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Battery Energy Storage System in Peak Shaving Application

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Abstract: This paper focuses on the performance of battery energy storage system (BESS) in peak shaving application. BESS technologies have a great potential in supplying the power especially during on-peak period, thus reducing the peak generation. This technique is very important especially for commercial and industrial sectors since they have to pay to a utility company some additional costs of 30% of their peak demand due to the usage of expensive open-cycle gas power plants. This paper also discusses the effectiveness of using a lithium-ion battery in reducing the power generation during peak demand. This kind of battery is chosen due to its high efficiency in charging and discharging as well as its high energy density. The performance of the proposed battery is analysed using Matlab/Simulink simulation. The result shows that the lithium-ion battery is very effective in supplying demand during on-peak period.

Keywords: Battery energy storage system; Inverter; Lithium-ion battery; Peak shaving; Rectifier.

1. INTRODUCTION

Power demand keeps changing from time to time according to the customers' activities. To meet the varying demand especially during peak hours, an additional capacity is required to support the load. Peak demand is the largest instance of power usage in a given time frame. Normally, utility companies have a variable pricing based on demand, and the pricing for peak demand hours is the highest [1-2]. In industrial and commercial sectors, peak demand charge is contributed almost 30% of their electricity bill, hence it is important for them to reduce the amount of energy purchased from the utility company during peak demand hours. The technique of reducing this peak demand is called as peak shaving approach.

To avoid entirely dependent on natural gas and fossil fuel especially during peak hours, the government has launched various programs to promote the usage of renewable energy (RE) [3]. Other than RE programs, stationary electrical energy storage also has a great potential in supplying the peak demand, where it will store energy at the time the price is lower (off-peak period) and supply back to the grid when the price is higher (on-peak period) [4]. There are several types of electrical energy storage system (ESS) which have been developed or currently under development such as pumped hydro storage, compressed air energy storage, battery energy storage system (BESS), supercapacitors, flywheel, and thermal energy storage [4]. Among these ESS, BESS is more preferable by utility networks due to its fast ramping time, high stability and reliability, and lower operating cost and capital investment [5-6]. Figure 1 shows the charging and discharging mode of BESS in peak shaving application. It is in charging state when the load is lower and in discharging state when the load is at peak, hence smoothing the typical mountain and valley shape of the power production curve [7-10].

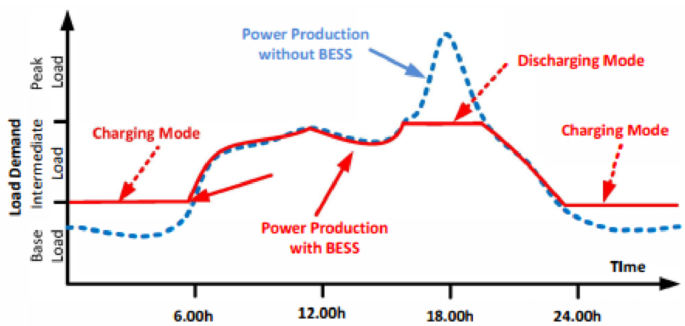

Figure 1. Charging and discharging of BESS in peak shaving application [7]

Table 1. Performance of the different types of batteries [14]

Type of battery	Ni-Cd	Lead acid	Li-ion	NiMH	NaS
Cell Voltage (V)	1.0-1.3	2.0	3.7	1.0-1.3	2.08
Life Cycle	2000-2500	500-1000	1000-10,000	300-500	2500
Energy Density (W h/L)	60-150	50-80	200-500	~ 170-420	150-250
Efficiency (%)	~ 72-78	85	~ 97	~ 85	85
Self-Discharge/Daily (%)	~ 20-60	~ 10-20	~ 10-30	~ 5-20	~ 0

BESS is a device that convert chemical energy into electrical energy. In general, there are several types of BESS that are applicable in power system such as Lead Acid, Lithium-ion, Nickel-Cadmium, Nickel-metal Hydride and Sodium-Sulphur batteries. Table 1 provides comparisons of the performance characteristics for each battery.

From the above comparison, the Lithium-ion battery is a good candidate for energy storage system since it has longer life cycle which is up to 10,000, higher energy density which is between 200-500 W h/L, lower self-discharge which an average of 10-30%, as well as higher efficiency which is up to 97% [10-15]. In a conventional system, the lead acid battery is used as energy storage system since it is cheaper and easy to manufacture. However, this kind of battery is not environmental friendly and cause health problem as it contains sulfuric acid and large amount of lead. Lead is a highly toxic metal that produces a range of adverse health effects particularly in young children. Exposure to excessive levels of lead can cause damage to brain and kidney, impair hearing, and lead to numerous other associated problems. Thus, as an alternative, Lithium-ion is a good solution to be used as energy storage system. To investigate the performance of this battery especially in peak shaving application, this research has simulated the Lithium-ion battery in Matlab/Simulink software.

The paper is organized as follows: Section 2 presents system modeling in Matlab/Simulink software, Section 3 presents results and discussion, and Section 4 concludes the study.

2. SYSTEM MODELING IN MATLAB/SIMULINK SOFTWARE

To study the performance of the Lithium-ion battery in peak shaving application, the proposed system's study is shown in Figure 2. In this model, a battery is connected to the grid system. In the Simulink library, the load is modelled as a fixed load, which is not suitable for this testing. To set the load demand varies throughout the time, "*Repeating Sequence Interpolated"* block is used, which allowing the user to manually specify the power demand at each time interval. Thus, this block is representing the daily demand profile for the load.

Since the Lithium-ion battery works in DC voltage, it cannot be connected directly to the grid system hence DC-AC inverter is necessary in this design. A control system for the inverter is illustrated in Figure 3. The Universal Bridge block for two-level voltage-sourced converters (VSC) is used to convert AC voltage from the grid to the DC voltage of the battery system.

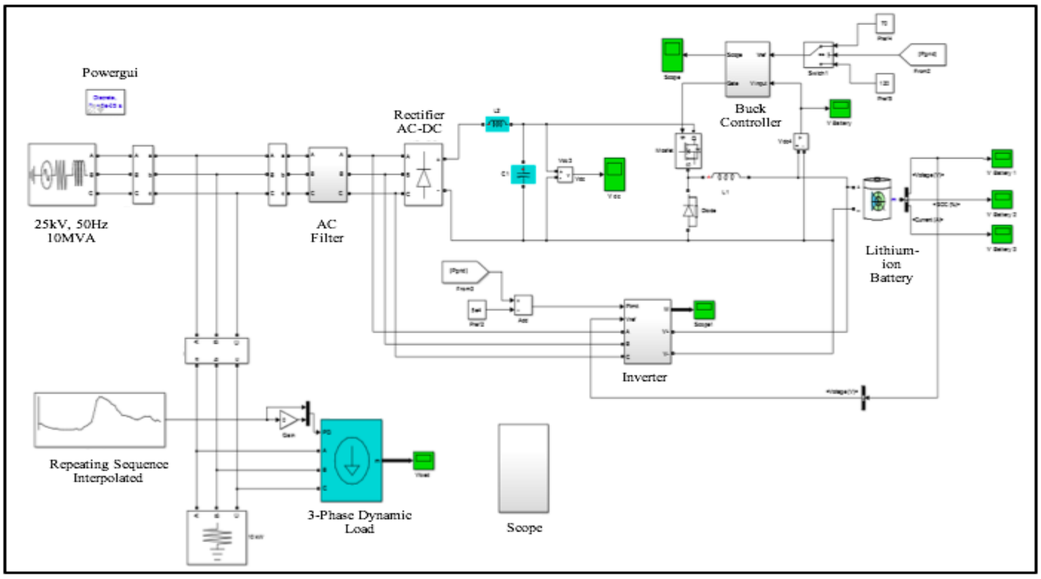

Figure 2. Proposed system's study

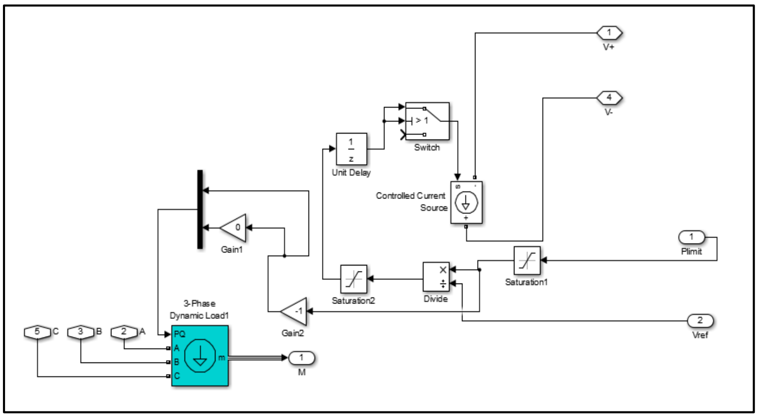

Figure 3. Control system for DC-AC inverter

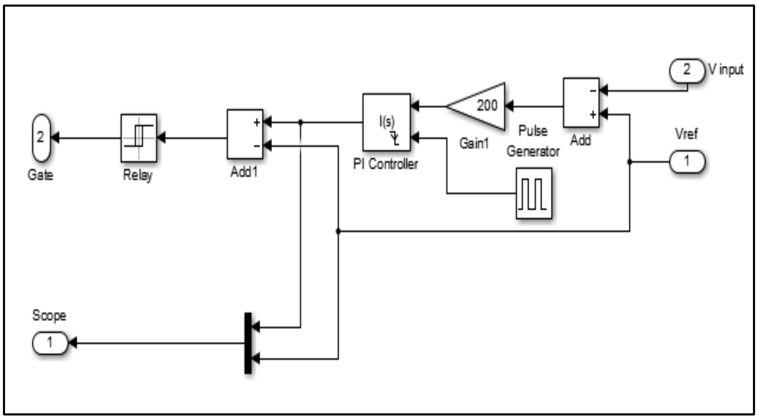

Figure 4. Control system for buck converter

A buck converter is designed to step-down the output of DC voltage from the rectifier, so that, it met the voltage specified by the Lithium-ion battery. In this simulation, the voltage limit is set to 100 V. This limit can be varied depending on the specification stated by the manufacturer. This limit must be followed to avoid the permanent damage of the battery due to overvoltage. Figure 4 illustrates the control system for the buck converter.

3. RESULT AND DISCUSSIONS

Figure 5 shows the generation and daily load curves for the proposed system, which the power varies from 25.8 kW to 63.5 kW. In this case, the peak demand period occurred between 22 and 32 seconds. The simulation is executed in secondly time frame to speed-up the simulation time. From the simulation, it is clearly showed that the generation met the load demand. However it was a slight higher due to some losses in the transmission lines.

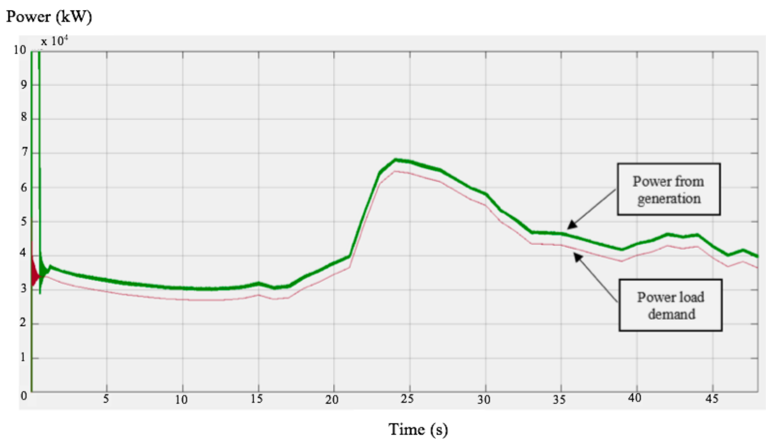

Figure 5. Power production and load demand profile

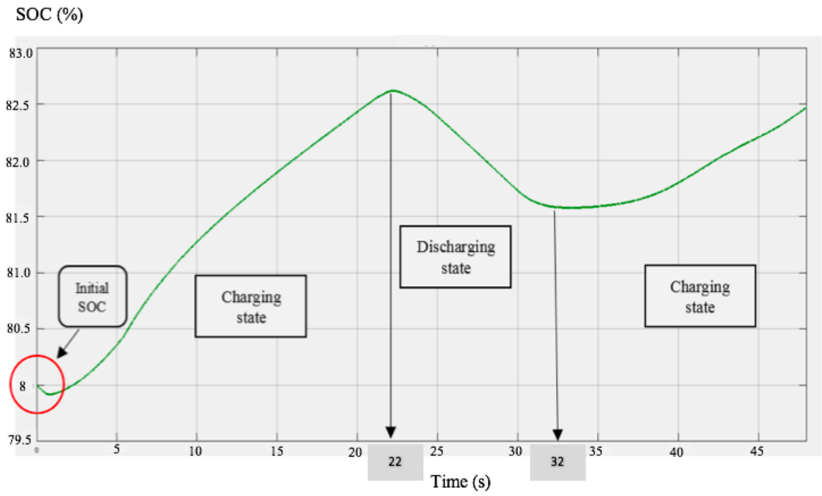

Figure 6. SOC at charging and discharging state

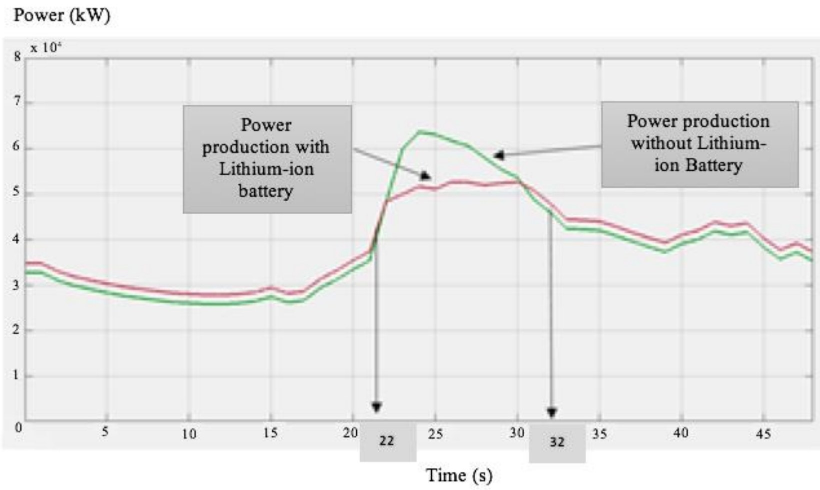

Figure 7. Load demand before and after installing the Lithium-ion

Meanwhile, the performance of battery can be observed from the state of charge (SOC) parameter, which describes the percentage of its capacity. The battery is considered has full capacity is when its SOC is equal to 100%. To extend its life cycle and to ensure the battery in safe condition, the SOC should be within the range of 20%-80%. For this simulation purpose, initial capacity was set to 80%. Figure 6 shows the SOC of the battery during the charging and discharging state. Based on the result, the battery was initially charged up to 82.53% in 22 seconds, and started to discharge until 32 seconds before it was charging again. The SOC at that time was 81.52%.

Figure 7 shows the generation curve supplied to the load before and after installing the battery. It is found that power production during the peak-period (22 s to 32 s) is lower when having the battery system. During this period, the load is also supported by the battery hence avoiding the operation of expensive generators which is usually triggered during the peak demand period. In the case of without battery system, the load is fully supplied by the generators hence the total power production during the peak period is higher. The installation of battery is aimed to reduce the power production during peak period hence it will charge and discharge accordingly depending on the load demand. In this study, the cut-off power for charging and discharging state is set to 50 kW. The value for cut-off power is determined based on generation capacity and peak demand rating. By setting this value, the battery started to supply the load (discharging state) when the demand was higher than 50 kW. Below than that, the battery was in charging state, causing a slight higher in power production during off-peak period.

4. CONCLUSION

This paper presents the performance of Lithium-ion battery in peak shaving application where the load during peak period is supplied by the battery. The main purpose of this peak shaving is to reduce the peak demand cost charged by the utility company especially to the commercial and industrial users. The simulation result showed that the peak generation was significantly reduced while during the off-peak period, the power production was slightly higher due to charging state of the Lithium-ion battery. As a conclusion, installation of Lithium-ion battery would benefit to both utility company and the users, by reducing the usage of expensive generators and electricity bill, respectively.

REFERENCES

[1] Energy management best practices peak shaving generators. http://www.sustainableplant.com/assets/WP00010.pdf (accessed 12.10.17).

[2] Clifford Power, Peak shaving in power generation (Website). http://www.cliffordpower.com/peak-shaving-with-generators-1 (accessed 05.07.17).

[3] K. H. Chua, Y. S. Lim and S. Morris, Battery energy storage system for peak shaving and voltage unbalance mitigation, *International Journal of Smart Grid and Clean Energy*, 2(3), 357–363, 2013.

[4] A. Rahimi, M. Zarghami, M. Vaziri and S. Vadhva, A simple and effective approach for peak load shaving using battery storage systems, *North American Power Symposium*, Manhattan, USA, 2013, pp. 1–5.

[5] E. Telaretti and L. Dusonchet, Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. *IEEE 16th International Conference on Environment and Electrical Engineering*, Florence, Italy, 2016, pp. 1–6.

[6] M. F. M. Siam, A. Busrah, H. Takami and J. Hagihara, Feasibility study of battery energy storage system with power quality support in Malaysia, *18th International Conference and Exhibition on Electricity Distribution*, Turin, Italy, 2005, pp. 1–5.

[7] T. H. Mehr, M. A. S. Masoum and N. Jabalameli, Grid-connected lithium-ion battery energy storage system for load levelling and peak shaving, *Australasian Universities Power Engineering Conference*, Hobart, Australia, 2013, pp. 1–6.

[8] E. Telaretti and L. Dusonchet, Battery storage systems for peak load shaving applications: Part 2: Economic feasibility and sensitivity analysis, *IEEE 16th International Conference on Environment and Electrical Engineering*, Florence, Italy, 2016, pp. 1–6.

[9] K. H. Chua, Y. S. Lim and S. Morris, Cost-benefit assessment of energy storage for utility and customers: A case study in Malaysia, *Energy Conversion and Management*, 106, 1071–1081, 2015.

[10] J. Leadbetter and L. Swan, Battery storage system for residential electricity peak demand shaving, *Energy and Buildings*, 55, 685–692, 2012.

[11] A. Nasiri, Integrating energy storage with renewable energy systems, *34th Annual Conference of IEEE Industrial Electronics*, Orlando, USA, 2008, pp. 17–18.

[12] H. Chen, T. N. Cong, W. Yang, C. Tan, Y. Li and Y. Ding, Progress in electrical energy storage system: A critical review, *Progress in Natural Science*, 19(3), 291–312, 2009.

[13] E. Reihani, M. Motalleb, R. Ghorbani and L. S. Saoud, Load peak shaving and power smoothing of a distribution grid with high renewable energy penetration, *Renewable Energy*, 86, 1372–1379, 2016.

[14] ABB, Peak shaving (Website). https://new.abb.com/substations/energy-storage-applications/peak-shaving (accessed 10.10.17).

[15] X. Luo, J. Wang, M. Dooner and J. Clarke, Overview of current development in electrical energy storage technologies and the application potential in power system operation, *Applied Energy*, 137, 511–536, 2015.