Performance of SLB application in power system for substation reliability improvement using fuzzy logic control

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ABSTRACT

Second-life batteries (SLB) are thought to be adequate to store and provide significant energy to meet the stationary application's requirements after being employed in first-life applications. SLBs offer an affordable and environmentally friendly choice for power grid applications, but their performance relies on some variables that must be properly assessed and maintained. This work focused on the improvement of SLB performance in the power grid during the charging and discharging period by using a fuzzy logic control technique to correctly filter fault magnitude and manage the battery operation based on the available SOC and to enhance the resilience and power output of a substation. The validity of the work is evaluated in Matlab-Simulink using a distribution substation in Nigeria and the results indicate that the suggested method successfully manages the operation of the SLB in the power grid, improves the substation's output reliability, and delays the SLB's end-of-life (EOL) date.

1. Introduction

Electric vehicle (EV) batteries tend to reach their maximum usage and enter retirement in transportation when their total energy reaches 70-80% because they are considered inappropriate for traction from that point onwards [1]. EV batteries used in first-life applications are referred to as second-life batteries (SLB), and they are thought to be adequate to store and provide significant energy to meet the usage needs of stationary applications. According to the Guardian, 145 million electric vehicles will be in use by 2030, and 12 million tons of Li-ion batteries will be phased out [2]. Using SLB under various conditions can decrease new battery demand from 5.1 TWh to 1.4 TWh, corresponding to a 73–100% reduction [3]. The use of SLB applications is starting to gain traction with several companies commercializing second-life storage systems as it's a great substitute for the high cost of purchasing a new battery and limits the recycling cost of retired battery which as well contribute to the greenhouse reduction. The major application of SLB based on research currently revolves around stationary usage in power systems and other situations where high energy demand is not required. Subsequently, some studies have explored the use of SLBs in various applications such as Keeli et al. [4] which studied the optimal use of SLBs in terms of the peak load management and cost-effectiveness of powering commercial buildings. Lacey et al. [5] applied an SLB grid for peak-shaving and upgrade deferral and suggested an all-encompassing SLB application within the distribution power grid to balance excess demand during peak periods.

Based on the revised literature, it has been shown that SLB is a good alternative to new battery energy storage systems (BESS) in stationary applications and can improve greenhouse reduction. However, the performance of SLB during charge and discharge considering its reduced state of charge (SOC) is yet to be explored. Therefore, this study proposed an effective application of SLB in power systems using a different approach not only for peak shaving and upgrade deferral but to improve the power output reliability through a central substation. A novel fuzzy logic control system was proposed to manage the operation of the SLB while charging and discharging over a varying SOC range and in combination with an optimal sizing method that caters for the capacity handling of the particular substation. The performance of the proposed method is validated by subjecting it to mitigate a common grid fault in a substation that is model in Matlab-Simulink.

2. Methodology

It is crucial to understand the system's load requirements to develop a battery system that can minimize the flaws in the power grid. The actual amount of electricity required is approximated because the system is filled with residential buildings. A homogeneous SLB capacity is assumed in order to construct the battery pack required in both series ns and parallel np connections based on the system capacity. Maximum care must be exercised to create an ideal battery size that will meet the load demand and minimize cost. This study employed the use of Peukert's rule and evaluated load conditions to determine the best size for a Li-ion battery system [6], taking into account its non-linear characteristics. The objective was to determine the required number of SLBs connected in series and parallel, as expressed by Eq. (1). The power of the battery pack during charging and discharging was taken into account for the PCS efficiency, which is expressed in Eq. (2). Establishing a safety margin is crucial when using a battery system as expressed in Eq. (3) and the SOC margin is set at 20–90% in this work due to this capacity level of SLB where $\overline{SOC}$ and $\underline{SOC}$ are the upper and lower bounds of the SOC respectively.

$$min J = n_s \times n_p \tag{1}$$

$$\underline{I_{bat}} = W_{bat}/U_{bat} \tag{2}$$

$$\overline{SOC} \leq SOC \leq \underline{SOC} \tag{3}$$

Fuzzy logic control (FLC) was used as the mitigation control system between the sized SLB and grid system, performing switching operations of the battery during charging and

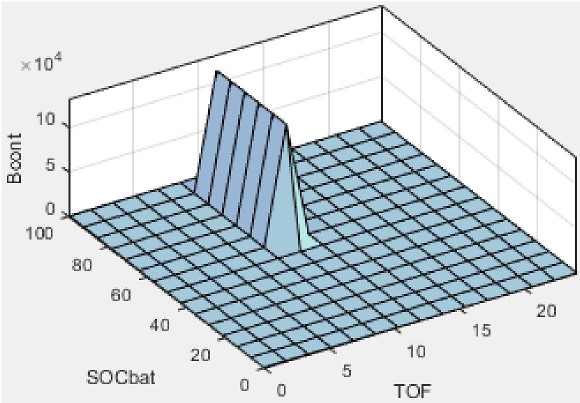

Fig. 1. FLC of battery output

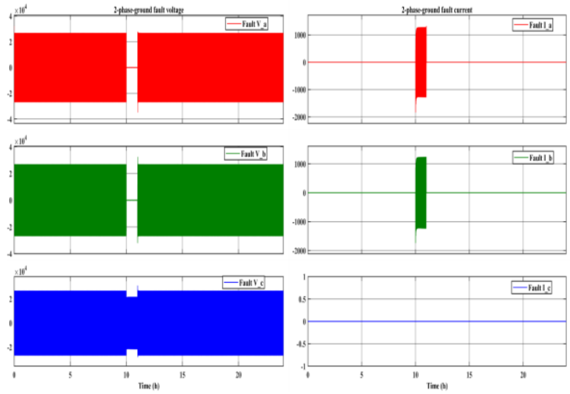

Fig. 3. Two-phase-ground-fault

discharge in the event of a fault occurrence. FLC is an example of an artificial-intelligence-based control technique that performs in relation to a specific set rule given as a command and has been mainly used in photovoltaic (PV) and power-grid integration control Three parameters are used as inputs fed into the FLC: the time of fault (ToF), SOC, and grid-fault magnitude. The output is set as the battery control, which triggers the battery to charge or discharge into the grid based on the rule and in relation to the fault magnitude sensed. Table 1 shows the training rules for the FLC and the FLC effect of the battery output is shown in Figure 1.

Table 1. Training rules for the fuzzy logic control

Input 1 Time of fault (h)	Input 2 SOC (%)	Input 3 Fault magnitude (A)	Output Battery Control
NFP1	Ch1	NF1	ZZ
FP	Dch1	F	DM
NFP2	Ch1	NF2	CM
NFP1	Dch1	NF1	ZZ
NFP2	Dch1	NF2	ZZ

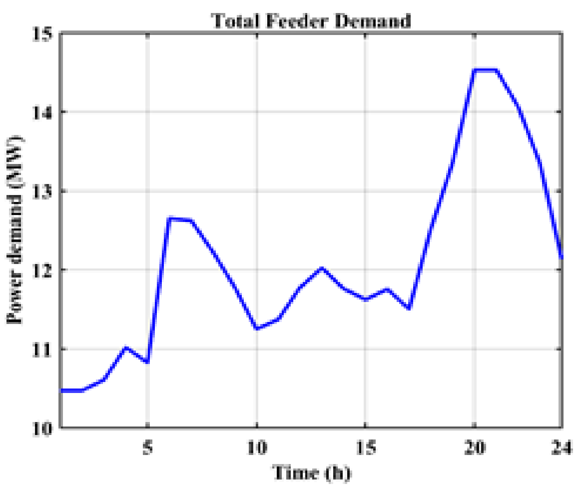

Fig. 2. Substation load capacity

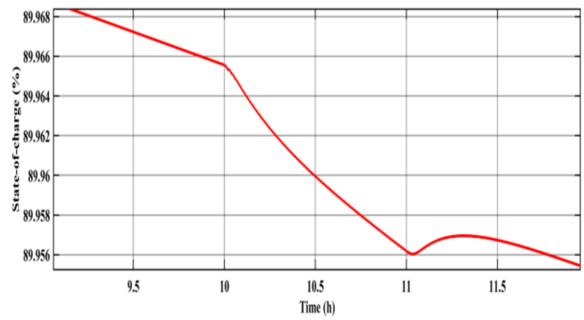

Fig. 4. Battery SOC during two-phase fault

3. Simulation and Results

A 33/11KV injection substation located in Nigeria with different load profiles totaling to a load capacity of 15MVA which was depicted in Figure 2. Major transmission and distribution faults is designed and injected into the grid for one hour duration using MATLAB/Simulink and it was simulated based on a 24-hour load sample. The current magnitude lies between −20A and 20A, while the voltage magnitude is between −2.61×104 V and −2.61×104 V. A two phase to ground fault mitigated with the performance of the SLB was shown if Figure 3. The results of the simulations shows that the proposed method actively manage the performance of the SLB to capture the disdain in the substation during faults and control its operation while discharging into the grid. The SOC of the battery was shown in Figure 4. The SOC of the battery shows the rate at which the battery discharged and became incapacitated for the stated purpose. The SOC contributes to the rate at which the battery reaches the end of its life owing to the charge and discharge cycle. The relationship between the SOC and battery fault time, revealing 0.015% capacity at a 1C rate-discharge over a one-hour fault time of a single phase, which is a good discharge result for the battery's remaining-useful-life (RUL). Figure 5 shows the battery power discharged during mitigating fault occurrence. The proposed method allows the SLB to operate based on the immediate condition within the grid thereby reducing the blackout occurrence in

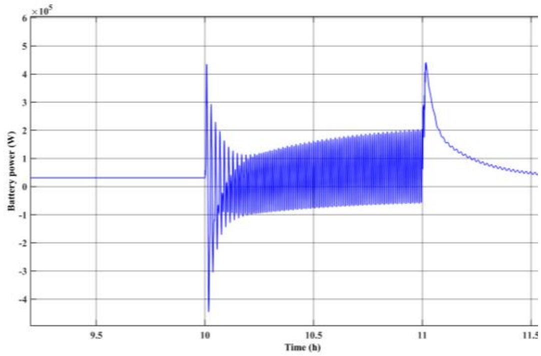

Fig. 5. Battery power discharged

the substation and improving its output efficiency. Three-phase and three-phase-to-ground faults are similar in a reaction, as they exhibit the same attributes. This situation arises when a fault forms across all three lines with or without connecting to the surface of the ground. The effect of the proposed method is subjected to the three-phase line and distribution faults and the result shows that the proposed method actively rescues rescue the disdain without subjecting pressure on the battery performance. Figure 6 shows the result of the three-phase signal for the current and voltage during the simulations while Figure 7 shows the battery SOC during the operation of the system mitigations.

4. Conclusion

This study involved the appreciation of SLB application in power grid to reduce the cost of recycling and add value to its traction after the first life. A Fuzzy logic control (FLC) method is used to manage the operations of SLB in a substation during charge and discharge conditions while there is a fault occurrence. The validity of the work is verified by using it to mitigate the common faults in the power grid systems through a 33/11Kv injection substation. The output of the work shows that the proposed method effectively manages the performance of the SLB and the substation reliability is improved.

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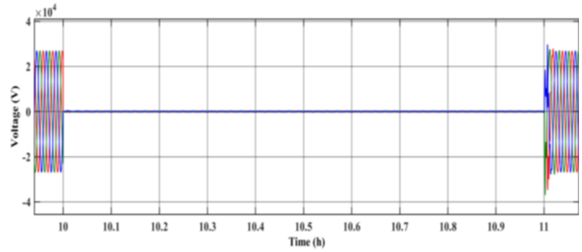

Fig. 6. Three-phase fault

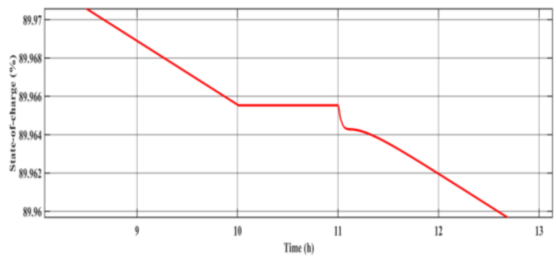

Fig. 7. SOC curve during three-phase faults

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