energies

MDPI

Review

A Review on Peak Load Shaving in Microgrid—Potential Benefits, Challenges, and Future Trend

Md Masud Rana [1], Mohamed Atef [1], Md Rasel Sarkar [2], Moslem Uddin [2] and GM Shafiullah [3,*]

1 Centre for Smart Grid Energy Research (CSMER), Department of Electrical and Electronic Engineering, University Teknologi PETRONAS, Seri Iskandar 32610, Malaysia; emdmasudrana@gmail.com (M.M.R.); Muhamed.Atef1408@gmail.com (M.A.)
2 School of Engineering & Information Technology, The University of New South Wales, Canberra, ACT 2610, Australia; raselbdeee@gmail.com (M.R.S.); moslem.uddin.bd@gmail.com (M.U.)
3 Discipline of Engineering and Energy, Murdoch University, Perth, WA 6150, Australia
* Correspondence: GM.Shafiullah@murdoch.edu.au

Abstract: This study aims to review the potential benefits of peak load shaving in a microgrid system. The relevance of peak shaving for a microgrid system is presented in this research review at the outset to justify the peak load shaving efficacy. The prospective benefits of peak shaving in microgrid systems, including technological, economic, and environmental advantages, are thoroughly examined. This review study also presents a cost–benefit numerical analysis to illustrate the economic viability of peak load shaving for a microgrid system. Different peak shaving approaches are briefly discussed, as well as the obstacles of putting them into practice. Finally, this review study reveals some potential future trends and possible directions for peak shaving research in microgrid systems. This review paper lays a strong foundation for identifying the potential benefits of peak shaving in microgrid systems and establishing suitable projects for practical effectuation.

Keywords: peak shaving; microgrids; battery energy storage system; energy distribution technique

check for updates

Citation: Rana, M.M.; Atef, M.; Sarkar, M.R.; Uddin, M.; Shafiullah, G. A Review on Peak Load Shaving in Microgrid—Potential Benefits, Challenges, and Future Trend. *Energies* **2022**, *15*, 2278. https://doi.org/10.3390/en15062278

Academic Editor: Luis Hernández-Callejo

Received: 31 January 2022
Accepted: 18 March 2022
Published: 21 March 2022

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 [3–5]. 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 [8–10]. 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 [11–13]. 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]. Peak load is a particularly sensitive issue for microgrids as it happens occasionally for a small percentage of the time in a day [16]. 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.

In the past, the peak load problem is often solved by capacity additions [17]. 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 [18,19], increases maintenance cost, and leads to higher carbon emission [20,21]. 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 [22]. 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) [23]. 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 [24]. 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 [25].

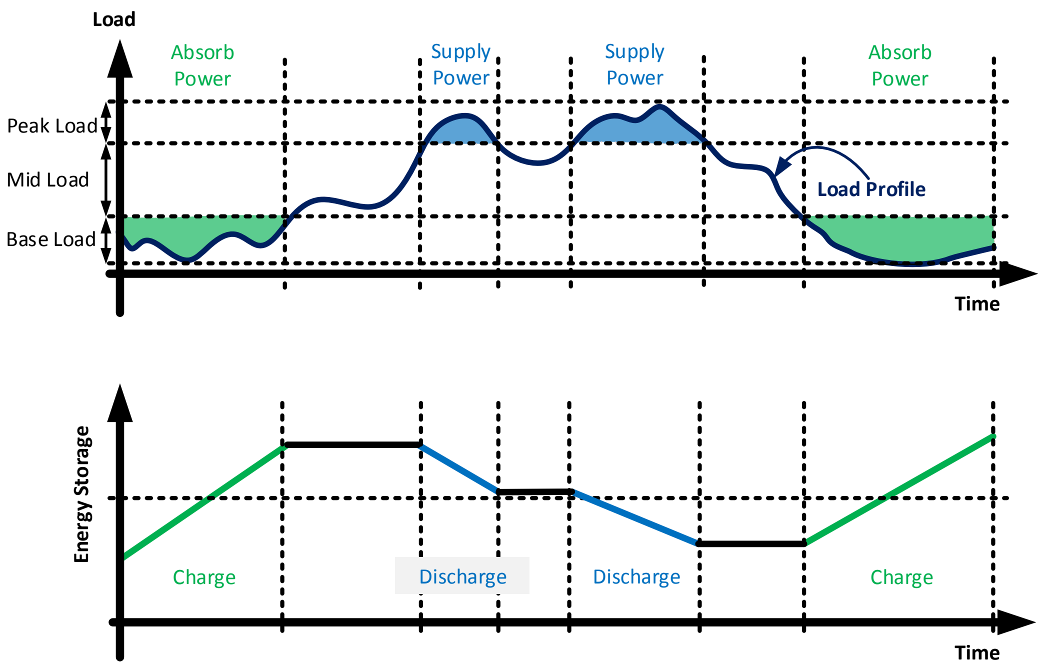

Figure 1. Illustrative example of storage based-peak shaving.

Peak shaving offers several benefits to the customer, as well as microgrids utilities, including technical, economic, and environmental benefits. However, the information on the benefits of microgrid peak shaving is scattered in the current literature. Thus, it might be challenging for practitioners and policymakers to pinpoint the important aspects that will lead to global developments in microgrid projects. Therefore, this study has been undertaken to review the potential benefits of peak load shaving in microgrids for mobilizing this sector globally for a sustainable future. To the authors' best knowledge, a review of potential benefits of peak shaving in microgrid contexts is still unreported in any other studies and hence it implies the main contribution of this study.

- Impact of peak load demand in microgrid are discussed. Then, peak load shaving in microgrids are demonstrated (Section 2).
- Potential benefits of microgrid peak shaving are reviewed and discussed in detail (Section 3).
- In order to examine the economic viability of peak load shaving in microgrids, a simple mathematical model is developed (Section 4)
- Several challenges of microgrid peak shaving are identified after performing an in-depth analysis of the state-of-the-art peak shaving strategies (Section 5).
- Future work and possible research areas worth exploring for microgrid peak shaving are directed (Section 6).

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 [26,27]. 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 [18,28–33]. If the generation system fails to perfectly match the electricity demand, several issues arise, including instability [34], voltage fluctuation [35], and reliability [34,36,37], all of which have an impact on the entire electrical system [38,39]. These issues can manifest themselves as wear and tear on generation equipment as well as poor power quality [18]. 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 [40,41]. 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 [42]. 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 [43–45]. 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 [46].

Furthermore, they use more fuel, cause more wear and tear, and result in substantial carbon emissions [42]. As a result, peak load shaving is becoming a topic of interest in academia [33]. It enables microgrid utilities to drive down the cost of energy production while prolonging investment in generation and distribution assets [47].

3. Potential Benefits of Peak Load Shaving

This section reviews the potential benefits of peak shaving in microgrids. Peak shaving benefits may be divided into three broad categories (in general): (i) Technical benefits, (ii) Economic benefits, and (iii) Environmental benefits.

3.1. Technical Benefits

The subsections cover a few things that may be greatly improved by implementing peak load shaving in the system.

3.1.1. Improved Power Quality

Various peak load shaving approaches have been presented in previous studies to address the generation–demand mismatch. These methods are aimed at establishing a more efficient demand profile, which will result in better power quality [48].

3.1.2. Efficient Energy Utilization

The load factor is a simple metric that shows how much of the installed plant capacity is being used. It determines the efficiency with which power is used. The load factor (LF) is defined as follows: [49–52]:

$$F_{load} = \frac{P_{avergae}}{P_{peak}} \tag{1}$$

where $P_{average}$ represents the average power demand and P_{peak} represents the peak load for a specified time period. The value of load factor may be significantly improved by reducing peak load demand [53]. A high load factor enables a higher average load by maximising the use of the full plant capacity for the longest possible time [54].

3.1.3. Reduced Energy Loss

Peak load shaving reduces supply current, which reduces energy loss since current is nonlinearly related to power loss [40,41]. Furthermore, the reduced energy loss will aid in the reduction of system losses.

3.1.4. Renewable Energy Integration

With rising awareness of environmental concerns, the adoption of renewable energy sources (RESs) is increasing to reduce CO_2 emissions [55]. As a result, future power generation will become less reliant on fossil fuels [18,56]. However, as most RESs are intermittent in nature, maintaining the grid's stability and reliability has become a challenge [57].

The net load P_{net} is significant for analyzing the penetration level and effect of large-scale wind, solar, and other renewable sources. The properties of P_{net} differ substantially from those of traditional load P_{load}, which must be taken into account while planning microgrid operations. The conventional load (P_{load}) is subtracted from the non-dispatchable generation, $P_{g(non-dispatchable)}$, to obtain the net load (P_{net}) [41]. The dispatchable generator must supply this net amount of load. The net load may be estimated using the following formula:

$$P_{net} = P_{load} - P_{g(non\text{-}dispatchable)} \tag{2}$$

The net load patterns vary dramatically with large-scale integration of wind and solar electricity, as seen in Figure 2. Increases in non-dispatchable generation in the microgrid increase net load variability, which must be considered in the design and functioning of the electric plant [58]. When solar and wind energy are incorporated into the microgrid, net load demand is reduced throughout the day and the largest peak is shifted to the evening.

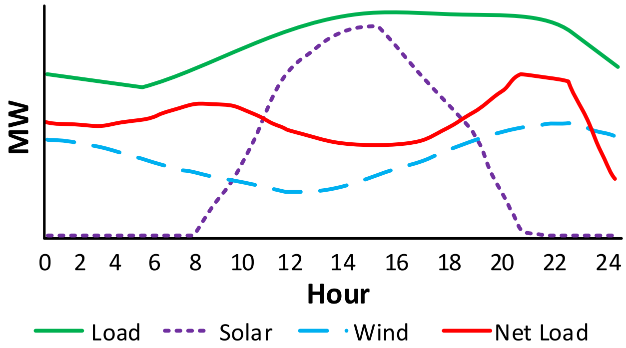

Figure 2. Illustrative example of net load profile with solar and wind supply.

3.1.5. Power Reliability of Microgrid

The high experience of peak load poses a threat to grid reliability [36]. As a result, introducing an ESS for peak demand shaving can also assist with power reliability [59].

3.1.6. Support for Reactive Power (VAR)

By injecting or absorbing reactive power, an ESS for peak shaving helps to keep the grid voltage stable [60–62].

3.1.7. Efficient Use of T&D Infrastructure

Peak shaving will also guarantee that the transmission and distribution (T&D) infrastructure is used efficiently. As a consequence, system upgrades will be postponed, and the equipment used in T&D systems will have a longer lifespan [63].

3.2. Economic Benefits

Peak electrical demand in microgrids influences the operation expenses by (i) requiring the utility to operate a high-cost and inefficient "peaking" generator to meet the demand [49], (ii) contributing to higher transmission charges, which are set based on peak demand, (iii) pushing base generators to be operated with part load for most of the operational time, and (iv) forcing the utility to offset supply shortages by purchasing electricity in the wholesale market at an inopportune time, i.e., when it is the most expensive. Thus, reducing peak demand and its impact on capital expenses is an important part of the ongoing smart grid research efforts [20]. The following sub-sections discuss the economic benefits of microgrid peak shaving in detail.

3.2.1. Replacing Expensive Generators

In order to satisfy the time-varying peak demand, less efficient (in terms of the economics and the environment) generators (also known as peaking generators) are occasionally used. As a result, the cost of electricity generation per kWh rises during peak hours [64,65]. Therefore, peak shaving is also important for end users. In some cases, microgrids set aside a portion of their entire capacity (at least 10%) to deal with peak demands. This backup capacity is often supplied by small diesel and gas generators [31,66]. This sort of power plant, on the other hand, has high operation and maintenance (O&M) expenses [43,45,53]. These plants' power becomes more expensive than that of any base-load plant to recover capital and O&M expenses during their lifetimes [46]. Furthermore, they require more fuel, experience more wear and tear, and emit more CO_2 [42,67]. As a result, peak load shaving is becoming a popular study topic [33,68,69]. It enables microgrid utilities to lower the cost of energy production while deferring investments in generating and distribution infrastructure [47,65].

3.2.2. Reduced Cost of Reserve Capacity

The microgrid system's components are sized to provide a reserve margin of around 20% over the maximum load. This reserve margin ensures that peak demand load can be fulfilled even if certain generators are out for maintenance [42]. However, the load is usually significantly lower than the peak load, and the surplus capacity is underused. As a result, the capital investment of this surplus capacity will not be recouped at an acceptable pace. Peak shaving can reduce capital investment by reducing reserve margin.

3.2.3. Reduced the Expense of Wear and Tear

The lifespan of equipment (e.g., generators, transformers, lines, distribution systems, and so on) is reduced as a result of microgrid operation during peak electrical demand. This raises the microgrid's wear and tear costs [42,67]. Peak shaving helps to reduce the expense of wear and tear.

3.2.4. Reduced Cost for Additional Fuel

Due to the multiple start–stops and greater losses, additional fuel is wasted when power plants are dispatched to meet the variable demand load. The cost of gasoline rises as a result of the increased use. Peak shaving reduces fuel costs by preventing excessive consumption from many starts and stops.

3.2.5. System Upgrade Deferral

Peak electricity usage in a microgrid shortens the life of lines and distribution systems. As a result, costly improvements to existing line cables and distribution systems are required in a short period; however, these costs can be deferred by offering peak shaving [70–72].

3.3. Environmental Benefits

Peak shaving has various environmental benefits, the most important of which is the capacity to replace inefficient and polluting generators [73]. The use of diesel generators to meet peak demand is usual. These generators emit carbon dioxide (CO_2), nitrogen oxide (NO_X), and particulate matter, all of which have a significant impact on air quality in the surrounding areas [74–76]. In addition, microgrids use more fuels to meet peak demand (due to the operational mode of peaking generators with numerous start-stops). Carbon emissions rise when more fuels are consumed. Peak load shaving will allow power plants to operate more efficiently and minimize load fluctuation. Carbon emissions will be reduced as a result [42,77]. In addition, storage-based peak shaving units help to penetrate more renewable energy sources. It will result in reduced carbon emission from per kWh energy production [78,79].

4. Cost–Benefits of Peak Shaving

This section presents a numerical analysis of the cost-effectiveness of the peak shaving application for microgrid systems to demonstrate economic feasibility. The cost–benefits of peak shaving for the perspective microgrid utility can be determined considering three indicators, namely annual cost savings, return on invested capital, and net profit.

4.1. Annual Cost Saving

Yearly cost savings from the peak shaving projects can be determined using Equation (3).

$$C_{s(t,y)} = C_{s(f,y)} + C_{s(ea,y)} + C_{s(su,y)} + C_{s(lr,y)} + C_{s(rce,y)} \quad (3)$$

where, $C_{s(f,y)}$ = annual saving from reduced fuel consumption.
$C_{s(ea,y)}$ = saving from the economic arbitrage.
$C_{s(su,y)}$ = saving from system upgrade.
$C_{s(lr,y)}$ = savings from reduced losses.
$C_{s(rce,y)}$= saving from reduced carbon emission.

(a) Cost Saving from Reduced Fuel Consumption

The annual cost savings from lower fuel use due to peak shaving can be calculated as follows:

$$C_{s(f,y)} = F_{s,y} \times F_p \tag{4}$$

where $F_{s,y}$ is the yearly fuel-saving and F_p is the price of the fuel per m^3 unit. Equation (5) can be used to calculate annual fuel savings:

$$C_{s(f,y)} = \kappa_{f,im} \frac{E_{p,y}}{C_{f,y}} \tag{5}$$

where $C_{s(f,y)}$ represents annual savings of consumption in m^3, $\kappa_{f,im}$ indicates the improvement of fuel efficiency, $E_{p,y}$ represent the annual production of energy, and $C_{f,y}$ represent annual consumption of fuel.

(b) Saving from Economic Arbitrage

Microgrid utility operators can use ESS-based peak shaving to take advantage of electricity price differences. They can store energy during off-peak hours when prices are lower and then sell it to customers when demand and prices are higher. The following formula can be used to compute the savings through economic arbitrage:

$$S_{c(ea),y} = \left(C_{e,op} - C_{e,p}\right) \times h_{p,d} \times 365 \tag{6}$$

where $C_{e,op}$ is cost of energy (kWh) during the off-peak hours, $C_{e,p}$ is cost of energy (kWh) during the peak hours, and $h_{p,d}$ is average peak hours (h) in a day.

Equation (7) can be used to compute net yearly savings/income through arbitrage:

$$S_{c(ea),y,net} = S_{c(ea),y} - \left(S_{ess,kW} \times C_{om,y}\right) \tag{7}$$

$S_{ess,kW}$ = actual size of the ESS in kW and $C_{om,y}$ = annual operational and maintenance cost of the ESS (USD/kW).

(c) Saving from System Upgrade

The ESS decreases the impact of peak demand on microgrid assets and allows them to be utilized for extended periods. As a result, the need for expensive upgrades to microgrid assets is postponed [70–72]. Based on the previous yearly marginal investment, the saved system upgrade cost values may be determined.

(d) Saving from Reduced Losses

Some loss is involved in energy flow from generation to consumption. Wire resistance and others equipments such as transfers are the main reasons for this loss. It is 2.5–5% of peak load for transmission lines and 5–8% for distribution systems [47]. Thus, peak shaving can reduce losses due to the square of current relationship with losses. Aside from the square current relationship, two other variables contribute to peak shaving loss reduction: (i) during the peak times, the resistance of T&D wires and transformers is high due to the high temperature and (ii) during peak periods, the cost of energy losses is often high. Therefore, peak shaving can save a substantial amount by reducing losses. Equation (8) may be used to calculate annual savings from reduced loss:

$$S_{c(lr),y} = E_{r,y} \times POE_{kWh} \tag{8}$$

where $E_{r,y}$ represents energy loss reduction in a year and POE_{kWh} represent price of energy per kWh [$].

(e) Saving from Reduced Carbon Emission

Many carbon emissions trading systems have recently been implemented across the world in order to mitigate climate change [80]. The price of carbon emissions varies depending on the program. The Swedish carbon tax is the highest, at USD 168/ton CO_2, while the Mexican carbon tax is the lowest at USD 1/ton CO_2. Emission trading system prices are clustered under USD 12/ton CO_2 [29]. Equation (9) may be used to describe the cost savings from reduced carbon emissions.

$$S_{c(rce),y} = R_{c,y} \times T_c \tag{9}$$

where $R_{c,y}$ indicates yearly reduction of CO_2 in tons and T_c is tax [USD/tons CO_2].

4.2. Return of the Capital

The following equation can be used to determine the capital investment recovery time.

$$P_{p(y)} = \frac{C_{i,net}}{S_{c(tot),y}} \tag{10}$$

where $C_{i,net}$ indicates the net capital investment. It can be calculated using following Equation:

$$C_{i,net} = C_{i,ess} + C_{i,conv} \tag{11}$$

where $C_{i,ess}$ = capital investment for ESS and $C_{i,conv}$ = capital investment for converter/inverter.

4.3. Net Profit

Net profit, also known as net income, is the key indicator of economic feasibility analysis for peak shaving projects. It can be obtained from the following equation:

$$P_{net} = (C_{s(tot),y} \times PL_{time}) - C_{i,net} \tag{12}$$

where PL_{time} is the project lifetime.

5. Peak Shaving Strategies and Challenges

This section aims to discuss the peak shaving methods briefly and outline the main issues and challenges encountered during their deployment. There is a growing number of techniques have been proposed for peak shaving. Proposed methods may be divided into several groups: (a) DSM, (b) integration of EVs, (c) integration of ESS, and (d) integration of hybrid PV/ESS system. The advantages and limitations of each method are summarized in Table 1.

Table 1. A summary of advantages and limitations of different peak shaving strategies.

Technique	Advantages	Limitations
DSM-based	(i) Allows a more efficient use of system assets [81]. (ii) Allows a more efficient use of resources [82]. (iii) Reduces the capacity requirements of the system. (iv) Enhances system reliability [83].	(i) Requires ICT infrastructure [84,85]. (ii) Increases system complexity [81]. (iii) Depends on customer. willingness [84–86]
ESS-based	(i) Facilitates a higher penetration of RESs [83]. (ii) Shaves peak demand without affecting customer comfort level [24]. (iii) Defers the investment on generation and distribution assets [47,65]. (iv) Provides reactive power support.	(i) Requires high capital cost [83]. (ii) Difficult to schedule ESS [87–90]. (iii) Difficult to integrate large-scale ESS [91].

Table 1. *Cont.*

Technique	Advantages	Limitations
EV-based	(i) Allows efficient use of EV batteries to their full potential [92]. (ii) EV owners can enjoy economic benefit from energy arbitrage [93].	(i) Requires large number of EVs [93]. (ii) Depends on the availability of EVs. [94] (iii) Synchronized charging is challenging for large number of EVs [36]. (iv) Necessary infrastructure and control system need to be ready for EVs.
PV/ESS-based	(i) Facilitates a higher penetration of PV [95,96]. (ii) Reduces fuel consumption. (iii) Reduces carbon emission. (iv) Small-scale ESS can participate in peak shaving service [97].	(i) ESS requires efficient control technique [37]. (ii) Coordination of ESS, load, and PV is challenging [37].

The details of challenges associated with each peak shaving technique are broadly discussed in the following sub-sections.

5.1. 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 [98–100]. 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 [101]. 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.

5.2. Peak Shaving Using ESS

The most promising peak-shaving option is to connect energy storage systems to the grid [102–104]. 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 [8,31,105]. Electrochemical technology-based battery energy storage systems (BESSs) are most commonly used for peak load shaving, among other energy storage technologies [40,106–108]. Applications of various batteries for peak shaving are reported in literature, such as lithium battery [109], sodium sulfur (NaS) battery [110], and redox flow battery [111]. The benefit of BESS-based peak shaving in microgrids is well documented in [112]. 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.

5.3. 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 [113]. Since electric vehicles' storage energy is rarely fully utilized each day, this technology has the potential to provide peak shaving services [114,115]. Padhi et al. has examined EV-based peak shaving in microgrids [116]. The author proposed an optimal recharging strategy for EVs using quadratic programming (QP) to flatten the peak demand. This study concluded that the end user can enjoy substantial savings using the proposed technique. Alam et al. [117] 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 [118–121].

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.

5.4. 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 [122]. 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. [37] investigated PV/BESS-based peak shaving opportunities for the microgrid. The findings of this study shed new light on peak shaving with a hybrid PV/BESS system. This study 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.

6. Future Trends in Microgrid Peak Shaving

Various approaches have been used to study microgrid peak shaving. Validating the reliability of these techniques will require a significant amount of effort. However, further research and investigation are imperative for implementing these peak shaving approaches. The following are some suggestions for future study in the subject of microgrid peak shaving on this review:

- *Scheduling of ESS*—Recently, there has been a growing interest in ESS–based peak shaving. Many attempts have been made to ensure optimal operation ESS. However, these approaches have significant flaws. Therefore, ESS is still require a robust and fully functional scheduling strategy for providing peak shaving service [87–90].
- *Sizing of ESS*—Economic benefit of storage–based peak shaving technique is directly impacted by the size of ESS. Also, size of ESS has major effect on peak shaving ability. Further research is required to determine optimum size of ESS for peak shaving application [112].
- *Economic feasibility*—The high capital cost of ESS makes this peak shaving strategy impractical to employ. To offset the high capital cost, an investigation is needed on the economic feasibility of the ESS. This can also be extended to developing high-efficiency, low-cost physical storage technologies.
- *Distributed ESS*—Application of ESS is more effective for grid peak shaving. However, installation of large-scale ESS is a practical issue. Also, operation and maintenance of large-scale ESSs in grid is challenging. Therefore, it will be interesting for reader to investigate the opportunity of distributed ESSs for providing peak shaving service in grid.
- *Validity*—Feasibility study for ESS-based peak shaving technique is crucial before implementing in real–world microgrid projects. To validate this technique, further studies need to be carried out for the perspective of small grids in rural locations with limited or no access to the primary grid.
- *Assessing EV-based PS*—As EVs can only deliver electricity while parked, the key problem of this technique is the availability of EVs [36,94]. Furthermore, electric vehicles are yet to be generally adopted [123,124]. Thus, EVs–based peak shaving will be more realistic for small isolated electric system such as an island or a remote area that is not connected to the main grid. Therefore, future study on EVs-based peak shaving can be conducted for the perspective of a remote isolated area to determine the maximum benefits of it.
- *Synchronize EVs*—It is difficult to synchronize the charge and discharge operations of multiple electric vehicles. Further research could also be conducted to develop an algorithm that will allow the charging and discharging of a large number of EVs to be synchronized [36,94,124].
- *Smart home energy management system*—For DSM-based peak shaving strategies, customers need to move their activities from peak to off-peak times. However, customers or end-users may not be willing to move their activities. This is especially true in countries where the peak demand price has yet to be implemented [84,85]. Future studies on this technique could concentrate on the use of DR in conjunction with a smart home energy management system (which includes improved metering infras-

tructure, sensing devices, enabling information and communication technology, and smart appliances, among other things) [82,125]. This reduces the need of customers' willingness to follow the DSM peak shaving technique. However, technical assistant education is required to maximize the efficiency of DR.

- *Application of DSM with ESS system*—The implementation of demand response solutions may have an impact on customers' comfort levels. In this particular, application of an ESS can help customers' to perform regular activities while reducing their peak demand [82,125]. Therefore, future research should focus exclusively on how to employ DSM in coupled with the ESS system for peak shaving.
- *Requirements of ICT infrastructures*—The implementation of DR programme requires information and communication technology (ICT) infrastructures such as communications systems, advanced metering and control methods. However, these infrastructures are not fully available in today's power systems [83]. Therefore, require ICT infrastructures need to be ready before implementing DR.
- *Energy mix*—Utilize of hybrid energy (PV, wind, hydropower, etc.) is another possible method to perform peak shaving. However, this technique has not much been deliberated in the existing literature. Therefore, readers should think about that possibility as well [96].

7. Conclusions

This paper reveal the technical, economic, and environmental benefits of peak load shaving for a limited capacity power system such as a microgrid system. Power system efficiency, reliability, reduction of operational risks, environmental sustainability, economic feasibility, etc., are directly and indirectly correlated to the peak demand reduction, which is the main theme of this article. This review article presents the key features as follows:

- This review article discusses the consequences of peak load shaving application, the recent popular topic for a microgrid system based on the latest literature.
- The significance of peak load in a microgrid system and the importance of minimizing the peak demand for economical and realistic operation are discussed.
- The advantages and positive influences of peak demand shaving for microgrid systems are presented after an extensive analysis.
- A numerical analysis of the cost-effectiveness of the peak shaving application for microgrid systems is discussed broadly to demonstrate the economic feasibility.
- Possible constraints of peak shaving applications for microgrid systems are identified after an in-depth investigation of the existing literature.
- The existing trends and prospective approaches for exploring other branches of microgrid applications with peak load shaving are well demonstrated.
- This review article has established a strong benchmark for future research into peak load shaving application in microgrid systems.

In this work, however, a comparative analysis of cost–benefit for different peak shaving strategies is not examined. Hence, there is insufficient information to verify the better economic performance of the techniques. It is reasonable to expect different results for the different techniques. Therefore, it will be interesting to conduct a comparative cost–benefit analysis for different PS strategies as the future extension of this study.

Author Contributions: Conceptualization, M.M.R. and M.R.S.; methodology, M.R.S.; formal analysis, M.M.R., M.A. and G.S.; writing—original draft preparation, M.M.R., M.R.S., M.A. and M.U.; writing—review and editing, M.U. and G.S.; supervision, G.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

O&M	Operation and maintenance
LF	Load factor
ESS	Energy storage system
T&D	Transmission and distribution
DSM	Demand-side management
EV	Electric vehicle
EVs	Electric vehicles
PV	Photovoltaic
RESs	Renewable Energy Sources
DR	Demand response
ICT	Information and communication technology
QP	Quadratic programming
PEV	Plug-in electric vehicle
BESS	Battery energy storage system
PS	Peak shaving
EECS	Electrochemical energy conversion and storage

References

1. Domenech, B.; Ferrer-Martí, L.; Pastor, R. Comparison of various approaches to design wind-PV rural electrification projects in remote areas of developing countries. *Wiley Interdiscip. Rev. Energy Environ.* **2019**, *8*, e332. [CrossRef]
2. Kyriakarakos, G.; Papadakis, G. Multispecies swarm electrification for rural areas of the developing world. *Appl. Sci.* **2019**, *9*, 3992. [CrossRef]
3. Topa Gavilema, Á.O.; Álvarez, J.D.; Torres Moreno, J.L.; García, M.P. Towards Optimal Management in Microgrids: An Overview. *Energies* **2021**, *14*, 5202. [CrossRef]
4. Kreishan, M.Z.; Zobaa, A.F. Optimal Allocation and Operation of Droop-Controlled Islanded Microgrids: A Review. *Energies* **2021**, *14*, 4653. [CrossRef]
5. Son, I.W.; Jeong, Y.; Son, S.; Park, J.H.; Lee, J.I. Techno-economic evaluation of solar-nuclear hybrid system for isolated grid. *Appl. Energy* **2022**, *306*, 118046. [CrossRef]
6. Sechilariu, M.; Locment, F. *Urban DC Microgrid: Intelligent Control and Power Flow Optimization*; Butterworth-Heinemann: Oxford, UK, 2016.
7. Poullikkas, A. An overview of current and future sustainable gas turbine technologies. *Renew. Sustain. Energy Rev.* **2005**, *9*, 409–443. [CrossRef]
8. Faisal, M.; Hannan, M.A.; Ker, P.J.; Hussain, A.; Mansor, M.B.; Blaabjerg, F. Review of energy storage system technologies in microgrid applications: Issues and challenges. *IEEE Access* **2018**, *6*, 35143–35164. [CrossRef]
9. Hirsch, A.; Parag, Y.; Guerrero, J. Microgrids: A review of technologies, key drivers, and outstanding issues. *Renew. Sustain. Energy Rev.* **2018**, *90*, 402–411. [CrossRef]
10. Kuang, Y.; Zhang, Y.; Zhou, B.; Li, C.; Cao, Y.; Li, L.; Zeng, L. A review of renewable energy utilization in islands. *Renew. Sustain. Energy Rev.* **2016**, *59*, 504–513. [CrossRef]
11. Córdova, S.; Cañizares, C.; Lorca, Á.; Olivares, D.E. An Energy Management System with Short-Term Fluctuation Reserves and Battery Degradation for Isolated Microgrids. *IEEE Trans. Smart Grid* **2021**, *12*, 4668–4680. [CrossRef]
12. Moon, H.J.; Kim, Y.J.; Chang, J.W.; Moon, S.I. Decentralised active power control strategy for real-time power balance in an isolated microgrid with an energy storage system and diesel generators. *Energies* **2019**, *12*, 511. [CrossRef]
13. Lee, H.J.; Vu, B.H.; Zafar, R.; Hwang, S.W.; Chung, I.Y. Design Framework of a Stand-Alone Microgrid Considering Power System Performance and Economic Efficiency. *Energies* **2021**, *14*, 457. [CrossRef]
14. Polleux, L.; Guerassimoff, G.; Marmorat, J.P.; Sandoval-Moreno, J.; Schuhler, T. An overview of the challenges of solar power integration in isolated industrial microgrids with reliability constraints. *Renew. Sustain. Energy Rev.* **2022**, *155*, 111955. [CrossRef]
15. Kanakadhurga, D.; Prabaharan, N. Demand side management in microgrid: A critical review of key issues and recent trends. *Renew. Sustain. Energy Rev.* **2022**, *156*, 111915. [CrossRef]
16. Nazari, M.H.; Sanjareh, M.B.; Hosseinian, S.H. A new method for energy management of residential microgrid for sizing electrical and thermal storage systems. *Sustain. Cities Soc.* **2021**, *76*, 103482. [CrossRef]
17. Rana, M.M.; Rahman, A.; Uddin, M.; Sarkar, M.R.; Shezan, S.A.; Ishraque, M.; Rafin, S.; Atef, M. A Comparative Analysis of Peak Load Shaving Strategies for Isolated Microgrid Using Actual Data. *Energies* **2022**, *15*, 330. [CrossRef]

18. Uddin, M.; Romlie, M.F.; Abdullah, M.F.; Halim, S.A.; Kwang, T.C. A review on peak load shaving strategies. *Renew. Sustain. Energy Rev.* **2017**, *82*, 3323–3332. [CrossRef]
19. ABB. *Microgrids: Integration for Power Cost and Control*; ABB Data Centers: Cary, NC, USA, 2015. Available online: www.abb.com/datacenters (accessed on 15 January 2021).
20. Mishra, A.; Irwin, D.; Shenoy, P.; Zhu, T. Scaling distributed energy storage for grid peak reduction. In Proceedings of the Fourth International Conference on Future Energy Systems, Berkeley, CA, USA, 21–24 May 2013; pp. 3–14.
21. International Electrotechnical Commission (IEC). *Electrical Energy Storage: White Paper*; IEC: Geneva, Switzerland, 2011.
22. Neves, S.A.; Marques, A.C.; Fuinhas, J.A. On the drivers of peak electricity demand: What is the role played by battery electric cars? *Energy* **2018**, *159*, 905–915. [CrossRef]
23. Farsadi, M.; Sattarpur, T.; Yazdaninejadi, A. Simultaneously Optimal Placement and Operation Scheduling of BESSs and DGs in Distribution Networks in order to minimizing net present value related to power losses. *IU-J. Electr. Electron. Eng.* **2016**, *16*, 2081–2089.
24. Arcos-Vargas, A.; Lugo, D.; Núñez, F. Residential peak electricity management. A storage and control systems application taking advantages of smart meters. *Int. J. Electr. Power Energy Syst.* **2018**, *102*, 110–121. [CrossRef]
25. Sun, C.; Negro, E.; Vezzù, K.; Pagot, G.; Cavinato, G.; Nale, A.; Bang, Y.H.; Di Noto, V. Hybrid inorganic-organic proton-conducting membranes based on SPEEK doped with WO3 nanoparticles for application in vanadium redox flow batteries. *Electrochim. Acta* **2019**, *309*, 311–325. [CrossRef]
26. Gao, D.W. *Energy Storage for Sustainable Microgrid*; Academic Press: New York, NY, USA, 2015.
27. Oriti, G.; Julian, A.L.; Anglani, N.; Hernandez, G.D. Novel economic analysis to design the energy storage control system of a remote islanded microgrid. *IEEE Trans. Ind. Appl.* **2018**, *54*, 6332–6342. [CrossRef]
28. Aderibole, A.; Zeineldin, H.; Al Hosani, M. A Critical Assessment of Oscillatory Modes in Multi-Microgrids Comprising of Synchronous and Inverter Based Distributed Generation. *IEEE Trans. Smart Grid* **2018**, *10*, 3320–3330. [CrossRef]
29. Chua, K.H.; Lim, Y.S.; Morris, S. Cost-benefit assessment of energy storage for utility and customers: A case study in Malaysia. *Energy Convers. Manag.* **2015**, *106*, 1071–1081. [CrossRef]
30. Allam, M.A.; Said, A.; Kazerani, M. A Generic Modeling and Power-Flow Analysis Approach for Isochronous and Droop-Controlled Microgrids. *IEEE Trans. Power Syst.* **2018**, *33*, 5657–5670. [CrossRef]
31. García-Plaza, M.; Carrasco, J.E.G.; Alonso-Martínez, J.; Asensio, A.P. Peak shaving algorithm with dynamic minimum voltage tracking for battery storage systems in microgrid applications. *J. Energy Storage* **2018**, *20*, 41–48. [CrossRef]
32. Dongol, D.; Feldmann, T.; Schmidt, M.; Bollin, E. A model predictive control based peak shaving application of battery for a household with photovoltaic system in a rural distribution grid. *Sustain. Energy Grids Netw.* **2018**, *16*, 1–13. [CrossRef]
33. Joshi, K.A.; Pindoriya, N.M. Day-ahead dispatch of battery energy storage system for peak load shaving and load leveling in low voltage unbalance distribution networks. In Proceedings of the 2015 IEEE Power & Energy Society General Meeting, Denver, CO, USA, 26–30 July 2015; pp. 1–5.
34. Telaretti, E.; Dusonchet, L. Battery storage systems for peak load shaving applications: Part 1: Operating strategy and modification of the power diagram. In Proceedings of the 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, Italy, 7–10 June 2016; pp. 1–6.
35. Uddin, M.; Romlie, M.F.; Abdullah, M.F. Performance Evaluation of Islanded Microgrid Using Load Flow Analysis Technique. In Proceedings of the 2018 International Conference on Intelligent and Advanced System (ICIAS) (ICIAS2018), Kuala Lumpur, Malaysia, 13–14 August 2018.
36. Masoum, A.S.; Deilami, S.; Moses, P.; Masoum, M.; Abu-Siada, A. Smart load management of plug-in electric vehicles in distribution and residential networks with charging stations for peak shaving and loss minimisation considering voltage regulation. *IET Gener. Transm. Distrib.* **2011**, *5*, 877–888. [CrossRef]
37. Rana, M.M.; Romlie, M.F.; Abdullah, M.F.; Uddin, M.; Sarkar, M.R. A Novel Peak Load Shaving Algorithm for Isolated Microgrid Using Hybrid PV-BESS System. *Energy* **2021**, *234*, 121157. [CrossRef]
38. Gajduk, A.; Todorovski, M.; Kocarev, L. Stability of power grids: An overview. *Eur. Phys. J. Spec. Top.* **2014**, *223*, 2387–2409. [CrossRef]
39. Bruch, M.; Mnch, V.; Aichinger, M.; Kuhn, M.; Weymann, M.; Schmid, G. *Power Blackout Risks: Risk Management Options Emerging Risk Initiative*; Position Paper; CRO Forum: Amsterdam, The Netherlands, 2011.
40. Kalkhambkar, V.; Kumar, R.; Bhakar, R. Energy loss minimization through peak shaving using energy storage. *Perspect. Sci.* **2016**, *8*, 162–165. [CrossRef]
41. HA, M.P.; Kumar, L.; Ananthapadmanabha, T. A novel approach for optimal allocation of a distributed generator in a radial distribution feeder for loss minimization and tail end node voltage improvement during peak load. *Int. Trans. Electr. Comput. Eng. Syst.* **2014**, *2*, 67–72.
42. Koh, S.L.; Lim, Y.S. Evaluating the economic benefits of peak load shifting for building owners and grid operator. In Proceedings of the 2015 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE), Offenburg, Germany, 20–23 October 2015; pp. 30–34.
43. Shirazi, E.; Jadid, S. Cost reduction and peak shaving through domestic load shifting and DERs. *Energy* **2017**, *124*, 146–159. [CrossRef]

44. Chua, K.H.; Lim, Y.S.; Morris, S. Battery energy storage system for peak shaving and voltage unbalance mitigation. *Int. J. Smart Grid Clean Energy* **2013**, *2*, 357–363. [CrossRef]
45. Zheng, M.; Meinrenken, C.J.; Lackner, K.S. Smart households: Dispatch strategies and economic analysis of distributed energy storage for residential peak shaving. *Appl. Energy* **2015**, *147*, 246–257. [CrossRef]
46. Van den Bergh, K.; Delarue, E. Cycling of conventional power plants: Technical limits and actual costs. *Energy Convers. Manag.* **2015**, *97*, 70–77. [CrossRef]
47. Nourai, A.; Kogan, V.; Schafer, C.M. Load leveling reduces T&D line losses. *IEEE Trans. Power Deliv.* **2008**, *23*, 2168–2173.
48. Thompson, C.C.; Oikonomou, P.K.; Etemadi, A.H.; Sorger, V.J. Optimization of data center battery storage investments for microgrid cost savings, emissions reduction, and reliability enhancement. *IEEE Trans. Ind. Appl.* **2016**, *52*, 2053–2060. [CrossRef]
49. Mehta, V.; Rohit, M. Principles of power system: Including generation, transmission, distribution, switchgear and protection: For BE/B. tech. In *AMIE and Other Engineering Examinations*; S. Chand Publishing: New Delhi, India, 2005.
50. Gotham, D.; Muthuraman, K.; Preckel, P.; Rardin, R.; Ruangpattana, S. A load factor based mean–variance analysis for fuel diversification. *Energy Econ.* **2009**, *31*, 249–256. [CrossRef]
51. Nag, P. *Power Plant Engineering*; Tata McGraw-Hill Education: New Delhi, India, 2002.
52. Kothari, D.P.; Nagrath, I.J. *Modern Power System Analysis*; Tata McGraw-Hill Education: Delhi, India, 2011.
53. Chua, K.H.; Lim, Y.S.; Morris, S. Energy storage system for peak shaving. *Int. J. Energy Sect. Manag.* **2016**, *10*, 3–18. [CrossRef]
54. Grigsby, L.L. *Electric Power Generation, Transmission, and Distribution*; CRC Press: Boca Raton, FL, USA, 2016.
55. Uddin, M.; Romlie, M.F.; Abdullah, M.F. Feasibility study of grid connected solar home system: The perspective of Malaysia. In Proceedings of the 4th IET Clean Energy and Technology Conference (CEAT 2016), Kuala Lumpur, Malaysia, 14–15 November 2016; pp. 1–6. [CrossRef]
56. Nayak, P. Many PQ Events Result in End-User Problems. *Power Today*, August 2016. Available online: http://www.powertoday.in/News.aspx?nId=6I/+NZbR4YWfOja8Q27K8w== (accessed on 22 January 2021).
57. Luo, X.; Wang, J.; Dooner, M.; Clarke, J. Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Appl. Energy* **2015**, *137*, 511–536. [CrossRef]
58. Shaker, H.; Zareipour, H.; Wood, D. Impacts of large-scale wind and solar power integration on California's net electrical load. *Renew. Sustain. Energy Rev.* **2016**, *58*, 761–774. [CrossRef]
59. Wang, Z.; Wang, S. Grid power peak shaving and valley filling using vehicle-to-grid systems. *IEEE Trans. Power Deliv.* **2013**, *28*, 1822–1829. [CrossRef]
60. Rastler, D. *Benefit Analysis of Energy Storage: Case Study with Sacramento Municipal Utility District*; EPRI: Palo Alto, CA, USA, 2011.
61. Rouco, L.; Sigrist, L. Active and reactive power control of battery energy storage systems in weak grids. In Proceedings of the 2013 IREP Symposium Bulk Power System Dynamics and Control-IX Optimization, Security and Control of the Emerging Power Grid (IREP), Rethymno, Greece, 25–30 August 2013; pp. 1–7.
62. Yeh, H.G.; Doan, S.H. Battery placement on performance of VAR controls. *arXiv* **2013**, arXiv:1311.6199.
63. Yan, X.; Zhang, X.; Chen, H.; Xu, Y.; Tan, C. Techno-economic and social analysis of energy storage for commercial buildings. *Energy Convers. Manag.* **2014**, *78*, 125–136. [CrossRef]
64. Bradley, P.; Leach, M.; Torriti, J. A review of the costs and benefits of demand response for electricity in the UK. *Energy Policy* **2013**, *52*, 312–327. [CrossRef]
65. Chua, K.H.; Lim, Y.S.; Morris, S. A novel fuzzy control algorithm for reducing the peak demands using energy storage system. *Energy* **2017**, *122*, 265–273. [CrossRef]
66. Percebois, J. The French paradox: Competition, nuclear rent, and price regulation. In *Evolution of Global Electricity Markets*; Elsevier: Amsterdam, The Netherlands, 2013; pp. 59–91.
67. Arshad, A.; Ali, H.M.; Habib, A.; Bashir, M.A.; Jabbal, M.; Yan, Y. Energy and exergy analysis of fuel cells: A review. *Therm. Sci. Eng. Prog.* **2019**, *9*, 308–321. [CrossRef]
68. Rozali, N.E.M.; Ho, W.S.; Alwi, S.R.W.; Manan, Z.A.; Klemeš, J.J.; Yunus, M.N.S.M.; Zaki, S.A.A.S.M. Peak-off-peak load shifting for optimal storage sizing in hybrid power systems using Power Pinch Analysis considering energy losses. *Energy* **2018**, *156*, 299–310. [CrossRef]
69. Ghasemi, A.; Enayatzare, M. Optimal energy management of a renewable-based isolated microgrid with pumped-storage unit and demand response. *Renew. Energy* **2018**, *123*, 460–474. [CrossRef]
70. Eyer, J.M. *Electric Utility Transmission and Distribution Upgrade Deferral Benefits from Modular Electricity Storage: A Study for the Doe Energy Storage Systems Program*; Technical Report; Sandia National Laboratories: Albuquerque, NM, USA, 2009.
71. Eyer, J.; Corey, G. *Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide*; Sandia National Laboratories: Albuquerque, NM, USA, 2010; Volume 20, p. 5.
72. Dasgupta, K.; Hazra, J.; Rongali, S.; Padmanaban, M. Estimating return on investment for grid scale storage within the economic dispatch framework. In Proceedings of the 2015 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA), Bangkok, Thailand, 3–6 November 2015; pp. 1–6.
73. Staubo. Peak-Shaving with Li-Ion Batteries. Report. Available online: http://www.staubo.com/en/peak_shaving.html (accessed on 28 July 2018).

74. Jakhrani, A.Q.; Rigit, A.R.H.; Othman, A.K.; Samo, S.R.; Kamboh, S.A. Estimation of carbon footprints from diesel generator emissions. In Proceedings of the 2012 International Conference on Green and Ubiquitous Technology, Bandung, Indonesia, 7–8 July 2012; pp. 78–81. [CrossRef]
75. Hanania, J.; Martin, J.; Stenhouse, K.; Donev, J. Diesel Generator. Energy Education, Report. 2015. Available online: https://energyeducation.ca/encyclopedia/Diesel_generator (accessed on 28 July 2018).
76. Cossutta, M.; Pholboon, S.; McKechnie, J.; Sumner, M. Techno-economic and Environmental Analysis of community energy management for peak shaving. *Energy Convers. Manag.* **2022**, *251*, 114900. [CrossRef]
77. Sardi, J.; Mithulananthan, N.; Gallagher, M.; Hung, D.Q. Multiple community energy storage planning in distribution networks using a cost-benefit analysis. *Appl. Energy* **2017**, *190*, 453–463. [CrossRef]
78. Reihani, E.; Motalleb, M.; Ghorbani, R.; Saoud, L.S. Load peak shaving and power smoothing of a distribution grid with high renewable energy penetration. *Renew. Energy* **2016**, *86*, 1372–1379. [CrossRef]
79. Du, M.; Niu, Y.; Hu, B.; Zhou, G.; Luo, H.; Qi, X. Frequency regulation analysis of modern power systems using start-stop peak shaving and deep peak shaving under different wind power penetrations. *Int. J. Electr. Power Energy Syst.* **2021**, *125*, 106501. [CrossRef]
80. Jouvet, P.A.; Solier, B. An overview of CO_2 cost pass-through to electricity prices in Europe. *Energy Policy* **2013**, *61*, 1370–1376. [CrossRef]
81. Parrish, B.; Heptonstall, P.; Gross, R.; Sovacool, B.K. A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response. *Energy Policy* **2020**, *138*, 111221. [CrossRef]
82. Astriani, Y.; Shafiullah, G.; Shahnia, F. Incentive determination of a demand response program for microgrids. *Appl. Energy* **2021**, *292*, 116624. [CrossRef]
83. Jordehi, A.R. Optimisation of demand response in electric power systems, a review. *Renew. Sustain. Energy Rev.* **2019**, *103*, 308–319. [CrossRef]
84. Cappers, P.; MacDonald, J.; Goldman, C.; Ma, O. An assessment of market and policy barriers for demand response providing ancillary services in US electricity markets. *Energy Policy* **2013**, *62*, 1031–1039. [CrossRef]
85. Cappers, P. *Market and Policy Barriers for Demand Response Providing Ancillary Services in Us Markets*; Lawrence Berkeley National Laboratory: Berkeley, CA, USA, 2013.
86. Chen, Y.; Xu, P.; Gu, J.; Schmidt, F.; Li, W. Measures to improve energy demand flexibility in buildings for demand response (DR): A review. *Energy Build.* **2018**, *177*, 125–139. [CrossRef]
87. Sedighizadeh, M.; Esmaili, M.; Jamshidi, A.; Ghaderi, M.H. Stochastic multi-objective economic-environmental energy and reserve scheduling of microgrids considering battery energy storage system. *Int. J. Electr. Power Energy Syst.* **2019**, *106*, 1–16. [CrossRef]
88. Wong, L.A.; Ramachandaramurthy, V.K.; Taylor, P.; Ekanayake, J.; Walker, S.L.; Padmanaban, S. Review on the optimal placement, sizing and control of an energy storage system in the distribution network. *J. Energy Storage* **2019**, *21*, 489–504. [CrossRef]
89. Kim, W.W.; Shin, J.S.; Kim, S.Y.; Kim, J.O. Operation scheduling for an energy storage system considering reliability and aging. *Energy* **2017**, *141*, 389–397. [CrossRef]
90. Lee, W.; Kang, B.O.; Jung, J. Development of energy storage system scheduling algorithm for simultaneous self-consumption and demand response program participation in South Korea. *Energy* **2018**, *161*, 963–973. [CrossRef]
91. Li, X.; Wang, W.; Wang, H. A novel bi-level robust game model to optimize a regionally integrated energy system with large-scale centralized renewable-energy sources in Western China. *Energy* **2021**, *228*, 120513. [CrossRef]
92. Lee, J.W.; Haram, M.H.S.M.; Ramasamy, G.; Thiagarajah, S.P.; Ngu, E.E.; Lee, Y.H. Technical feasibility and economics of repurposed electric vehicles batteries for power peak shaving. *J. Energy Storage* **2021**, *40*, 102752. [CrossRef]
93. Li, X.; Tan, Y.; Liu, X.; Liao, Q.; Sun, B.; Cao, G.; Li, C.; Yang, X.; Wang, Z. A cost-benefit analysis of V2G electric vehicles supporting peak shaving in Shanghai. *Electr. Power Syst. Res.* **2020**, *179*, 106058. [CrossRef]
94. Gerards, M.E.; Hurink, J.L. Robust peak-shaving for a neighborhood with electric vehicles. *Energies* **2016**, *9*, 594. [CrossRef]
95. Zhang, L.; Yang, Y.; Li, Q.; Gao, W.; Qian, F.; Song, L. Economic optimization of microgrids based on peak shaving and CO_2 reduction effect: A case study in Japan. *J. Clean. Prod.* **2021**, *321*, 128973. [CrossRef]
96. Schram, W.L.; Lampropoulos, I.; van Sark, W.G. Photovoltaic systems coupled with batteries that are optimally sized for household self-consumption: Assessment of peak shaving potential. *Appl. Energy* **2018**, *223*, 69–81. [CrossRef]
97. Pimm, A.J.; Cockerill, T.T.; Taylor, P.G. The potential for peak shaving on low voltage distribution networks using electricity storage. *J. Energy Storage* **2018**, *16*, 231–242. [CrossRef]
98. Yang, X.; Zhang, Y.; He, H.; Ren, S.; Weng, G. Real-time demand side management for a microgrid considering uncertainties. *IEEE Trans. Smart Grid* **2018**, *10*, 3401–3414. [CrossRef]
99. Li, D.; Chiu, W.Y.; Sun, H. Demand side management in microgrid control systems. In *Microgrid*; Elsevier: Amsterdam, The Netherlands, 2017; pp. 203–230.
100. Bhamidi, L.; Sivasubramani, S. Optimal planning and operational strategy of a residential microgrid with demand side management. *IEEE Syst. J.* **2019**, *14*, 2624–2632. [CrossRef]
101. Shen, J.; Jiang, C.; Liu, Y.; Qian, J. A microgrid energy management system with demand response for providing grid peak shaving. *Electr. Power Compon. Syst.* **2016**, *44*, 843–852. [CrossRef]

102. Agamah, S.U.; Ekonomou, L. A heuristic combinatorial optimization algorithm for load-leveling and peak demand reduction using energy storage systems. *Electr. Power Compon. Syst.* **2017**, *45*, 2093–2103. [CrossRef]
103. Choudhury, S. Review of Energy Storage System Technologies integration to microgrid: Types, control strategies, issues, and future prospects. *J. Energy Storage* **2022**, *48*, 103966. [CrossRef]
104. Agamah, S.U.; Ekonomou, L. Peak demand shaving and load-levelling using a combination of bin packing and subset sum algorithms for electrical energy storage system scheduling. *IET Sci. Meas. Technol.* **2016**, *10*, 477–484. [CrossRef]
105. Agamah, S.U.; Ekonomou, L. Energy storage system scheduling for peak demand reduction using evolutionary combinatorial optimisation. *Sustain. Energy Technol. Assess.* **2017**, *23*, 73–82. [CrossRef]
106. Shin, M.; So, S.; Kim, K. A Control Approach of Battery Energy Storage Systems to Reduce kW Demand. In *MATEC Web of Conferences*; EDP Sciences: Les Ulis, France, 2016; Volume 68, p. 10001.
107. Motalleb, M.; Reihani, E.; Ghorbani, R. Optimal placement and sizing of the storage supporting transmission and distribution networks. *Renew. Energy* **2016**, *94*, 651–659. [CrossRef]
108. Sebastián, R. Application of a battery energy storage for frequency regulation and peak shaving in a wind diesel power system. *IET Gener. Transm. Distrib.* **2016**, *10*, 764–770. [CrossRef]
109. Sun, B.; Su, X.; Wang, D.; Zhang, L.; Liu, Y.; Yang, Y.; Liang, H.; Gong, M.; Zhang, W.; Jiang, J. Economic analysis of lithium-ion batteries recycled from electric vehicles for secondary use in power load peak shaving in China. *J. Clean. Prod.* **2020**, *276*, 123327. [CrossRef]
110. Liao, Q.; Sun, B.; Liu, Y.; Sun, J.; Zhou, G. A techno-economic analysis on NaS battery energy storage system supporting peak shaving. *Int. J. Energy Res.* **2016**, *40*, 241–247. [CrossRef]
111. Lucas, A.; Chondrogiannis, S. Smart grid energy storage controller for frequency regulation and peak shaving, using a vanadium redox flow battery. *Int. J. Electr. Power Energy Syst.* **2016**, *80*, 26–36. [CrossRef]
112. Uddin, M.; Romlie, M.; Abdullah, M.; Tan, C.; Shafiullah, G.; Bakar, A.H.A. A novel peak shaving algorithm for islanded microgrid using battery energy storage system. *Energy* **2020**, *196*, 117084. [CrossRef]
113. Shahab, M.; Wang, S.; Junejo, A.K. Improved Control Strategy for Three-Phase Microgrid Management with Electric Vehicles Using Multi Objective Optimization Algorithm. *Energies* **2021**, *14*, 1146. [CrossRef]
114. Achour, Y.; Ouammi, A.; Zejli, D. Model predictive control based demand response scheme for peak demand reduction in a Smart Campus Integrated Microgrid. *IEEE Access* **2021**, *9*, 162765–162778. [CrossRef]
115. Dagdougui, H.; Ouammi, A.; Dessaint, L.A. Peak load reduction in a smart building integrating microgrid and V2B-based demand response scheme. *IEEE Syst. J.* **2019**, *13*, 3274–3282. [CrossRef]
116. Padhi, C.K.; Panda, S.; Biswal, G.R. Optimal Recharging of EVs for Peak Power Shaving and Valley Filling using EV-Aggregator model in a Micro-grid. *J. Phys. Conf. Ser.* **2021**, *1854*, 012016. [CrossRef]
117. Alam, M.J.E.; Muttaqi, K.M.; Sutanto, D. A controllable local peak shaving strategy for effective utilization of PEV battery capacity for distribution network support. *IEEE Trans. Ind. Appl.* **2014**, *51*, 2030–2037. [CrossRef]
118. Singh, S.; Jagota, S.; Singh, M. Energy management and voltage stabilization in an islanded microgrid through an electric vehicle charging station. *Sustain. Cities Soc.* **2018**, *41*, 679–694. [CrossRef]
119. Sbordone, D.; Bertini, I.; Di Pietra, B.; Falvo, M.C.; Genovese, A.; Martirano, L. EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm. *Electr. Power Syst. Res.* **2015**, *120*, 96–108. [CrossRef]
120. Ioakimidis, C.S.; Thomas, D.; Rycerski, P.; Genikomsakis, K.N. Peak shaving and valley filling of power consumption profile in non-residential buildings using an electric vehicle parking lot. *Energy* **2018**, *148*, 148–158. [CrossRef]
121. Van Roy, J.; Leemput, N.; Geth, F.; Büscher, J.; Salenbien, R.; Driesen, J. Electric vehicle charging in an office building microgrid with distributed energy resources. *IEEE Trans. Sustain. Energy* **2014**, *5*, 1389–1396. [CrossRef]
122. Ouammi, A. Peak loads shaving in a team of cooperating smart buildings powered solar PV-based microgrids. *IEEE Access* **2021**, *9*, 24629–24636. [CrossRef]
123. Coffman, M.; Bernstein, P.; Wee, S. Electric vehicles revisited: A review of factors that affect adoption. *Transp. Rev.* **2017**, *37*, 79–93. [CrossRef]
124. Lee, S.J.; Oh, Y.S.; Sim, B.S.; Kim, M.S.; Kim, C.H. Analysis of peak shaving effect of demand power using Vehicle to Grid system in distribution system. *J. Int. Counc. Electr. Eng.* **2017**, *7*, 198–204. [CrossRef]
125. Pallonetto, F.; De Rosa, M.; D'Ettorre, F.; Finn, D.P. On the assessment and control optimisation of demand response programs in residential buildings. *Renew. Sustain. Energy Rev.* **2020**, *127*, 109861. [CrossRef]