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Simulation of an Energy Management Algorithm for a house with Photovoltaic System in Bogotá

[1]Jorge Ospina, [2]Olga Ramos, [3]Dario Amaya

[1]Research Assistant, Mechatronic Engineering, Nueva Granada Military University, Bogotá, Cundinamarca, Colombia.
[2]Professor and Research, Mechatronic Engineering, Nueva Granada Military University, Bogotá, Cundinamarca, Colombia

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Address For Correspondence:
Jorge Ospina, Nueva Granada Military University, Mechatronic Engineering, Faculty of Engineering, 57+16500000 – Ext 1280, Bogotá Colombia.

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BACKGROUND
With the energy from renewable sources, it has been possible to supply homes and buildings of power without requiring of a connection to the grid through techniques and methods of energy management, achieving control and prolongation of autonomous days for the system.

OBJECTIVE
Propose an algorithm that allows the energy management of a battery bank taking into account the state of charge (SOC) of the system and solar radiation of the area. Allowing the permutation of the surplus energy from the solar panels in order to or redirect it to an inverter.

RESULTS
The results shown how the battery discharged over the first day until the reference value of 60 was reached. The algorithm then used the generated energy by the solar panels on the second day, to charge the battery and redirect the surplus energy when the battery reached the same reference value.

CONCLUSION
The energy management algorithm made possible the usage of the surplus energy for charging and/or redirecting the obtained power from the solar panels when required and according to parameters set by the user.

KEY WORDS
Energy Management, Solar Radiation, State of Charge, Storage System.

INTRODUCTION

Over the years, the use of fossil fuel based energies is decreasing due to its scarcity and the need to reduce the carbon emission into the atmosphere. To achieve this, strategic initiatives involving the replacement of the current energy generator and reduction of the negative effects are being implemented worldwide [1][2].

Solar and wind power have an easy installation and collection process, which puts them among the most widely used renewable energy by countries that wish to venture into alternative energies [3]. Recent research in renewable energy focus to improve the efficiency of photovoltaic systems, taking advantage of the high energy, economic and environmental potential solar energy offers [4][5].

Photovoltaic systems provide an effective solution to the growing problem of energy consumption. By storing the generated power in battery packs, allows an effective way to transport the energy to places where a connection to the grid is not possible [6][7]. Their implementation is strictly related to the environmental conditions of the area, such as solar radiation, affecting the base architecture of the system and the sizing of the storage system [8][9].

Besides the sizing, the PV systems must supply at least the minimum requirements of the load in order to ensure its proper functionality [10]. Due to the stochastic nature of solar radiation, the generated power has to be

several times higher than the required in order to prevent any type of power shortage [11]. The oversizing implicates higher costs when implementing this kind systems [12]. A solution to this problems is the implementation of different methods that affect the operation and sizing of the energy storage system, thus reducing the economic impact on the user [13][14].

Among the methods and studies regarding energy management are the control strategies that allow quantifying the requirements of the storage system for energy plants of different types, in order to prevent power fluctuation[15].

Likewise, there are studies in Spain where PV systems connected to grid use predictive control techniques to foresee and avoid future saturations of the battery bank. The deviations or shortage of power represent economical loss and need to be controlled to ensure the delivery of the fixed energy quota [16].

A different approach is an algorithm that proposes a power-per-hour constant as reference by predicting the different variations during the day thus ensuring a constant energy production [17]. Similarly, a study uses the solar radiation of the area to find the maximum and minimum values of the energy storage independent of the size of the plant, thus affecting its sizing and cost [18][19].

Based on the above, this paper proposes an algorithm that allows the energy management of a battery bank taking into account the state of charge (SOC) of the system and solar radiation of the area. Allowing the permutation of the surplus energy from the solar panels in order to or redirect it to an inverter.

Methodology:

The solar radiation signal for the first day is replicated to obtain the signal for the second day. These signals are used as input for the algorithm in order to monitor the behavior of the energy management system for two days. In Figure 1, both radiation signals can be seen.

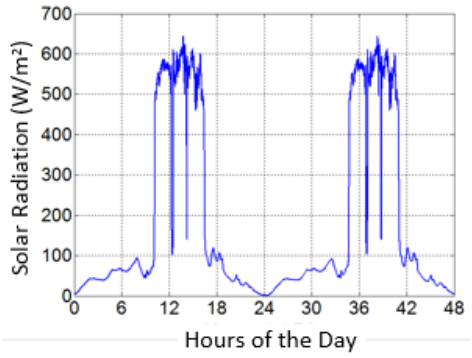

Fig. 1: Solar radiation signals for two days.

To simulate the behavior of an energy bank connected to a PV system, lithium-ion batteries are created using the simulation tool Simulink™. They are connected in a series-parallel configuration (4 batteries in series each with 8 cells in parallel) with a capacity of 810 AH, in order to supply the required energy to the load for two days. By using the variable of the State of Charge (SOC), it is possible to monitor and control the charge and discharge of the battery bank. A reference value of the SOC is chosen, in order to establish the maximum allowed discharge value the battery bank can reach. The configuration of the system is shown in Figure 2.

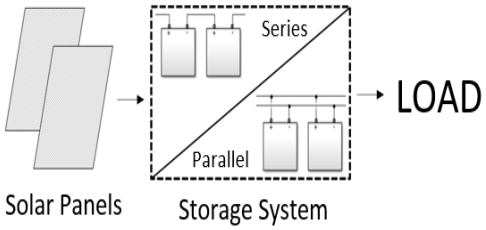

Fig. 2: PV and storage system configuration.

To make the power adjustment of the batteries, an algorithm is programmed based on equation 1, which is commonly used in storage management systems [17].

$$P_{es} = P_{pv} - P_{Load} \quad (1)$$

Where P_{es} is the required battery power to supply the load, P_{pv} is the generated power from the solar panels and P_{Load} is the power consumed by the house at a given moment.

The scheme of the algorithm is then created by implementing the variables affecting the system to the previous equation. The resulting scheme can be seen in Figure 3.

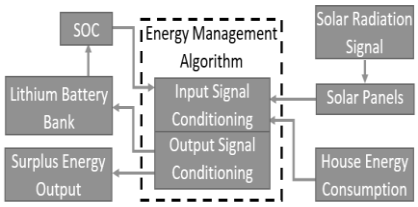

Fig. 3: Scheme of the energy management algorithm.

From the acquired values, the algorithm does the conditioning of the signals in two stages: the input signal conditioning and the output signal conditioning. In the first stage, the value of the generated power from the solar panels and energy consumption are evaluated using the conditions of equation 2.

$$P_{es}{}^{*}(t) = \begin{cases} P_{es}, & P_{pv} \leq Load \\ -P_{es}, & P_{pv} > Load \end{cases} \tag{2}$$

The result of the evaluation indicates the charging/discharging state of the storage bank. Where a positive value means that energy is being consumed while a negative value means the system is charging.

For the second stage of conditioning, the reference SOC value is compared with the instantaneous value of SOC. This comparison is made by evaluating the result of the first stage and the conditions given in equation 7.

$$P_{es}(t) = \begin{cases} P_{es}{}^{*}, & SOCbat \leq SOCref \\ P_{es}, & SOCbat > SOCref \end{cases} \tag{1}$$

The result of the process determines how the surplus energy is going to be used by the system. The algorithm manages the power given the results by redirecting the surplus energy to the inverter or charging the batteries.

Results:

By applying the algorithm with the values of the house energy consumption, the generated power from the solar panels and battery bank, the following graphics with the behavior of the system were obtained.

The first test was made using a SOC reference value of 60, due to that value being used when sizing the battery bank for the configuration and being commonly used as discharge point in PV systems.

The power consumption signal for two days, as well as the evolution of the SOC of the battery bank and the surplus energy can be seen in Fig. 2.

In the upper part, is shown how the battery discharged over the first day until the reference value of 60 was reached. The algorithm then used the generated energy by the solar panels on the second day, to charge the battery and redirect the surplus energy when the battery reached the same reference value.

The same test was performed with a SOC reference value of 80 to evaluate the behavior of the system at different SOC values.

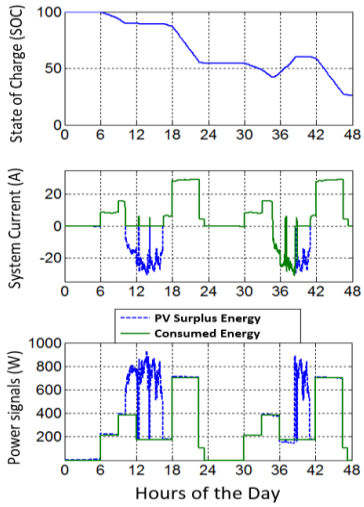

Fig. 2: Results of the energy consumption test with a reference SOC value of 60.

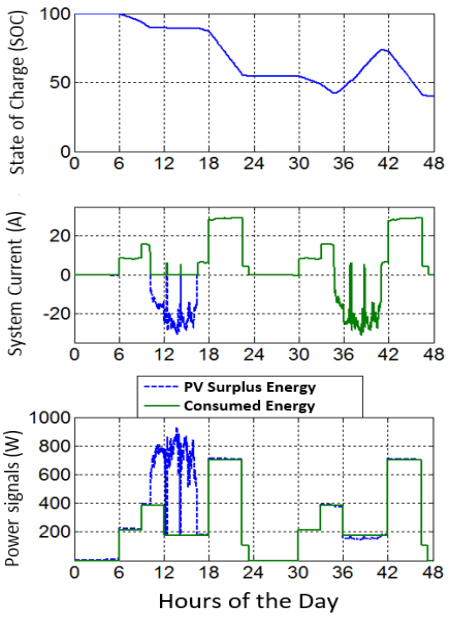

Fig. 3: Results of the energy consumption test with a reference SOC value of 80.

In Fig. 3, the results of the second test are shown. Similar to the previous test, the energy was redirected during the first 24 hours until the selected SOC value was reached. On the second day, all the energy generated by the PV system was used to charge the batteries.

The system ended with a higher value of SOC but with no surplus energy on the second test, unlike the first test that maintain the system in the reference SOC value and redirected the generated energy.

The surplus energy can be used to feed the grid or be connected to another load, depending of the preferences of the user. For the experiment, the energy was converted to an AC signal.

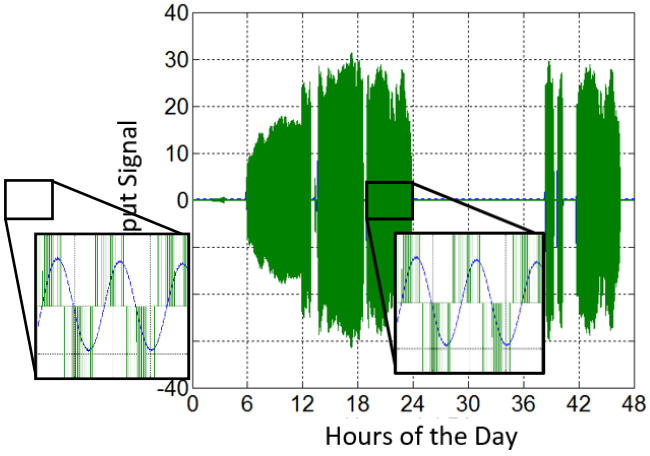

Fig. 4: Resulting AC Signal from the surplus energy at a SOC level of 60.

The surplus energy redirected during the day in the first test was converted using a monophasic wave inverter, in order to obtain an AC signal to supply another load according to the needs of the user. The AC signal can be seen In Fig. 4.

Conclusions:

The energy management algorithm made possible the usage of the surplus energy for charging and/or redirecting the obtained power from the solar panels when required and according to parameters set by the user.

The minimum SOC value can be found with the behavior graphs of the system at different levels of radiation, in order to redirect a daily surplus energy, supply the required power to the house and maintain the battery bank charged.

By applying the management algorithm along with predictive methods is possible to know the behavior and consumption of the house for more days.

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