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A review on peak load shaving strategies

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ABSTRACT

In this study, a significant literature review on peak load shaving strategies has been presented. The impact of three major strategies for peak load shaving, namely demand side management (DSM), integration of energy storage system (ESS), and integration of electric vehicle (EV) to the grid has been discussed in detail. Discussion on possible challenges and future research directions for each type of the strategy has also been included in this review. For the energy storage system, different technologies used for peak load shaving purpose, which include their methods of operation and control have been elaborated further. Finally, the sizing of the ESS storage system is discussed. For the demand side management system, various management methods and challenges associated with DSM implementation have been thoroughly explained. A detailed discussion on the electric vehicle strategy has also been included in the review, which considers the integration, control and operation techniques for implementing the peak load shaving.

1. Introduction

Electricity demand or load varies from time to time in a day. Meeting time-varying demand especially in peak period possesses a key challenge to electric utility [1]. The peak demand is increasing day by day as result of increasing end users (excluding some developed countries where peak shaving has been already deployed such as EU member states, North America, and other similar countries [2]). Continuous growth in peak load raises the possibility of power failure and raises the marginal cost of supply. Therefore, supply (production of electricity) and demand (consumption of electricity) balancing or meeting peak load has become a major concern of utilities [3–5]. To mitigate the peak power demand, small capacity of power plants such as gas power plants are usually used. Diesel generators are also exceedingly use to meet peak demand in isolated power systems [6]. However, this type of power plants possesses expensive operation and maintenance (O & M) cost [7,8]. Since peaking or standby plants operate only during peak load hours, old and low-efficient plants are also used to cope the peak demand. The capital cost of these plants are low, but the O & M cost is high. In addition, the electricity of the peaking plants become more expensive than that of any base-load plants in order to recover the capital costs as well as O & M costs within their lifespans [9]. Thus, peak load shaving is becoming an important area of active research [10]. Peak load shaving is a process of making the load curve flattens by reducing the peak amount of load and shifting it to times of lower load [11]. There is a growing number of researches performed on peak shaving. In this study, three different strategies of peak load shaving have been reviewed thoroughly, which are:

1) Integration of Energy Storage System (ESS)
2) Integration of Electric Vehicle (EV) to grid
3) Demand Side Management(DSM)

A comprehensive literature review on peak the load shaving methods is presented in this study. Different approaches proposed by previous researchers have also been categorised in these three major strategies. The novelty of this review lies in the discussion of significant challenges and future research directions that are possible for the peak load shaving strategies. This study is structured as follows:

- Significant outcomes and benefits of the peak shaving for both utility and customer.
- Review on the demand side management technique for peak shaving and the challenges of implementing this strategy.
- Different energy storage technologies used for peak shaving are included in the review. Next, the operation, control and sizing of ESS are discussed further.
- The peak shaving methods using EV are also presented, by

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Table 1
Potential impacts and benefits of peak load shaving.

Market participant	Function	Impact or benefits
Power producers	Generating electricity from primary sources which is the first process of utility in delivering electricity to the consumer.	Less efficient and expensive peaking plants can be displaced [18–21].
T & D grid operators	Managing the real time security of power system and coordinating the electricity supply to individual consumers.	The need of expensive upgrades for T & D systems will be delayed as peak shaving allows the existing T & D systems to be used for a longer time [22–24].
Electricity traders	Buying electricity directly from producers or via energy suppliers and selling at competitive prices.	Electricity traders can take advantage of electricity price difference. They can store energy at off-peak period when price is low and sell out to customers when electricity demand and price are high.
Electricity consumers	The end user (residential, commercial, industrial, etc.) of electricity.	Monthly electricity bill can be reduced by shifting some of the load from peak hours to off peak hours when the price of electricity is relatively low [22,23,25,26].

reviewing on various integration, control, and operation techniques of EV.

2. Importance of peak load shaving

Peak load is a sensitive factor for the grids, as it occurs occasionally and takes place only for a small percentage of the time in a day. To supply the peak load, a conventional approach which involves capacity addition is commonly used. However, this approach is not economically feasible and inefficient in term of the generators usage, since the utilities need to maintain the generation capacity that will be used only for a few hours per day [12]. It also possesses several disadvantages, such as high fuel consumption and carbon dioxide (CO2) emission, increase in transportation and maintenance costs and faster deterioration of equipment [13–15]. Thus, peak load shaving is a preferable approach to overcome these disadvantages, associated with the capacity addition approach. As many countries (e.g. European Union member states) have already introduced completely unbundling of the power market, hence, it is important to distinguish the impacts and the benefits of peak shaving for market participants (shown in Table 1) - power producers, transmission and distribution (T & D) grid operators, electricity traders and electricity consumers [16,17].

However, the benefits of peak shaving can be grouped into three categories (in general).

- Benefits for the Grid Operator
- Benefits for End-User
- Carbon Emission Reduction

2.1. Benefits for the grid operator

The following subsections elaborate several factors that can be significantly improved by utilising the peak load shaving in the system.

2.1.1. Power quality

One of the significant ongoing challenges experienced by the utilities is to maintain a balance between electricity generation and demand [10]. If the generation system fails to match the electricity demand perfectly, several problems such as instability, voltage fluctuation, and total blackout will possibly occur, thus impacting the grid system [27,28]. Those problems can take the form of stress on generation machinery and low power quality. Previous researches had proposed different peak load shaving techniques to mitigate the generation-demand imbalance. These techniques particularly focus on creating an efficient demand profile, which will result in improved power quality [29].

2.1.2. Efficient energy utilisation

Load factor is a useful technique to measure the variability of consumption in a plant. It determines how efficiently electricity is being used. A low load factor means that load is highly variable. Load factor (*LF*) is defined as [1,30,31]:

$$LF\,(\%) = \frac{P_{AVG}}{P_{Peak}} \tag{1}$$

where, LF is load factor, P_{AVG} is average real power demand, and P_{Peak} is peak real power demand.

High load factor is essential for the economic feasibility of plant. From the load factor equation, high load factor results in low energy cost. So, the load factor improvement is obligatory to reduce the energy cost and make the plant economically feasible. To improve the load factor, peak electrical load needs to be reduced.

2.1.3. System efficiency

To mitigate the peak load, supply current need to be increased significantly. However, increasing the supply current will reduce the system efficiency, as current is nonlinearly related to the power loss [32]. The power loss can be calculated as

$$P_{LOSS} = I^2 \times R \tag{2}$$

where, P_{LOSS} is power loss, I is current flowing through the transmission line, and R is ohmic resistance in the transmission line.

As the power loss is proportional to the square of the current, it is necessary to reduce the supply current by reducing peak demand to improve the system efficiency [33].

2.1.4. Cost reduction

Generally, the utility has no storage system. Therefore, generated electricity should not be more than electricity demand. Otherwise, the wasted electricity will increase the per unit electricity generation cost. For this reason, peak shaving is emergent to match supply and demand perfectly. This will result in the reduction of energy production cost. However, typically a power grid is designed in such a way that it can meet maximum projected demand with peak. Since peak occurs occasionally, it is economically not feasible to design a system much higher than the capacity needed. In addition, peak shaving will increase the system efficiency, therefore, grid operator can enjoy saving in fuel costs and maintenance costs. Moreover, peak shaving will ensure efficient use of transmission and distribution (T & D) system. This will result in deferment of system upgrading and extend the life span of T & D systems equipment [34]. Therefore grid operator will enjoy saving in capital cost expenditure. Peak shaving will also minimise losses in transmission and distribution system which will contribute further towards the cost saving. Therefore, to ensure maximum financial benefit for utility, peak shaving is essential. The economic benefits of peak shaving are elaborated in [35–37].

2.1.5. Renewable energy integration

With a greater respect for the environment, the use of renewable energy sources is growing to reduce CO_2 emission [38]. Hence, future electricity generation will progress with diminishing reliance on fossil fuels [39]. However, because of intermittent nature of most renewable energy sources, maintaining the stability and reliability of power network has become a challenge [40].

In order to analyze the penetration level and the effect of large-scale

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