Practical Experiences from Project Development of Utility-Scale Solar and Storage Projects for Weak Grid Applications

Dipl.-Ing. Peter Hussinger, M.Sc. Martin Dennenmoser, M.Sc. Zaid Al-Jallad, M.Sc.Thorsten Althaus, Eng. Mohammed Helmy, M.Sc. Philipp Kunze
BayWa r.e. solar projects GmbH
Munich, Germany
peter.hussinger@baywa-re.com

In this paper, experiences from project development of utility-scale solar and storage systems for weak grid applications are highlighted. The first case describes a peak generation support during evening hours to reduce diesel genset operation in a transmission grid. The second case is a solar park combined with battery storage, where two different battery applications are presented and analyzed. Project opportunities are pursued in Sub-Saharan Africa. For both cases, different challenges were identified within the technical and economic assessment of the projects, which are presented at the end.

Keywords: utility scale battery storage, PV plant, Diesel genset, hybrid power system, energy flow analysis, peak generation, smoothing, capacity firming

I. Introduction

In the last years more and more genset running utilities are thinking about integrating solar PV and battery storage since system prices are falling: Utility-scale PV systems have seen a decrease in LCOE of around 88% in the US between 2009 and 2018 [1]. Even more, the cost of utility-scale Li-ion battery systems dropped by more than 60% in only 27 months from 2014-2017 [2]. In contrast, the cost for Diesel for selected countries in Sub-Saharan Africa is rather staying constant or even rising during the last 10 years [3][4]. In addition, aging generator units with increased maintenance, but also rising loads make utilities reflect on which technology makes the most sense for future investments.

II. Case 1: A grid connected utility battery system to operate as peaking generation unit

A. Case description

A utility and transmission system operator (TSO) coordinates ~700 MVA of capacity in its grid. Most of the energy is purchased and imported from third parties. A fleet of diesel gensets with a combined capacity of ~80 MVA is located at important industrial customer sites of the TSO. The gensets are operated as emergency backup power as well as for peaking generation to reduce the resulting third-party demand charge cost. This is a profitable case since about 65% of third-party import energy cost are driven by the demand charge. Diesel fuel expenditure is around ~1 USD per liter and gensets currently running are up to 50 years old and must be replaced. The gensets deliver peaking power to the grid between 6 and 10 pm caused mainly by the residential sector. The generators are started well ahead of time before they are needed and run hence often in no load mode. In order to keep the imported power purchases under a certain demand level, the generators must be able to supply power immediately during evening hours. Figure 1 shows the average daily operation of the gensets. The generation time is mainly in the evening hours. There are also low loading times during the afternoon visible.

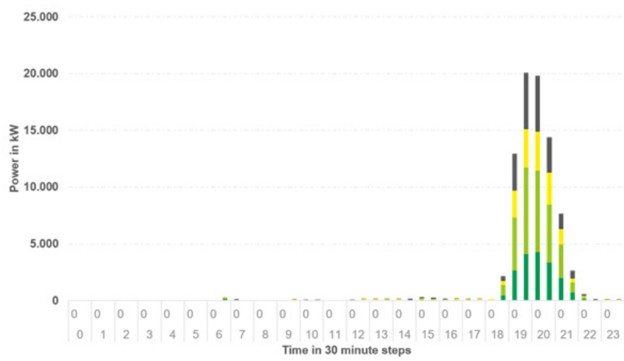

Figure 1: Genset operation during the average day; different colors represent different genset plants

In an energy flow simulation, a battery-based solution is compared to the existing gensets with the goal of reducing demand charge costs by supplying peaking power in the evening.

B. Economic assessment

For the analysis, historical operation data were analyzed. Based on that, two benefits for the implementation of the battery system are highlighted: Firstly, the peak generation supplied by battery system can reduce demand charge cost

more efficiently due to faster deployment and response time comparing to the gensets. Secondly, the operation of the remaining generators can be optimized through battery systems. Gensets can run in a more favorable efficiency range and no load/idle times can be reduced. Better utilization of remaining gensets with the help of a standalone battery system can result in fuel savings up to 25% per day.
Figure 2 presents the total relative fuel savings for battery scenarios in dependence of the storage capacity.

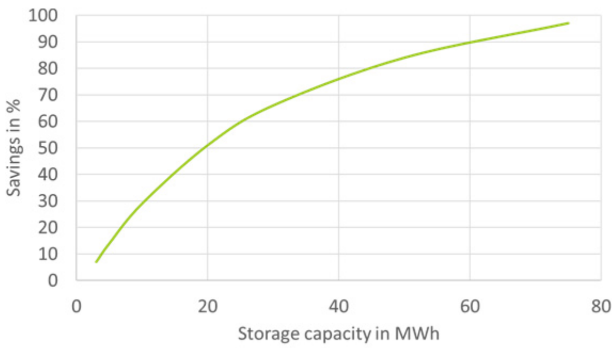

Figure 2: Fuel savings for battery discharge in peak demand hours in dependence of the storage capacity (1C battery is assumed for all scenarios)

Savings are rising significantly for smaller capacities. A saturation effect can be detected for higher capacities. An economically interesting size is between 20 to 30 MWh of storage capacity with yearly savings of 3.2 to 4.2 million USD per year. For this range of battery size, the payback time is quite attractive with 4 to 5 years.

III. Case 2: Assessment of Utility Solar PV + Battery Storage Applications in Sub-Saharan Africa

A. Case description

In Europe, solar parks are installed without a battery system up to the present. PV curtailment due to grid overload can occur once or twice per month during the summer period. In some rural regions with weak grid connections, there is a potential of excess voltage problems. Energy arbitrage is not considered as a viable business case for battery storage yet, since a feed-in tariff (FIT) scheme is mostly applied. The grid is interconnected and relatively strong. Firming of renewable energy (RE) output by battery storage is not compensated. This might change in future looking at higher total shares of RE in the European grid.

In Sub-Saharan Africa, there are many countries with high solar irradiation but often with weak electric grids. FITs are often not established and concerns about the integration of RE in the grids are rising. Nowadays, Grid codes state the requirement of changing the power export of PV by maximum 10% per min of nominal AC power [5][6].This implies the need for using storage co-located at solar parks already.

Moreover, utilities are typically interested in having additional electricity available during peak hours in the evening, which would be a viable case for a supply shifting battery application. For utilities aiming at bigger PV pipelines, smoothing strategies can be also interesting in order to reduce overall PV fluctuations in the grid. The generation of the solar park becomes hence more predictable for the off-taker.

In our case study, a 20 MWp fixed-tilt solar park is compared to a similar system including a battery to firm solar production [7]. Irradiation data for 2016 is taken from [8] to reflect a specific year in high resolution instead of TMY data. Based on an energy flow simulation with 1-minute time steps and no forecasting compatibility, two different battery applications are compared:

a) Smoothing: reduce fluctuation rate of solar power output to comply with the ramp rate requirement of +/- 10% per min of nominal park power (AC)

b) Supply shifiting: limit solar power peak generation and shift energy to the evening

B. Technical results

a) Smoothing

The simulation of the reference solar park shows a maximum fluctuation rate of 78% per min and a quantity of 19,461 limit violations of the +/- 10% ramp rate due to cloud movements. In order to comply with the ramp rate requirement, a minimum usable storage sizing of 12.1 MW – 4.8 MWh has been determined through energy flow simulation.

Figure 3 shows the power output of solar plus storage and of the reference solar park during two example days with notable cloud influences.

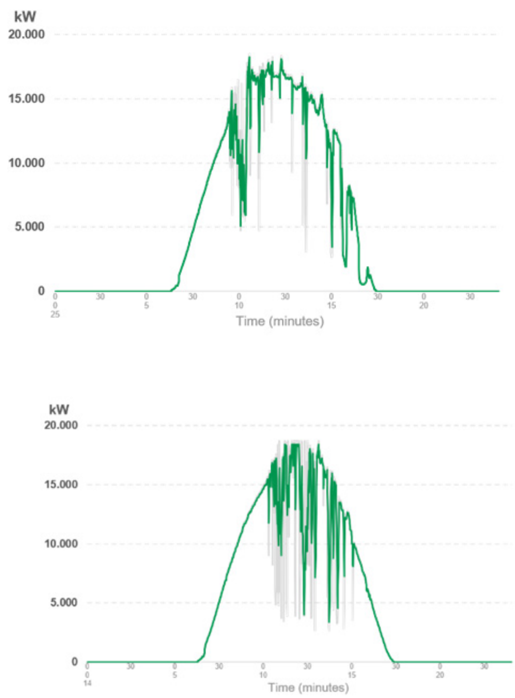

Figure 3: Smoothing during a day with cloud movements; grey=solar production, green= smoothed plant output upper: medium cloud movements, lower: very strong cloud interference

The fluctuations in PV power output are reduced considerably with the help of the battery storage system and hence comply with the limit of +/- 10%/min.

b) *Supply shifting*

With respect to the supply shifting scenario, the peak output of the solar park is limited to 65% of its nominal output. Doing so, the grid connection cost of the solar park can be reduced as well as fluctuations, since nominal power is never directly fed into the grid. The direct feed-in of solar power is limited to 13 MW of active power. The excess energy during peak production time is stored in a battery to be shifted to evening hours. During evening peak hours, power is supplied back to the grid through battery discharge.

In order to shift the 35% peaking power to the evenings, the simulation resulted in a minimum battery sizing of 6.4 MW – 13.8 MWh. Figure 4 shows two example days on a sunny and a cloudy day. The duration of the evening power block is dependent on the amount of stored energy during the day.

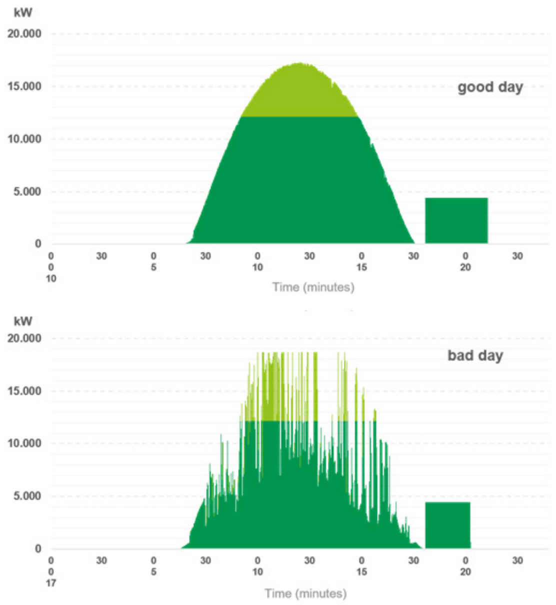

Figure 4: supply shifting – dark green=energy supplied to the grid, light green=energy stored during the day due to limit 65% limit of solar park.

Reviewing the two storage applications, it can be concluded that adding a battery storage unit results in an added technical value of the solar power. This is represented either by a higher power quality in case of the smoothing scenario or by the advantage of a planned/predictable generation in the evening times in case of the supply shifting scenario. Each case has its own requirements when it comes to battery sizing and specifications. Table 1 presents key parameters of each application.

Table 1: Review of storage use cases and required battery specifications

	Smoothing	Supply shifting
Battery sizing	12 MW 4.8 MWh	6.4 MW 13.8 MWh
C- rate	2,5C	0,46C
Cycles/yr	135	283
Storage type	Power storage	Energy storage

Smoothing requires a high-power storage and doesn't perform many cycles per year. It results in short charge and discharge actions. Supply shifting on the contrary requires an energy storage with a low C-rate and a typical cycle count for a PV battery system in self-consumption mode. This leads to different requirements not only affecting the system size, but also the choice of battery cell type. The comparison underlines that possible battery applications need to be clearly agreed on beforehand with the customer. Also, grid services like black start capability or voltage control require a different hardware setup that need to be planned and included before.

C. *Economic evaluation*

Adding a battery system to the solar park increases the total system cost. The added value and associated increased cost of the energy needs to fulfill the requirements by the off-taker in technical and economic matters. Looking at the LCOEs of the two scenarios, Figure 5 shows that LCOEs are not multiplied by adding the battery system.

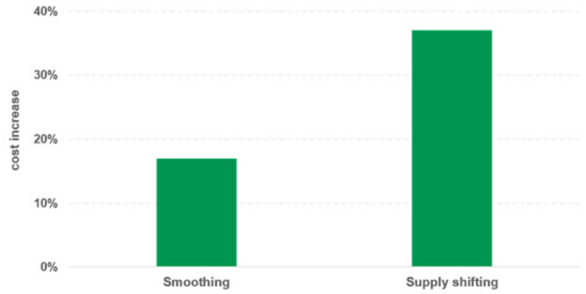

Figure 5: LCOE extra cost of battery use scenarios vs. standard PV park (25 yrs project lifetime)

An LCOE cost increase of 17% and 37% can be expected compared to the PV-only scenario. This represents an absolute plus of about 1-2 USD ct/kWh as additional cost.

Utility PV-battery systems are becoming more and more attractive also on economical point. Due to falling battery and PV system costs, battery implementation will become even more attractive in the future. From a technical point of view, this is due to the improved quality and/or plannability of PV generation. From an economical point of view, batteries need to find their role in Hybrid PPAs.

IV CHALLENGES

Different hurdles can appear when realizing utility-scale hybrid and battery projects. Utility-scale battery systems can be technically unknown to customers in Sub-Saharan Africa and major concerns with respect to operational know-how must be overcome.

Batteries can bring flexibility into electric grids. For the off-taker, it is often hard to determine the benefit of using a battery. In the first case, the value of peak shaving savings were able to be calculated. In the second case, the value of smoothed PV power compared to fluctuated PV power is harder to determine. For other applications like black start capability or voltage control, it is even harder to translate the technical benefit into a financial value. Stacking of battery services is important to increase the overall revenue streams in order to improve economy of the project.

What's more, a standalone battery behaves different than assets typically known by the customer. It does not generate electricity like a PV plant or a diesel genset. There is less customer or investor experience in terms of IRR or payback period. Furthermore, PV developers are used to structure their PPAs as single technology PPA. Developing a battery storage/hybrid PPA might be very challenging, especially for including hard to be measured services like black start support or voltage regulation.

In order to reach an accurate battery system size and realistic economic results, a reliable and accurate data source is a prerequisite. In order to understand possible storage integration in a holistic way, local site visits are very important to assess the current situation and collect the necessary performance data. A deep understanding of the current diesel operation is important to identify a suitable solution which offers a maximized fuel saving potential while not disrupting operating procedures familiar to the client. This means to capture human behavior and translate that into an algorithm for modeling.

During the project development phase, it is also very important to understand the existing energy contracts of customers. The first case describes a contract for third party power purchases which is very focused on the demand charge rate. The energy charge itself is very low. But even the short payback time of this project is longer than the contract with the third party. This is an investment hurdle to the customer since future price adjustment mechanisms are still unknown.

In addition to that, the price of batteries affects the project payback time. Considering the rapid development in the battery market in the past years, especially with respect to price and manufacturing volume, customers expect even more declining prices in near future. This might delay the decision making when it comes to new investments.

References

[1] Lazard 2018 https://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2018/

[2] IRENA2017 https://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

[3] World Bank database for pumped diesel fuel prices in Sub-Saharan Africa https://data.worldbank.org/indicator/EP.PMP.DESL.CD

[4] Global petrol prices database https://www.globalpetrolprices.com/diesel_prices/

[5] ERB, Zambian Distribution Grid Code, May 2016

[6] ERC, Kenya National transmission grid code, May 2016

[7] Techno-Economic Assessment of Utility-Scale Photovoltaic Battery Systems for Weak Grid Applications; 2018, Zaid Al-Jallad; Masterthesis; Albert-Ludwigs-University of Freiburg, Germany

[8] Energy Sector Management Assistance Program (ESMAP)