# Peak Load Shaving in Microgrid

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Contributor: Moslem Uddin , Md Masud Rana , Mohamed Atef , Md. Rasel Sarkar , GM Shafiullah

Peak load is a particularly sensitive issue for microgrids as it happens occasionally for a small percentage of the time in a day. Peak load increases the risk of microgrid failure and also leads to power quality issues. To maintain grid stability and improve power quality, the microgrids must solve the peak loading problem.

peak shaving | microgrids | battery energy storage system | energy distribution technique

## 1. Introduction

Rural electrification is a critical issue around the world. It is widely acknowledged that distributing electrical power to rural areas has always been a significant challenge due to the nature of rural communities, which are separated and located far from power generation plants [1][2]. Long-distance cable/line construction and maintenance are inefficient in remote locations. As a result, rural communities with little or no connection to primary grids can only rely on microgrids or independent smaller power networks for power [3][4][5]. Traditionally, these microgrids used diesel generators and backup systems (peaking generator) because of the low initial cost and simplicity [6]. Similarly, industries that are far away from the power grid, such as oil platforms in the sea, have the same issue. These industries rely on the expensive gas turbine generators (both as primary generators and peaking generators) [7]. In recent years, the advancements in grid technologies have allowed microgrid technologies to reach a more mature state where wind and solar renewable energies are the commonly integrated sources in a microgrid [8][9][10]. Despite the advantage of renewable sources, these microgrids, if isolated from the main grid, can be easily affected by power fluctuations, which will subsequently lead to unbalances in the power demand and supply system [11][12][13]. This undesirable event is mainly caused by the intermittent nature of the sources of renewable energy as well as the dynamic load profile, particularly during peak load [14][15].

In the past, the peak load problem is often solved by capacity additions [16]. Commonly, a percentage of total installed capacity must be reserved for managing peak loads, where the rest of the capacity is dedicated to the base-load. However, the solution leads to inefficient use of generators, where it is economically not feasible for utilities to maintain generation capacity that will be used only for a very few hours in a day. It has also several disadvantages, such as it consumes more fuel, creates higher wear and tear on equipment [17][18], increases maintenance cost, and leads to higher carbon emission [19][20]. Thus, peak load shaving is a more desirable method to face the challenges of peak load demand. Potential peak shaving strategies identified in the literature are: implementation of demand-side management (DSM), incorporation of electric vehicle (EV), incorporation of energy storage system (ESS) and integration of hybrid photovoltaic (PV)/ESS. However, the integration of ESS is the most appealing prospective peak load shaving options [21]. This technique can be applied in microgrids, grid, industries and residential buildings to achieve "peak shaving". With this strategy, peak shaving (PS) can be performed by charging the ESS when demand is low (off-peak period) and discharging it when demand is high (peak time) [22]. The functions of storage-based peak shaving are illustrated in **Figure 1**. This operation of the ESS can provide economic benefits as it mitigates the need to use high-priced peak electricity generation. The real benefit of ESS-based peak shaving is that it allows a microgrid utility to cut peak demand while maintaining customer comfort [23]. To address the intermittent nature of renewable energy sources, appropriate energy storage solutions for the power grid must be developed. Electrochemical energy conversion and storage (EECS) systems are particularly promising in this area due to high turnover efficiencies, quick response times, ease of scalability, and lack of geographical limits [24].

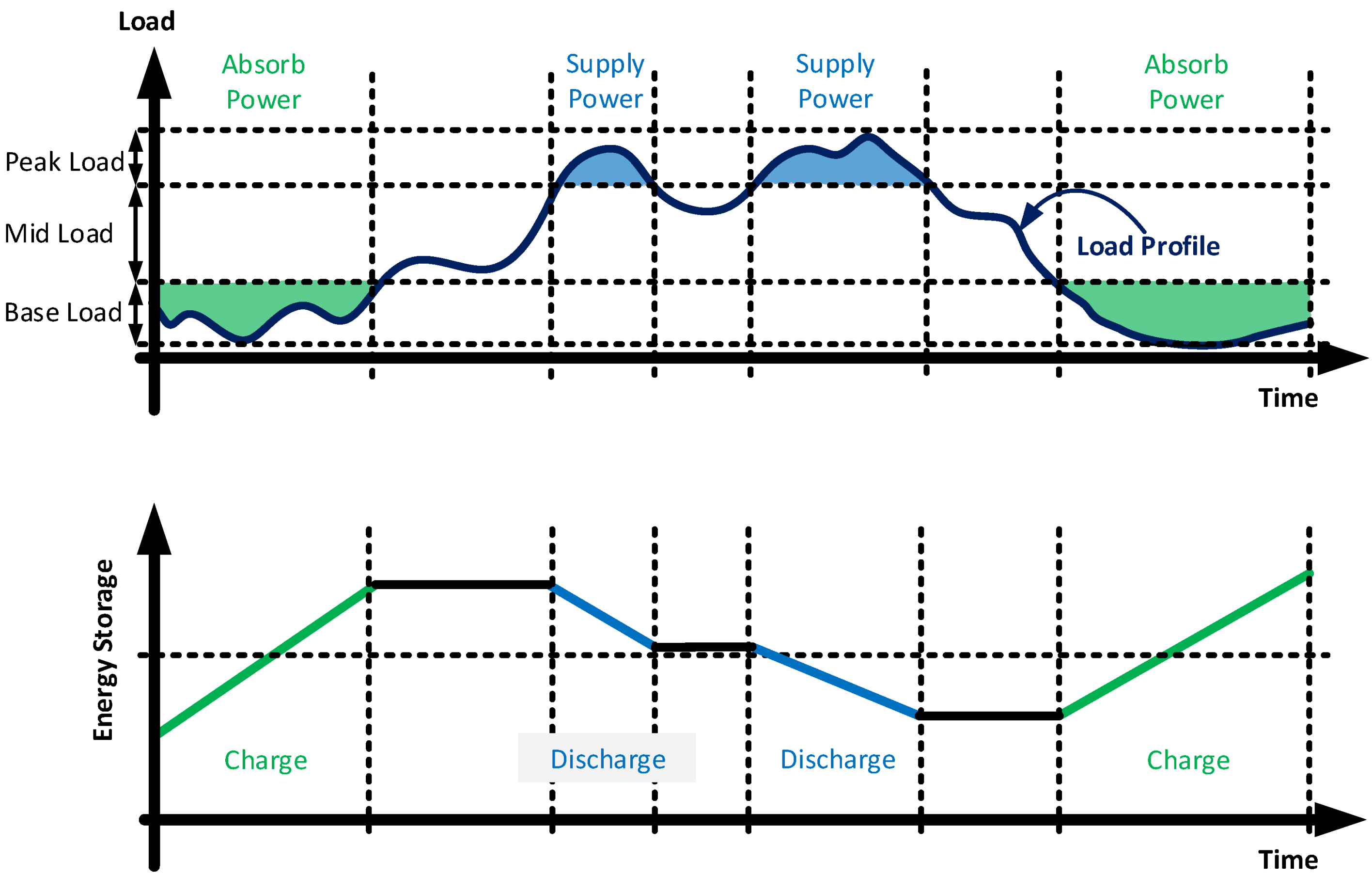


**Figure 1.** Illustrative example of storage based-peak shaving.

## 2. Peak Demand and Peak Shaving in Microgrid

In this section, the impact of peak load demand in a microgrid system is presented. In addition, the importance of minimizing the peak demand for economical and realistic operation is discussed.

Microgrids, particularly those in isolated operations, have a lot of volatility in demand across time, which causes peaks in load profile [25][26]. Peaks in electrical demand introduce many perplexities in microgrid operation. Generators in fuel-based islanded microgrids typically perform inefficiently due to peaks in demand, with some even experiencing low load operation. A microgrid utility faces a significant challenge in managing time-varying demand during peak periods [17][27][28][29][30][31][32]. If the generation system fails to perfectly match the electricity demand, several issues arise, including instability [33], voltage fluctuation [34], and reliability [33][35][36], all of which have an impact on the entire electrical system [37][38]. These issues can manifest themselves as wear and tear on generation equipment as well as poor power quality [17]. Meanwhile, to reduce peak load, the supply current must be greatly increased. On the other hand, increasing supply current will reduce system efficiency as current is nonlinearly related to power loss [39][40]. Furthermore, the microgrid system's components are all oversized to meet peak demand, although peak demand appears infrequently. As a result, when running at part load, some system components, such as transformers, are less efficient [41]. This has an impact on the system's total losses.

As microgrids are small, they do not usually include a peaking generator, such as a primary grid system, to deal with peak demand. As a result, microgrids are designed to accommodate both base and peak loads. However, generators mostly operate inefficiently (during periods of light loads) as peaks only last a few hours in a day. Increased power consumption at peak periods necessitates an increase in the supply of raw materials (gas, fuel, and so on) to the generators. Thus, stress on microgrids keeps increasing, which has an impact on efficiency. In some cases, microgrids set aside a percentage of their total capacity (at least 10%) to mitigate peak demands. This backup capacity is primarily supplied by small diesel and gas generators. This type of power plant, however, has high operation and maintenance (O&M) costs [42][43][44]. As these generators are only operated during peak load hours, outdated and inefficient plants are employed to meet peak demand. These plants have a cheap capital cost, but a high operating and maintenance cost. To recover capital expenses, as well as operating and maintenance costs, within their lifetimes, these plants' electricity becomes more expensive than that of any base-load facility [45].

Furthermore, they use more fuel, cause more wear and tear, and result in substantial carbon emissions [41]. As a result, peak load shaving is becoming a topic of interest in academia [32]. It enables microgrid utilities to drive down the cost of energy production while prolonging investment in generation and distribution assets [46].

## 3. Peak Shaving Using DSM

Demand-side management, in the context of electric utilities, refers to programs that may persuade customers to balance their electricity use with the generation capacity of the power supply system [47][48][49]. The DSM is divided into two sections: (i) demand response (DR) and (ii) energy efficiency. DR is mainly used to reduce peak height. It is described as deviations from normal consumption patterns by demand-side resources in reaction to variations in electricity prices over time or to incentive payments aimed to induce lower energy use at times of high wholesale market prices or when system dependability is compromised. The implementation of DR programs is more difficult. A novel peak shaving approach was proposed using DR in [50]. The results show that the grid-tied peak line's power is significantly reduced while achieving optimal energy management.

The following are some challenges encountered during deployment of the DR-based peak shaving strategy:

- The installation of demand response solutions may have an impact on customers' comfort levels.
- Customers may be unwilling to move their activity from peak to off-peak times. This is especially true in countries where the peak demand price has yet to be implemented.
- Implementing demand response strategies will enhance the complexity of the overall system operation.
- Advanced metering, control methods, communications systems, and information technologies are not fully available in the existing power systems. These information and communication technology (ICT) infrastructures need to be introduced which require multi–million dollar investment.

## 4. Peak Shaving Using ESS

The most promising peak-shaving option is to connect energy storage systems to the grid [51][52][53]. This method can be employed in residential structures, industries, and grids to accomplish "peak-shaving". Peak shaving is accomplished with this strategy by charging ESS when demand is low (off-peak period) and discharging when demand is high [8][30][54]. Electrochemical technology-based battery energy storage systems (BESSs) are most commonly used for peak load shaving, among other energy storage technologies [39][55][56][57]. Applications of various batteries for peak shaving are reported in literature, such as lithium battery [58], sodium sulfur (NaS) battery [59], and redox flow battery [60]. The benefit of BESS-based peak shaving in microgrids is well documented in [61]. It is found that overall revenue from the proposed system is 1.84 times that of the capital investment of the battery.

Despite the potential benefits of ESS for peak shaving, some important hurdles in ESS deployment must be overcome:

- A fundamental challenge for such a system's implementation is determining the ideal ESS size. The installing ESS at a random or non-optimal size can result in higher system losses and increased capital investment for storage.
- It is also difficult to schedule ESS for optimal performance.
- Storage–based peak shaving is more practical for grid application. However, it requires large-scale ESS installation which is a real concern. It is challenging to operate and maintain the large-scale ESSs in the grid.
- The high capital cost of ESS makes this peak shaving strategy impractical to employ.

## 5. Peak Shaving Using EVs

Electric vehicles (EVs) are not commonly used at the moment. However, given the growing worry over energy depletion, they are projected to become more popular globally in the future years [62]. Since electric vehicles' storage energy is rarely fully utilized each day, this technology has the potential to provide peak shaving services [63][64]. Padhi et al. has examined EV-based peak shaving in microgrids [65]. It was proposed an optimal recharging strategy for EVs using quadratic programming (QP) to flatten the peak demand. It was concluded that the end user can enjoy substantial savings using the proposed technique. Alam et al. [66] presented a viable technique for using plug-in electric vehicle (PEV) batteries for both travel and peak shaving. A dynamic discharge rate was introduced to make the best use of PEV batteries for peak shaving. Finally, the proposed technique was tested in Australia using real-world PEV data. Other research using EVs to provide peak shaving service can be found in [67][68][69][70].

The following are some of the potential obstacles to using EVs for peak shaving:

- Multiple EVs are required to provide peak shaving service as a single EV is unable to meet the peak demand. Thus, the discharge operation of a large number of EVs must be coordinated. However, owners' may not be willing to hand over the control of their vehicles to a third party. Therefore, willingness of car owners' is a real barrier for implementing this strategy.
- As EVs can only deliver electricity while parked, the key problem of this technique is the availability of EVs. Furthermore, electric vehicles are yet to be generally adopted.
- As electric vehicles have yet to be extensively adopted, parking spaces for them are plentiful. Furthermore, the require control system and necessary infrastructure for EV grid integration is not universally available. These could be the biggest obstacles to EV adoption in densely populated places.
- It is difficult to synchronize the charging and discharging of a large number of electric vehicles.

## 6. Peak Shaving Using Hybrid PV/ESS System

Photovoltaic (PV) units with BESSs can significantly lower system operating costs. BESSs can store electrical energy generated by solar panels and/or generators [71]. The primary requirement for a BESS in a PV-connected power system is charge–discharge operation. The BESS charge–discharge process has a direct impact on the price of electricity per unit. During off-peak periods, the BESS unit can absorb electrical energy and deliver the stored energy during peak periods. In general, the price of power per unit is lower during off-peak periods than during peak periods. The charge–discharge operation of BESS in a PV-connected microgrid system should be the first priority for economic operation in order to reduce total electricity consumption costs. Rana et al. [36] investigated PV/BESS-based peak shaving opportunities for the microgrid. The findings shed new light on peak shaving with a hybrid PV/BESS system. It was concluded that the proposed technique could mitigate the available power issues for hybrid PV-BESS connected systems and minimize the operating cost by optimally dispatching the generation units.

The possible challenges for implementing this technique are highlighted below:

- The output of PV is constrained by its fluctuating nature.
- Energy storages are used to improve the availability and quality of microgrid supply. However, they require an efficient control strategy to manage the charge/discharge cycles.
- Coordination of renewable sources, storage system, and load are not straightforward/trivial.

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