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Article

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PV generator and energy storage systems for laboratory building

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Abstract

A microgrid contains a PV generator and energy storage system connected in a laboratory building. Power generation is scheduled to meet the load of the building to adjust optimally the generation exchange within the microgrid. In this study, the problem of decreasing the cost of energy under varied system constraints and user decisions is addressed. In addition, minimizing electricity costs of the utility grid is proposed as an optimization model. To minimize the using of the grid, ESS is scheduled according to the peak demand. The proposed algorithm schedules the charging and discharging of the battery. A switching control technique is implemented for optimal scheduling of the hybrid system. Simulation is performed using GAMS, the obtained results validate that the intended model can minimize the operation cost.

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Keywords: Day ahead; PV generation; Optimization; Multi objective scheduling; Energy management

1. Introduction

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 [1,2]. 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 [3]. Several techniques have been studied to solve Energy management system (EMS) in MG, in the literature including, dual decomposition [4] to develop a distributed EMS in MG, neural networks [5], genetic algorithms [6]. The use of those methods does not prove the optimal solution. Besides, using optimization methods can ensure the optimal solution if it is feasible. Energy Storage Units are planned for balancing production and load demand [2,7]. The power production of different REs and ESSs needs to be coordinated to raise the reliability of the MG. The ultimate purpose in the proposed study is

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Nomenclature

OF	Objective function
T	Time scheduling
i	Index of units of Res
$C_{\text{sell}}^{\text{grid}}$	Cost of selling energy
$C_{\text{buy}}^{\text{grid}}$	Cost of buying energy
MG	Microgrid
$P_{\text{min}}^{\text{bat}}$	Minimum battery power level
ESS	Energy Storage Systems
EMS	Energy Management System
PV	Photovoltaic
P_{pv}	Power from photovoltaic (kW)
$P_{\text{buy}}^{\text{grid}}$	Power bought from the utility (kW)
$P_{\text{sell}}^{\text{grid}}$	Power sold to the utility (kW)
P_{bat}	Power of the battery (kW)
$P_{\text{max}}^{\text{bat}}$	Maximum battery power level
$\eta^{\text{bat},ch}$	Battery charging efficiency
$\eta^{\text{bat},disch}$	Battery discharging efficiency
$\lambda_{\text{grid}}(t), B_t$	Binary variable

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.

- ON/OFF control strategy of the grid.
- Adequate management of charging and discharging rates of storage systems, to obtain a proper running of the system.

The proposed algorithm is suitable to offer a proper solution to minimize the power obtained from the grid, based on the maximization of PV and ESS generation. 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 addressed as follows: Section 2 the operation of the MG, Section 3 comprises the proposed algorithm of optimization; Section 4 introduces and interprets the obtained results and Section 6 conclusion 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.

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).

3. System description

The MG made up of solar energy with 2.4 kW, battery, and electrical loads. 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. However, the grid can only provide the deficit of power required by the load.



Fig. 1. The view of the studied laboratory.

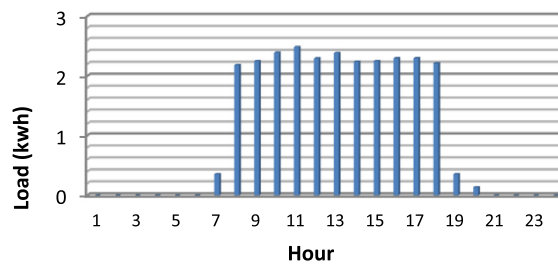


Fig. 2. Daily load profile for the studied building.

3.1. PV model

The PV generator is defined by the current I and voltage V and by the equivalent circuit. Various mathematical models developed in this context to describe the performance of PV [8,9]. The power of PV generator is given as follows [10]:

$$P_{pv} = \eta_{pv} * A_{pv} * I_r \quad (1)$$

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.

3.2. Data collection

Weather Station (Vantage Pro 2) [11] (see. Fig. 4) is used for collecting data. The data estimated for one day (24 h) to be used in order to test the system presented in Figs. 3 and 4.

3.3. Tables

Table 1 presents the kind of energy applied for all the periods in the day. The shifting from a source to the other one is scheduled at the time required.

Table 1. Distribution energy per period in the day (24 h).

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



Fig. 3. Real site in laboratory.



Fig. 4. Microgrid site in laboratory.

4. Proposed scheduling and optimization model

The PV is supposed to be connected meeting the load demand. However, the grid constraints are taken on consideration. The proposed model solves the optimization problem by reducing the running cost of the grid. During the scheduling, SoC data and PV generation will be used to inform the scheduler of the available power. Based on this information's the optimization strategy based controller can facilitate the shifting power with the grid (see Fig. 5).

4.1. Optimization model

This study aims to reduce the grid cost by achieving the optimal solution of the scheduling power in the working day while meeting to the total load demand. This study is formed as a hybrid system composed PV-battery Microgrid turned to the self-consumption and exchanging energy to the grid. The control of the grid can be performed using 'ON/OFF' control.

```

if ( $P_{pv} < P_l$ )
  if (Soc > 20%)
    if ( $P_{pv} + P_{dis}^{bat} \geq P_l$ )
       $P_l = P_{pv} + P_{dis}^{bat}$ 
    else
       $P_l = P_{pv} + P_{grid/buy} + P_{dis}^{bat}$ 
    end
  else
     $P_l = P_{pv} + P_{grid/buy}$ 
  end
else
  if ( $P_{pv} = P_l$ )
     $P_l = P_{pv}$ 
  else
    if (Soc < 95%)
       $P_{pv} \rightarrow P_l + P_{ch}^{bat}$ 
    else
       $P_{pv} \rightarrow P_l + P_{grid/sell}$ 
    end
  end
end

```

Fig. 5. Proposed algorithm.

4.2. Objective function

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.

$$OF = \sum_{t=1}^T \frac{P_{sell(t)}^{grid} - P_{buy(t)}^{grid}}{C_{sell(t)}^{grid} - C_{buy(t)}^{grid}} * 100 \quad (2)$$

Constraints: the power balance (2) is the first condition that the model should include between generators, renewables, storage systems and load demand in the micro grid. The formulation can be shown as follow:

$$\sum_{t=1}^T \frac{P_{sell(t)}^{grid} - P_{buy(t)}^{grid}}{C_{sell(t)}^{grid} - C_{buy(t)}^{grid}} * 100 * \lambda_t + \sum_{i=1}^2 P_{pv,i}(t) + P_{bat}(t) = P_l(t) \quad (3)$$

where λ_t is a switching control that allows to manage the energy by sending ON/OFF controls. $\lambda_t = 0$ means that the grid is switched off throughout t, while $\lambda_t = 1$ means that the grid is turned on. 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 PV and battery. In addition, the boundaries related to the power production of PV and utility grids are defined as follow:

$$0 \leq P_{pv,i}(t) \leq P_{pv,i}^{max}(t) \quad (4)$$

$$0 \leq P_{sell}^{grid} \leq P_{max}^{grid}(t) * \lambda_t \quad (5)$$

$$0 \leq P_{buy}^{grid} \leq (1 - \lambda_t) * P_{max}^{grid}(t) \quad (6)$$

$$0 \leq \lambda_t \leq 1 \quad (7)$$

4.3. Energy storage system

The generated power from the PV 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:

$$P_t^{bat} = P_{t-1}^{bat} + P_{ch,t}^{bat} * \eta^{bat,ch} - P_{dis,t}^{bat} / \eta^{bat,dis} \quad (8)$$

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:

$$(1 - B_t) + B_t = 1 \quad \forall t \in T \quad (9)$$

$$0 \leq P_{ch,t}^{bat} \leq B_t * P_{ch,max,t}^{bat} \quad B_t \in \{0, 1\} \forall t \in T \quad (10)$$

$$0 \leq P_{dis,t}^{bat} \leq (1 - B_t) * P_{dis,max,t}^{bat} \quad B_t \in \{0, 1\} \forall t \in T \quad (11)$$

5. Results and discussion

The aimed process control is executed by combining MATLAB 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 PV source and ESS characteristic unit is given in Table 2. 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. The figure below presents the actual power of PV in 24 h (see Fig. 6).

Table 2. Parameter system.

Parameter	Value
PV rated power	2.4 kW
ESS rated power	2 kW

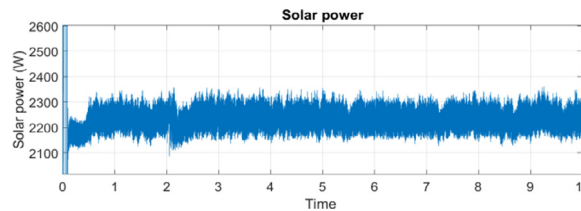


Fig. 6. Power profile for PV generator.

The achieved strategy control is able to control the main grid off as long as the storage system is fully charged, which means the battery can ensure the desired value. From 20 h to 7 h, the PV generation is 0 W. It reaches the peak amount (2.4 kW) from 13 h to 15 h. In addition, at 8 h, the load demand of the laboratory starts consuming the power generation from PV. Besides, the operation of the MG is performed with the EMS. The shifting power with the utility grid is presented in this section (see Fig. 7). The measured load demand leads to peak consumption from 11 h to 17 h, between (2.94 kW and 3.19 kW). The energy storage provides insufficient power in the micro-grid and receives surplus energy from the micro-grid when PV generation is surpassing the load demand. During the weekend all energy produced by the PV will be sold to the grid in order to offset the deficit cost during the working week.

The achieved aims prove that the PV generation has a huge part of satisfying in energy production reaches a significant percentage of excess power. As can be noted, there is an excess of power during the day and a part of this energy is operated while some reduction is applied. In this case, the profile is positive when microgrid injects

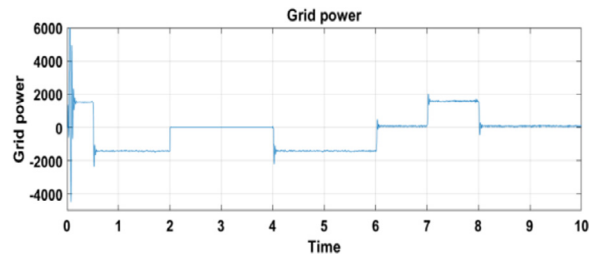


Fig. 7. Exchange power with utility grid (W).

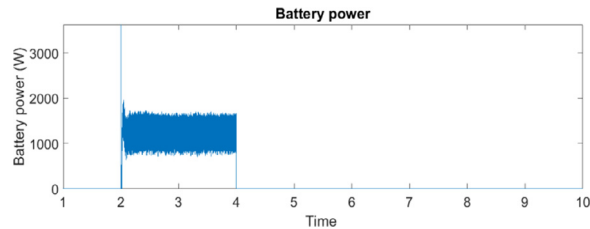


Fig. 8. Power profile of the battery.

power into the grid (sells) and negative when receives power (buys). As a conclusion, the excess of PV is shifted to the grid where the local demand is satisfied. As achieved results of the MG, the optimization strategy schedules to absorb power from the grid during the day, when the local demand of energy in growing and PV production with the battery cannot contribute to ensuring the local demand. Besides, from 08 h the part of the energy generated by PV is employed in the local demand and it is insufficient. It is needed to absorb energy from the utility. However, the battery is used in the next hours as presented in Fig. 8 to manage the inequality between PV generation and load demand during the periods.

The scheduled power of the charging/discharging of the battery during the day is presented in Fig. 9. As can be observed, the battery is discharged when the power stored from the PV is low while it is charged when there is high power in the PV.

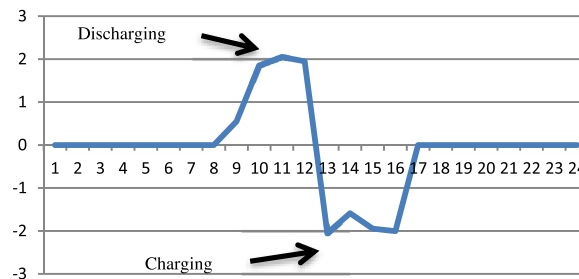


Fig. 9. Charging/Discharging of battery.

6. Conclusion

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 775.3 kWh, while the monthly energy consumption is 496 kWh. Moreover, it is noted that the hybrid system can supply 279.3 kWh per month of excess power to the utility grid with the optimal solution.

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