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Cost-benefit assessment of energy storage for utility and customers: A case study in Malaysia

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ABSTRACT

Under the existing commercial framework of electricity in Malaysia, commercial and industrial customers are required to pay for the peak power demand charge every month. Usually, the peak demand charge can contribute up to 30% to their electricity bills due to the use of open-cycle gas power plants that deliver expensive electricity to the customers. Therefore, alternative means are sought after in order to reduce the peak demand for the customers. Distributed small-scaled energy storage can offer a good option to reduce the peak. This paper aims to identify the financial benefits of the energy storage system for utility companies and customers. An energy dispatch model is developed in HOMER to determine the cost of electricity. The model considers the heat rates of power plants in calculating the costs of electricity under different regulatory frameworks of natural gas with various prices of battery components. Apart from that, the cost-benefit for the customers under various electric tariff structures is evaluated. Four battery storage technologies, namely lead acid, vanadium redox flow, zinc-bromine, and lithium-ion are considered. The simulation results show that the storage system with lead acid batteries is more cost-effective than other battery technologies. The customers can reduce their electricity bills with the payback period of 2.8 years. The generation cost for the power system with energy storage is lower than that without energy storage. Besides, the system with energy storage has lower greenhouse gas emissions than that without energy storage. The deferral of the reinforcement of transmission and distribution infrastructure can be achieved with the installation of energy storage at distribution network.

1. Introduction

The inherent variability of the load demand increases the complexities of modern power plant operations. The variable load demand requires additional equipment to vary the power output effectively which increases the system complexity and results in the high cost of electricity production. Peak power plants are used to cope with high demand during peak periods. They are required to supply electricity for several hours, say 8 h, per day. To recover the operating and maintenance costs as well as the capital costs of the power plants within their lifespans, the electricity of the peak power plants has to be more expensive than that of any base-load plants [1]. Furthermore, these power plants have to operate in partial loading that can reduce efficiency of the plants. Additional fuel is needed for the peak power plants, hence making the price of the electricity to be further increased. Therefore, utility companies often charge the commercial and industrial customers at a premium price based upon their maximum demand during the billing cycle, in addition to the energy consumption charges. The maximum demand is calculated by taking the demand over the successive time period of 30 min and then multiplied by 2 [2]. However, this maximum demand charges increases the operating costs of the commercial and industrial sectors, hence affecting their competitiveness in the market.

Malaysia aspires to become a fully developed nation to achieve a self-sufficient industrialized nation by the year 2020. The vision encompasses the economic prosperity, social and political stability, world class education, and psychological balance. However, the recent price hikes of electricity may alleviate the industrialization process. In January 2014, the average electricity tariff in Malaysia hiked 15% from the average rate of RM 0.3354/kW h (USD 0.0906/kW h) to RM 0.3853/kW h (USD 0.104/kW h) [3]. The hike of electricity prices is part of the government's strategy to stabilize the country's economy by reducing fuel subsidies for the power sector. Moreover, the increment in electricity price is unavoidable because the prices of fossil fuels continue to increase. Furthermore, the continuous increment in the peak demand requires more new power plants as well as the grid reinforcement.

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The price-based programs such as time-of-use (TOU), real-time pricing (RTP), and demand response (DR) are introduced to reduce the peak demand by shifting some of the peak demand to off-peak periods [4,5]. Relatively high scarcity prices during certain periods of time would provide the customers a motivation for voluntary demand curtailment. From the customer perspective, the price-based programs can provide a means of controlling their electricity bills because they will be rewarded with relatively low price during off peak periods [6]. The utilities will be benefited because they can avoid any significant thermal stress on their networks during peak hours. However, the lack of the smart metering and communication infrastructure are the main barriers to the implementation of the price-based programs in Malaysia [7]. The DR program requires time-sensitive and automated equipment that could increase the electricity cost to the customers. Moreover, most of the customers may not be willing enough to switch off their air conditioners in Malaysia during peak hours because such action can reduce their productivity, hence reducing their profits.

Photovoltaic systems can offer an alternative solution to the reduction of the peak demand because it can supply power to the customers during peak hours [8,9]. However, the output of the photovoltaic systems is highly intermittent due to its cloudy weather conditions in Malaysia. Hence, additional spinning reserves may be required from the utility to regulate network frequency, hence increasing the operating cost for the utility.

In the recent years, energy storage has emerged as a promising technology in cutting down the peak demand. Large-scale energy storage such as thermal storage, pumped hydro storage, fuel cell storage, compressed air storage, batteries, flywheel, ultra capacitor, and super conducting magnetic energy offer the similar functionality of the peaking power plants. Nevertheless, each of these technologies still has financial and technical barriers to be resolved [10–15]. Many large-scale battery storage systems have been installed for the purposes of peak shaving and load shifting worldwide. Table 1 shows the worldwide large-scale battery storage systems for peak shaving and load shifting applications.

Distributed small-scale energy storage is a good option for the customers to reduce their peak demand. The benefits of distributed small-scaled energy storage are high portability, short setup time, simple installation and commission, low capital cost investment, minimal space occupation and low maintenance and operating cost [19,20]. In addition, the distributed energy storage located downstream from transmission lines can reduce the loading on the transmission system during peak periods, hence deferring the upgrade of the transmission and distribution (T&D) and extending the T&D equipment life [21].

The authors of [22] carried out an economic assessment to understand whether the energy storage system is financially viable or not to provide primary reserves and peak shaving in small isolated power systems with the renewable energy sources. However, the study was carried out with the assumption that the efficiencies of the gas-fired power plants are constant under the variation of loads. It is known that the efficiencies of the power plants are varied with the loads due to the changes in the heat rates of the plants. Therefore, the assessment may not be complete without considering the changes in the heat rates. Also, the authors of [23] proposed an approach to evaluate the possible contribution of the grid-connected energy storage to the operation cost, generation investment, transmission investment, interconnection investment, and distribution investment. The findings showed that the energy storage system can bring benefits to the whole power systems. However, the authors did not specify the types of the battery technologies being used in the studies. As a result, the studies may need to be improved by using the updated parameters of the specific types of the battery technologies. Other research works such as [24] and [25] showed the feasibility of using the energy storage system for reducing the peak demand by using a dynamic programming method and a demand tracking management model. However, these studies did not consider the savings in the fuel cost in order to justify the financial viability of the energy storage system.

The authors of [26] developed a sizing algorithm for the storage devices used in the residential buildings based on the storage capacity, power capability, and a grid demand limit. The authors of [27] proposed another sizing strategy for the energy storage in the residential power distribution feeders with the PV systems to reduce peak demand. The appropriate size of the energy storage system is important because it enables the customers to achieve the successful reduction in the peak demands. However, the two authors didn't consider the investment cost of the energy storage system in their sizing methods. Therefore, the size of the energy storage system determined by using the two methods may not be able to achieve the maximum financial savings for the customers.

This study is very important to the developing countries like Malaysia because the findings can be disseminated to regulatory bodies, utility companies and customers in order to reduce the electricity prices for the effective growth of economics in the country. This paper presents the research work with the aim at identifying the financial benefits of the energy storage system for utility companies and customers in Malaysia. The savings in the cost of electricity indicate the worth of the energy storage system for the utility companies. The changes in the heat rates or efficiencies of the power plants with respect to the load profiles are considered in the studies. Hence, the savings in the fuel cost or cost of electricity due to the energy storage systems can be accurately determined. In addition, the studies include various design options with the appropriate parameters such as the prices of the energy storage, battery cycle life, and fuel costs with and without subsidy from the government in order to determine which battery technologies and design options allow the utility companies to achieve the maximum financial gains. Apart from that, the energy storage is sized such that it can achieve a balance between the electricity bill savings and the investment cost on the energy storage, hence allowing the customers to achieve the maximum financial gains.

Table 1
Worldwide large-scale battery storage systems for peak shaving and load shifting applications.

Project	Operational dates	Location	Battery type	System size	
				MW	MW h
Crescent electric membership cooperative BESS [a]	1987–2002	Carolina, USA	Flooded cell, lead acid	0.5	0.5
Sumitomo Densetsu office battery system [a]	2000 to present	Japan	Vanadium redox flow	3	0.8
New York bus terminal energy storage systems [a]	2008 to present	New York, USA	Sodium–sulphur	1.2	6.5
ZBB energy corporation battery storage systems [b]	2005 to present	California, USA	Zinc–bromine	2	2
Zurich battery energy storage system [c]	2012 to present	Dietikon, Switzerland	Li-ion	1	0.5

[a] Data collected from [16].
[b] Data collected from [17].
[c] Data collected from [18].