Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

The Study of Energy Management Scheme of Hybrid Energy Storage System for Responding High Demand with Long Period

Praphun Pikultong[1,*], Sahataya Thongsan[1], Somchai Jiajitsawat[2]

[1] School of Renewable Energy and Smart Grid Technology, Naresuan University, Thailand
[2] Department of Physic, Faculty of Science, Naresuan University, Thailand

ARTICLE INFO

Article history:
Received 20 March 2022
Received in revised form 24 June 2022
Accepted 7 July 2022
Available online 1 August 2022

Keywords:
Hybrid energy storage system; high demand; peak shaving; multi-level threshold

ABSTRACT

Most large and controlled buildings require high power demand with long period. However, there are restrictions on building facilities and image when it comes to reducing electricity consumption. Another option is to install a roof-top solar power system, though due to the small installation area, it will only partially reduce energy use. Hybrid energy storage systems in combination with AGM batteries and LFP batteries are now offered as a lower cost energy management solution. AGM batteries are constrained in their ability to produce current, hence a larger current supply will reduce the battery's useable capacity. Therefore, in order to respond to high demand with long period, this research proposed a separate multi-level threshold control of the battery packs, and used the control factor in the form of current ratio to divide the load response for each battery type: On-Peak in AGM: LFP at 0.7:0.3, Off-Peak in AGM : LFP at 0.5 : 0.5. And when one battery was not ready for use, the other battery would be run at full capacity. The results showed that the AGM battery had a peak discharge current of 12.7A, or approximately 0.5C when coupled with an LFP battery, and when processing power storage system capacity, a loss of 8.99 kWh occurred. or 6.8% of the overall capacity.

1. Introduction

"Energy" is one of the main economic drivers since it is the main cost and affects industrial expansion, and energy and access to energy are considered factors that contribute to the better quality of life of the population. Moreover, with the increasing demand for energy, "electricity" is a type of energy that is crucial to our daily lives. Long-range scenarios on energy have been established in many countries, focusing on a higher ratio of renewable energy, such as Maximum Renewable Energy Scenario (MRES), 50% renewable share by 2050 Scenario (50-50 Scenario), and Optimistic Energy Scenario (OES), compared to Business-as-usual (BAU), or a situation where there is no significant change in energy patterns and activities [1] with the aforementioned awakenings and rising energy costs, large public and private buildings have installed rooftop solar panels to reduce their energy usage, and their use has started to spread into the residential sector. This approach is

* *Corresponding author.*
E-mail address: mr.praphun@gmail.com

https://doi.org/10.37934/arfmts.98.1.146156

one of the fundamental concepts of green building focusing on reducing energy consumption and being more energy efficient [2]. However, most of the installed rooftop photovoltaic systems are aimed solely at reducing electricity consumption without focusing on efficient energy management. This may partly be due to the high cost of energy storage systems and the need for specialized knowledge for setup and maintenance. One of the main reasons is that the limited installation space for solar panels means that it does not produce enough electricity to meet demand and that it needs to be powered from the grid instead of charging batteries for use in the absence of solar power. These issues have resulted in EGAT being unable to reduce power generation despite the increasing number of buildings installed with rooftop solar panels.

Due to this challenge, the cost of energy storage systems must be taken into consideration when making decisions about the launch of new projects. This is consistent with the wide range of projects in the group that developing countries are facing, making some projects unable to start [3]. High-efficiency storage systems, such as lithium batteries, have a much higher cost than lead-acid batteries. For reasons of material cost and technology cost, if a low initial cost energy storage system [4-6] can be chosen, such as a hybrid energy storage system consisting of Lithium iron phosphate (LFP) batteries and Absorbent Glass Mat (AGM), it will bring significant overall energy benefits. However, one of the disadvantages of lead-acid batteries is that they are affected by high-current applications, leading to a significant reduction in their capacity, thus affecting the application and design of the energy storage system size. However, the control by limiting the current supply range is not fully possible, as this will cause the energy storage system to not function at full efficiency. As a result, for hybrid energy storage systems, lithium batteries with higher current efficiency serve to provide compensation for the efficient operation of the energy storage system.

When reconsidering the main problem of this research, the use of energy storage systems to respond to the electrical load of large and controlled buildings, many of which have high demand with long period, estimation of the storage capacity of the energy storage system and the distribution of electricity in response to the load are therefore very important especially in such buildings where rooftop solar power generation systems are installed with limited space and can reduce some energy consumption, but not enough to meet the demand. Hence, energy management in the form of Load Leveling [7,8], that is to say, taking advantage of the difference in power costs in the On-Peak and Off-Peak periods and reducing the peak power demand is essential to manage power across large loads and over long periods of time, which for hybrid energy storage systems, the operating capacity must be taken into account during response to different current demands.

Thus, this research aims to study the interaction of LFP batteries and AGM batteries with a total capacity of 130 kWh, installed in experimental buildings using grid power and solar power generation system with an installed capacity of 50 kW. The hybrid energy storage system will be put to the test for its responsiveness to reduce the peak power demand of large buildings with long usage periods by using a multi-threshold method to study the impact that can be applied in the future.

2. Research Background and Experimental Setup

Energy storage system is a key instrument for effective energy management, with the most popular application being inevitably the reduction of peak power cost, which has outstanding economic results and is an ongoing research issue. For example, Davis and Hiralal developed a smart home control system that backed up electricity during low demand periods when electricity cos was low and restored electricity for use when power demand was high. This resulted in reduction of costs and a cost-effectiveness in terms of economics [9]. Mishra *et al.,* designed and developed a feedback control system and implemented it to reduce peak power demand by up to 18% with system stability improvement [10]. In addition, Son and Song had developed further by connecting the backup power system to renewable energy sources and using a fuzzy logic control system to control the compression and discharge of the power backup system. They predicted the real-time cost of electricity that could be generated from wind power, combined with the energy stored in batteries to supply it to the grid to reduce peak demand. It was found that the high demand for electricity was reduced and the peak demand period could be postponed [11]. Uddin *et al.,* [12] researched ways to reduce peak power using cumulative and load management systems. It was found that different types and sizes of energy storage systems and load management had an effect on reducing the maximum power cost. In addition, Oudalov *et al.,* [13] researched to determine the optimal sizing and management of battery energy storage (BESS) systems to reduce peak power. It was found that the suitable size of the battery to store energy depended on the maximum power cost that needs to be reduced. And in implementing an energy storage battery system, the resulting savings would be depended on the power demand and battery life, in which when a 250 kWh lead-acid battery was applied to a simulated load in an industrial plant, energy costs were reduced by 4%. Telaretti and Dusonchet [14] have introduced a Battery Energy Storage System (BESS), where the system was charged at night with low electricity costs and used during the day when electricity costs are high. This would reduce the peak power cost that occurred during the day. In addition, energy storage systems are used to reduce high power demands. For example, a case study of the use of an energy storage system with an EV Quick Charge system for residential homes where pre-scheduling can be used to divide the power draw from the grid [15].

However, the energy storage system will only function at its best when it is properly sized for the use of electricity. Larger buildings consume more electricity and require larger energy storage systems. However, investments in lithium energy storage systems are costly. From an economic point of view, the long payback period means it is necessary to slow down investments and prevent the technology from being fully utilized. However, because the hybrid electric power storage system for solar power generation system is a collaboration between the lithium-ion combined with lead-acid to bring out the advantages of both types of energy storage systems by using a control system, which reduces the cost of using lithium-ion batteries alone; In addition, when starting a project on a large system, the cost can be reduced compared to per unit in a smaller system. But initially it can be said that lead-acid batteries have limitations in their applications in the form of energy storage systems in response to applications in supporting load changes and maintaining a lower voltage of the solar power generation system than the lithium ones. Consequently, considering the limitations can make overall battery management more efficient. Managing a longer battery life is an extremely important part of the energy storage system where different types of batteries are used as the life of each battery type affects overall system performance as well as end-of-life replacement and maintenance. In terms of battery life, the AGM has 2000 charge cycles at 80% discharge depth and the LFP battery has 3,000 charge cycles at 80% discharge depth and up to 3,000 charge cycles at 80% discharge depth and 2000 charge cycles at 100% discharge depth. The two selected batteries have a discharge rate of 80% for AGM batteries and 100% for LFP batteries, respectively, without much difference [5, 16]. There have been researches that use a hybrid energy storage system between lead-acid batteries and lithium-ion batteries with a focus on reducing project initial costs. For example, Arita *et al.,* designed a hybrid energy storage system from lead-acid and lithium-ion batteries by using a control system in order to respond to changes in electric power demand and reduce the volatility of the wind power generation system which can reduce the cost of the energy storage system by up to 40% [4]. For areas that are far from transmission lines or where the power grid is unstable, energy storage systems can play a role in reducing power uncertainty by reducing the use of gasoline-powered generators, or, for example, in a healthcare facility in Africa, a hybrid electric energy storage system, consisting of lithium-ion and lead-acid batteries, along with a solar power generation system, is used as an additional power source. Rahe found that the experimental-designed model found that hybrid energy storage systems would have a longer lifespan and lower cost [17]. However, lead-acid batteries have limitations in their ability to supply current. At higher currents, the usable capacity of the battery will be lower due to limitations in the electrolyte movement [18]. This makes the Peukert Constant for lead-acid batteries higher than lithium batteries [19] and affect the use and design of the energy storage system size, as well as the command set to control the operation. Therefore, considering the efficiency of a hybrid energy storage system working in conjunction with a lead-acid battery and a lithium-ion battery in terms of working capacity is a priority to assess the potential of the system. According to research by Somchai, it was found that the optimal ratio of AGM:LFP is 70 :30, which when increasing the ratio of LFP batteries, although they provided higher efficiency, but the cost was much higher [5].

As mentioned above, hybrid energy storage systems that work together between LFP batteries and AGM batteries all require a suitable control system to meet power demands and reduce the impact on lifespan of the energy storage system itself. In this research, the focus was on the response of hybrid energy storage systems to the system's response to reduce the peak power demands in large buildings and for longer period by working with the solar power generation system installed on the roof which was smaller than the overall requirements of the experimental building which can be shown in Figure 1 (above). It can be seen that most of the building's electricity demand was on-peak and solar energy would only partially reduce the energy consumption. Figure 1 (bottom) shows the differential power that still required from the grid and the Threshold (N) line to contrast and control the energy storage system to discharge into the building. The shaded area represents the power to be supplied from the energy storage system, which can be shown in Eq. (1).

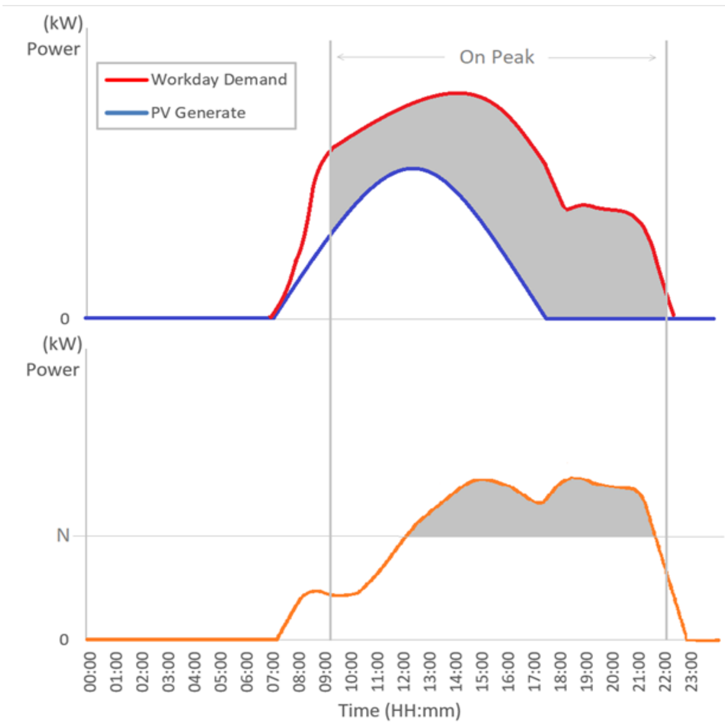

Fig. 1. The building's power demand data relative to the power generated by the solar panels

$$E_{sh} = \sum_{h=H_0}^{H} \left(P_{l,h} - P_{PV,h} - N\right) \quad (1)$$

where E_{sh} is Energy of Load needed to shaved (kWh), $P_{l,h}$ is Power of load at hour h (kW), $P_{PV,h}$ is Power of PV system at hour h (kW), H is the number of hours$N$ is the threshold level (kW).

From the equation it can be seen that Threshold is the primary control for peak shaving. In this section, the capacity of the energy storage system and the amount of current must be taken into account. However, with the concept of Load Leveling power management, it was still difficult to adjust the load to achieve the same level of grid power demand because the energy storage system must be designed to be large enough to compensate for the uncertainty of the electric power produced by the solar panels that may be affected by the weather and environmental conditions. Therefore, in this study, a hybrid energy storage system was designed to work in conjunction with an LFP battery and AGM battery with a total capacity of 130 kWh, controlled using a multi-step threshold method to respond to time and conditions for the electrical power demands of the buildings.

3. Experimental Setup

The system used in the study consisted of an Absorbent Glass Material (AGM) and a lithium-ion phosphate (LFP) battery with a total capacity of 130 kWh, combined with a 50 kW solar power system to respond to energy use of a building with a continuous high energy consumption pattern. Both types of batteries were designed to operate independently of each other to respond to loads at an appropriate current rating, with the Energy Management System acting as the primary control system for energy management. The system diagram can be shown as shown in Figure 2.

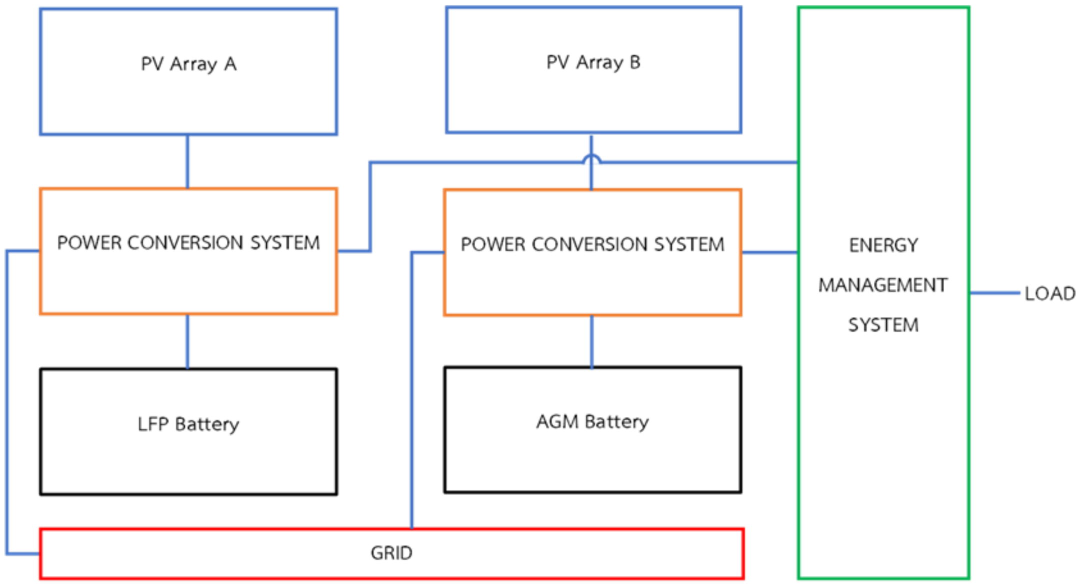

Fig. 2. Diagram showing the overall system

3.1 Hybrid Energy Storage

For the hybrid energy storage system, an 80 kWh Absorbent Glass Material (AGM) and a 50 kWh Li-ion Phosphate (LFP) battery were chosen, or AGM to LFP battery ratio at 61.5:38.5, which in response to the load at higher current demands, each type of battery had a different reduced capacity as shown in Table 1. Therefore, current limiting is one solution to achieve the maximum efficiency of the energy storage system. However, when responding to loads at high current levels, the control system would prioritize supplying current to the higher potential LFP batteries.

Table 1
The characteristics of each type of battery in response to a current supply

Battery Characteristic	AGM	LFP
Nominal Discharge C Rate (max)	0.1 (0.8)	0.5 (3)
Battery Module Capacity	1,200 Wh	10,000 Wh
Available Module Capacity @ max C rate	628.26 Wh	8,000 Wh
Battery System Capacity	81.6 kWh	50 kWh
Available System Capacity @ max C rate	42.72 kWh	40 kWh

3.2 Building Load

In this hybrid energy storage system study, the focus was on operating in response to the high power demands and long spans that were one of the limitations of energy storage systems, which included lead-acid batteries as a component. The building being experimented was an office building with a 50 kW solar power generation system. In this regard, the data of the power demand on a working day has been recorded by selecting the date of overtime (OT) operation as shown in Figure 3. Each point represented the measured data and the red line graph was the average of the data set for the period February-March 2022. The same as Figure 4 showing the energy produced from the solar power generation system on that day. Each point was the data that can be measured and the red line graph was the mean of the data set.

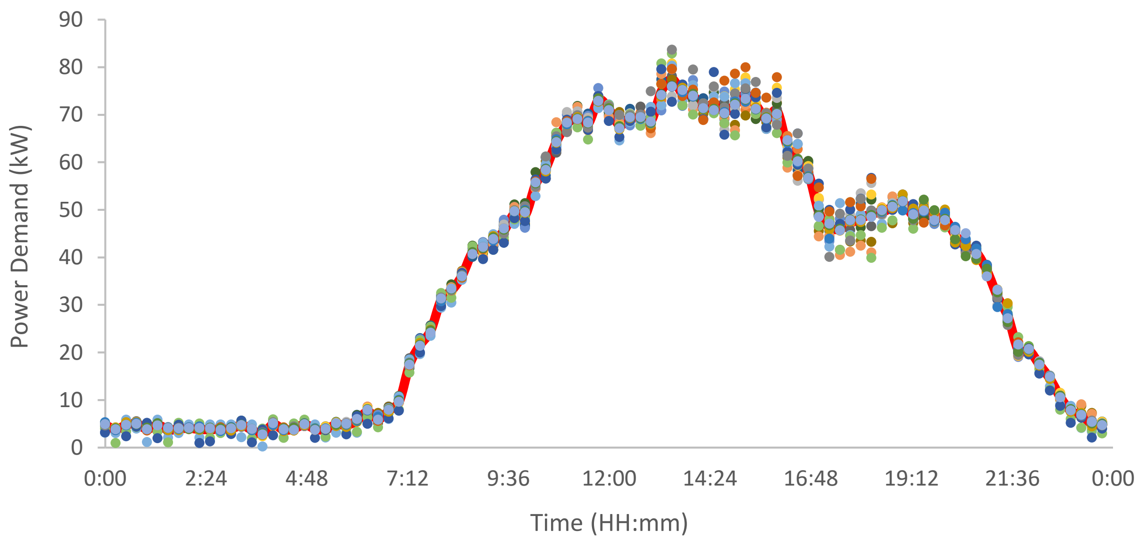

Fig. 3. Power demand data on working days by selecting the days of overtime (OT) operations

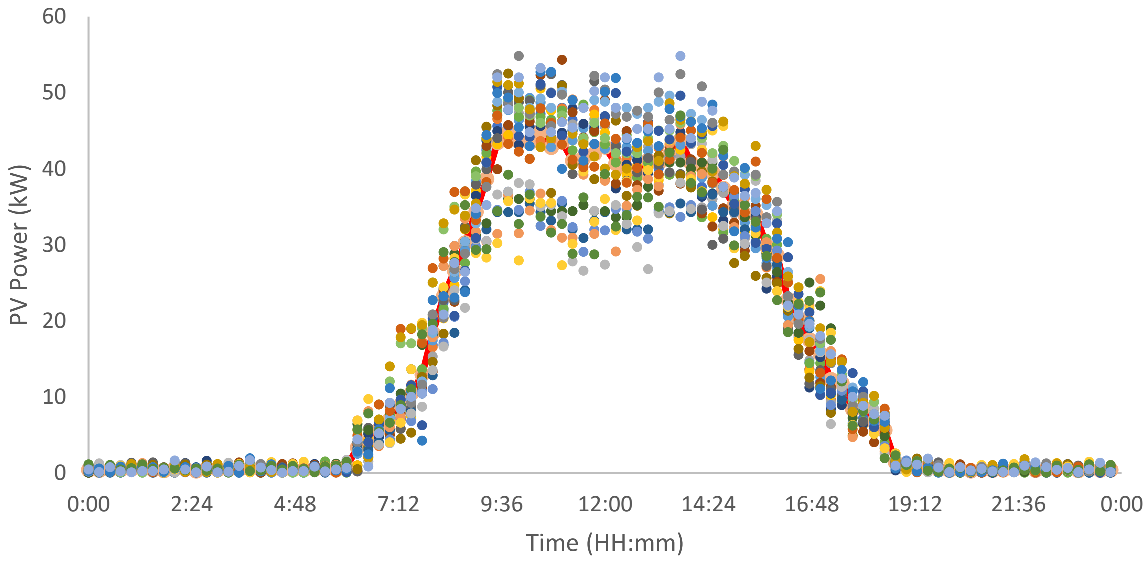

Fig. 4. Power generated from the solar power generation system on the same day in Figure 2

From Figure 3, it can be seen that the building used relatively stable energy consumption. This may partly be due to the fact that electrical appliances are in routine use, and during the same month, the large temperature changes resulted in the air conditioner still operating and using a similar level of energy. As with research by Hwang *et al.,* [20], stating that outdoor temperatures significantly affected a building's energy use. But for the solar power generation system, the fluctuation was evident. This fluctuation would affect the actual power demand of the building ($P_{l,h} - P_{PV,h}$) and the operation of the energy storage system.

3.3 Energy Management System

In the control system, the time interval was mainly used to determine the operation of the energy storage system, with an on peak operating time of 13 hours (9:00 AM - 10:00 PM.) and the off-peak period was a period outside of that period. However, since the power demand data for the experimented towers varied with low power requirements, the operating intervals can be determined as shown in Table 2, and set the work to divide the current into a ratio form to reduce the discharge load of the AGM battery, which affected the working capacity. When one type of battery was in idle condition or had an SoC that was lower than its operating range, the other type would operate to provide full current.

In the Threshold configuration section, the building's power demand and power demand data from the rooftop solar power generation system is imported to assess the actual building's power demand and the energy storage system's usable capacity using the calculation as in Eq. (1) and estimating the Off-Peak period to determine the Threshold to charge back into the storage system to 25kW for AGM batteries and 20kW for LFP batteries by setting the Threshold to the AGM o be higher because the overall capacity of the system had a higher ratio of the AGM, which should be provided in a standby state before the next phase of operation.

Table 2
Operating Conditions of the energy storage system

Condition	AGM	LFP
Threshold > Demand	Charge	
Demand > Threshold	Discharge	
Working SoC	20% - 95%	10% - 95%
On-peak Threshold	40 kW	40 kW
Off-Peak Threshold	25 kW	20 kW
- Load Response		
- On-Peak	0.7	0.3
- Off-Peak	0.5	0.5
- LFP Low SoC	1	0
- AGM Low SoC	0	1

4. Experimental Results

To test the operation of the energy storage system inside the experimented building, the initial capacity of both batteries was set to 20% by measuring the power required by the building after compensation for the power generated by the building's solar power generation system, power drawn from the grid, and input and output power for each type of battery, as shown in Figure 5. The AGM and LFP battery performance curves are shown by orange and gray graphs respectively. When the graph shows negative, it means the battery is discharged to peak shaving, and when the off-peak period is reached, each battery starts charging again, which State of Charge of each type of battery is shown per time period and compared to the building's net power demand (Secondary Vertical Axis) as shown in Figure 6. This represents a rapid decline in AGM battery levels between 15:00 and 17:00 and between 18:00 and 20:00 due to high current discharge levels.

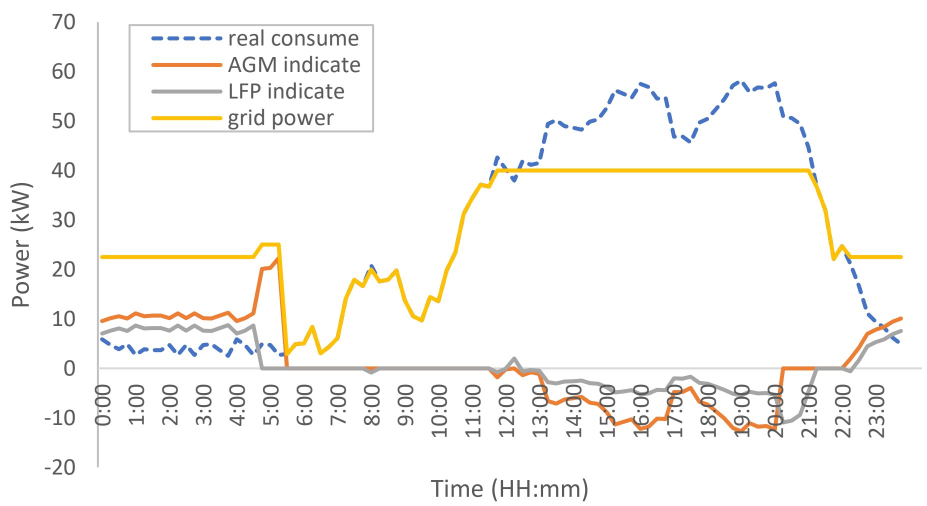

Fig. 5. System response when high and continuous power demand

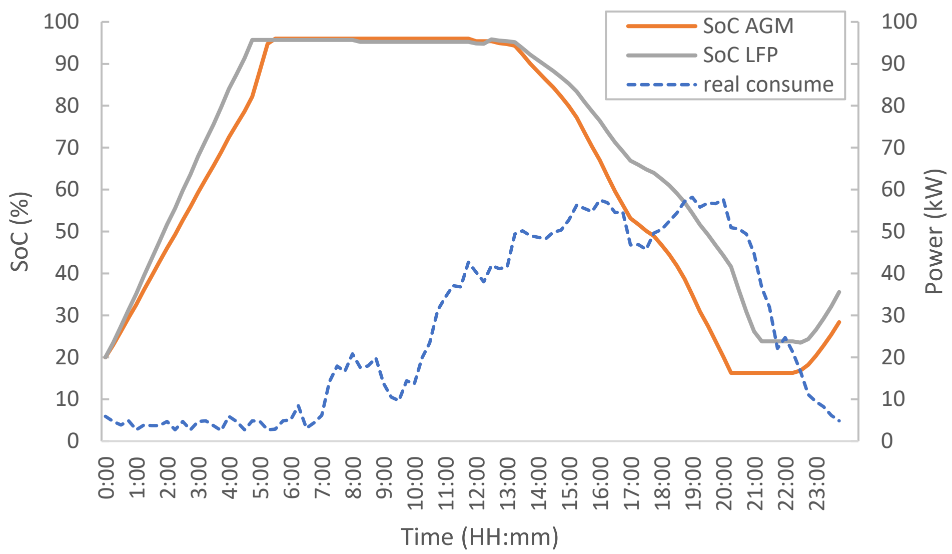

Fig. 6. Capacity level of the energy storage system throughout the power factor operation

When considering the current ratio for load response, the AGM battery had a maximum discharge current rating of 12.7A, or approximately 0.5C, when coupled with an LFP battery. The test showed that the capacity of the AGM battery was reduced until it stopped supplying current (below 20% SoC), causing the LFP battery to charge at full current instead, with a maximum current rating of 10.9 A, or about 0.1C. When performing processing capacity of the energy storage system, a loss of 8.99 kWh was found and if the LFP battery malfunctions, the AGM battery must be running at full capacity at a maximum current of 18.18 A or approximately 0.7C, resulting in a considerable impact on capacity based on the data in Table 1 (maximum 0.8C remaining capacity 42.72 kWh).

5. Conclusion

An 80 kWh AGM battery and a 50 kWh LFP battery were chosen for the hybrid energy storage system in this study, resulting in an AGM battery to LFP ratio of 61.5:38.5. The control scheme was studied in response to high demand with long period, therefore, this research presented a multi-level threshold control that separated the operation of the battery pack independently with the control factor in the form of a current ratio to divide the load response for each type of battery: On-Peak in AGM : LFP at 0.7 : 0.3, Off-Peak in AGM : LFP at 0.5 : 0.5 and when one battery was not ready for use, the other battery would run at full capacity, which resulted in an thresholds adjustment to provide a more flexible and independent hybrid power storage response. This is good for working operation when a particular system is unavailable or needs maintenance. The added distribution of current ratios in respect of each battery's operation allowed the storage system to maintain its current potential in response to the load by reducing the impact of capacity due to the discharge rate in lead-acid batteries and losing only 8.99 kWh of capacity throughout the day, or 6.8% of overall capacity. However, if this hybrid energy storage system lost the LFP battery's functionality, the AGM battery would have to run at full capacity with maximum current of 18.18 A or about 0.7C, which had a large impact on the capacity.

When conducting an initial economic evaluation, it was found that each day (Considering only the days of overtime work) with a Time of Use Tariff (TOU) charge based on the Provincial Electricity Authority (PEA) rates, the difference between on peak and off peak power was approximately 1.5 baht per kWh [21], enabling peak shaving energy management services with hybrid energy storage systems to save an average of 164 baht/day without calculating the reduction of demand charge each month.

However, this research illustrates a time-based control model with reference to the On-Peak and Off-Peak intervals. The Load Forecast system is crucial to responding successfully to high, long-period loads so that it can be expanded into various building types with erratic daily power demands.

References

[1] Samsudin, Muhammad Syazwan Nizam, Md Mizanur Rahman, and Muhamad Azhari Wahid. "Sustainable power generation pathways in Malaysia: Development of long-range scenarios." *Journal of Advanced Research in Applied Mechanics* 24, no. 1 (2016): 22-38.

[2] Amran, Mohd Effendi, and Mohd Nabil Muhtazaruddin. "Renewable Energy Optimization Review: Variables towards Competitive Advantage in Green Building Development." *Progress in Energy and Environment* 8 (2019): 1-15.

[3] Yee, Ha Chin, Radzi Ismail, and Khoo Terh Jing. "The Barriers of Implementing Green Building in Penang Construction Industry." *Progress in Energy and Environment* 12 (2020): 1-10.

[4] Hirota, Hiroshi Arita Yohei Kawahara Shoichi, and Kenji Takeda. "Large Format Hybrid Energy Storage System for Power Leveling." *Hitachi Chemical Technical Report* (2015): 20.

[5] Somchai Jiajitsawat, et. al., "The Development of Energy Storage System for Photovoltaic System." *Research Report, Enconfund* (2019): P-17-50440.

[6] Anuphappharadorn, Suratsawadee, Sukruedee Sukchai, Chatchai Sirisamphanwong, and Nipon Ketjoy. "Comparison the economic analysis of the battery between lithium-ion and lead-acid in PV stand-alone application." *Energy Procedia* 56 (2014): 352-358. https://doi.org/10.1016/j.egypro.2014.07.167

[7] Kim, Hyung Tae, Young Gyu Jin, and Yong Tae Yoon. "An economic analysis of load leveling with battery energy storage systems (BESS) in an electricity market environment: The Korean case." *Energies* 12, no. 9 (2019): 1608. https://doi.org/10.3390/en12091608

[8] Kim, Hyung Tae, Young Gyu Jin, and Yong Tae Yoon. "An economic analysis of load leveling with battery energy storage systems (BESS) in an electricity market environment: The Korean case." *Energies* 12, no. 9 (2019): 1608. https://doi.org/10.3390/en12091608

[9] Davis, M. J. M., and P. Hiralal. "Batteries as a service: a new look at electricity peak demand management for houses in the UK." *Procedia Engineering* 145 (2016): 1448-1455. https://doi.org/10.1016/j.proeng.2016.04.182

[10] Mishra, Aditya, David Irwin, Prashant Shenoy, and Ting Zhu. "Scaling distributed energy storage for grid peak reduction." In *Proceedings of the fourth international conference on Future energy systems*, pp. 3-14. 2013. https://doi.org/10.1145/2487166.2487168

[11] Son, Subin, and Hwachang Song. "Real-time peak shaving algorithm using fuzzy wind power generation curves for large-scale battery energy storage systems." *International Journal of Fuzzy Logic and Intelligent Systems* 14, no. 4 (2014): 305-312. https://doi.org/10.5391/IJFIS.2014.14.4.305

[12] Uddin, Moslem, Mohd Fakhizan Romlie, Mohd Faris Abdullah, Syahirah Abd Halim, and Tan Chia Kwang. "A review on peak load shaving strategies." *Renewable and Sustainable Energy Reviews* 82 (2018): 3323-3332. https://doi.org/10.1016/j.rser.2017.10.056

[13] Oudalov, Alexandre, Rachid Cherkaoui, and Antoine Beguin. "Sizing and optimal operation of battery energy storage system for peak shaving application." In *2007 IEEE Lausanne Power Tech*, pp. 621-625. IEEE, 2007. https://doi.org/10.1109/PCT.2007.4538388

[14] Telaretti, Enrico, and Luigi Dusonchet. "Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram." In *2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC)*, pp. 1-6. IEEE, 2016. https://doi.org/10.1109/EEEIC.2016.7555793

[15] P. Pikultong, N. Intaboot, T. Vilasmongkolchai, P. Donthuam, S. Dangeam. "Adaptable Energy Management of Home Energy Storage to Support EV Quick Charging." *The International Journal of The Computer, The Internet and Management (IJCIM)* 27, no. 1 (2019): 37-42.

[16] Avelar, Victor, and Martin Zacho. "Battery Technology for Data Centers: VRLA vs. Li-ion." *International Journal of Science and Innovative Technology* 1, no. 1 (2018): 76-87.

[17] Rahe, Christiane. *Lead-acid Batteries and Lithium-ion Batteries in parallel Strings for an Energy Storage System for a Clinic in Africa*. No. FZJ-2017-02842. Helmholtz-Institut Münster Ionenleiter für Energiespeicher, 2016.

[18] Spiers, David. "Batteries in PV systems." In *Practical Handbook of Photovoltaics*, pp. 721-776. Academic Press, 2012. https://doi.org/10.1016/B978-0-12-385934-1.00022-2

[19] Omar, Noshin, Peter Van den Bossche, Thierry Coosemans, and Joeri Van Mierlo. "Peukert revisited—Critical appraisal and need for modification for lithium-ion batteries." *Energies* 6, no. 11 (2013): 5625-5641. https://doi.org/10.3390/en6115625

[20] Hwang, Jin Sol, Ismi Rosyiana Fitri, Jung-Su Kim, and Hwachang Song. "Optimal ESS scheduling for peak shaving of building energy using accuracy-enhanced load forecast." *Energies* 13, no. 21 (2020): 5633. https://doi.org/10.3390/en13215633

[21] Provincial Electricity Authority (PEA), 2015, Electricity Reconsider.