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End-of-Life Determination of Hybrid Energy Storage System on Peak Shaving and Solar Power Regulated Application

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Abstract

Energy Storage System (ESS) is the one of best practice in energy management. ESS can implemented as the renewable energy regulation and also peak shaving for building up to Smart Grid. Lithium ion battery has a higher cost than lead-acid more than 200% and it's the big barrier to project starting decision. This work presents the hybrid energy storage using li-ion battery and lead-acid battery in 30:70 ratio. The response of the difference battery types on the application of regulate the solar power and peak shaving have been used for end-of-life testing condition. The results shown hybrid energy storage system has cost per lifetime only 10% greater than pure LFP system but can reduce project initiation cost to 34%.

Keywords: *Hybrid Energy Storage, Peak Shaving, Solar Fluctuation, End-of-Life.*

1. Introduction

Energy crisis has been the world's most attention issue for a decade. During the electrical energy demand still increased and the existing electrical power plants almost reach their limits. Besides, the Environmental concerning raise the use of renewable energy and energy conservation to face up the energy problem. Solar energy is the most popular renewable energy resource, it is clean, easy to installation, and generate electricity that ready to use. Nowadays, solar PV was inexpensive and household sector can be invested to a small-scale solar power plant. However, solar power would directly affect from the changing of weather and environment. So, energy storage system is the correct answer to manage solar power to best efficacy.

The use of energy storage system and supplying electrical power from solar power by focusing on reducing cost for energy. J. Neubauer and M. Simpson had experimented small energy storage system that help supplying electricity when high electricity demand in short period which really benefits the cost without concerning energy from solar power and reduce the electricity demand to 2.5% [1]. Solar power system could be easy for houses which is suitable as energy sources to reduce demand of grid power. However, renewable energy like solar power which directly affect from the changing of weather as well as affecting energy combination. F.A.T. Al-Saedi has brought information from Yahoo Weather Forecast to analyze data and trends by using statistics through weather information. The analyzed information was used to evaluate by main control system of energy storage system. So, this research has shown the sample uses of smart home by having electrical system in houses, such as on-off lighting system to reducing energy usage [2].

For electrical backup system or battery has developed along with control system with the type of battery that has high efficient supply of power battery and suitable for quick charge which is known as lithium ion (li-ion) [3] which is the battery with high capacity and popular in using for energy storage. Also, European Commission Joint Research Centre in cooperation with frontier Economics has tested li-ion batteries for using in energy industries and found the efficiency is raised to 85% [4] which was related to the experiment from S.M. Schoenung and W.V. Hassenzahl [5]. For the self discharge test from L. Beurskens, the results showed that li-ion batteries have low self discharge ratio (0.03-0.1% per day) [6]. However, in the meantime, this type of batteries still having disadvantages, for example, easily depreciates and temperature could affect performance as well as high price. This could also lead to fire explosion when high temperature or electrolyte leaks. While designing, it is important to prevent and support all mentioned situations.

In Thailand, there was not only peak management that need to concern, most of Thailand has a tropical wet and dry or savanna climate and tropical monsoon climate, cloudy environment would get high fluctuation of solar energy. Therefore, the energy storage system was necessary for stabilize energy generated from PV arrays. The fluctuation of solar energy due to environment can be analyze to short and medium period of daytime (cloudy and rain), then energy storage would select by electricity discharge rate and voltage regulation criteria. Moreover, most of solar unit in Thailand was grid connected without energy storage. That means when the sun had been shading the electrical energy that supplies to grid had lessen, the electricity authority cannot be estimated electrical energy correctly and cannot completely reduce production capacity.

Li-ion battery is the economical and high efficiency one of electrical energy storage. With the advantages on size, weight, energy density, and the capability on current supply, it should be perfectly to use as a large-scale energy storage system, but the cost is too high to investment. Comparing the total installed cost of li-ion batteries, lead-acid batteries, the lithium ion battery has a higher cost than lead-acid more than 200%. Actually, lead-acid technology is continuous improvement and go better in efficiency and lifetime. The advance lead-acid technology add carbon-based material to the negative electrode for lower sulfating, improves conductivity and increases charge acceptance. In the economical view, hybrid energy storage with the combination of li-ion and lead-acid battery increase a change to initiate the energy storage project and take opportunity following energy management in corporate. However, the cost per lifetime is the most significant indicator, this research aims to study the response of energy storage system to the support the solar power fluctuation and load leveling. Under the real load running, the response of li-ion batteries and lead-acid batteries has been collected to the simulation for end-of-life of energy storage in comparison.

2. Research Background and Experimental Setup

2.1 Hybrid Energy Storage

The hybrid energy storage system is the cooperation of two or more types of energy storage to enhance in advantages [7]. The combination of energy storage maybe in different type such as electrical-chemical, electrical-thermal, electrical-mechanical, electrical-hydrogen, electrical-electromagnetic, and also electrical-electrical energy storage. The electrical energy storage is the most flexible and easy to integrate, that's why the electrical energy storage is the main part of general hybrid energy storage. Focusing on the electrical-electrical energy storage, the different types of battery has been selected to design for efficiency enhancement based on required storage time [8]. Besides, the use of hybrid energy storage can be design as the cost reduction too, to emphasize only the high efficacy may cause too high cost and difficult to investment. In the case of wind power, H. Arita et.al. was implement the hybrid energy storage using lead-acid and li-ion battery to solve the intermittent and also reduce the energy storage cost by 40% [9]. Likewise the distance area and off-grid system, the smooth and continuous power is the very important. The one of health center in South-Africa is the good practice of solar power integrated with hybrid energy storage system which leading advantages in lower cost and longer lifespan [10].

Li-ion battery is popular in electrical energy storage. Their energy density is superb comparison with another commercial battery. The European Commission Joint Research Centre in cooperation with frontier Economics has been test li-ion battery in found that energy efficiency reached to 85% [11]. Moreover, li-ion was leading advantage on low self-discharge (0.03-0.1% per day) [12] and also in high response rate. However, li-ion battery's cost is too high and battery's life is too sensitive to charging scheme. Hence, the use of li-ion battery as largescale energy storage was needed to concern.

The deep cycle valve-regulated lead-acid (VRLA) is the up-to-dated technology of lead-acid battery that doesn't need to install in upright position and routine electrolyte check. On the view of energy conversion, AC/DC and DC/AC conversion efficiency of VRLA assumed to 92% with consistent to the li-ion system [13].

According to the difference in physical; the response time, discharge period, and lifetime, the storage capacity ratio is the challenged issue for hybrid energy storage design. On considering on the environmental parameter, fluctuation frequency and require storage time during daylight were inappreciable because, both battery types are good at response time. The lifetime lead-acid has shorter useful life to li-ion so, the discharge too much in transient daylight is proper to use li-ion as the main storage. The lead-acid works well in the night-time because lower ambient temperature, hence the lifetime cost is 18% cheaper than the li-ion. For economical design and introduce hybrid energy storage in Thailand, initial investment costs should not higher than the costs of pure lead-acid system. Therefore, lead-acid battery would be selected in the bigger ratio. Approximately Thailand has five hours of sun per day and assuming variance of solar power each day to 40% in cloudy environment, so the intermittent power can be determined as two hours in total. For energy management, the electricity demand in each day needed to consider. The daily critical peak event needs to shave-out to reduce the demand charge (four hours during daytime and three hours at night). For the preliminary calculation the storage capacity ratio should be 70/30 lead-acid to li-ion respectively.

In this work, system consists of 100kWh hybrid energy storage with 30:70 ratio of Lithium Iron Phosphate battery (LFP) and lead-acid battery with absorbed glass material (AGM). The system connected to the 50kW capacity solar roof-top building using 6 hybrid inverters for separate battery types and able to work individually. For the control system, each battery should work on the priority-based controlling scheme (Table 1), with the lower value of response priority represent more intensive and zero meant the most important condition.

Table 1: priority-based controlling scheme

Condition	**Response priority**		**remark**
	AGM	**LFP**	
Cell temperature > 50 ^{o}C	0		Limit Current
Very High-Power Demand	1		
Low Battery (< 20%)	0	n/a	Limit Current
Low Battery (< 10%)	0		Stop Discharge
Day Peak	4	3	Prior on higher capacity
Night Peak	4	3	
Solar Fluctuation	n/a	2	

2.2 Solar Fluctuation

In Thailand's energy management, there was not only peak management that need to concern, most of Thailand has a tropical wet and dry or savanna climate and tropical monsoon climate, cloudy environment would get high fluctuation of solar energy. Therefore, the energy storage system was necessary for stabilize energy generated from PV arrays. The fluctuation of solar energy due to environment can be analyze to short and medium period of daytime (cloudy and rain), then energy storage would select by electricity discharge rate and voltage regulation criteria.

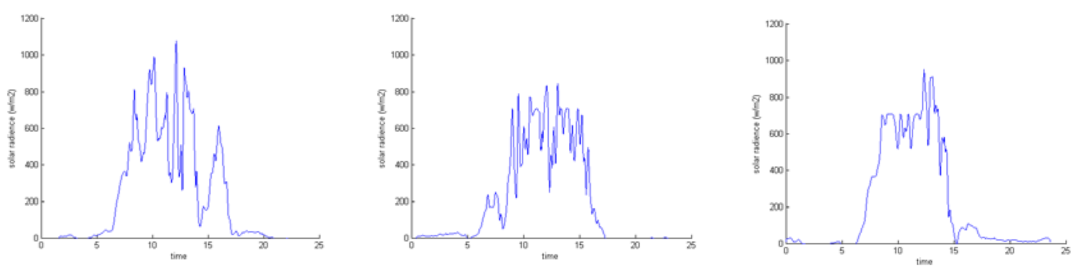

Fig. 1 example of solar radiance dataset

Table 2: summarize of solar fluctuation data (30 days)

Fluctuation Parameter	**30 Days Fluctuation Data**		
	Minimum	Maximum	Average
Frequency rate (per hour)	4	45	24
Duration (minute)	1	80	6.5
Power Dropped (%)	10	90	28
Daily Energy Produce (kWh)	66	226	184

Li-ion battery suitable for high current discharge and having high cycle-life. So, it capable to support the power intermittent change of solar power. Table 2 shown the summarize of the solar power fluctuated for 30 days (10 November 2019 to 9 December 2019 at Phitsanulok, Thailand). The energy produced from 50kW PV array is actually 184kWh daily and the losing power that need li-ion battery to support 5.72kW for average solar fluctuation. That is about 20 percent of overall li-ion battery capacity.

2.3 Battery End-of-Life

The battery will reach the end of its usefulness and/or lifespan and can no longer operate up to 80% of peak capacity, called End-of-Life (EoL). Generally, EoL has been designed by manufacturer around 70-80% of initial capacity [14-16]. On EoL test, battery would stop discharge when State of Charge (SoC) of battery reached the level that describe by manufacturer. In some manufacturer, EoL test would stop by the total energy throughput reach the threshold [14].

On the experiment, the response of the difference battery types on the application of regulate the solar power and peak shaving would be use for end-of-life testing condition. The maximum parameters of discharging current, depth of discharge, and cut-off voltage would be simulated the cell EoL test in room temperature. Fig. 2. shown the schematic of EoL test using electronics load bank connected to battery cell with programmed load pattern.

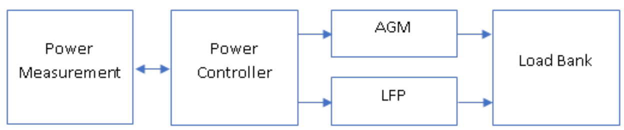

Fig. 2 EoL testing schematic

Table 3: details of EoL test

Factor	Number of Level	Value of Level
Current	3	LFP 0.5C, 1C AGM 0.16C, 0.5C, 1C
Battery Type	2	LFP 3.2V 6Ah AGM 12V 7Ah
Environment		Atmospheric/Room Temperature
Cycle Life	n/a	1, 100, 200, 300, …
Battery Capacity	n/a	measure

3. Experimental Results

In this research, the on-site experiment would be collected for analyze the response of the difference battery types. The building has constant energy consumption behavior with averaged 250kWh daily. The response of each battery type has been recorded by inverter separately with balanced load. Both inverters connected to 8kW installation capacity PV array and 5kWh energy storage. After 30 days record, the results have been focused on the working duration daytime and nighttime. On daytime, the energy storage system has to response for day peak and solar fluctuation. At night, energy storage system has to do energy management with their energy stored on the daytime. Accordingly, the high solar fluctuation is the dominant situation for consider system working in whole day.

On the experiment on the real load, case A the response due to high solar power fluctuation at daytime and peak shaving at night, and case B is same case A but higher fluctuation level. Figure 3 and 4 present the example of case A and case B respectively, focusing on the power (kW) and time (00:01 – 24:00), the solar power present as blue line, discharging power present as grey line, and charging power present as orange line. The percentage in horizontal axis is the Depth of Discharge (DoD) of the battery.

For case A, both battery response looks similar, but in the evening LFP start discharge before AGM until no sunlight two battery work coincident. During daytime, the solar fluctuation makes the charging process interrupt, but the fluctuation level

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in case A is not affect the energy consumption. On case B, the high fluctuation makes LFP response more frequent and confirm that solar power intermittent effected to battery cycle life.

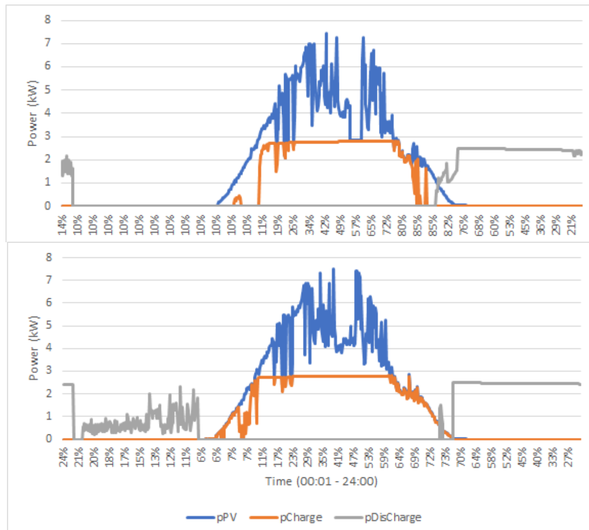

Fig. 3 the response of LFP (upper) and AGM (lower) case A

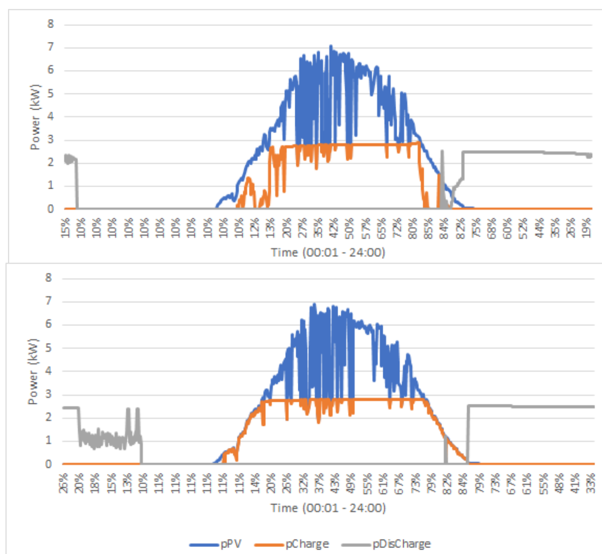

Fig. 4 the response of LFP (upper) and AGM (lower) case B

The response of the difference battery types have been use for end-of-life testing condition. The maximum parameters of discharging current, depth of discharge, and cut-off voltage would be simulated the cell EoL test in room temperature. The EoL has been measured as capacity ratio (cycle capacity : first use capacity) with 10% to 85% DoD per cycle. The EoL for hybrid energy storage is about 4 years lifespan with the 0.5C and 0.16C for LFP and AGM respectively. Subject to 100% LPF system, the discharge rate become lower and estimated lifespan about 7 years.

Table 2: Comparison between ESS type on economical

ESS	**Starting Cost (ratio)**	**Lifetime Cost (ratio)**	**LCOE (THB/kWh)**
Pure LFP	1	1	12.568
Hybrid	0.660	1.103	13.865

For the cost comparison, table 2 shown the comparison of pure LFP system and hybrid system using pure LPF as reference for easy to compare. On the economical view, the Levelised Cost of Electricity (LCOE) is the effective factor to compare in term of lifetime costs and energy production. Hence, the degraded factor for PV and inflation rate have to calculated. The major advantage of hybrid energy storage is reduced 34% of project starting cost compared to pure LFP system but only 10% additional cost for lifetime calculation. However, LCOE is too high to investment with current battery cost and need some government policy or the technology that make battery cheaper.

4. Conclusions

This research outcome shows that it improves the efficacy of the use of solar energy in high fluctuation environment. The three different application of energy storage has been present; to stabilize the solar power in case of grid connected solar power plant, to reduce electricity peak demand in the building, and the off-grid system. The hybrid energy storage consists of LFP and AGM battery connected together has been present for the lower investment cost. The initial investment is 34% lower cost than pure LFP energy storage system but the lifetime is 10% higher than pure LFP system.

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