Hybrid Systems for Laboratory Building

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Abstract- A laboratory building connected to a hybrid microgrid operates either in interconnected or islanded mode. This microgrid contains a PV generator and an energy storage system. Energy production should be scheduled to provide the load of the building properly in order to coordinate optimally the generation exchange within the microgrid according to a defined methodology. In this paper, we address the problem of reducing the cost of energy bills under different system constraints and user decisions with an optimization model minimizing electricity costs of the utility grid is proposed. The energy storage system performances are scheduled according to the peak demand to minimize the using of the grid taking account the state-of-charge limits and charging /discharging of the energy storage system. A control technique is used for optimal scheduling of the power from the hybrid system. Simulation is implemented using GAMS, the obtained results confirm that the proposed hybrid system model can minimize the operation cost.

Keywords day ahead, PV generator, optimization, forecasting, multi objective scheduling, energy management.

1. Introduction

Using renewable energy on residence recently has increased due to an increase in consumption. The load demand will grow to 20–40% of the total energy consumption in the future and have an important factor in the electricity market [1]. The concept of Microgrid (MG), will change the traditional habit of using energy for customers and metering methods of electrical energy will be completely changed.

In order to give a priority to energy-saving, it is important to obtain the intelligence of devices, which will encourage and help the customers to use electric power carefully. A MG includes different energy resources, Battery Units, and load demand [2], [3]. For the proper operations of a MG, it is required an energy management strategy (EMS) which controls the power in the microgrid by scheduling the power bought/sold to improve their operation within the MG [4]. The MG configuration includes several types of converters used between different energy sources and load demand. Usually, DC-DC, DC-AC, and AC-DC converters are used in the production system due to the various natures of the output voltages. Several techniques have been studied to solve Energy management system (EMS) in MG, in the literature including, dual decomposition [5] to develop a distributed EMS in MG, neural networks [6], genetic algorithms [7], particle swarm optimization and game theory [8]. The using of those methods does not prove the optimal solution.

Besides, using optimization methods can ensure the optimal solution if it is feasible. However, they consider the Renewable Energy (RE) as non-dispatchable sources, and accordingly, Energy Storage Units are planned for balancing production and load demand [3], [9], [10]. Several types of energy storage systems could be used in MGs such as batteries, plug-in-hybrid vehicle (PHEV) batteries, supercapacitors and flywheels [11]. Significant research has been adopted in the integration of energy sources and ESS into the MG. The power production of different REs and ESSs needs to be coordinated to raise the reliability of the MG. In addition, the ESSs and REs are used into the MG. Optimizing energy management between different sources of MG, some categories of research have been conducted out. A control method of a DC microgrid developed [12], forming of a hybrid system (wind turbine, energy storage system, and DC load). The obtained result present different problems related to the integration of MG with the grid. The fluctuation energy requires ESSs in decentralized production system [13].

To keep a constant production between different sources like solar energy (PV), power plants and ESS an energy management strategy is suggested. This strategy tries to control the SOC level to a reference value [14]. However, improving the performance of the batteries the charge and discharge cycle is recommended [15]. Considering ESS with REs will contribute to the cost minimization and energy-efficient [16]. Charging and discharging mode of ESS have a necessary function in power management. In addition, to compensate the intermittent power fluctuations from the renewables, a control strategy for the storage system is proposed. [17]. However, an optimization technique including building management and control of active power is proposed [18-20].

The ultimate purpose in the proposed study is to maximize the use of PV, and consider the ESS as a secondary source when the pick demand reached. Minimize the operation of the grid, and the excess of power produced from PV will be sold into the network.

In this work, a novel structure of EMS for energy storage system-based hybrid microgrids is designed and tested to improve the optimal power references for DERs by taking account their operation modes.

- The EMS includes the modeling and optimization problem that proposed to minimize grid distribution costs, controlling the stage of charge for ESS.
- ON/OFF control strategy of the grid and ESS are modeled and tested.
- Adequate regulation of charging and discharging rates of batteries, to secure a proper running of the system during events,

The proposed strategy is able to provide a proper and adjustable solution to avoid the maximization of the grid operation, based on the high penetrations of PV and ESS.

The scheduling strategy provides an order of power charge and discharge to the ESS and also informs the SoC level requirements prior to the schedule period.

This study is directed as follows: Section II the operation of the MG with components specified as a case study, Section III comprises the modeling and the optimization, Section IV introduces and interprets the results and Section VI closes the work.

2. Problem description

The studied building is located in Kenitra, Morocco. Fig. 1 represents the view of the building. The building has 2 floors and averages of 36 students are working in the building during the day. The suggested system is located on the roof of this building.

Fig.1. The view of the studied Laboratory.

The studied building has three rooms and two offices in the all floors. Therefore, we aim to provide the electricity demand for this laboratory by utilizing the proposed hybrid system. It is assumed that the load demand is almost constant during the working day. Fig. 2 presents the daily load profile of the laboratory. Peak demand recorded during the daytime when students using the laboratory (i.e., 8 am–6 pm)

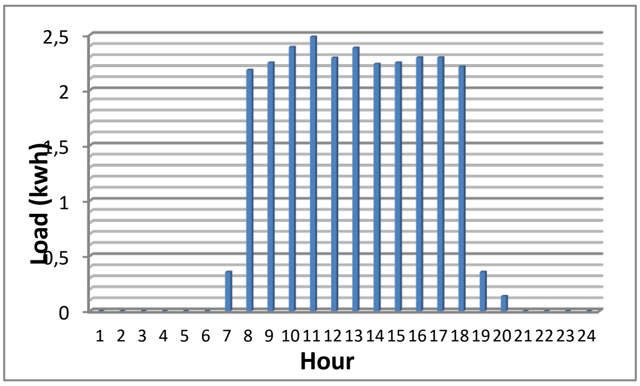

Fig. 2. Daily load profile for the studied building.

3. System description

The MG made up of solar energy with 2.4 KW, battery, and electrical loads. The main operations of the grid, operating quantities (e.g., storage capacity, power generation, weather data, and power demand) should be collected to the EMS through data communication infrastructure, and monitoring devices saved in the database of the EMS as historical data. The load demand is generally satisfied by the sum of the PV, and the battery. If the generator PV is over the demand, the surplus of energy is stored in the storage system. The grid is used when the output energy from PV and the battery cannot ensure the demand requirements. Generally, the grid can only provide the deficit of power required by the load. During the operation, data communication and devices perform this role with additional functions such as control actions, these actions can be secured by the EMS via data communication according to the device conditions [21].

Table 1. Specifications Adopted for the Simulated Inverter

Components	Description
OF	Objective function
T	Time scheduling
i	Index of units of Res
C_{sell}^{grid}	Cost of selling energy
C_{buy}^{grid}	Cost of buying energy
MG	Microgrid
ESS	Energy Storage Systems
EMS	Energy Management System
PV	Photovoltaic
SOC	State of Charge
$DERs$	Distributed Energy Resources
P_{pv}	Power from photovoltaic (kW)
P_{grid}	Power from the utility (kW)
P_{buy}^{grid}	Power bought from the utility (kW)
P_{sell}^{grid}	Power sold to the utility (kW)

P^{bat}	Power of the battery (kW)
P^{bat}_{max}	Maximum battery power level
P^{bat}_{min}	Minimum battery power level
$\eta^{bat,ch}$	Battery charging efficiency
$\eta^{bat,disch}$	Battery discharging efficiency
$\lambda_{grid}(t), B_t$	Binary variable

3.1. PV model

The PV generator is characterized by the current I and voltage V and by the equivalent circuit. Different mathematical models developed to represent the performance of PV [22-27]. In the literature different methods for PV model such as; current and voltage at MPPT and open circuit voltage which are used [28]. The power of PV generator is given as follows [30]:

$$P_{pv} = \eta_{pv} * A_{pv} * I_r \tag{1}$$

Where η_{pv} is the energy conversion efficiency of the module (power output from the system divided by power input from the sun); A_{pv} (m^2): The surface area of PV panels; I_r (W/m^2): The solar radiance. The generator efficiency is given by [31]:

$$\eta_{pv} = \eta_r * \eta_{pc} * [1-\beta(T_c - NOCT)] \tag{2}$$

With η_r present, the module efficiency; the efficiency of polycrystalline silicon has been used with13% [32]. η_{pc} account for power conditioning efficiency is equal to 0.9 with a perfect maximum point tracker [17]. β is the generator efficiency, ranging from 0.004 to 0.006. T_c is the cell temperature (C). $NOCT$ is the normal operating cell temperature (C) can be calculated when the cells operate under regular operating conditions [33].

Fig.3. Real site in laboratory.

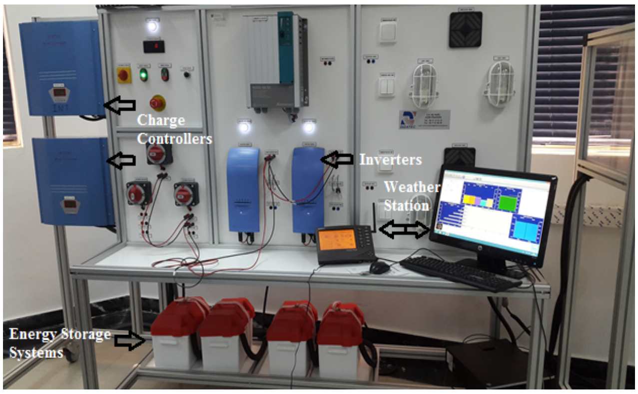

Fig.4. Microgrid site in Laboratory.

3.2. Data Collection

Data was collected by using a Weather Station (Vantage Pro 2) [34] (see. Fig.5). The data estimated for one day (24h) to be used in order to test the system presented in Figs. 3 and 4.

Fig.5. Hourly irradiance and temperature (C) for one day.

3.3. Forecasting

For the efficient operation of the EMS the forecasting of the PV generation and the load profile are important. Based on this, the EMS can decide in advance, the reserve quantity and risk strategies for grid operation. An adequate method to correct such quantities is studied [35] using real-time measurements. In Addition, ARIMA model, linear regression and polynomial curve fitting are used [36], [37] to predict load demand and energy production. In addition, Machine learning is used [38] as a technique for day-ahead wind power forecasting.

3.4. Tables

Table 2 presents the type of energy used for all the periods in the day. The shifting from a source to the other one is scheduled at the time required.

Table 2. Distribution energy per period in the day (24h).

Period (t)	00 :00-08 :00	08 :00-18 :00 (hrs)	20 :00-00:00 (hrs)
Energy product	OFF	$P_{grid} + P_{pv} + P^{bat}$ Buy energy from grid	OFF

Table 3. Parameter System

Parameter	Value
Photovoltaic rated power	2.4 kW
Energy Storage System rated power	2kW
State of charge initial condition	80%
State of charge max	100%

Table 3 set out system parameters for photovoltaic (PV), and battery that indicate the total ratings of renewable

Table 4. Parameter of the Battery

Battery unit	$\text{Energy}_{\text{min}}$	$\text{Energy}_{\text{max}}$	P_{MAX} ch	$P_{max}\ Disch$
2	100	1000	100	100

4. Proposed Scheduling and Optimization Model

The PV is considered to be connected supplying the entire load demand. However, the grid constraints are taken on consideration. The proposed model in this work solves the optimization problem by reducing the running cost of the grid and economic scheduling simultaneously. The execution of the approach is dependent on the control parameters and constraints handling. During the scheduling, SoC data and forecasting PV will be used to notify the scheduler of the available power. Based on this information's the optimization strategy based controller can facilitate the exchange power with the grid.

4.1. Optimization model

The optimization problem tackled in this study aims to reduce the grid cost by obtaining the optimal scheduling of power generation in the working day while responding to the total load demand. The selected study is a hybrid system composed PV-battery Microgrid turned to the self-consumption operation and selling energy to the grid. The control of the grid can be implemented using 'ON/OFF' control. Particularly, the power variables to be scheduled are the power of the battery, the power used from the grid, defined as a dispatchable source, and the power for the PV, which is defined as non-dispatchable source. The power profile correspond to the predicted production of the non-dispatchable source that, in this case, are equal to the predicted power in maximum power point (MPPT) for the output PV is delivered in Fig.1.

4.2. Objective function

The purpose is to find a proper solution of ON/OFF control of the grid that minimizes its operating cost. The PV is working as the principal source of energy supporting by the ESS. In addition, if a deficit is detected; the grid is turned on. Regarding the grid is switched ON/OFF and the PV and ESS battery is easily controlled to satisfy the demand, the objective function below is expressed as a mixed-integer programming. An optimization strategy considering energy storage Systems is proposed [39] to minimize energy production cost.

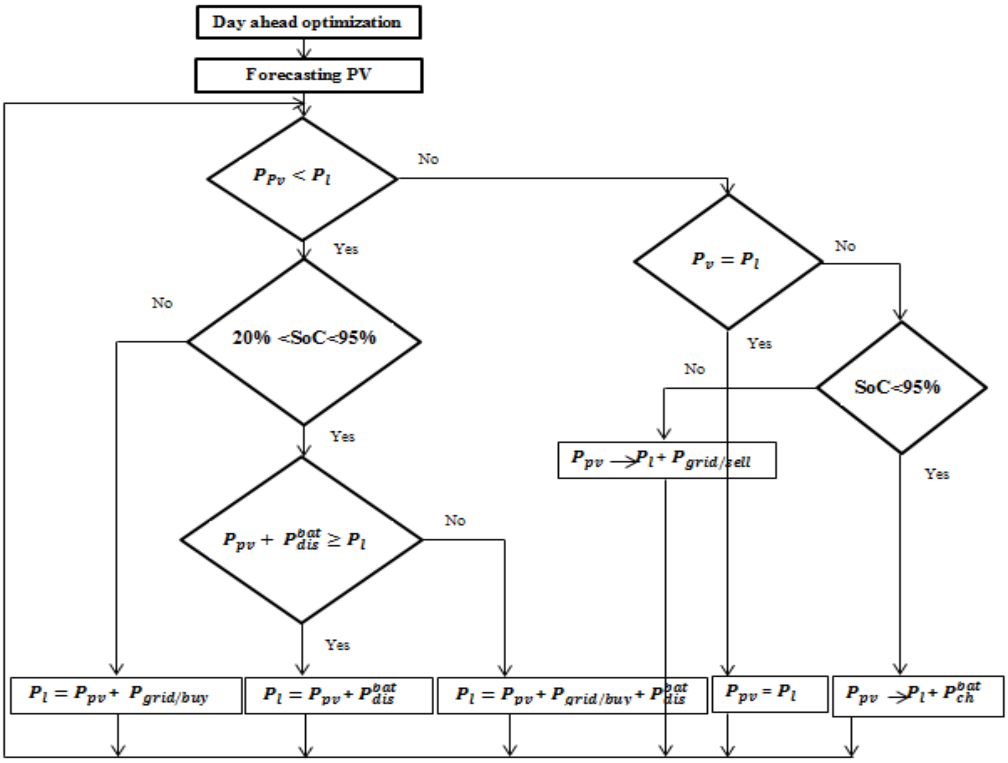

Fig. 6. Proposed strategy control.

$$\mathrm{OF} = \sum_{t=1}^{T}(P_{sell}^{grid}(t) * C_{sell}^{grid}(t) - P_{buy}^{grid}(t) * C_{buy}^{grid}(t)) * \lambda_t \quad (3)$$

where λ_t is a discrete-switching that enables to manage the energy by sending ON/OFF controls. λ_t = 0 signifies that the grid is switched off throughout t, while λ_t = 1 signifies that the grid is turned on.

Constraints: the power balance (4) is the first condition that the model should include between generators, renewables, storage systems and demand in the micro grid. The formulation can be shown as follow:

$$\sum_{t=1}^{T}(P_{sell}^{grid}(t) - P_{buy}^{grid}(t)) * \lambda_t + \sum_{i=1}^{2} P_{pv,i}(t) + P_{bat}(t) = P_l(t) \quad (4)$$

The first two terms are related to the energy absorbed from the grid and inserted into the grid respectively. In turns, the third expression is the energy provided by the renewables. In addition, the boundaries related to the power production of renewable energy and utility grids are defined as follow:

$$0 \le P_{pv,i}(t) \le P_{pv,i}^{max}(t) \quad (5)$$

$$0 \le P_{sell}^{grid} \le P_{max}^{grid}(t) * \lambda_t \quad (6)$$

$$0 \le P_{buy}^{grid} \le (1 - \lambda_t) * P_{max}^{grid}(t) \quad (7)$$

$$0 \le \lambda_t \le 1 \quad (8)$$

4.3. *Energy Storage System*

The generated power from the REs and the load demand at any interval t, define whether the battery is charging or discharging. The constraints related to the ESS are defined as follow:

$$P_t^{bat} = P_{t-1}^{bat} + P_{ch,t}^{bat} * \eta^{bat,ch} - P_{dis,t}^{bat} / \eta^{bat,dis} \quad (9)$$

where P_t^{bat} is energy storage in the battery, $P_{ch,t}^{bat}$ and $P_{dis,t}^{bat}$ are power charging and discharging of the battery, $\eta^{bat,ch}$ and $\eta^{bat,dis}$ are battery charging or discharging efficiency. Moreover, the boundaries related to the output of the ESS are defined as follow:

$$(1 - B_t) + B_t = 1 \quad \forall t \in T \quad (10)$$

$$0 \le P_{ch,t}^{bat} \le B_t * P_{ch.max,t}^{bat} \quad B_t \in \{0,1\} \; \forall t \in T \quad (11)$$

$$0 \le P_{dis,t}^{bat} \le (1 - B_t) * P_{dis.max,t}^{bat} \quad B_t \in \{0,1\} \; \forall t \in T \quad (12)$$

$$SOC_{min,t}^{bat} \le SOC_t^{bat} \le SOC_{max,t}^{bat} \quad (13)$$

$SOC_{min,t}^{bat}$ and $SOC_{max,t}^{bat}$ is the minimum and maximum SOC limit for battery at time t.

5. Results and Discussion

The aimed process control is executed by combining SPSS 20.0 software and GAMS environment solved by OSICPLEX solver working on an Intel®Core™i5 4200 CPU (1.73 GHz~2.30 GHz) PC with 8 GB RAM. It is connected to renewable sources and characteristic of ESS unit is given in Table II. The real data of load demand and solar generation at different hours are given in Fig.2 and Fig.5. The simulation study is taken out for one day. The power scheduling for all systems is performed in accordance with the general technical conditions in order to reduce the costs of the power grid. The proposed and studied strategy reduces the cost of the utility grid. Based on the economic scheduling strategy, each variation that happens during operation is accorded at the minimum cost among grid and energy storage systems, which can be controlled, so that the scheduled value can be met.

Generally, EMS take into consideration both economic and ecological factors. The performance of EMS is defined by presenting numerical results from the scheduling strategy. In addition, among the most important input data for power scheduling is the power forecast data for the planning horizon. The figures below present the forecasted and actual power of PV in 24 hours. The forecast has been provided with an acceptable accuracy.

5.1. *Forecasting Production*

In order to approve the performance of the proposed strategy, the power profile for PV shown in Fig. 10, have been collected based on real data of irradiance obtained from [35], as mentioned. The generation profiles used in the scheduling process are presented as $P_{forecasted}$ in Fig. 10, while the experimental verification is executed by using the $P_{real\,power}$ profile of PV. A controller included a power conditioning system and battery control system is connected directly to the Laboratory EMS. The grid is connected to the laboratory from a distribution transformer. It can absorb surplus power from Laboratory or can supply power to Laboratory.

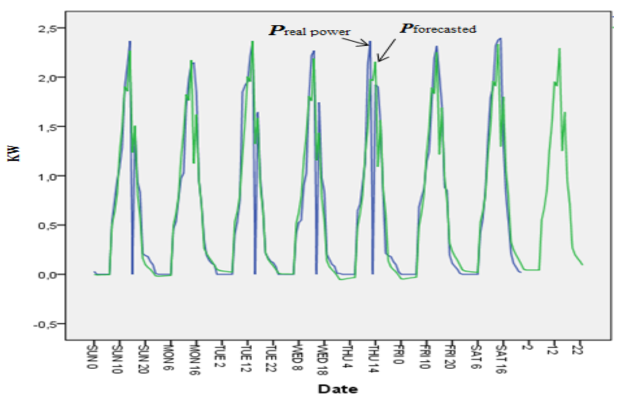

Fig.7. Input data: power profile and forecasted power shown in a) for PV.

In this case, the forecasting production is necessary for expecting in advance if the local energy is enough to supply the load without absorbing energy from the main grid.

5.2. Scheduling strategy

The implemented strategy control is able to maintain the main grid off as long as the storage system is fully charged, which means the battery can ensure the threshold value. From 20h to 7h, the PV power generation is 0 W. It reaches the peak amount (2.4 kW) from 13h to 15h. In addition, at 8h, electricity load of the laboratory starts consuming the power generation from PV.

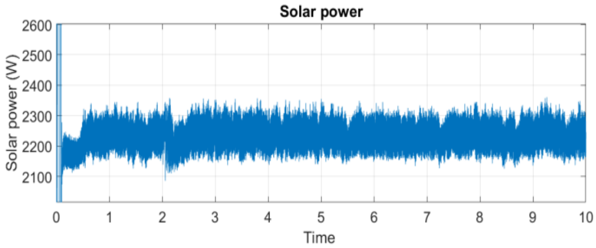

Fig.8. Power profile for PV generator.

For scheduling and experimental verification, the initial condition of SoC is set as 80%. Besides, the operation of the MG is performed with the EMS. The exchange power with utility grid will be represented in this section. As a typical load change in the laboratory, the amount of electric power load reaches peak consumption from 11h to 17h, between (2.94 kW and 3.19 kW). The energy storage battery supplies the insufficient power in the micro-grid is insufficient and absorbs surplus energy from the micro-grid when REs is surpassing the electric load. When there is an exceed energy in the microgrid, surplus energy is provided to the grid. During the weekend all energy produced by the REs will be sold to the grid in order to offset the deficit cost during the working week.

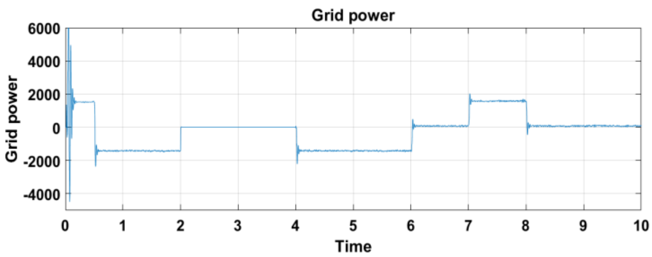

Fig.9. Exchange power with utility grid (W).

The obtained results point out that the PV generation has a high portion of supplying in energy production reaches the highest percentage of excess energy. Moreover, developing the performance of PV power allocates a basic part of the energy generation, and therefore, to develop the battery and inverter sizes. As can be observed, there are a surplus of energy during the day and just part of the energy is employed while some reduction is used. In this case, the profile is positive when microgrid injects power into the grid (sells) and negative when receives power (buys). It is possible to conclude that the surplus of PV is exchanged to the grid where the local production is sufficient to provide the load and thus, it is not needed to use the energy from the grid.

5.3. Power scheduling with battery

From the experimental results of the MG, the optimization strategy schedules to consume power from the grid during the day, when the consumption of energy increase and PV production and the battery cannot contribute to ensuring the energy demand. In addition, from 08h the part of the energy generated by wind energy is used in the local consumption and, at the same time, it is required to buy energy from the utility because the energy provided by the PV and battery are not enough to supply the demand. However, the battery is charged in the day before as presented in Fig. 12 for managing the inequality between PV generation and load demand during the periods.

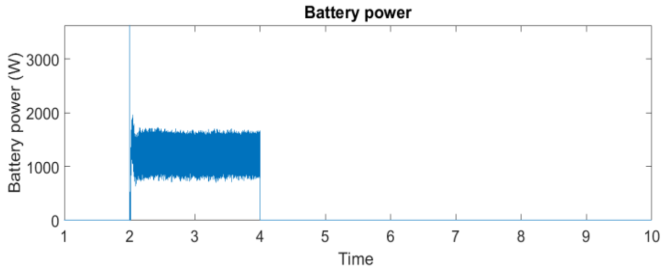

Fig.10. Power profile of the battery.

As can be pointed out, the battery is discharged when the power from the PV is low to the peak demand while it is charged when there is surplus power from the PV. The scheduled power profile, state of charge and the charging/discharging of the battery during the day are presented in Figures. 11 and 12.

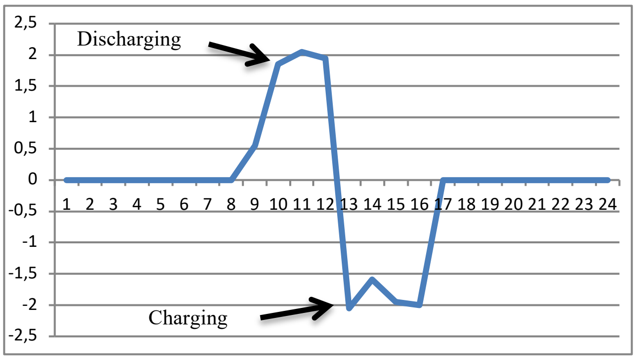

Fig.11. Charging/Discharging of battery during the day (24h).

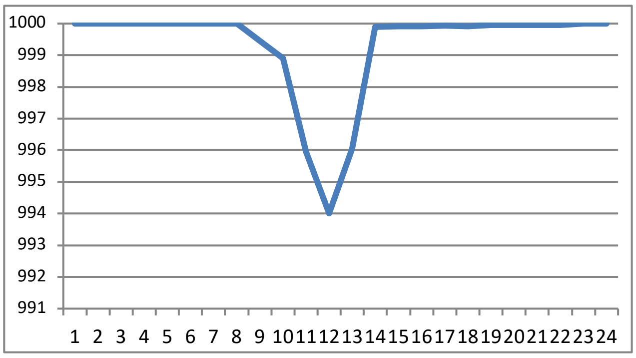

Fig.12. Energy of battery during the day (24h).

As can be noted, in Fig.12, the scheduling obtained by GAMS keeps the level of the battery to manage the power at the end of the day when the PV cannot generate the energy. The technical methods were validated experimentally by performing the MG with the EMS. It is possible to conclude that the EMS enables reducing the cost of the utility grid in the MG and also can include technical restriction for managing the storage system in the correct way.

6. Conclusion

The renewable energy generation forecast is a necessary part of an efficient MG based EMS operation. These energies, connected with a battery system, would contribute to system reliability, making it proper for stand-alone utilization.

In this study, the MILP was used to get the optimal solution for the economic utilities of the hybrid system installed in the laboratory. The proposed strategy has been executed to set optimal energy references for the energy sources of the microgrid. Besides, it has been done to decrease the running cost of the utility grid. Related to the results of the energy production, it was concluded that the PV generation produces 78.35% total energy per week. The monthly energy production was estimated to be 775.3kWh, while the monthly energy consumption is 496kWh. Moreover, it is noted that the hybrid system can supply 279.3kWh per month of excess power to the utility grid with the optimal solution.

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