graph, one can observe the voltages at the input point, as measured by the frequency converter in comparison to the voltages at the output of the LVLR. For almost all days, significant overvoltages and minor undervoltages in comparison to the nominal value of 230V were observed. However, they did not violate the ±10% limits as defined in EN50160, since the injected power was not high. The problems during constantly sunny days were much more intense leading to a violation of the limits for a longer time and with a higher voltage. For the whole week, all overvoltages were eliminated by the LVLR. The importance of the separate regulation of the different phases is also shown in these graphs, where the asymmetry between the three phases is highlighted.

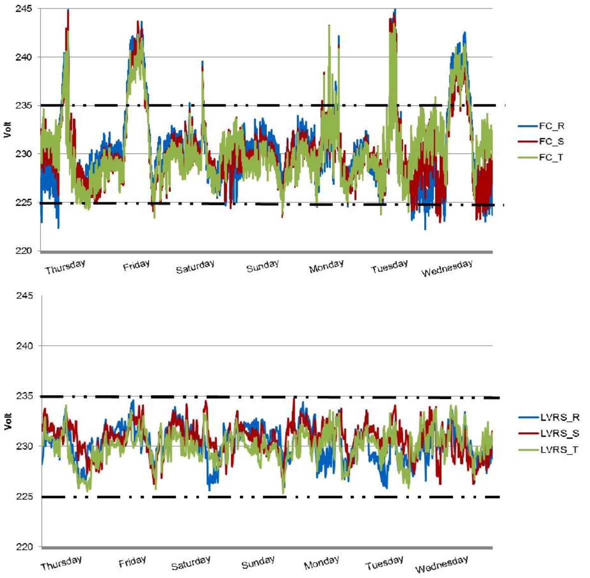

Figure 6. Voltage at the frequency converter (FC) and the low voltage line regulator (LVLR) during the test week.

In order for the results to be more apprehensible, the voltage level before and after the LVLR (explicitly at the frequency converter and at the output of the LVLR) for phase 1 and day 1 is presented in the following figure.

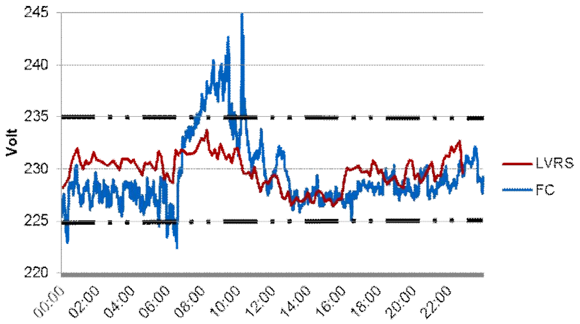

Figure 7. Voltage at the frequency converter and the line voltage regulator during one day of the test week.

In the test area around the LVLR there are three measurement points. Apart from the FC and the LVLR itself there is also one Gridbox at the house connection (HC) in the service area (Figure 8).

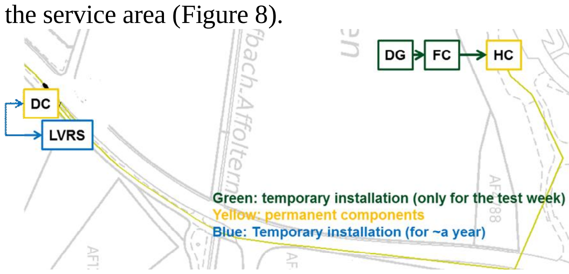

Figure 8. Test area LVLR.

It is interesting to study the development of the voltage in these three measurements points on a sunny day, here on the last day of the test period. Some missing values on the GridBox measurements are caused by communication failures, but since they are not during high PV hours, they do not affect the interpretation of the results. The expected voltage drop on the line is visible in Figure 9 with the last figure showing how the LVLR deals effectively both with over- and undervoltages. The three units have different measurement resolution; namely the FC produces 1-minute values, the Gridbox at the HC 1-second values and the LVLR 10-minutes average values.

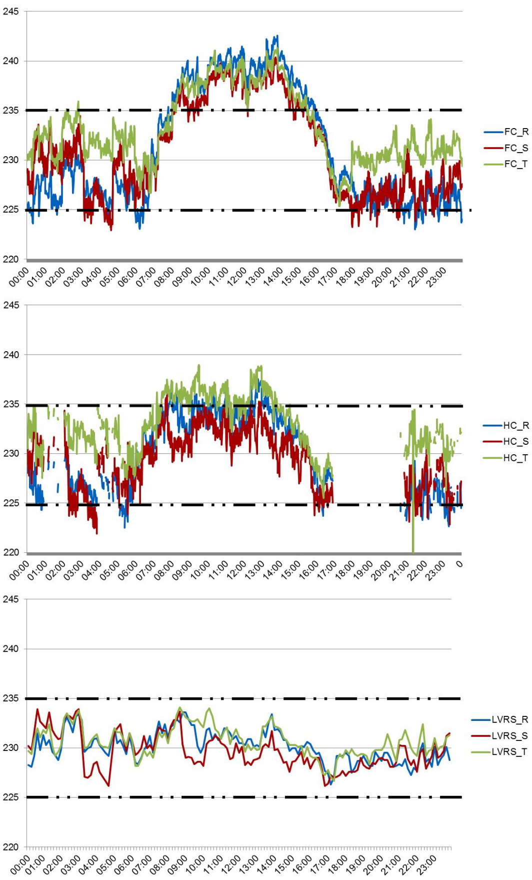

Figure 9. Voltage development on FC, HC and LVLR respectively during the last day of the test week.

BESS

In Figure 10, the voltage level of one day is shown at the building connection point without BESS operation. The three phases are presented in comparison to the nominal value of 230V. There are few hours in the evening when the voltage drops and violates the -10% limits as defined in EN50160. The high unsymmetrical load of the building is also observable in this graph. The load is badly distributed and problems arise only in phase S.

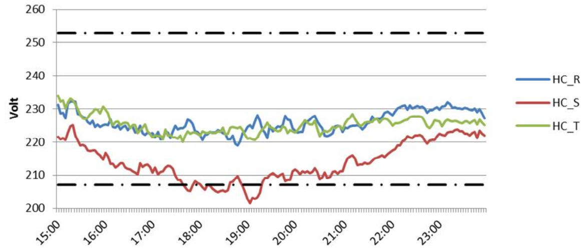

Figure 10. Voltage level at the building connection without BESS.

The second graph (Figure 11) shows how those voltage drops could be avoided through the BESS operation. However, the storage can only be controlled for all three phases simultaneously resulting to the elevation of the other two phases also, which were in limits from the beginning. The lack of phase-independent control is due to the 3-phase inverter module used in this case.

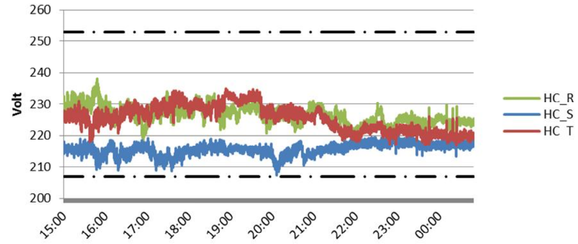

Figure 11. Voltage level at the building connection with BESS operation.

CONCLUSIONS

This pilot project offers valuable experience on how to deal with the grid integration of distributed generation, causing fluctuating nodal injections in remote areas of the grid. A comparison of the two alternatives examined in this paper is drawn.

More specifically, a LVLR can represent an economically meaningful alternative to traditional grid reinforcement, e.g. the construction of a new transformer station, for cases where voltage violations are the sole problem. LVLR is also the preferred solution in case of highly asymmetrical loads like the ones presented here, since it offers the possibility of independent control of the three phases. A BESS could also cope with that problem if it was equipped with three 1-phased inverters instead of a 3-phased one. If the increase in fluctuating renewable generation results also in overloading of the transformer or the lines, reaching their thermal limits, then a BESS or a combination of grid reinforcement and a LVLR can represent a solution. Since these technologies are relatively new and their costs, particularly in the case of batteries, are still relatively high, they are often not taken into account as potential solutions by DSOs today. This is expected to change in the coming years. Using a LVLR as a transitional solution to deal with overvoltages until the local transformer station and/or low voltage lines have to be replaced due to reaching the end of their lifetime could be one approach. Another approach for making a BESS economically viable would be a combination of different applications: distribution grid-oriented usage as discussed in this paper, maximization of self-consumption for the customer and participation in the spot or reserve power markets via pooling of multiple batteries.

REFERENCES

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