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CIGRE US National Committee
2021 Grid of the Future Symposium

Utilizing a BESS for Multi-Applications in a Distribution Grid

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SUMMARY

This paper presents a method to utilize a Battery Energy Storage System (BESS) to support a Distribution Grid. A BESS model is created in Synergi to perform case studies, to show that a BESS can be used in multiple grid support applications, such as active power application, reactive power application, and outage mitigation. The first application is to have the battery discharge during peak hours and charge during off-peak hours in order to shift peak load on the substation transformer. By reducing peak load on the transformer, this helps extend transformer insulation life and therefore delay or reduce the upgrade need for a substation transformer. This is also called a Non-Wire Alternative solution. The second application explored the reactive power functions, by modelling a reactive power source, and recording voltage and transformer tap position both at the BESS site and at the substation. Results show that this voltage support application assists in voltage regulation. The third and final application explored the utilization of a BESS as a backup power generation source. If the distribution system experiences an outage, the BESS site can enter an islanding mode and remain energized. Lastly, the possibility of value-stacking these three applications was discussed. Theses proposed applications and demonstrations help distribution planners to better understand BESS grid-support use cases, modelling in Synergi, and the future value stacking strategy.

KEYWORDS

Battery energy storage system, distribution grid planning, non-wire alternatives, peak-shaving, voltage support, outage mitigation

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I. INTRODUCTION

A Battery Energy Storage System (BESS) is a rechargeable system that can store energy generated at one time and use it at another time [1]. Traditionally, electric energy has been very difficult to store in large quantities. Although pumped hydro has demonstrated this ability, the costs, site availability, and construction lead times minimize its use through industry. The technological improvement and economic development have accelerated the commercialization of the stationary BESS. In addition, with stakeholders driving storage implementation activities through sustainability goals and public policy, a grid-scale BESS is now becoming a, reliable, competitive, and beneficial solution for some grid applications [2].

A BESS can provide various grid-support applications including electric supply, ancillary services, Transmission and Distribution (T&D) services, customer management services, and Renewable Energy (RE) integration [3]-[4], based on its power and energy capacity, charging/discharging schedules, and objectives.

Existing research certifies that a BESS presents an enormous opportunity to improve power system operations and support existing distribution grids in an increasingly cost-competitive manner [5]-[6]. However, research seems to be focused on BESS applications and their benefits as a replacement for fossil fuels and the environmental advantages of pairing with renewable energy sources rather than an analysis of these potential applications. There is a disconnect between the existing literature and academic information on BESS uses or benefits. Also, since there is a lack of detailed analysis of the effects of a BESS model for a particular utility sample site, confirming these potential applications and how they can be used together by value-stacking to achieve optimal results is warranted.

Therefore, this paper presents methodologies for the utilization of a BESS for three different grid support applications. The main contributions are highlighted as follows:

(1) Proposed BESS modelling and utilization methodologies in Synergi to simulate active power, reactive power, and outage mitigation applications.
(2) Discussed a value stacking strategy for system planners to optimally use the BESS as a future distribution grid solution.

In Section II, the active power application is studied and demonstrated. BESS for reactive power support and additional voltage regulation are presented in Section III. Section IV shows a case study for outage mitigation on a distribution feeder. Section V discusses the final integration/value stacking strategies for future considerations. Section VI summarizes the conclusion and future work.

II. ACTIVE POWER APPLICATION

The first grid support application of a BESS to be presented in this paper is the active power application. Active power is defined as the power which is actually consumed in the circuit and measured in kW or MW. For this application, a BESS is used for load shifting on a substation transformer. Transformer overloading limits and insulation life are affected by both the load on the transformer as well as ambient temperature, therefore load shifting can be used strategically to extend the life of a device and delay the need for device upgrades or replacements. This is also known as a Non-Wire-Alternative (NWA) solution, as it is an alternative to traditional system upgrades. To accomplish this, the battery is first modelled in Synergi using a generator model as shown in Figure 1. Next, a schedule is created such that the battery is able to discharge during peak hours (when the load on the substation transformer is the highest) and charge during off-peak hours (when the load on the substation transformer is the lowest), effectively shifting these peaks on the transformer.

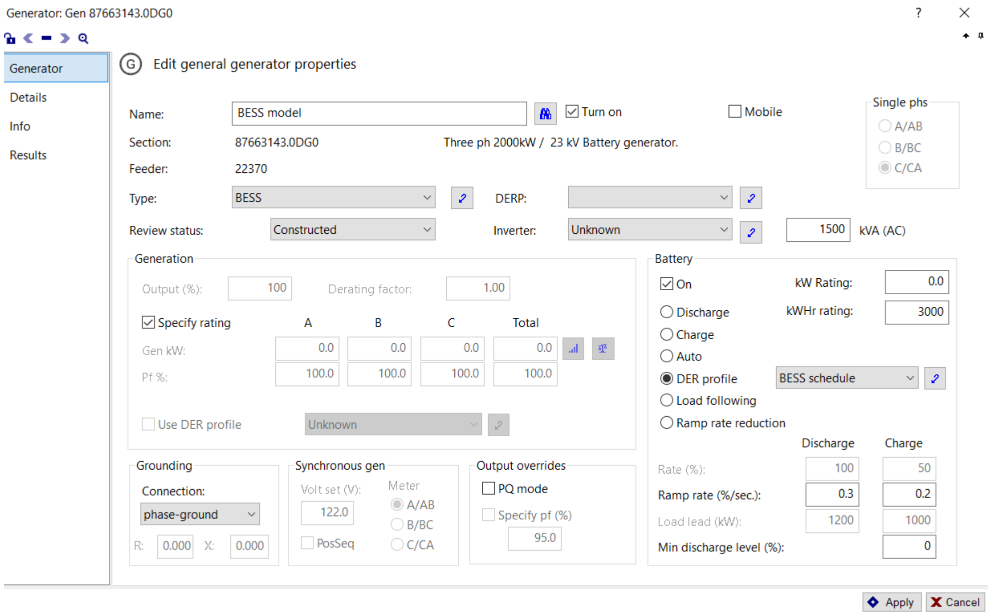


Figure 1: BESS Model – 1.5MW/3MWH Battery Generator Modeled in Synergi

In order to find the peak and off-peak hours to create an optimal charging schedule, substation loading data for each month is first analysed to find the hottest month. For this analysis, it was determined that the peak month was July, and the peak and off-peak hours are 15:00PM-17:00PM and 5:00AM-7:00AM respectively. Once this information was gathered, a schedule was created such that the battery discharges 1.5MW for two hours during the peak hours and charges 1.5MW for two hours during the off-peak hours. This schedule is shown in Figure 2.

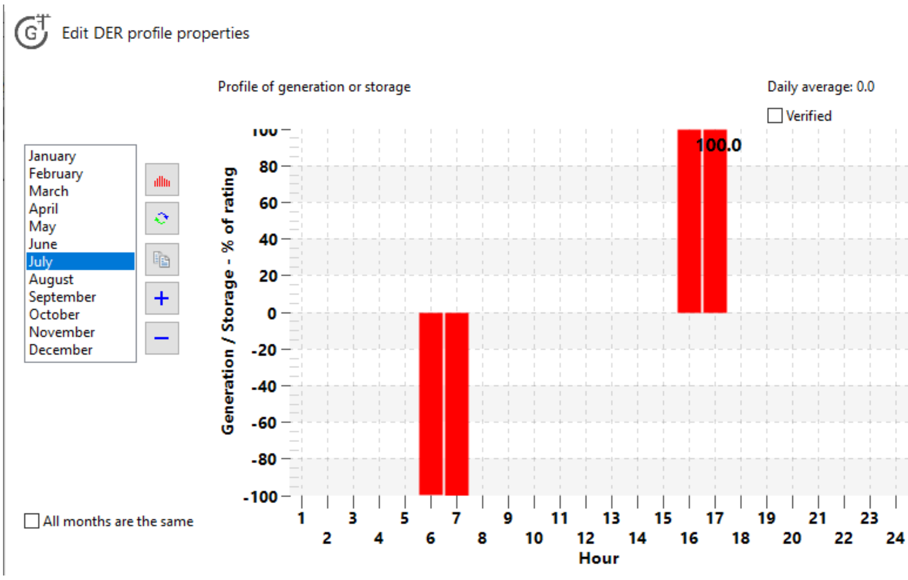
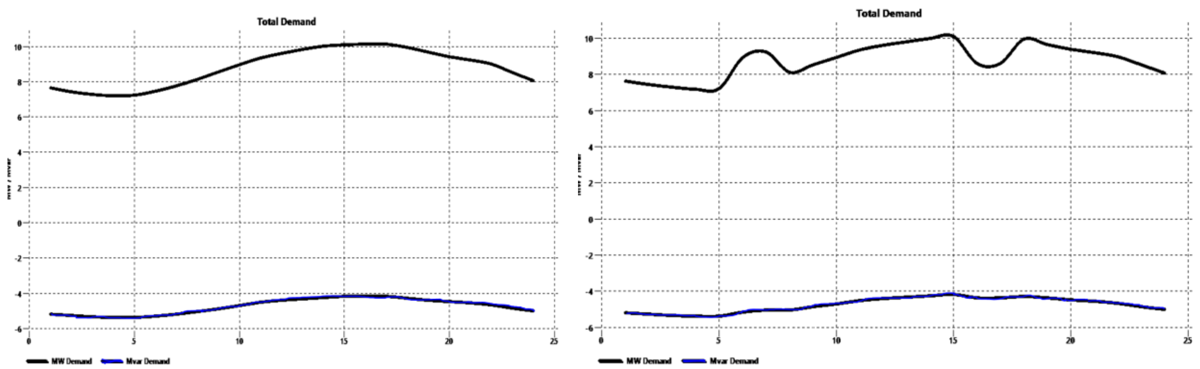


Figure 2: BESS Schedule, Discharging/Charging 1.5 MW for 2 hours during the peak & off-peak hours

Next, a 24-hour analysis was performed to show the impact of the implementation of the BESS. The results of this analysis is shown in Figure 3, where the demand on the transformer without the BESS model (a) vs. with the BESS model (b) are shown. By plotting the results of these changes as shown in Figure 3, it is clearly demonstrated that the use of the BESS model shifts the peak and off-peak loads substantially, providing support to the transformer as expected.



(a) No BESS connected *(b)With BESS connected*

Figure 3: Comparision of Demand With and Without BESS Shifting Peaks

Lastly, this information was verified by exporting the load data and plotting the same information, manually shifting the load during the peak and off-peak hours by editing those data points. Graphing this produced the output shown in Figure 4:

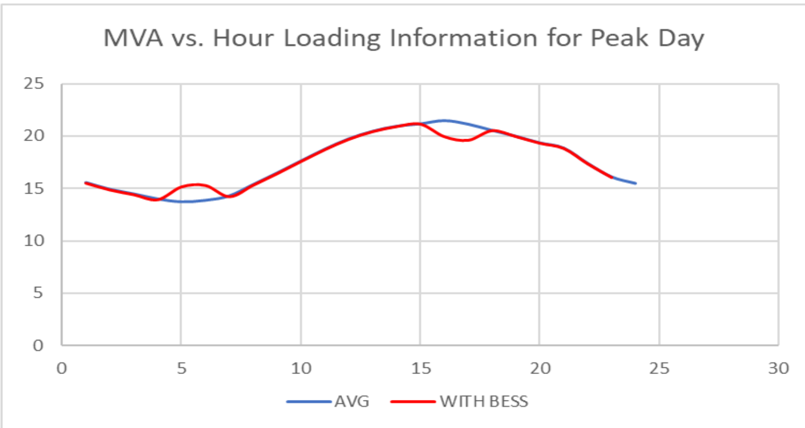


Figure 4: Comparison of Average Loading Information With vs. Without BESS Model

These results further confirm the output shown in Figure 3 and demonstrate that a BESS can serve in a grid-support capacity in the form of an NWA solution by shifting the load during peak and off-peak hours to reduce the need for system upgrades.

III. REACTIVE POWER APPLICATON

The next grid support application of a BESS to be presented in this paper is the reactive power application. Reactive power is defined as the power transmitted back and forth between the non-resistive components of the source and the load. Reactive power is measured in kVAR or MVAR. For this application, a BESS is used for voltage regulation on a distribution circuit. To accomplish this, the battery is first modelled in Synergi. Since the generator model in Synergi does not support a reactive power application, a reactive power source was instead modelled using a Static Synchronous Compensator (STATCOM) model with a pre-defined inverter model and constant number to achieve the required reactive power output. This is shown in Figure 5.

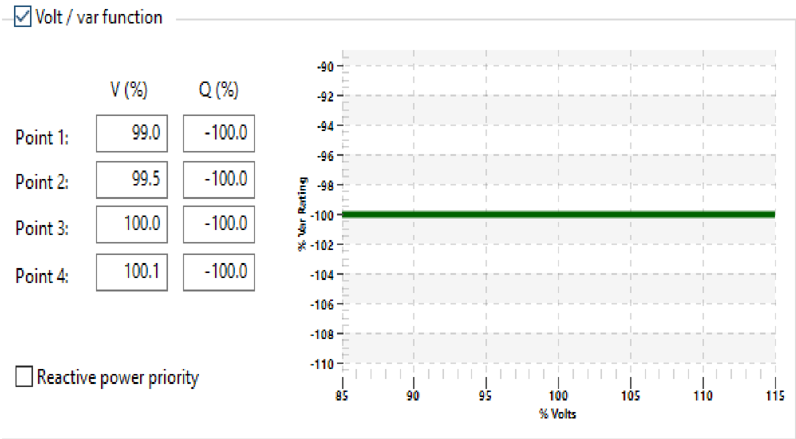


Figure 5: PV Inverter with Volt/Var Function

In order to demonstrate the voltage support functionality, an over voltage scenario was manually created in Synergi to record the statice power flow with and without the BESS implemented. The corresponding transformer Load Tap Changer (LTC) tap position was recorded as well as the voltage both at the BESS site and the substation. Table I outlines the reactive power response results.

Table I: Reactive Power Response Results

Tap Setting (p.u.)	Substation Voltage (V)	Site Voltage (V)	LTC Mode	LTC Position	BESS Reactive Power Output (kVAR)
1	122.9	122.3	Auto	-6	0
0.995	123.5	123	Manual	-6	0
0.995	122.9	122.2	Manual	-6	1000
0.995	122.9	122.2	Auto	-6	1000
0.995	122.7	122.2	Auto	-7	0

First, an overvoltage scenario was manually created by changing the Tap Setting and switching the LTC Mode to manual, effectively locking the tap position in place. In the second row, the voltage at the substation increased to 123.5V. Then, with the tap position still locked at -6, the BESS was enabled and set to absorb reactive power. Next, the LTC mode was switched back to manual, where the LTC position remained at -6 (row 4). Then in the last row of the overvoltage data, the BESS is turned back off, and the tap position changes to -7. This shows that without the BESS, the LTC reacts by changing its tap position from -6 to -7, but with the BESS implemented the tap position remains at -6 to respond to the same overvoltage scenario. This confirms that the battery does regulate the voltage and reduce the LTC tap position actuations.

IV. OUTAGE MITIGATION / ISLANDING MODE APPLICATION

The final grid support application of a BESS to be presented in this paper is the outage mitigation application. With this application, it is shown, that a BESS can serve as backup power generation source. With a BESS, if the distribution system experiences an outage due to a fault on the line, this site can remain energized. In this application, the battery is modelled in Synergi by changing the node at the end of the line to a micro source feeder, resulting in the node changing to a “F” in Synergi as shown in Figure 7.

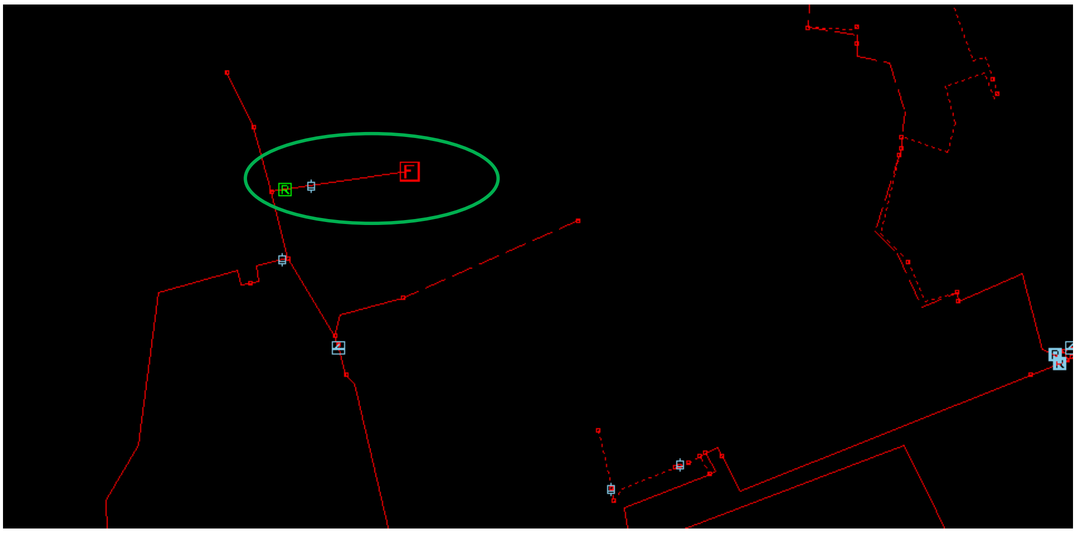


Figure 7: Visualization of Micro-source Model of Battery

Figure 7 shows even though the recloser is open, meaning the section of line connected to the battery is disconnected from the main distribution grid, the line still has power due to generation from the BESS.

In order to demonstrate the outage mitigation functionality of a BESS, a fault was manually created in the Synergi model. An outage on the distribution system was modelled by opening the substation breaker as shown in Figure 8. With this breaker open, even though the rest of the circuit was unfed and thus has no power, the line connecting the battery location is still red, meaning that location is still energized and fed by the BESS source.

Figure 8: Visualisation of BESS Islanding Mode – Battery Serves as Backup Power Generation Source

This distribution circuit was then analysed by running load flow and comparing the voltage at the BESS site and at the breaker with a fault modelled on the line and without. Table II shows that the voltage at the battery site is constant with the recloser open, regardless of faults elsewhere on the circuit. This shows that the site has entered an islanding mode as expected.

Table II: Islanding Mode Voltage Results

Fault Condition	Site Voltage (V)	Voltage at the Substation Breaker (V)
No Fault	123	123.7
Fault	123	0 (Not Energized)

V. FINAL INTEGRATION/VALUE-STACKING

To maximize the benefits of installing a BESS at a given site, these three applications discussed in this paper can be implemented concurrently and in different priorities. For example, during specific hours as discussed in Active Power Application section, the battery can be charging and discharging to provide the load shifting application and prolong transformer life. The BESS can be set up for this application, as well as to perform voltage regulation and reduce transformer tap position actuations in the event of an over-voltage or under-voltage scenario, as described in the Reactive Power Application section. Lastly, if there is a fault elsewhere on the line the battery can enter the islanding mode, the BESS is able to provide an alternate power source to the site.

VI. CONCLUSIONS AND FUTURE WORK

To conclude, this paper outlines three methods of utilizing a BESS to support the distribution power system. The first method is an active power application, in which a BESS can be used to charge during off-peak hours and discharge during peak hours, resulting in a shifted peak load on the transformer. This is useful as it reduces peak transformer load, which in turn prolongs transformer life as an NWA solution. The second method is a reactive power application, in which a BESS can be used to assist in voltage regulation and improve response to over-voltage and under-voltage scenarios. The third and final method explored is an outage mitigation application, in which a BESS is used as backup power generation, entering an islanding mode if there is a fault on the line, ensuring the site location may remain energized. Lastly, the prospect of value-stacking these applications is explored. The content presented in this paper can assist distribution system planners in better understanding of BESS, different ways to model a BESS in Synergi, various grid support applications, and the potential value stacking strategy. Future work includes value stacking strategy implementation and cost benefit calculation.

BIBLIOGRAPHY

[1] M. Hannan, et al., “State-of-the-art and energy management system of lithium-ion batteries in electric vehicle applications: Issues and recommendations,” *IEEE Access*, vol. 6, pp. 19362-19378, March 2018.

[2] Y. Wang, et al., “Sizing and Scheduling of the BESS as an NWA Solution to the Distribution System,” *IEEE PES General Meeting*, pp. 1-5, July 2021.

[3] A. A. Akhil, et al., DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, Jan 2015.

[4] J. Eyer and G. Corey, Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, Feb. 2020.

[5] Y. Yang, S. Bremner, et al., “Battery energy storage system size determination in renewable energy systems: A review,” *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 109-125, 2018.

[6] A. Oudalov, R. Cherkaoui and A. Beguin, “Sizing and Optimal Operation of Battery Energy Storage System for Peak Shaving Application,” *IEEE Lausanne Power Tech*, pp. 621-625, 2007.