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Methodology for assessing viability of energy storage system for buildings

Siong Lee Koh [a, *], Yun Seng Lim [b]

[a] Department of Engineering and Physical Sciences, Heriot Watt University, Malaysia
[b] Department of Physical Science, Electrical and Electronic Engineering, Universiti Tunku Abdul Rahman, Malaysia

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ABSTRACT

The viability of energy storage systems is evaluated from technical, cost and emission reduction perspective in this paper. With the rising penetration rate of renewable energy sources, ESS (energy storage systems) are widely researched on the ability to overcome the mismatch of generation and load profiles. This research develops a methodology to assess the financial benefits of ESS connected to conventional power systems in reducing the load variability. These include reduced network losses, increased plant factor, reduced system costs, deferment of network upgrade, improved power system stability and improved power quality. These factors are weighted against the additional cost of ESS. The methodology is applied in a case study based on the electrical load collected from a building, with a peak load of 736 kW and load factor of 0.371. From the results, ESS is found to be effective to reduce the overall cost of the system. A large portion of the saving is obtained by the power operator when ESS is installed by the customer. In order to incentivize the building owner to install ESS, these savings need to be shared with the building owner.

1. Introduction

In early 1900s, Svante Arrhenius had already found that the earth surface temperature could increase by 5–6 °C if the CO_2 concentration doubled [1]. More than one hundred years later, the world is still grappling with mitigating climate change caused by excessive GHG (greenhouse gas) emission from human activities. In the latest IPCC (Intergovernmental Panel on Climate Change) report, the climate change science has confirmed again with 95% certainty that global warming over the last century is mainly caused by the human activities. The global average temperature has increased by 0.85 °C in the period from 1880 to 2012. Despite the recent focused effort of the world on low carbon technologies and processes, the anthropogenic climate change is a reality now and the adverse effects are set to intensify in the coming years. It is projected in the report that, with the best measures in place, human activities will emit 990 $GtCO_2$ into the atmosphere from 2012 to 2100. This will result in a further temperature rises of 2 °C [2]. Hence, every single known option for the emission reduction must be explored and exploited. In addition, more advanced technologies need to be developed. These mitigation efforts must be undertaken by both the developed and developing countries.

As a developing country, Malaysia has committed to the reduction of the national carbon emission intensity by 40%, benchmarked against the 2005 level. The government has implemented various initiatives towards this objective. In 2010, Malaysian Green Technology Corporation (GreenTech) was tasked by the government to spearhead the country's National Green Technology Policy. It carries the mandate to catalyst the deployment of green technologies with the objective of minimising the impact of the human activities on the natural environment and resources. Flagship programmes to reduce the GHG emission have been introduced across all sectors, including electric transportation, green building, green government procurement and sustainable living [3].

In the energy sector, the emphasis is placed on RE (renewable energy). In the National Renewable Energy & Action Plan, the government has set a target to increase the share of RE capacity from 1% in 2011 to 10% in 2020 [4]. The identified indigenous RE sources include biomass, biogas, mini-hydro, solar PV and solid waste. Feed-in Tariffs (FiT) were implemented as the key instrument in achieving the target. Subsequently, the Sustainable Energy Development Authority of Malaysia was established in 2011 to implement FiT.

* Corresponding author. Tel.: +60 163126759.
E-mail address: siongleek@gmail.com (S.L. Koh).

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This anticipated high penetration rate of RE will have adverse effect on the stability of electrical power systems. As renewable energy sources are intermittent and non-dispatchable, load matching cannot be carried out. Hence, ESS (energy storage systems) is required so that excess energy can be stored and used later during peak demand periods [5–7]. Grid scale ESS is expensive. If the cost is borne by the grid operator, it will be passed down to the consumers through the increase in electricity tariffs. Under the existing commercial framework of electricity in Malaysia, there is no mechanism to enable the grid operator to impose this additional charge. There is no incentive for the grid operator to install ESS. Without ESS, the high target for RE penetration may not be achieved.

Instead of grid-scale ESS, small-scale ESS can also be installed at the loads by either consumers or the grid operator. With ESS, the power quality can be improved and load variability can be reduced. Reduced power quality problems and load variability brings the benefits of reduced network losses, increased plant factor, reduced network costs, deferment of network upgrade and improved network stability [8,9]. In this paper, these benefits are assessed against the additional costs of ESS. In section 2, current ESS technologies together with recent research on them and their applications are reviewed. A methodology to assess the financial benefits of ESS is described in section 3. The methodology is then applied in a case study described in section 4. The results from the analysis are presented and discussed in section 5. Further analyses are carried out with the discussion presented in section 6. In section 7, the conclusions are discussed.

2. Energy storage and load variability

In an electrical power system, the total power generated must always equal to the total power consumed. With the current trend in increasing penetration rate of grid-connected RE, the balancing of demand and supply becomes more challenging. ESS provides a mechanism to decouple the rate of power consumption from the rate of generation. The generated electrical power can be stored in an intermediate form of energy in ESS for subsequent consumption at a later time according to the demand. This decoupling of generation from consumption enables extensive deployment of RE.

RE generation is typically intermittent and non-dispatchable. Solar PV systems, for example, are dependent on the availability of solar irradiance to generate power during the day when the sun is not shaded by cloud. The availability of power may not coincide with the demand profile. With this limitation, the power system has to incorporate other dispatchable power plants, such as traditional fossil fuel power plants, to fully meet the demand profile. Hence, the amount of renewable energy sources that can be connected to the grid and utilized fully is limited. The same limitation applies to an off-grid system. A PV system will be able to supply to the load only during the sunny day. At night, alternative power sources will be required to power the lights and other electrical consumptions. With ESS, these limitations can be overcome. Power from the RE sources can be converted and stored in ESS, which can be dispatched to meet the demand. Hence the utilization of RE sources can be maximized. As RE sources are low in carbon emission, the ability to increase RE utilization will result in reduced carbon emission.

High load variability is another factor which increases the carbon emission of the electrical power system. In order to meet the varying demand profile of a power system, the power plants are typical categorized into base load power plants, load following power plants and peak load power plants. The base load power plants are running at a constant capacity factor to cater for the base load throughout the day and they are typically most efficient with lowest carbon emission at this level. The load following power plants are required to vary the capacitor factor to meet the demand profile. They are mostly run below the optimal level with lower efficiency and high carbon emission. The peaking power plants are required to start up to supply to load above the load following power plants. The hot standing by and start–stops of these power plants consume fuel and emit CO_2, even though no electricity was generated. The requirement of spinning reserve required to meet the sudden increase in load further increases fuel consumption and CO_2 emission. With the increase in grid-connected RE generation, the residual load variability increases further, due to the intermittent nature of RE sources [6–8,10]. With ESS, the load profile could be flattened by storing energy during off-peak and discharging to meet the peak demand. With less load variability, the load following plants can be operated at a more constant and efficient capacity factor while the peaking plants can reduce the number of their start–stops. The power system will be more efficient with lower carbon emission factor.

Recent research has focused on the application of ESS coupled with renewable energy sources in both standalone systems [11–15] and grid-connected system [9,16,17]. It was found that ESS is effective in increasing the utilization of RE and reducing the load variability by load shifting. However, the application of ESS is wide ranging and not limited to complementing RE systems. The authors of [18] present a computer modelling approach to study various benefits of energy storage systems to the power systems with the effects of wind energy. However, some of the benefits are not expressed in financial terms. Therefore, it is difficult to justify the financial viability of using the ESS in power systems. In this research, a general methodology is developed to investigate the technical and environmental benefits of ESS to the general electrical power systems, without the effect of RE. All the benefits are translated into financial terms so that the benefits can be easily weighed against the additional cost of ESS. The methodology is essential to assess the viability of ESS application and to provide financial justification for such system to be implemented for any electrical power system.

3. Methodology

In this section, a generic methodology accessing the viability of ESS in buildings is presented. In this methodology, a comprehensive analysis is carried out to evaluate all the benefits derived from the installation of ESS. These benefits are analysed and measured in terms of financial gains. The total financial gains can then be compared to the cost of ESS implementation to evaluate the viability.

Fig. 1 shows how the electricity generated in a power plant is supplied to meet a building demand via the transmission network, the distribution network, and the building internal distribution system. With the installation of ESS and reduction in load variability, the peak power to be generated and distributed in the system will be reduced. Hence, the following benefits can be derived:

a) Building owner: With ESS and lower load variability, the building owner may save cost in the form of reduced connection charges, reduced monthly power charges and reduced capital cost for distribution system. Charging the ESS during off-peak hours reduce the energy cost further as the off-peak rate is 20% lower than the on-peak rate [19]. Other non-financial benefits include the improved power quality and reliability.
b) Grid operator: Less load variability results in more efficient operation of the power plants. The operator will enjoy savings in fuel costs and maintenance costs of the power plants. Better