INVESTIGATING APPLICATIONS OF ENERGY STORAGES FOR THE INTEGRATION OF RENEWABLES IN THE DISTRIBUTION GRID – VIEW FROM A DISTRIBUTION GRID OPERATOR

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ABSTRACT

The electric utility of the city of Zurich, ewz, expects the grid load to receive additional intermittent components due to distributed generation and electric vehicles. Although the distribution grid generally has reserve capacity to cope with altered and additional loading, local temporary congestions are probable – especially during peak production and peak demand. Instead of the conventional method, grid reinforcements, battery energy storage systems (BESS) have the potential to mitigate the congestion by shifting the peak loads. Therefore, the investigations in this paper comprise the utilization of BESS as grid components. Three applications of BESS in the distribution grid and their economic aspects are presented in this paper. A pilot project is planned to demonstrate the feasibility of the applications and to gain experience with BESS.

INTRODUCTION

The distribution grid of ewz is likely to face new challenges that result from excessive distributed generation and additional demand from plug-in electric vehicles (PEVs). The installation of renewables in the distribution grid of ewz will probably increase in the coming years and load the distribution grid stochastically. Furthermore, ewz expects that PEVs will be used and charged to an extent, which make planning necessary. Both the production and the additional demand might lead to congestion in the outskirts of the city of Zurich. Currently, Swiss legislation says that the electric utilities must connect producers to the grid [1]. Furthermore, the produced power of renewables must be purchased by the utilities at any time. Unless the legislation is changed, ewz must find an adequate way to integrate renewables and electric cars into the grid. The conventional method is the reinforcement of the grid. However, grid reinforcements mean costs and construction. Another method is demand side participation [2] or storages [3]. Compared to BESS, demand side participation is more complex to control as a higher number of devices are involved. BESS have the advantage to be installed with less construction and offer the potential for synergy by solving the problems stated above. Furthermore, ewz controls them and is responsible for their performance. However, Swiss legislation says that grid operations must be independent from other activities of the electric utility [4]. As a result, it is e.g. not possible to trade energy with the BESS. Hence, the following questions are addressed in this paper:

- What are the possible applications of BESS in the distribution grid?
- Is a central BESS or are distributed BESS more appropriate?
- Which synergies can be exploited?
- What are the costs compared to grid reinforcements?

Three applications are discussed in this paper. Results of simulation show the potential of the individual version. In order to confirm the simulation results, a pilot project is planned in the outskirts of Zurich.

CONFIGURATION OF PILOT PROJECT

The pilot project comprises a building complex with nine apartment buildings in the outskirts of Zurich which are equipped with solar panels and a transformer substation (TS). Figure 1 shows the plan of site with the TS and the low voltage cables c1 and c2 which connect the TS to the buildings.

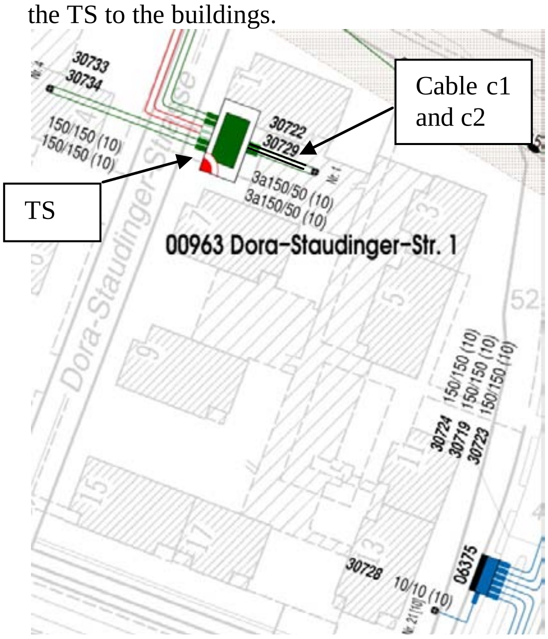

Figure 1: Top view showing location of the pilot project

The TS supplies the nine houses of the complex and an additional 10 houses nearby.

PV-Production

The nine buildings considered in this study have solar panels on the roof. The installed power per house depends on the roof size and the PV- modules which are placed. In total, the 171 modules provide 110 kWp – between 10 and 30 kWp per building.

Transformer Substation

The TS consists of two transformers, each has a rated power of 1 MVA, low and medium voltage distribution and measurements. In Figure 2, the measured PV-production is depicted by the blue, dotted line. The measured loading of the two transformers is shown with and without PV-production, by the red, dashed line and by the black line, respectively. It can be observed that the loading of the transformers is higher during the day if the PV power generation is not considered. Therefore, PV power shaves the peak during midday.

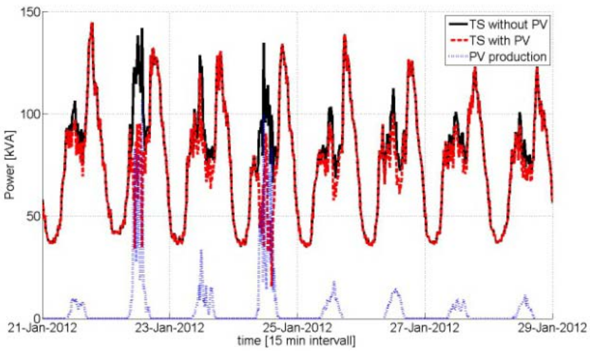

Figure 2 Loading of the transformers with and without PV power generation

Private Mobility

Future private mobility is an interesting topic among grid operators. An internal study predicts that 34% of all vehicles will be PEVs (hybrid or pure electric) in the year 2030. The nine apartment buildings of the pilot project have an underground parking for 200 cars. Currently, there are no installations for charging PEVs. On average, ewz assumes PEVs are charged with 3 kVA. The additional 200 kVA consumption in the evening is considerable and would change the typical day curves. Therefore, PEVs are a new factor to build the grid of the future.

STORAGE TECHNOLOGOY

The type of battery will be Lithium-ion (Li-ion). The advantages of this battery type are:

- Practically free of maintenance
- Very low self-discharge
- No memory effect
- Voltage is constant during discharge

The expected lifetime of Li-ion batteries is between 10 and 40 years. The lifetime depends on the operating temperature, the material of the battery and the number of cycles. The expected life cycle of a Li-ion battery can range from 3’000 to over 15’000, depending on the negative electrode materials. If the electrodes are graphite, the lifecycles reach only 3’000 cycles, until the battery loses 30% of its capacity. When the material is titanate, the lifecycles can exceed 15’000 cycles. The round trip efficiency of the BESS is about 90 % but neglected in the simulations for a preliminary assessment.

OPERATIONAL REQUIREMENTS

Various applications are possible for BESS in the distribution grid. In this paper, the following three are discussed:

- Optimize PV-generation for grid
- Optimize PEV-consumption for grid
- Optimize transformer load (Peak Shaving)

All have the goal to prevent grid reinforcements. Furthermore, there is a potential of controlling the power flow and the production of the grid. The overall system used in the studies is shown in Figure 3.

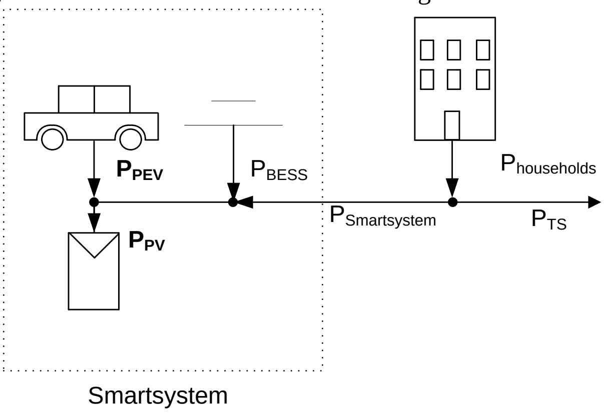

Figure 3 Model of the overall system.

A subsystem called Smartsystem comprises the demand of PEVs (P_{PEV}), the production of the photovoltaic (P_{PV}) and the power of the BESS (P_{BESS}). Equation 1 describes the relation between the various components.

Equation 1

$$P_{Smartsystem} = P_{PV} - P_{BESS} - P_{PEV}$$

The Smartsystem and the demand of the households ($P_{households}$) together load the TS with P_{TS} which is formulated by Equation 2:

Equation 2

$$P_{TS} = P_{households} - \underbrace{P_{PV} + P_{BESS} + P_{PEV}}_{-P_{Smartsystem}}$$

In the following, the three applications are discussed for a BESS with a capacity of 500 kWh.

Version 1: Optimize PV-Generation for Grid

In this version, the BESS (500 kWh) is applied to reduce cables c1 and c2 (Figure 1). The PEVs are not considered in this version. Therefore, Equation 1 can be simplified:

Equation 3

$$\boldsymbol{P_{Smartsystem} = P_{PV} - P_{BESS}}$$

Nowadays, the cables have to be dimensioned according to the peak power of the solar panels ($P_{cable,\ no\ BESS}$ = 110 kVA). The BESS can reduce the loading of the cables by shifting the power generation on a daily basis: when the PV-power generation exceeds the predefined $P_{Smartsystem}$, the BESS is charged and vice versa. Simulations show that $P_{Smartsystem}$ would be maximally 37 kVA with a BESS and the cable could be dimensioned for 40 kVA ($P_{cable,\ with\ BESS}$) instead of 110 kVA. With an infinite seasonal BESS, the PV-generation for the whole year could be shaved. In this case, $P_{Smartsystem}$ would be 17 kVA which is the minimal, theoretically possible loading of the cable. Figure 4 shows all three cases: the grey, dashed line shows the PV-generation during five months ($P_{Smartsystem,\ no\ BESS}$) the black line depicts $P_{Smartsystem}$ for a daily power shift (500 kWh, $P_{Smartsystem,\ daily}$) and the black, dashed line $P_{Smartsystem}$ for a seasonal BESS (infinite capacity, $P_{Smartsystem,\ seasonal}$).

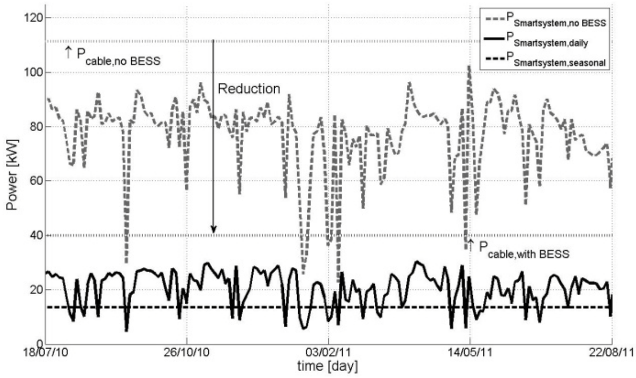

Figure 4 Optimize PV-power generation for the grid. The cable can be reduced from 110 kVA to 40 kVA

Version 2:Optimize PEV-Consumption for Grid

Version 2 investigates the impact of PEVs on cable c1 and c2 with and without a 500 kWh BESS. The PV-power generation is ignored (P_{PV} =0). Without a BESS, P_{PEV} is maximally 200 kVA. With a BESS, the PEVs can consume the majority of energy from the BESS and only a small part from the grid – instead of 200 kVA(P_{PEV}), only 35 kVA ($P_{Smartsystem}$) are required to charge the PEVs. Therefore, the reduction is 165 kVA.

Version 3 Optimize Transformer Load for TS

The goal of this version is to shave the loading of the transformers on a daily basis. In order to investigate the effects of the PV-generation on the loading of the transformers, two situations are discussed in this section: firstly, the power produced by the solar panels is not considered (hence added to loading of the TS) and secondly, the power of the solar panel is considered. The maximal loading of the transformers is 145 kVA for both cases since it occurred during the evening (see Figure 2). PEVs are not considered in this version (P_{PEV} =0).

3a): Optimize Transformer Load for TS without PV
When the PV-generation is not considered, peak shaving of the transformers is possible at P_{TS}=75 kVA. This means the BESS discharges when P_{TS} exceeds 75 kVA and charges, when P_{TS} is lower than 75 kVA. Obviously, the conditions are that the state of charge of the BESS is between 0% and 100%. Therefore, the loading of the transformers can be reduced by 70 kVA.

3b): Optimize Transformer Load for TS with PV
On the other hand, when the PV-generation is considered, peak shaving of the transformers is possible at P_{TS}=65 kVA. Therefore, the loading of the transformers can be reduced by 80 kVA. It can be observed that P_{TS} is lower for version 3b compared to version 3a. The reason is that PV-generation reduces the loading of the TS during the day.

ECONOMIC IMPACT

The BESS has the potential to optimize the operation of the distribution grid. The costs for reduced grid reinforcement or capacity utilization of the existing equipment are taken as a benchmark for each version. In practice a grid usually already exists. Therefore, the reduction of cost depends on whether reinforcement measures can be prevented in the specific situation by a BESS. For better comparability we assume in a first step that the grid is designed according to the additional capacity regardless of potential synergies. So the full potential cost reduction is taken into account. Furthermore, we assume that the service life of the BESS is 40 years and therefore comparable to the grid components. Operational costs are neglected, as maintenance for the BESS and for the grid does not deviate significantly. For all versions the BESS chosen for the pilot project (500 kWh, 120 kW) is used for optimization. A BESS system with Li-ion batteries costs 500'000 CHF (1 CHF = 0.83 EUR) for one central BESS and 530'000 CHF for six small BESS. Table 1 shows the grid capacity required in kVA for all three versions.

	Required Grid Capacity [kVA]			
	V 1	V 2	V 3a	V 3b
Grid no BESS	110	200	145	145
Grid with BESS	40	35	75	65
Reduction	70	165	70	80

Table 1 Grid capacity requirements in kVA for all three versions.

Two scenarios are considered to calculate the prevented cost:

- The existing grid has enough capacity to take the additional load; a share tariff (dimensions according to basics of network planning in ewz) is calculated.
- The grid has to be reinforced when no BESS is used. The full cost of the cable with the minimum deployable nominal power available and a share of a standard TS (2x1'000 kVA) is taken into account for the specific case.

The length of the LV-cable connection varies in practice between 50 - 500 m. Therefore, a minimum (Min) and a maximum scenario (Max) is analyzed. In Figure 5, the resulting investment costs are displayed in relation to the estimated costs of the given BESS (530'000 CHF).
In practice PV-production (version 1) will in most cases be installed together with household loads. Due to the opposite power flow directions, the capacity of the grid will generally be sufficient, when it is dimensioned for loads with similar power as PV-production. This is also the case in version 3b. For version 2 the power flow directions are the same for PEV-consumption and household loads which leads to an increasing capacity requirement.

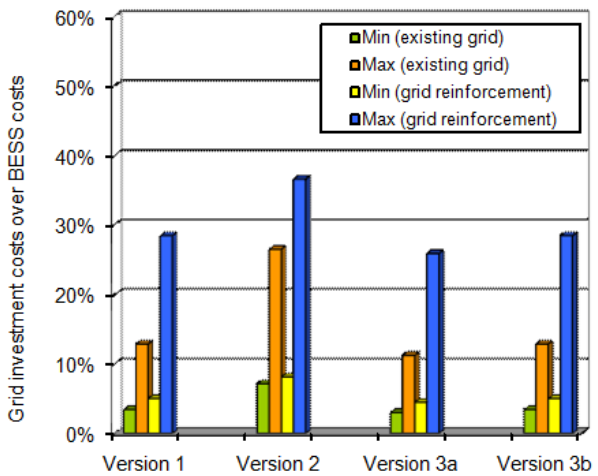

Figure 5 Prevented reinforcement costs in relation to BESS

Figure 5 shows that the grid costs do not reach the estimated costs for the BESS in any of the cases considered here. It is evident, that prevented costs increase with the feasible capacity reduction by BESS of given size and with the length of the LV cable connection. Normally, capacity is available in the grid. In this case a BESS is no competitive solution. BESS could however become a potentially interesting solution in the future in those special cases, where the existing installations have reached the capacity limit and reinforcement measures are necessary.

CONCLUSIONS

In this paper, three versions for BESS in the distribution grid have been studied: optimization of PV-generation for grid, optimization of PEV-consumption for grid and optimization of transformer load. All three versions are able to reduce the cable or transformer capacity for the specific application. However, the economic investigation has shown that the costs for a BESS must decrease significantly in order BESS can be an economic alternative to grid reinforcements. Nevertheless, BESS might be realized, e.g. when no construction is possible or space is not available for a new TS. Furthermore, the prices for Li-ion batteries are expected to decrease in the next years. With falling prices of batteries and rising copper prices, BESS could become an economic alternative to grid reinforcements.
In any case, the regulator has firstly to accept proposed grid reinforcements and secondly BESS as a grid component. This is the condition that ewz can include BESS costs in the user fees. In addition to preventing extensive construction works it is an advantage that local smoothing of the voltage can be performed by the BESS. Smoothing of the voltage, which has not been quantified here, may become necessary when intermittent load or production is connected to the grid.
For these reasons, ewz conducts the pilot project to gain experience with BESS.

REFERENCES

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