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Research Paper

Peak Management in Grid-Connected Microgrid Combining Battery Storage and DSM Systems

N. Attou*(C.A.), S. A. Zidi*, S. Hadjeri* and M. Khatir*

Abstract: Demand-side management has become a viable solution to meet the needs of the power system and consumers in the past decades due to the problems of power imbalance and peak demand on the grid. This study focused on an improved decision tree-based algorithm to cover off-peak hours and reduce or shift peak load in a grid-connected microgrid using a battery energy storage system (BESS), and a demand response scheme. The main objective is to provide an efficient and optimal management strategy to mitigate peak demand, reduce the electricity price, and replace expensive reserve generation units. The developed algorithm is evaluated with two scenarios to see the behavior of the management system throughout the day, taking into account the different types of days (weekends and working days), the random profile of the users' demand, and the variation of the energy price (EP) on the grid. The simulation results allowed us to reduce the daily consumption by about 30% to 40% and to fill up to 12% to 15% of the off-peak hours with maximum use of renewable energies, demonstrating the control system's performance in smoothing the load curve.

Keywords: Battery Energy Storage System, Demand-Side Management, Load Shifting, Microgrid Peak Shaving, Valley Filling.

1 INTRODUCTION

OVER the past decade, the uncertainty associated with the intermittency of renewable energies has demonstrated the crucial importance of maintaining the energy balance. Increasing the flexibility of energy consumption, improving reliability, and ensuring the energy supply at the lowest possible cost are the main objectives of the future grid, Demand Side Management (DSM) appears to be an effective solution for managing customer load.

This management system assists utilities in reducing energy prices, reducing peak demand, and improving the load demand profile on the one hand, and on the other, it helps consumers to make an informed decision about their electricity consumption. The DSM mechanisms that have been designed can help mitigate load shedding and peak demand management [1].

DSM is currently becoming an important part of the future grid system, not only because it reduces the peak load of the system by reducing or shifting consumption, but also because it can take benefit of excess renewable resources by filling the off-peak hours [2],[3].

This management method is based on a set of techniques to encourage the customer to flexibly change or shift their energy demand according to their needs. Air conditioning units, water heaters, EVs, washing machines, and pumps are some of the modifications that a customer can postpone. As an illustration, the energy provider could gradually alter the electricity price to motivate end users to reduce their consumption [4],[5]. DR programs help

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* Electrical Engineering Department Intelligent Control & Electrical Power Systems Laboratory (ICEPS), Djillali Liabes University, Sidi Bel-Abbas, 22000, Algeria.
E-mails: attioun12@gmail.com, sbzidi@yahoo.fr, shadjeri2@yahoo.fr, med_khatir@yahoo.fr.
Corresponding Author: N. Attou.
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protect the grid against the risk of outages and the use of peaking plants. In addition, they enhance energy efficiency and smooth the demand profile, which helps to reduce energy costs and maximize the use of renewable energy.

Another advanced clipping solution is widely used in storage-based microgrids [1],[9].

The deployment of storage systems can offer another benefit besides reducing customer demand charges. They play an important role in modernizing the grid to provide a variety of services, including peak load shaving, provision of spinning reserves, leveling, and reducing power fluctuations from renewable energy resources. They can reduce the peak load during a specific period (by storing energy during off-peak periods and releasing it during peak periods) to smooth the typical mountain and valley shape of the load curve and reduce the cost of electricity [10],[11],[12].

In this regard, several demand-side management strategies have been proposed by various researchers. For example, in some papers, researchers have studied the role of the storage system in peak reduction. In reference [13], Kein Huat Chua et al proposed an efficient sizing method and an optimal clipping technique for an energy storage system. They also developed a fuzzy control algorithm to reduce the daily peak demands while working within the capacity of the BESS, which they tested in two different buildings. In a paper [14], Teki et al modeled a solar PV system with battery storage for a 5 kW residential load as supplementary power and grid power as the main power, with a power conditioning controller to reduce load demand.

Reference [15] describes a new cost-effective method of demand side management and peak shaving through optimized scheduling of renewable energy sources integrated with a grid-connected hybrid microgrid and vanadium redox flow battery storage (VRFB). As a long-life and scalable battery storage solution, VRFB storage is adopted for peak shaving and reliable microgrid performance.

In the literature, a few methods to use DSM to reduce peak demands have been suggested.

For example, in reference [16] a demand response (DR) model based on dynamic pricing (DP) is developed for demand management in a smart grid. The proposed DR model can shift the peak electricity demand, thus improving the stability and reliability of the power system. The game theory model is used to explore the interaction between the energy service provider and electricity consumers. Similarly, in electric vehicle applications, energy management systems based on V2G technology are presented in several types of research for peak management, e.g., a peak shaving and off-peak filling strategy for the electric system was proposed by researchers in [17] using vehicle-to-grid (V2G) technology.

In the paper [18], the authors proposed a demand response (DR) model that maximizes the profits of energy retailers, in this case, microgrid customers. DR models examine the utility and elasticity of different customers, taking into account their different behavior during peak and off-peak periods.

A comprehensive optimization process has been introduced to calculate the optimal value of the incentive. In reference [19] a new application of the Pelican Optimization Algorithm (POA) for optimal energy management (EM) in microgrid (MG) considering a demand response program (DRP) has been developed. The proposed hybrid DRP is based on incentive demand response (IDR) to reduce the peak load and ensure the reliability of the MG. The reliability is achieved by applying the hybrid technique to encourage customers to reduce their consumption during peak hours. In reference [20], an optimal appliance load scheduling model for smart home energy management is proposed, considering demand response for different pricing schemes. The Henry gas solubility optimization method is used to obtain optimal load scheduling solutions, and then these solutions are sorted using the VIKOR multi-criteria decision-making method. Other researchers have devoted their work [21] to solving the microgrid energy management problem in conjunction with both customer and utility-oriented energy management strategies. A stochastic EMS framework is developed to implement and analyze the flexible DSM strategy of load shaping, price-based, and incentive-based demand response programs (DRP) in the presence of non-dispatchable energy resources. In reference [22] an economic DSM strategy is implemented to restructure the load demand forecasting model for different participation levels. For this purpose, they developed a CSAJAYA hybrid optimization algorithm for two microgrid distribution systems.

In reference [23], a financial analysis was carried out to determine revenues of electric vehicle users in V2G peak shaving services when the peak price of electricity injected into the grid is higher than the valley price. Other researchers have successfully combined several energy sources to reduce grid peaks, as in reference [24] K. Mahmud presented a strategy for domestic battery storage in households equipped with a V2G compatible electrical system and a photovoltaic system. In reference [25], he continues his research on an improved decision tree-based algorithm to reduce peak load in residential distribution through coordinated control of electric vehicles (EVs), photovoltaic (PV) units, and battery energy storage systems (BESS). Peak load reduction is achieved by measuring the residential load in real-time through a smart meter and using the proposed algorithm to coordinate an efficient synchronized behavior through a controller.

Many studies on peak shaving with energy storage systems and hybrid energy systems to reduce peak load and optimize the financial benefits of peak shaving have been presented in [13]-[14]-[15]-[24]. In addition, for applications based on demand-side management schemes, most of the research focuses on demand-side management schemes to improve the stability and reliability of the power system on one side [16]-[20] and others have studied demand-side management from an economic point of view depending on the pricing scheme [20], some papers have developed the V2G technology for peak shaving [23]-[17]-[25]. However, the main originality of this paper is focused on a new decision-tree-based energy management strategy that combines two methods of peak shaving and valley filling, a battery storage system, and a demand response program. The demand-side management system coordinated by DSM and BESS is applied to a residential microgrid connected to the grid.

The selected control mechanism enables consumers to carry out their daily routine activities while reducing or shifting their use during peak hours or feeding high-demand loads during off-peak hours to improve system management. The main contribution lies in the different solutions proposed by the algorithm in optimal management such as peak shaving, off-peak filling, and energy exchange with the grid, which improves the economics ensuring increased reliability and stability of the power system.

The management algorithm is preferred because it requires no complex mathematical modeling and can build a comprehensive and intuitive energy management strategy based on simple linguistic rules that can effectively simplify the energy management process in the case of many system states and operating modes. This power management system minimizes peak demand while optimally charging and discharging the BESS.

2 METHOD

2.1 DESCRIPTION OF THE SYSTEM

This paper's analysis is designed for a residential MG connected to the grid [26]. The structure of the microgrid includes a photovoltaic (PV) system [27], a battery energy storage system (BESS), and Residential and industrial loads.

Two inverters are used to connect the PV and the BESS to the AC bus. The first one is a unidirectional inverter; the second is a bidirectional inverter for charging/discharging the battery. Voltage and frequency stability are ensured by a two-way connection between the microgrid and the main grid, which allows electricity to be bought and sold. The microgrid structure that will be examined in this paper is illustrated in Fig. 1.

An energy management system [28] based on the DSM technique is used with bi-directional communication between the flexible dynamic load, the BESS, and the grid systems [29].

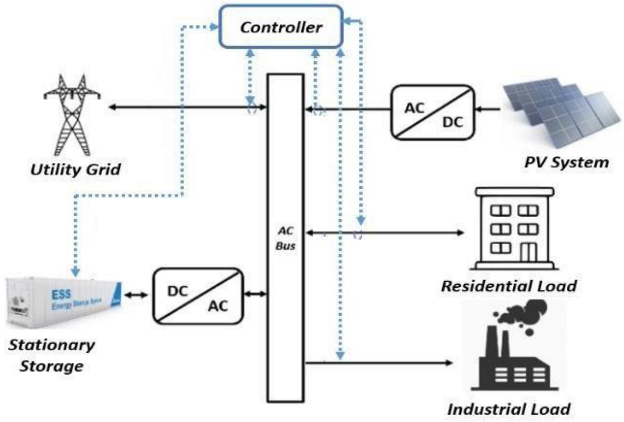

Fig. 1 The architecture of the proposed microgrid.

The microgrid parameters are shown in Table 1:

Table 1 Microgrid parameters.

Symbols	Description	Value	Unit
Ppv	Photovoltaic Rated Power	235	kW
PL	Load rated Power	200	kW
PBAT	Battery rated Power	500	kWh
SOCB-max	Maximum Battery SOC	95	%
T	Simulation time	24	h

2.2 PEAK SHAVING AND VALLEY FILLING

Peak shaving is used to reduce or shift peak demand caused by commercial and industrial customers over relatively short periods, approximately two to four hours per day. The aim is to shift renewable energy from periods of low demand to periods of high demand to increase the use of green power and reduce the use of more expensive peaking units [30], [31].

DSM is used to manage household loads, either by reducing them or shifting them to off-peak hours. To do this, loads are first prioritized according to their ability to tolerate operating delays. The operating time of non-critical loads can be altered to minimize demand during peak hours; these loads are therefore flexible. For example, because it is not essential to run a washing machine for a certain period, its use can be postponed. On the other hand, light loads must be switched on at nightfall and cannot be changed or rescheduled.

An incentive system to reduce demand can be put in place using the price of electricity. Demand for flexible loads should decrease as market prices increase.

To achieve peak shaving, load leveling, and valley filling, the DSM-based management strategy encourages consumers to modify their consumption in real-time.

2.3 BATTERY ENERGY STORAGE SYSTEM

In this study, a battery energy storage system (BESS) is designed to reduce peak demand by providing energy to the load during peak hours and releasing it during off-peak hours when the electricity price is low, and injecting energy into the grid during periods of high electricity consumption when the price is high.

The control strategy for optimal charge/discharge of the storage system is shown in the following figure (Fig. 2).

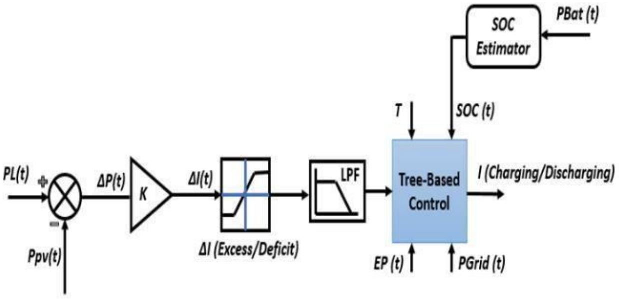

Fig. 2 The control diagram of battery storage.

Based on the power difference between the load power and the renewable generation (Deficit/ Excess), the electricity price, and time, and using the SOC estimator, the control algorithm generates the charging/discharging current to ensure peak management.

The BESS consists of a Li-ion battery, a bidirectional AC/DC converter that can transfer energy in both directions and the measurement equipment that provides inputs to the control schematic block to generate trigger signals for the converter's semiconductor switches.

The optimal charging and discharging of the BESS for peak shaving and load leveling [29] is shown in Fig. 3.

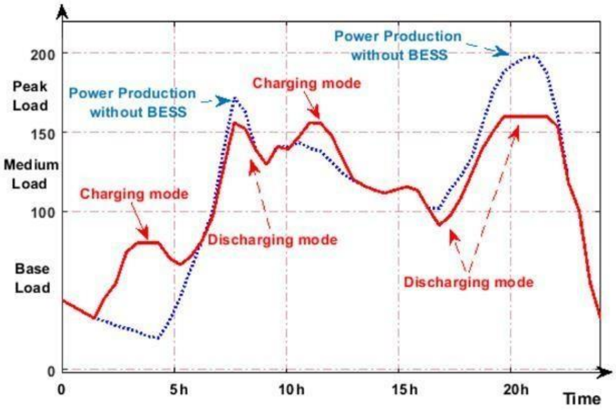

Fig. 3 Optimal charging and discharging of BESS for peak shaving and load leveling [29].

Equation (1) describes the battery's state of charge.

$$SOC(t) = \frac{C(t)}{C_{ref}(t)} \tag{1}$$

where $C_{ref}(t)$ is reference capacity and $C(t)$ is battery capacity at all times.

The battery must not be overcharged or over-discharged, and the SOC limits of the battery can be specified as shown in the following constraint:

$$the\ SOC_{Bmin}(t) \le SOC_B(t) \le SOC_{Bmax}(t)$$

where SOC_{Bmax} and SOC_{Bmin} are the maximum and minimum state of charge respectively, to preserve the battery life.

The relation of the battery power $P_{BAT}(t)$ and battery SOC can be formulated as:

$$SOC(t_1) = \frac{1}{C_{BAT}} \int_{t_0}^{t_1} P_{BAT}(\tau) d\tau + SOC(t_0) \tag{2}$$

where $P_{BAT}(t)$ is the battery power, C_{BAT} is the battery energy capacity (kWh) and $SOC(t_0)$ is the battery SOC at initial time t_0.

To keep consistency and repeatability for different optimization periods, the beginning SOC and ending SOC of the battery are confined to be the same.

$$SOC_i = SOC_f$$

2.4 Load Profiles (Flexible Load)

A dynamic three-phase load model based on a daily load curve is used. Load estimation is a crucial part of the design of any type of power system. For this study, the load was estimated using two scenarios, a working day and a weekend day respectively.

The load profile represents a community that contains residential and small industrial loads with a maximum power of 200 kW. The residential community consists of modern houses equipped with communication technologies and a two-way exchange with the energy manager. Each house contains energy-consuming appliances such as air conditioners, electric heaters, and other energy-saving devices. First, we classified the energy consumers according to their lifestyle and the nature of the day (weekdays or weekend days).

Consumers participate in peak shaving as desired by load owners and the grid through incentive systems that encourage consumers to manage their consumption [5].

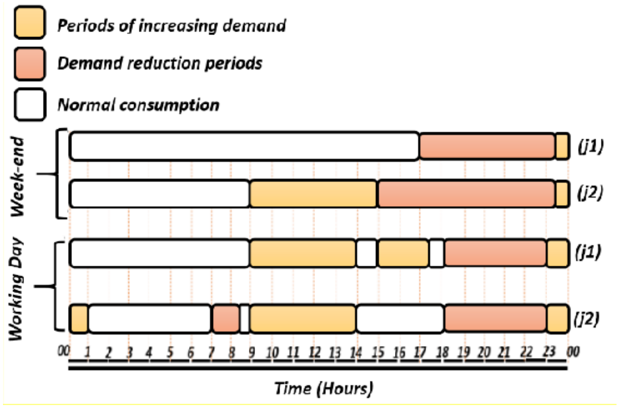

Fig. 4 Load scenario to test the DSM system.

Fig. 4 shows the periods during which consumers contribute to peak shaving and valley filling during the day according to their needs.

The contribution of consumers follows a random distribution throughout the day. Five consumer profiles are implemented:

- Consumers who can shift their consumption before the evening peak.

- Consumers who can increase their demand during surplus periods.

- Consumers who can reduce their consumption during peak periods.

- Consumers who are sensitive to price fluctuations.

Different DR scenarios have been developed during the day to encourage customer participation while ensuring a more reliable grid with responsible consumers taking into account the evolution of the electricity price.

3 PROPOSED APPROACH

This section describes the proposed decision Tree-based algorithm for coordinating DSM and BESS system components to load management during off-peak hours. The detailed architecture of the system is shown in Fig. 5.

A control algorithm is developed based on a daily load profile. We assume that the predicted load curve is known. A controller connected to the home meter and the BESS reads the load profile and the battery state of charge (SOC) data to control the peak load at time t.

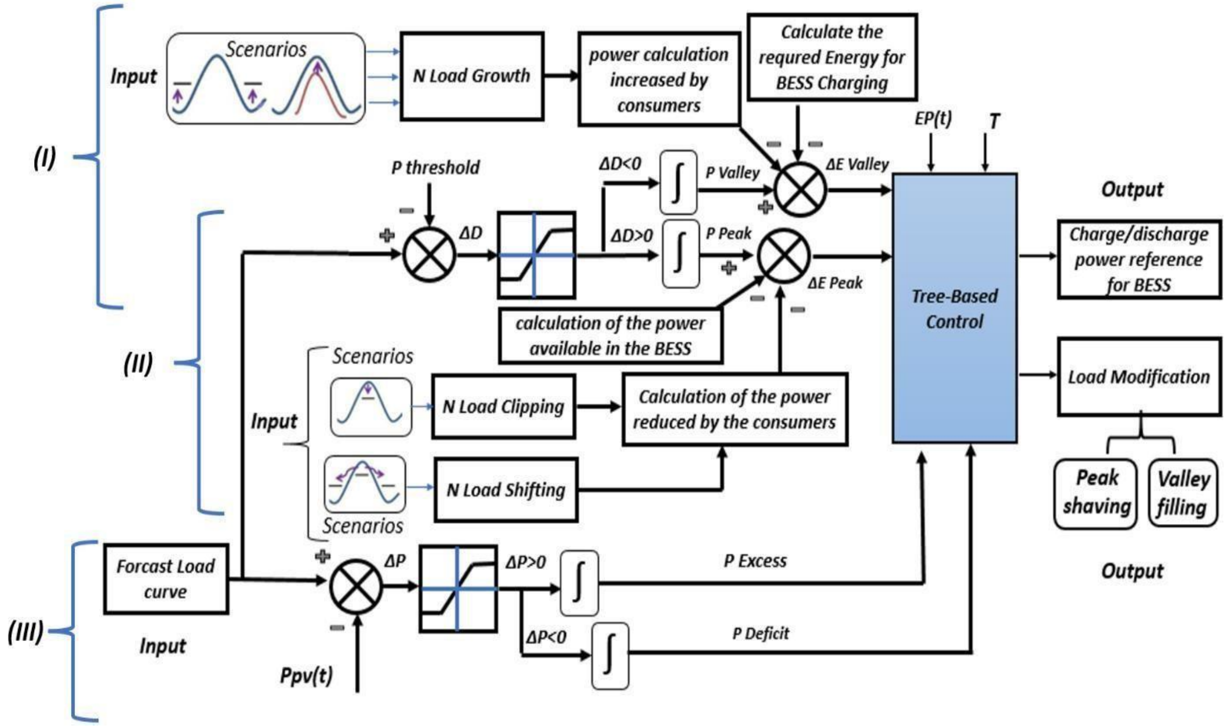

Fig. 5 Proposed peak clipping and valley filling algorithm control.

Depending on the load conditions and sources (PV and battery), the controller sends an information message including (peak/off-peak power at time t, and electricity price) to encourage consumers to modify their consumption on the one hand, and on the other hand, it controls the charge and discharge of the storage system.

The remaining surplus is sent directly to the grid. The objective is to smooth the load curve and optimize the power-sharing in both directions simultaneously to obtain the most efficient compromise solution. The peak power on the load curves is defined as the area above the reference value, the energy required to charge the BESS, and the total power augmented by the consumers is calculated to fill the off-peak hours as shown in (Fig. 5 section (I)).

The power is available in the BESS and the total power reduced by consumers is calculated to smooth out the peak demand (section (II)). Then based on the amount of excess or deficit power produced in section (III), the electricity price (EP), time, and power difference between (ΔE Valley) and (ΔE peak). The developed decision algorithm generates control signals to the BESS conversion devices for charging/discharging and to the load control systems for peak/off-peak management at time t.

Based on the load data, it manages the conditions as follows: if the load exceeds the threshold, the controller considers it to be a peak state and sends an incentive message to customers to reduce peaks. If the customers' reflection cannot reduce the peak demand, the controller will take energy from the BESS. On the other hand, if the load falls below the threshold, the controller charges the battery (fills the valley) and sells the surplus to the grid. According to the algorithm, the BESS charges during the night at off-peak hours and supports the grid during peak hours based on its SOC. The initial state of charge (SOC) was maintained at over 20% under all conditions [30].

The interest of the implemented algorithm is to develop a flatter consumption curve, which will minimize the utility's load during peak hours while increasing the economic gain.

The consumer response is random and depends directly on the user's behavior and the price of electricity at that time. The peak power is given by the following formula:

$$P_{peak}(\mathrm{t}) = P_{max}(\mathrm{t}) - P_{Threshold} \tag{3}$$

$$E_{Peak}(t) = \int_{t}^{t_{peak-end}} P_{peak}(\tau)d\tau \tag{4}$$

$$t_{peak-start} < t < t_{peak-end}$$

where P_{peak} is the peak power in (kW), P_{max} is the maximum load power in (kW), and $P_{Threshold}$ is the threshold power (kW).

The total energy to be shaved from time t to the end of the peak period can be calculated as:

$$P_{shave}(t) = \sum_{t2}^{t1}[(P_{CS-R}(t)) + \left(P_{BAT-peak}(t)\right)] \tag{5}$$

where P_{shave} is the total power used to shave the peak, $P_{cs-R}(t)$ is the total power reduced by the consumers, and $P_{BAT-peak}$ is the total power reduced by the storage system.

Constraints:

$$0 \leq P_{CS-R}(t) \leq P_{Peak}(t)$$

$$P_{\mathrm{shave}\ 2}(t) = P_{Peak}(t) - P_{cs-R}(t) \tag{6}$$

$$0 < P_{BAT-Peak}(t) < P_{shave\ 2} \quad \text{and}$$

$$SOC_{BAT} > 75\%$$

Where $t_{peak-start}$ and$t_{peak-end}$ are the times for the first and second intersection of the peak.

After determining the off-peak energy requirements and fully charging the batteries, the algorithm starts by specifying the valley fill power $P_{valley}(t)$. The algorithm starts by specifying the valley fill power $P_{peak}(t)$ as:

$$P_{valley}(t) = P_{PV}(t) - P_{L}(t) \tag{7}$$

$$\text{and } P_{valley}(t) > 0$$

$$t_{valley-start} < t < t_{valley-end}$$

Therefore, the energy required to fill the off-peak hours is calculated as follows:

$$E_{valley}(t) = \int_{t}^{t_{valley-end}} P_{valley}(\tau)d\tau \tag{8}$$

$$t_{valley-start} < t < t_{valley-end}$$

The total power consumed by the loads and the storage system at off-peak time is given by:

$$P_{filling} = \sum_{t2}^{t1}\left(P_{cs-fill}\right) + (P_{BAT-charging}) \tag{9}$$

$$P_{filling} < P_{Excess}$$

where P_{Excess} is the excess power produced by renewable energies, $P_{BAT-charging}$is the power consumed by the battery, and $P_{cs-fill}$ is the additional power consumed by the loads during the excess period.

The constraints applied to the system optimization operation are described below:

The energy flow in the microgrid system must always remain balanced as shown in equation (10).

$$P_{L}(t) = P_{pv}(t) + P_{BAT}(t) + P_{Grid}(t) \tag{10}$$

The maximum power purchased from the grid is limited in the following equation.

$$P_{Grid}(\mathrm{t}) \leq P_{Grid-\mathrm{max}}$$

where P_{L} is the Load power, $P_{BAT}$is the battery power, P_{Grid} is the power delivered by the grid, and P_{PV} is the photovoltaic power.

The load must always be supplied by a solar, grid, or storage system. A positive sign of $P_{Grid}$for the purchase of electricity from the grid, negative for the sale of electricity to the grid. P_{BAT} is negative for discharge and positive for Charging.

Battery state of charge constraint:

The state of charge of the battery is limited as follows:

$$SOC_{Bmin}(t) \leq SOC_{B}(t) \leq SOC_{Bmax}(t)$$

The detailed architecture of the system is shown in Fig. 6.

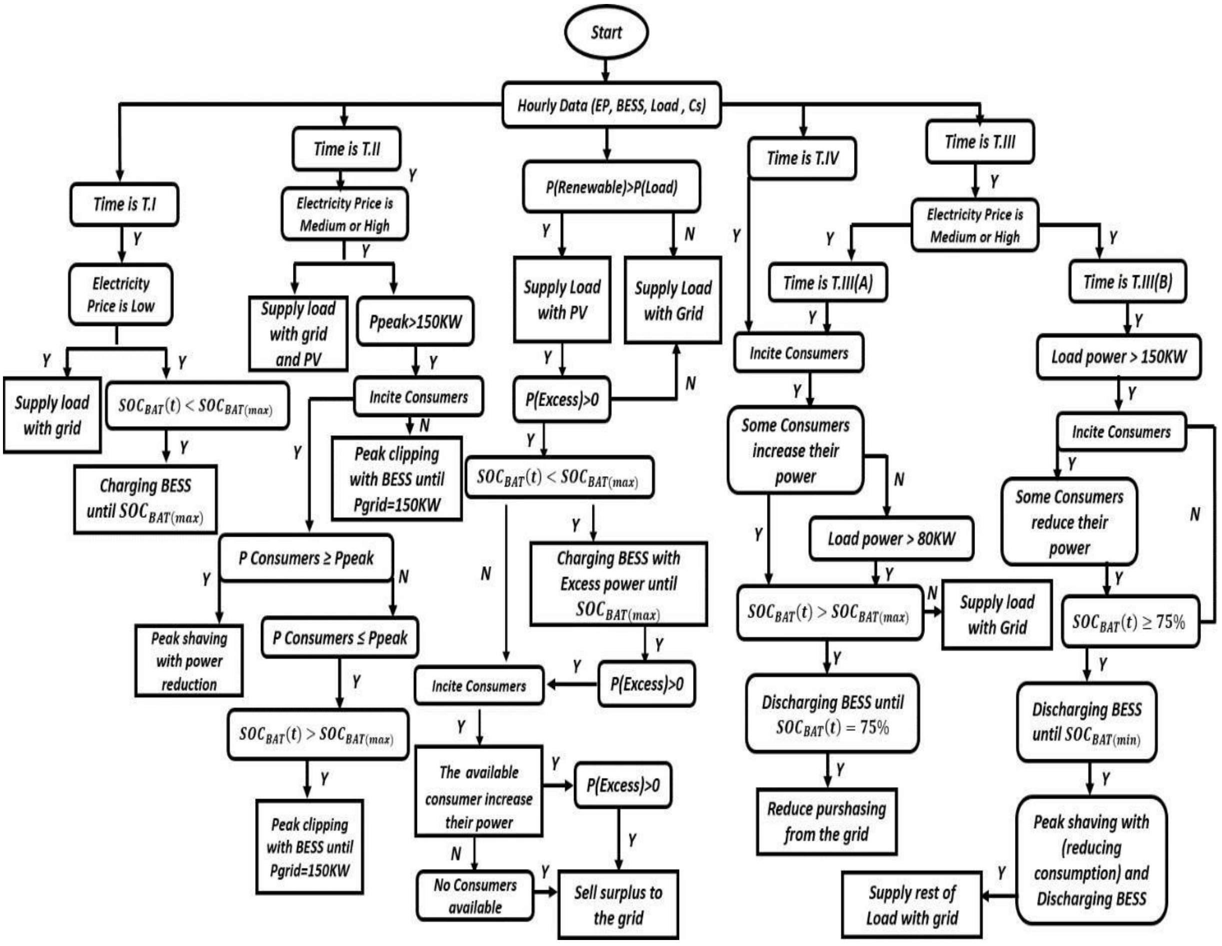

Fig. 6 Detailed flowchart of the control algorithm developed for peak shaving.

A control algorithm is developed according to the daily load profile.

The flowchart is divided into 4 periods T1, T2, T3 (A and B), and T4 as shown in Fig. 7.

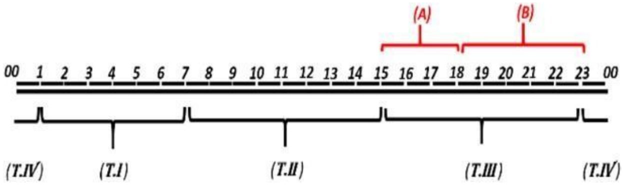

Fig. 7 Hourly distribution of the developed algorithm.

The controller reads the load data, electricity price, battery SOC, and solar irradiation data continuously and programs the outputs accordingly.

Photovoltaic energy is used to charge the BESS and/or feed the residential load, and the excess is sold directly to the grid.

The grid covers the demand when the PV system stops operating, taking into account the grid limit $P_{Gridmax}$.

To control peak and off-peak demand, the management system gives priority to customers; if the consumer contribution cannot meet this demand, the storage systems cover the demand according to their state of charge or both simultaneously in an optimal way.

The algorithm implemented in this study is developed as follows:

The BESS is charged during (T.I) up to SOC_{Bmax} at a low price.

- At (T.I), some consumers reduce their consumption during peak hours $P_{peak}(t)$ i.e., $P_{Grid} = 150\ KW$, or else;

- By using the second peak shaving solution, the BESS is discharged up to the limit of P_{Grid}.

- In (T.II), the estimable "excess demand" is prioritized according to the available quantity.

If Excess demand > 0

Additional power is available on the microgrid side.

When the electricity price is low and the BESS is not fully charged, the controller programs the battery charging to SOC_{Bmax} at first. Afterwards, the excess energy can be sold to the grid or the number of charges can be increased to cope with the production (valley filling).

- At (T.III-A) Two solutions are possible, either customers shift or postpone their consumption before the evening peak to contribute to the reduction of the foreseeable demand at night by using the grid and/or the storage system.

- In (T.III-B), Customer contributions in collaboration with BESS energy are used to reduce the evening peak.

- At (T.IV), when the electricity price decreases, the load will have less impact on users during the night and customers can increase their consumption.

The detailed flowchart is shown in Fig. 6.

4 RESULTS AND DISCUSSION

Based on the load variation curve, photovoltaic generation, and the SOC of the storage system during the day, a simulation under MATLAB Simulink is performed to see and analyze the behavior of the implemented energy management system in peak smoothing, load shifting, and valley filling during the day taking into account the electricity price variation.

Simulations were performed in discrete mode to obtain accurate results for each scenario.

The simulation takes into account typical residential tariffs for grid electricity as seen in Fig 8. The price of selling and buying energy is considered equal.

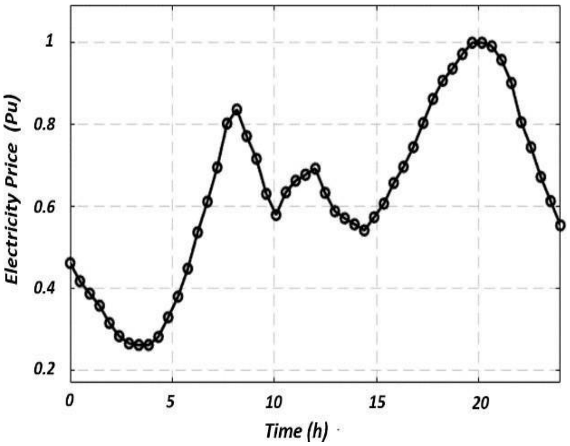

Fig. 8 Electricity price curve [28].

The performance of the demand-side management system is studied to examine the impact of the PV, DSM, and BESS scheduling systems on peak shaving and system cost reduction. The effectiveness of the proposed control system has been tested with two combination scenarios (BESS-DSM).

- **Case I:** Working Day (Industrial Site Operations).

On weekdays, the hourly load curve also shows two peaks during the day: the first at 8 a.m., caused by the start-up of industrial zones, and the other in the evening, when the majority of workers return home.

- **Case II**: Week-end (day of break).

On the Weekend, the load curve shows a peak in the evening and slightly high consumption during the day. Therefore, it would be beneficial to implement demand-side management programs for residential consumers.

The results of the simulation of peak management by coordinating DSM and BESS through a decision-tree-based controller are presented in the following figures.

Scenario-1 During the Working day (SOCi=20%)

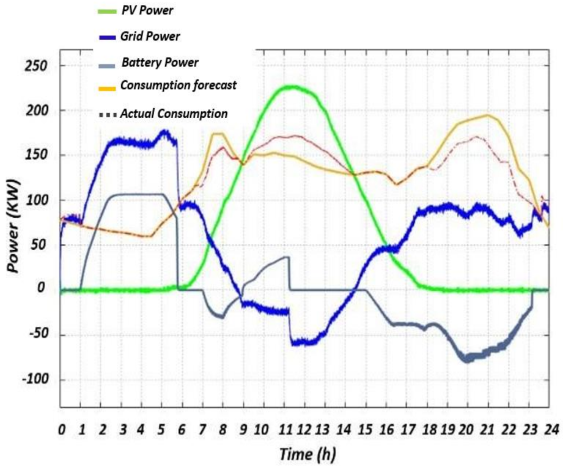

Fig. 9 Power variation microgrid during a day.

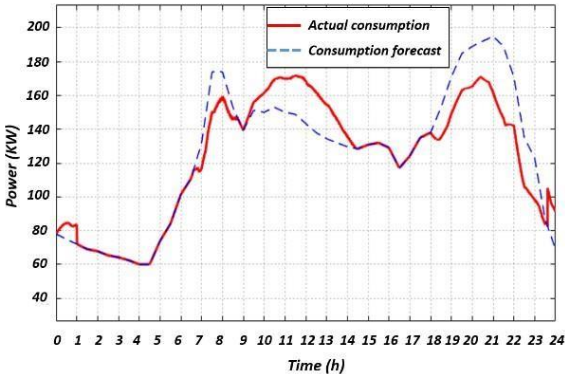

Fig. 10 Comparison of the power load before and after peak shaving and valley filling

Fig. 9 shows the variation of energy produced by the PV system, the grid, the storage system, and the total residential and industrial consumption demand during the day. It can be seen that the load curve shows several peaks and troughs throughout the day due to the large amount of energy consumed by commercial and industrial customers over relatively short time intervals of about two to three hours per day (at 8:00 a.m. and in the evening) as shown in Fig 10 in dotted line. These short intervals of high demand result in high demand fees for customers.

The result analysis shows that the management system schedules battery charging at night during off-peak hours from 1 to 6 a.m. at a low price to support the grid during peak hours (Fig. 9). At 7:00 a.m. a peak demand occurs due to the start-up of the industrial area, in this situation, the controller instructs the battery to discharge to a SOC of 75% and, at the same time, an incentive message is sent to the consumers to reduce their demand at that time, we notice that some customers participate in peak shaving as shown in Fig. 10 (Red).

At 8:00 a.m., the PV system starts producing energy to cover the demand, when the PV production exceeds the consumption, the excess energy is used by the management system to charge the BESS to its maximum SOC at a low cost (Fig. 8).

It can also be noticed that at the same time, consumers increase their power (by 18 kW) until 14:00 to match the production after receiving a tariff offer to benefit from the excess power, then the rest of the excess will be sent directly to the grid to make the most of the renewable energy. From 2 p.m. to 6 p.m., the photovoltaic production decreases, and the storage system discharges part of its power to limit the power demand on the grid.

From 7 p.m. to 9 p.m., demand rises rapidly when consumers enter their homes, the control system sends a discharge order to BESS to cover the demand, and most customers contribute to peak shaving by reducing their total loads by 20 kW. During the night, when the energy price drops (Fig. 8), we notice that demand increases slightly among some consumers to compensate for their peak-delayed tasks.

The following figures show the results of using our peak management approach in another scenario where the consumption contribution is different from the previous case.

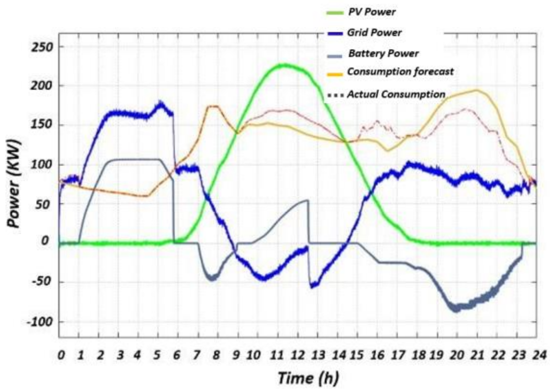

Fig. 11 Power variation microgrid during a day.

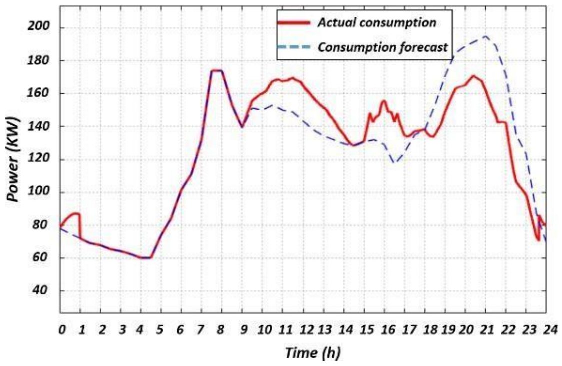

Fig. 12 Comparison of the power load before and after peak shaving and valley filling.

In this case, during the morning peak, when consumers are not responsive to utility proposals because of their electricity needs, the storage system is the only energy source that contributes to a reduction in peak demand of about 35 kW. Then, when generation exceeds demand, the batteries are fully charged and consumers increase their demands by 20 kW during this low-price period, and the rest of the excess is sent to the grid at full price.

From 3:00 p.m. to 6:00 p.m., customers shift their evening demand to this period (filling the valley) in order to switch off some appliances and smooth the load curve during the peak period. In this case, the load is fed from the grid and the storage system at the same time in order to respect the power limits imposed by the grid operator.

In the evening, from 6 p.m., when customers enter their homes and turn on their appliances, energy demand increases, which means that something must be done to control this spike through a system of incentives and direct load control or by shifting some load. It is therefore intuitive that even greater reductions can be achieved in a large group of residential households if energy providers encourage consumers to be more flexible, for example by offering subsidies for time-shifting appliances. To meet this peak demand, the implemented controller receives two simultaneous curtailment responses, the first from the consumers and the secondary from the storage system to smooth the demand at this very high price point. The aim is to keep the grid as reliable and as inexpensive as possible. During the night, i.e., during the off-peak period from 11 p.m. to 1 a.m., some customers feed their load to take advantage of the low energy price.

The results show a reduction in energy demand with a power of (38 kW). Note that the curve becomes steeper than the ideal curve (dotted line) (Fig.12).

Scenario-2 During Weekend (SOCi=20%)

On weekend days, i.e., when employees are at home, the majority of customers stay at home and the industrial area is out of operation.

Fig. 13 and Fig. 14 show the importance of peak shaving through a storage system and response to customer demand. At the beginning of the day, the load demand and battery charging are provided by the grid until 6 a.m., then the PV system starts to produce energy to meet the load when the controller detects excess power, it sends tariff offers to the customer to encourage him to increase his production, we can see that most connected consumers respond to this message and turn on their machines to take advantage of this moment and fill the off-peak hours, and then the whole production is sent to the grid, which brings a considerable economic gain.

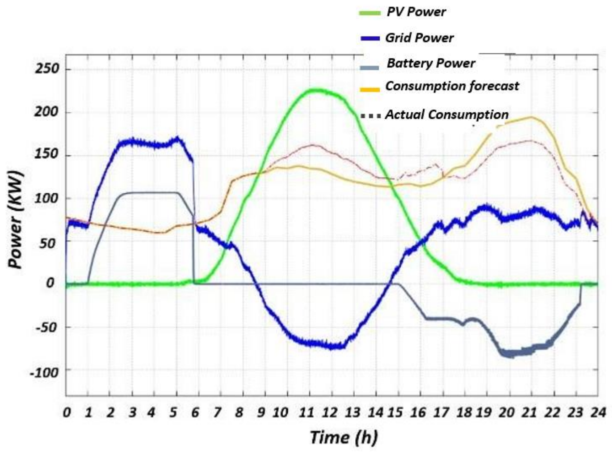

Fig. 13 Power variation microgrid during a day.

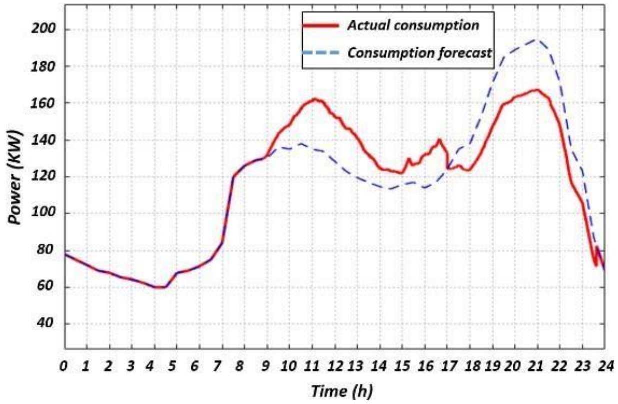

Fig. 14 Comparison of the power load before and after peak shaving and valley filling.

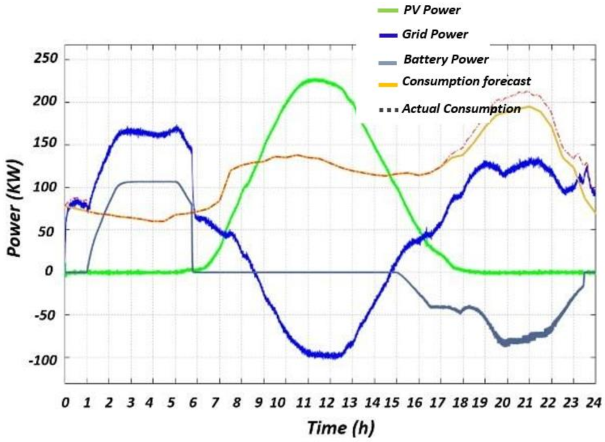

Fig. 15 Power variation microgrid during the day.

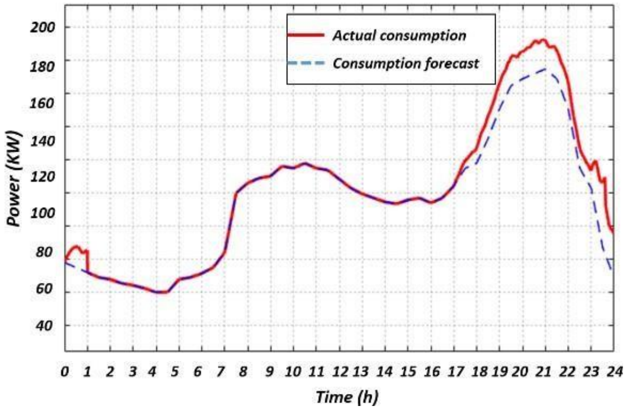

Fig. 16 Comparison of the power load before and after peak shaving and valley filling.

From this, we can see that the generation profile has flattened out due to the charging and discharging of the battery storage system and the contribution of consumers. Then, in the afternoon, some loads are moved before the peak, and we can see that the power has increased from the expected load from 3:00 to 5:00 p.m. and the photovoltaic power is not sufficient to supply the load. To do this, the storage system, in collaboration with the grid, must be used to supply part of the load.

When renewable energy production is low and the BESS cannot serve the loads, the system switches to grid-connected mode. In this mode, the system buys or sells electricity from the grid, depending on load conditions. In the afternoon, part of the load will be supplied by BESS, so it will be more cost-effective to buy electricity from the main grid than to reduce users' consumption.

Then, when consumers enter their homes and start using their loads, the energy demand reaches a peak of 220 kW, However, to solve this problem, we could consider incentive systems that encourage consumers to shave off a peak, as we can see in Fig. 16, where consumers reduce their consumption to avoid buying energy from the grid that has a high price. Fig. 16 shows the amount of peak reduction using demand response and battery storage systems.

In such a case, the centralized controller makes optimal decisions to reduce peak loads for the community of homes. Our strategy leads to a 40-kW reduction in peak load. This result confirms our hypothesis that the combination of BESS and DR has the greatest potential to reduce peak demand on the grid.

It can be concluded that this control system can change the shape of individual energy profiles and smooth the overall load without a significant increase in system power. While grid operators are usually concerned about extreme short-term peaks, analysis of the results shows that the energy profile tends to smooth out, which is the ultimate goal of the DSM program. The troughs are covered and the peaks are considerably reduced. Finally, it can be seen that the combination of the demand response program and the battery storage system ensures efficient demand management during the different periods of the day, which reduces the purchase of energy from the grid (peak shaving) and the energy expenditure at peak times. The results obtained in the different scenarios have shown that the use of the tree-based approach gives very good results when the consumer response to the DR program is favorable in the presence of BESS and among the management processes scenario 2 (Week-end day) produces the best results with a 40% reduction of power during the peak and massive use of photovoltaic production of the order of 15% during off-peak hours.

For working days scenario 2 produces the best results with several management processes a low-cost charging of the battery, a significant reduction of consumption during peak hours, and an optimal filling during off-peak hours. Comparing with results found in the literature e.g. [16] the amount of clipped power to be reduced from a value that varies between 5% and 10% in the game theory method to a reduction of 15 - 40% in our method. The financial advantages of this combination are greater. The above study concludes that a DSM technique can benefit both the utility and the user while contributing to the sustainable satisfaction of energy needs.

5 CONCLUSION

A decision tree-based peak management system has been presented in this paper to reduce/shift peak demand and cover troughs at low consumption times for a community of residential and an industrial area in a grid-connected microgrid. The results of the work demonstrate the performance, efficiency, and flexibility of the demand side management system in shifting peak demand and peak shaving by spreading the load over off-peak periods, load profiles will be smoothed. It can be concluded that the implemented controller reduces the peak load of the network by up to 54% and the most significant reduction in peak energy consumption was achieved in this case with a value of 30 kW. The proposed model significantly reduced the electricity bill, peak loads, and expenses of industrial customers. In this work, we have developed a state-of-the-art demand management technique. However, there are several potential avenues for developing our future research in this area. Aspects that could be considered in the future are to validate the developed models by real-time simulations to see the real behavior of the management system in front of energy fluctuations and to use algorithms based on artificial intelligence to find the best local and global solutions in optimal energy management.

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Nasreddine Attou: He received the diploma of Electrical Engineering degree from the University of Sidi-Bel-Abbes and The Master's degree, from the UDL of Sidi-Bel-Abbes, Algeria in 2016 and 2018 respectively. The Ph.D. from the UDL, SBA, Algeria, in 2022. He is currently interested in the Smart-grid, Electrical Vehicle, and renewable energy.

Sid-Ahmed Zidi: He received the diploma of Electrotechnical Engineering degree from the University of Science and Technology of Oran, Algeria. The Master's degree, from the UDL of Sidi Bel-Abbes, Algeria in 1994. The Ph.D. degree from the University of Sidi-Bel-Abbes, Algeria, in 2005. He is currently a professor within Djillali Liabes University. He is interested in the HVDC link, HVDC Light, smart grid and transient in power systems.

Samir Hadjeri: He received the diploma of Electrotechnical Engineering degree from the University of Science and Technology of Oran, Algeria. Received the Master's degree in Electrical Engineering from the University of Laval, Quebec, Canada, in 1990. The Ph.D. from the UDL, SBA, Algeria, in 2003. He was a teaching member. He is currently a professor within Djillali Liabes University.

Mohamed Khatir: He received the diploma of Electrotechnical Engineering degree and the Master degree, from the UDL of Sidi Bel-Abbes, Algeria in 2002 and 2006 respectively. The Ph.D. degrees from the University of Sidi-Bel-Abbes, Algeria, in 2010. He is currently a professor within Djillali Liabes University and He is interested in the HVDC link, smart grid and power systems. He is interested in the HVDC link, smart grid and power systems.