ANALYSIS OF THE OPTIMUM ALLOCATION OF BESS FOR CONTINGENCY SUPPORT

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ABSTRACT

Battery Energy Storage Systems (BESS) are modular and flexible assets that can provide a different set of services. One of these services is power quality improvement. BESS provides support during network contingencies, reducing the outage duration and the number of customers affected by the outage. The effectiveness of this service depends on the size and the location of the BESS in relation to the location of the failure. This paper presents a methodology to determine the optimal location of BESS for continuity of supply improvement and for facilitating the integration of renewable energy and distributed energy resources. The methodology is applied to a real network case in order to compare the optimal location of BESS in the transmission grid or in the distribution grid.

INTRODUCTION

The decarbonization of the economy goes through the decarbonization of the electricity sector. To achieve this objective, fuel based power generation must be replaced with renewable generation. In order to cope with the expected large increase in variability, the development of energy storage technologies is considered essential for the secure integration of renewable generation and the development of future power systems [1].

Among the different storage technologies, BESS are positioned to play an important role. BESS are highly flexible and modular assets that can provide a wide range of system services, as described in Figure 1. However, the ability to provide system services in an efficient way may be dependent on their size and location in the system [2].

The problem of battery sizing for different applications has been analysed from different perspectives, depending on the objective stated in the optimization problem. In [3] batteries are applied for load peak shaving in order to defer distribution network investments, whereas in [4] batteries are sized for peak shaving and load curve smoothing so that the transmission system is relieved from the aggregate fluctuations of rooftop PV generation. Others studies that consider the application of batteries for PV integration in the distribution network are reported in [4-5].

This paper studies the optimal location and sizing of batteries with the objective of providing support during network contingencies. The problem is analysed comparing the location of batteries in the transmission grid and in the distribution grid, for the same set of network contingencies.

PROPOSED METHODOLOGY

The methodology proposed in this paper is based on two consecutive stages. In the first stage, an optimal sizing and allocation problem is solved. The solution is a set of BESS with optimal size and location that minimizes the Energy Non Supplied (ENS) for a fixed investment budget.

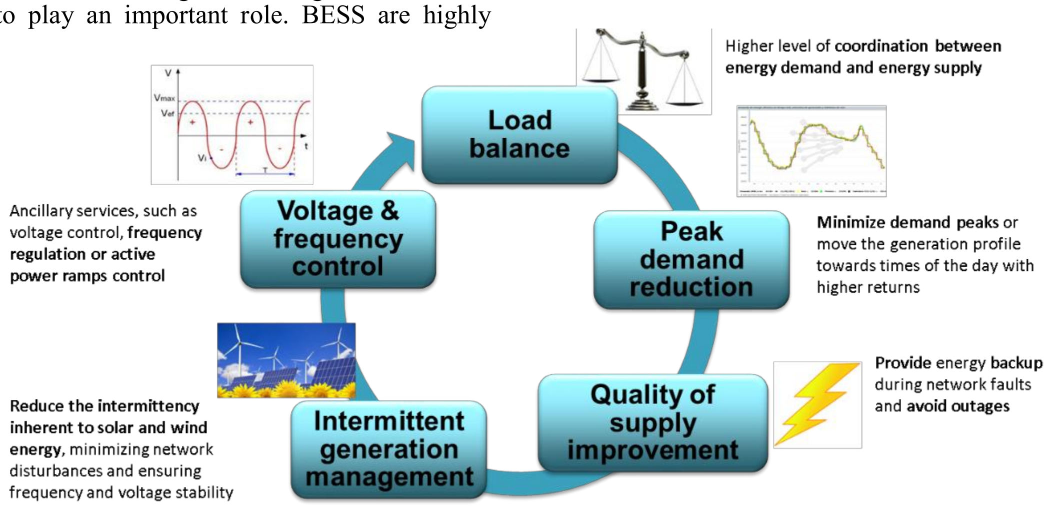

Figure 1. Services provided by batteries

In the second stage, an optimal dispatch problem is solved. The solution is the hourly dispatch of each BESS that optimizes the integration of renewable energy in the grid while minimizing the losses and maximizing the utilization of network assets.

Optimal sizing and allocation problem

The size and location of batteries is optimized for contingency management, taking into account a fixed economic budget for the installation of batteries. The rated power of the battery to be installed at a particular network location is equal to the maximum non-guaranteed power (PNG) caused by the worst contingency that produces the disconnection of the node.

The rated energy of the battery is calculated taking into account the duration of the contingency. The values considered in the study are 9 hours for transmission line outages, 3 hours for MV overhead line outages and 9 hours for MV cable outages.

The power to energy ratio defines the investment cost of the battery. As the objective is to reduce the ENS caused by network contingencies, batteries are located at those nodes with the largest accumulated PNG to battery cost ratio, until the total available budget is used.

Taking into account the duration of the outage, and the cost information in [6], the cost of batteries considered in the study are the following:

- 212.4 €/kWh for transmission overhead lines
- 212.4 €/kWh for distribution underground cables
- 232.6 €/kWh for distribution overhead lines

Mathematically, the optimal sizing and allocation optimization problem is formulated as:

$$J = \sum_{i=x}^{N} \frac{PNGR_i}{Cbs_i} \quad (1)$$

$$\sum_{i=x}^{N} Cbs_i \leq PT \quad (2)$$

where N is the total number of nodes that are candidates for housing a battery; PNGRi is the value of PNG avoided by the battery; Cbsi is the cost of the battery and PT is the total budget available for the installation of batteries.

Optimal dispatch problem

The dispatch of the batteries is optimized with the objective of minimizing the variance of the load in the network (demand minus renewable generation), taking into account that the state of charge of the batteries must be high enough to supply the energy required in case of a contingency. With this objective, the difference between the peak and the valley of the network load is minimized, which improves the integration of the renewable energy in the network and reduces the network losses.

Mathematically, the optimal dispatch optimization problem is formulated as:

$$J = \frac{1}{N}\sum_{i=0}^{N}[Pbs_i + APbs_i + LF_i]^2 - \left[\frac{1}{N}\sum_{i=0}^{N} Pbs_i + APbs_i + LF_i\right] \quad (3)$$

$$P_{max\_d} \leq Pbs \leq P_{max\_c} \quad (4)$$

$$\sum_{i=0}^{N}(Pbs_i) + SOC_0 \cdot Q \leq Q \quad (5)$$

$$\sum_{i=0}^{N}(Pbs_i) + SOC_0 \cdot Q \geq \sum_{i=0}^{M}(LF_i) \quad (6)$$

where N is the number of optimization periods per day (24 periods); Pbs is the power of the battery; APbs is the sum of the power of the other batteries connected to the network; LF is the expected load supplied by the transformer; Pmax_c and Pmax_d the maximum charge and discharge power; SOC_0 the initial state of charge of the battery; Q the rated energy of the battery and M the duration of the contingency

APPLICATION CASE

The methodology proposed in the paper is used to compare the solution provided by the installation of BESS in the transmission grid or in the distribution grid of the region of Murcia in Spain, shown in Figure 2. This region is expected to have a very large penetration of photovoltaic generation by 2025, the study year. The objective of the study is to evaluate which is the best location in terms of the overall impact in the power system.

Figure 2. Network application case

In the analysis, a future scenario with the actual transmission and distribution networks and a high penetration level of electric vehicles and PV self-consumption has been considered. In particular, a scenario with 20% penetration level of PV self-consumption, slightly concentrated in rural areas, has been adopted (Figure 3). The methodology applied to locate and size PV self-consumption installation is described in [7].

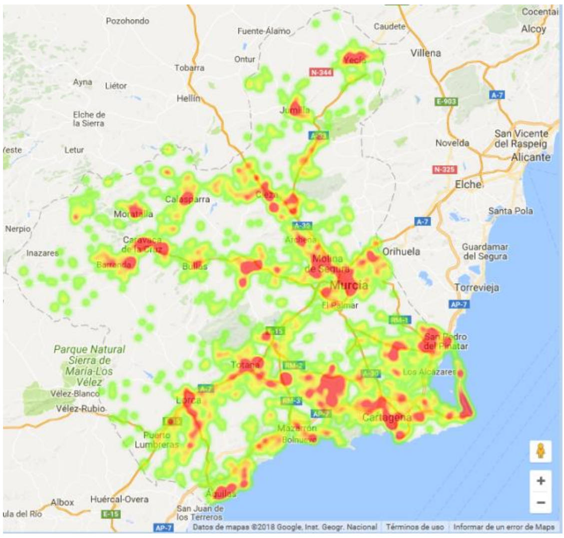

Figure 3. Distribution of PV plants in the base case scenario

Contingency analysis

A contingency analysis study for the 2025 winter and summer peak scenarios in the Murcia Region has been performed to evaluate the extension of network outages in the transmission grid (N-2 criteria) and in the distribution grid (N-1 criteria).

The results of the contingency analysis in the MV distribution network during the winter peak show a number of 529 N-1 outages producing a total of 354.95 MW of PNG (Figure 4).

In the case of the summer peak 418 N-1 outages have been identified, leading to 285.53 MW of PNG.

Figure 4. Location of outages in the winter peak scenario

For the transmission network, the worst event is an N-2 outage at 220 kV, consisting on the loss of the 220 kV coastal interconnector. This situation produces a voltage collapse at that and lower voltage levels, and the loss of several substations. To limit the extent of the outage, 51.6 MW of demand must be shed in Murcia in the winter peak and 44.4 MW in the summer peak.

Optimal sizing and allocation solution

With the results from the contingency analysis, the first step of the methodology has been applied to determine the optimal location of BESS in the transmission network and in the distribution network, for an investment budget of 100 million euros.

The result obtained shows that the optimum set of batteries to be installed in the distribution network to cope with loss of load events would consist of 63 batteries with an installed power of 76.5 MW and an energy storage capacity of 433.5 MWh, with the total cost of € 99.81 million.

The location of batteries has been optimized for the case of the winter peak since the value of ENS is higher than that obtained for the summer peak. In addition, a greater weight has been given to those batteries that, on top of resolving loss of load events in the distribution network, can also contribute to reduce the ENS due to losses in the transmission network.

In contrast, the budget available for batteries would allow the installation of 2 batteries in the transmission network, of 30.5 MW and 21.5 MW respectively, located in the 220 kV Hoya Morena and the 220 kV San Pedro del Pinatar nodes, for the management of transmission outages with a total installed power of 52 MW and an energy storage capacity of 468 MWh, the total cost in this case being 99.4 Mill. €.

Optimal dispatch solution

The second stage of the methodology has been applied to determine the optimal dispatch of the batteries for the case of installation in the distribution network, which has been determined to be more cost effective for the system.

Figure 5 presents an example of the operation of one of the batteries located in the distribution network. Because of the strategy adopted for the dispatch, the battery stores excess PV generation that is returned to the system at night. It can be observed that the battery does not discharge completely. A minim state of charge is maintained in order to allow supplying the energy required by the system in case of a contingency.

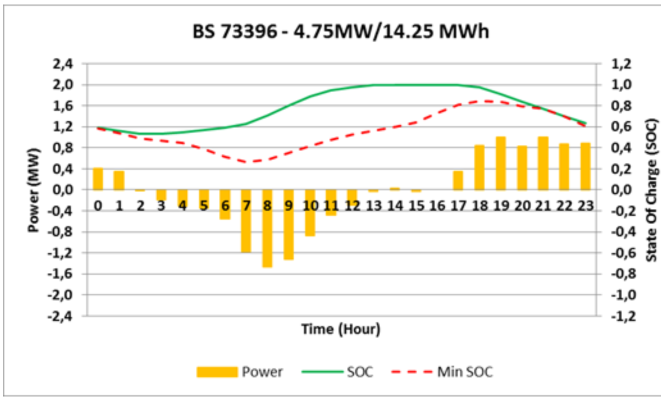

Figure 5. Effect of battery dispatch on the operation of battery located in node 73396

As a result of the optimization of the operation of the batteries installed in an area, the load curve of the transformer feeding that area is smoothed (Figure 6).

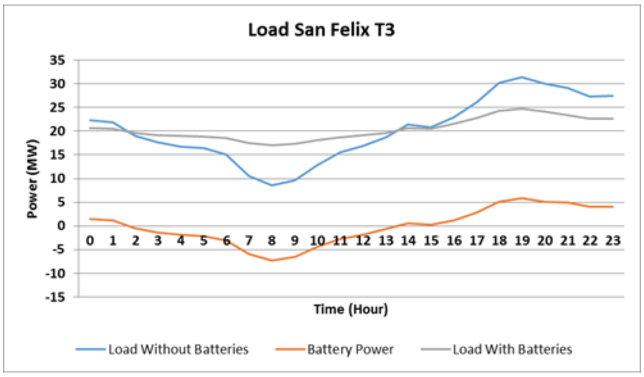

Figure 6. Effect of battery dispatch on the load curve of S. Felix transformer

With the two stage optimization approach, batteries flatten the load curve, improving the integration of renewable generation, while retaining the ability to respond to network outages

ANALYSIS OF RESULTS

ENS reduction

The contingency analysis has been run again with the BESS solution to evaluate the improvement in the continuity of supply for the same set of network outages. Figure 7 shows the reduction in ENS when the batteries are installed in the distribution grid (left) and in the transmission grid (right).

For the summer peak, the results are similar. There is a reduction in the ENS of 18% from the scenario with no storage if the batteries are located in the distribution network. When the batteries are located in the transmission network, the ENS reduction is 14%.

The results show that if batteries are installed in the distribution network, the effect for the system in terms of ENS reduction is larger than when they are installed in the transmission network

Voltage profile improvement

The presence of batteries in the network can influence the voltage profile. To analyse the influence on voltages, a simulation has been carried out over a full year, considering the batteries installed in the medium voltage distribution network or in the transmission network. Two different assumptions regarding the control of the batteries have been considered. Batteries without voltage control, injecting or absorbing only active power, and batteries with voltage control. Each battery controls the voltage of its node to the nominal value, operating with a power factor between ± 0.9.

The hourly values of the voltages obtained for each voltage control scenario have been compared against the voltages obtained in the base case, without batteries. Figures 8 and 9 show the range of variation of the distribution of voltage values obtained in each case. Specifically, the value of percentiles 5, 50 and 95 of hourly voltages is represented, compared to the limits of voltage variation allowed in the distribution network of ± 7%.

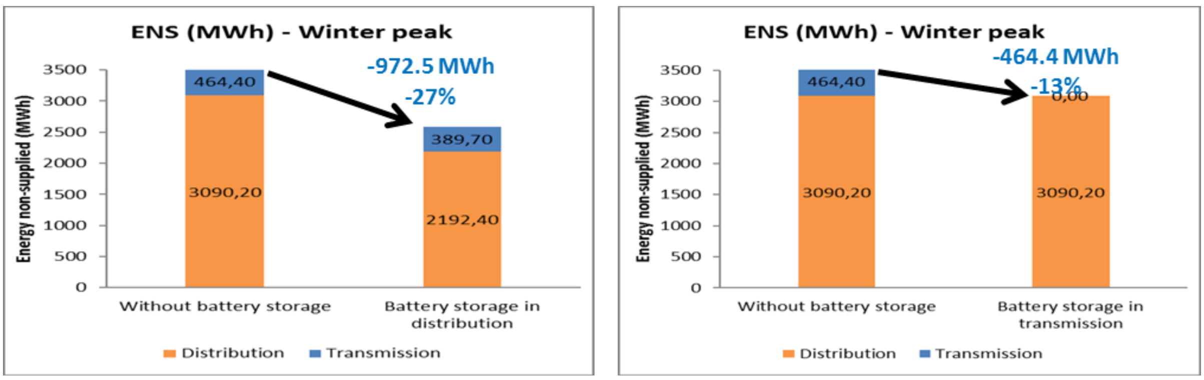

Figure 7. ENS reduction for location in distribution (left) and in transmission (right). Winter peak scenario

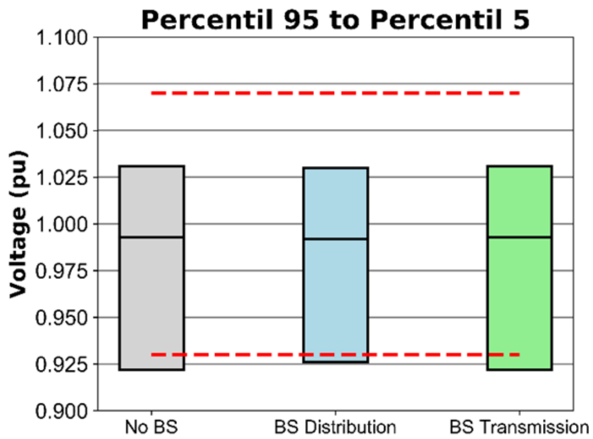

Figure 8. Distribution of network voltages. Batteries without voltage control

It can be observed that the installation of batteries in a distributed way has a positive effect on voltage, as it allows raising the lowest value of the voltage obtained with respect to the situation without batteries. The voltage improvement is only 0.2% for the case of operation of the batteries installed in the distribution network without voltage control (Figure 8), but it reaches a value of 2.2% if the batteries are operated with voltage control (Figure 9).

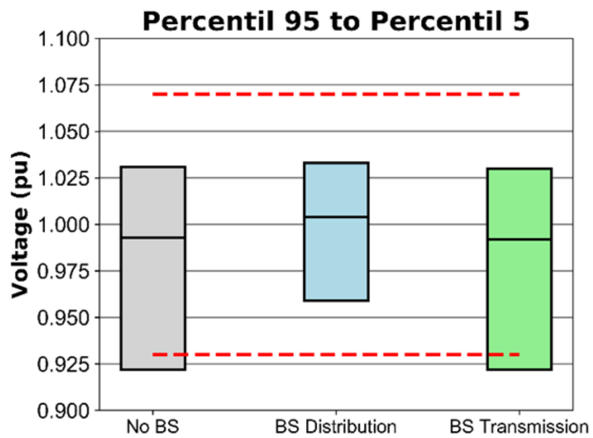

Figure 9. Distribution of network voltages. Batteries with voltage control

On the contrary, in the case of batteries installed in the transmission network, no difference is observed in the variation range of the hourly voltage distribution. The influence of the batteries on voltage is limited to a reduced area of the network, in comparison with the situation of deploying the same storage capacity in a distributed way throughout the network

CONCLUSIONS

This study has compared the location of battery storage in the transmission network and in the medium voltage distribution network with the main objective of providing network support services during outages. The results show that batteries located in the distribution network provide a better solution to reduce the energy not supplied in case of faults in the network.

The location of batteries in the distribution network achieves a better network voltage profile, by increasing the minimum voltages and reducing the range of variation. This effect is improved when batteries are operated with voltage control.

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