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Power management strategy for photovoltaic system with hybrid storage (Batteries/Supercapacitors)

Z. Mokrani[1], D. Rekioua[1], N. Mebarki[1], A. Oubelaid[1], K. Kakouche[1], T.Rekioua[1]

[1] Laboratoire LTII, Faculté de Technologie, Université de Bejaia, 06000 Bejaia (Algerie)
Phone/Fax number:+0021334 81 68 19, e-mail: **djamila.ziani@univ-bejaia.dz**

Abstract. This paper is presented in regard to the interesting continuous interest attributed to photovoltaic energy systems (PESs). To this aim, a study of an isolated photovoltaic system with hybrid storage (HS) is presented. Supercapacitors (SCs) are typically used because of their high specific power density.. Combining batteries and supercapacitors is a solution to maximize their benefits. In this work, the HS is a combinaison of batteries and supercapacitors. The goal of this work is to build a new management algorithm. This aforementioned technique will ensure the control of energy flow between system power sources. Furthermore, it will regulate the charge/discharge cycles of the proposed HS by maintaining their state of charge (SOC) between a desired minimum and maximum values. The proposed method is simple, efficient and it is not computationally heavy. The obtained simulation results are satisfactory and show the interest and effectiveness of the proposed management strategy.

Key words. Photovolaic, Power management strategy, Batteries, Supercapacties.

1. Introduction

Renewable energy systems are more widely used especially in remote locations [1-3]. In this case, a storage system is required [4-5]. The energy storage system is crucial to maintaining the proper power balance between the photovoltaic system and the demand for the charge [6, 7]. In terms of research analysis, the hybrid energy storage system (batteries and supercapacitors) has garnered the most interest among the many energy storage system types due to its numerous benefits and good performances. The supercapacitor primarily manages transient variations in power, whereas the battery is used to supply energy needs over an extended period of time [8, 9]. This increases the battery's cycle life. For power management of photovoltaic systems, many papers deal with this topic [10-19]. The focus is mainly based on controlling powers of the different sources, while supplying the load and protecting the storage system. A stand-alone photovoltaic system with batteries is optimized and controlled through power management.

The objective of this work is to present a management algorithm that allows for the control of energy transfers between various system components and the regulation of the charge and discharge process of storage by maintaining the SOC of the batteries and the supercapacitors between a range of minimally and maximally acceptable values. An application in Bejaia, a Mediterranean region with significant solar irradiation potential, is demonstrated for a day profile. To show that the suggested power management algorithm operates as intended, simulation findings are presented.

2. Proposed System

The system (Fig.1.) includes Photovoltaic panels, DC/DC converter and hybrid storage (batteries/supercapacitors). Battery storage allows for long-term energy storage. In order to reduce the risk to the batteries, supercapacitors can quickly absorb current variation..

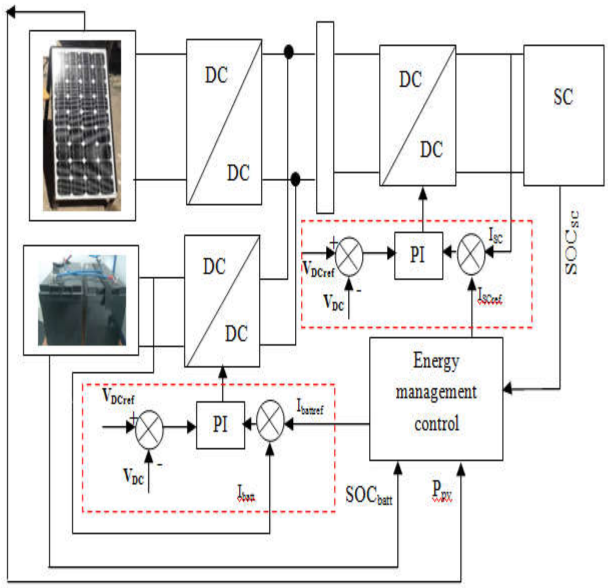


Fig. 1. Proposed system

a boost converter connected to the PV panels can increase the voltage of the solar panels and provide it to the DC bus. The use of a Pertur. & Observ maximum Power Point Tracking (MPPT) algorithm allows to optimize the power generated by the PV panels by adjusting the operating point of the PV panels to the maximum power point (MPP). This will maximize the power that can be extracted from the PV panels.The batteries and supercapacitors are connected to the DC bus, this means that the power from the PV panels, supercapacitors, and batteries is all connected to the DC bus and can be used to provide power to the load. The control and management strategy will use the MPPT algorithm to ensure that the PV panels are operating at their maximum power point, and it will also use the power flow control strategy to ensure that the power from the different sources is used in a coordinated manner to meet the power needs of the load.

A. Photovoltaic generator

The electrical current is [6], [20-25]:

$$I_{pv} = I_{ph} - I_0 \times \left[exp\left(\frac{q \times (V_{pv} + R_s \times I_{pv})}{A \times N_s \times K \times T_j} \right) - 1 \right] - \frac{V_{pv} + R_s \times I_{pv}}{R_{sh}} \quad (1)$$

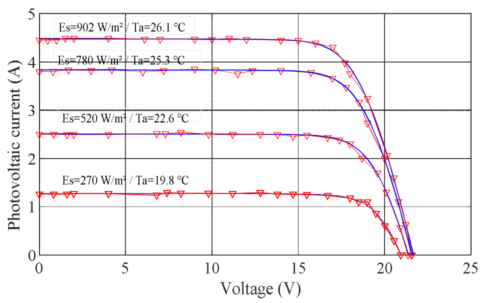
Where: I_{ph} photo-current, I_d diode-current and I_{Rsh} shunt resistance current.

Experimental tests (Fig.2) have been made to establish PV electrical characteristics (Fig.3) using panel parameters (Table1.).

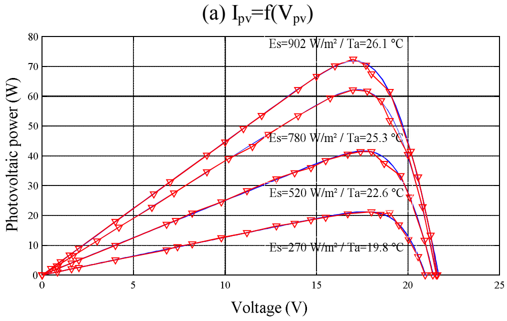
Fig.2 Experimental test bench

Table.1. PV Panel Parameters

Parameters	Values
Photovoltaic power	80 Wp
Maximum current at PPM	4.65 A
Maximum voltage at PPM	17.5V
Short circuit current	4.95A
Open circuit voltage	21.9V
Temperature coefficient of short-current	3 mA/°C
Voltage temperature coefficient of short-current	-150mV/°C



(a) I_{pv}=f(V_{pv})



(b) P_{pv}=f(V_{pv})

Fig.3.Electrical characteristics

B. Battery model

In our work the following model (Fig.3) has been used with the different equations of voltage and state of charge [1], [7].

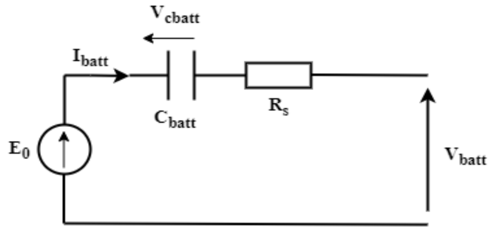


Fig.4. R-C model of the battery

$$\begin{cases} V_{batt} = E_0 - R_{batt} . I_{batt} - K \int \left(\frac{I_{batt}}{Q} \right) dt \\ SOC = 1 - \frac{I_{batt} . t}{C_{batt}} \end{cases} \quad (2)$$

C. Supercapacitors model

In literature, different models have been proposed for modeling the behavior of a supercapacitor (SC) in a circuit with several resistance-capacitance (RC) branches. These models take into account the effect of the voltage across the SC on the capacitance value. [26, 27]. The model used in our work is the equivalent electric circuit with two RC branches (Fig.5).

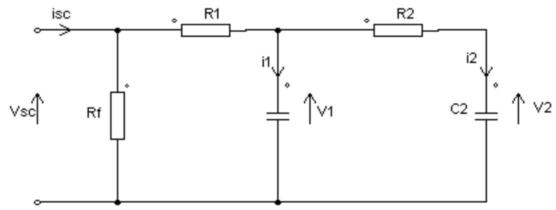


Fig. 5. Two branches model.

It consists of two branches. The R_1C_1 branch defines the immediate behavior of the supercapacitor during fast charge and discharge cycles within seconds [8,9]. The second branch R_2C_2 is the slow branch. The following equations describes the model [8]:

$$\begin{aligned} U_{SC} &= N_{SC-s} . V_{SC} = N_{SC-s} (V_1 + R_1 . I_{SC}) \\ &= N_{SC-s} (V_1 + R_1 . \frac{i_{SC}}{N_{SC-p}}) \end{aligned} \quad (3)$$

With U_{sc} and I_{sc} are the SC's pack voltage and current respectively. V_{sc} and i_{sc} are the elementary supercapacitor voltage and current respectively.

The voltage V_2 in the secondary capacity C_2 is given by:

$$\begin{aligned} V_2 &= \frac{1}{C_2} \int i_2 . dt \\ &= \frac{1}{C_2} \int \frac{1}{R_2} (V_2 - V_2) . dt \end{aligned} \quad (4)$$

Q_2 is the instantaneous charge of C_2, we have:

$$Q_2 = \int i_2 . dt \quad (5)$$

The current i_1 in the main capacitor C_1 is given as:

$$i_1 = i_{SC} - i_2 \quad (6)$$

3. Proposed Power management

The power management system uses a power flow control strategy and utilizes two DC/DC converters that are configured as buck-boost converters. These converters control the flow of power to ensure that the system operates efficiently and effectively(Fig.5).

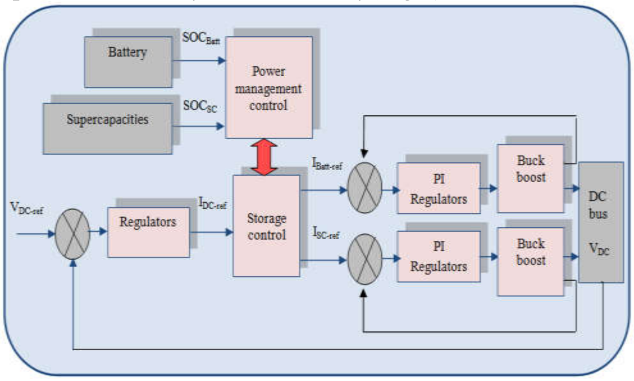


Fig.5. DC bus control

The load power demand is given as:

$$P_{load} = P_{PV} \pm (P_{cap} + P_{batt}) \tag{7}$$

ΔP is the variation of the power demand

$$\Delta P = P_{load} - P_{pv} \tag{8}$$

The algorihtm is given as (Fig.6). Six modes are possible:

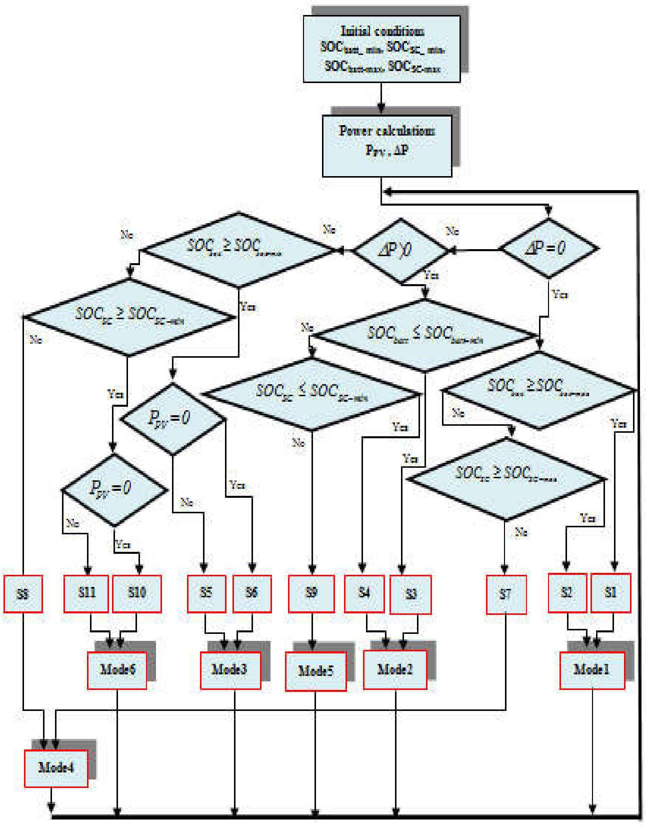


Fig. 8. Chart of the PV system with hybrid batteries/supercapacitor storage

1. Mode1.

- **Senario 1**: the batteries are fully charged so we disconnect them.

$$\begin{cases} \Delta P = 0 \\ P_{Load} = P_{pv} \\ SOC_{batt} \geq SOC_{batt-max} \end{cases} \tag{9}$$

- **Scenario 2**: the battery are fully charged so we disconnect them.

$$\begin{cases} \Delta P = 0 \\ P_{Load} = P_{pv} \\ SOC_{SC} \geq SOC_{SC-max} \end{cases} \tag{10}$$

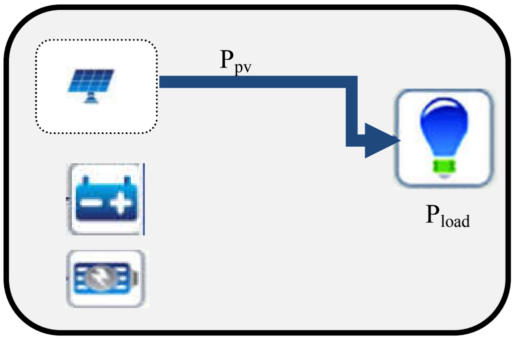


Fig.6. Scenarios 1 and 2 in mode1

2. Mode 2

- **Scenario 3**: the photovoltaic power is higher than the power required by the load, the excess power ΔP will be used to charge the batteries, in this case the load will be supplied by the generated photovoltaic power.

$$\begin{cases} \Delta P \rangle 0 \\ P_{Load} = P_{pv} \\ SOC_{batt} \leq SOC_{batt-min} \end{cases} \tag{11}$$

3. Mode 3

- **Scenario 4**: the photovoltaic power is higher than the power required by the load, so the batteries will be charged by the excess power ΔP, in this case the load will be supplied by the generated photovoltaic power.

$$\begin{cases} \Delta P \rangle 0 \\ P_{Load} = P_{pv} \\ SOC_{batt} \leq SOC_{batt-min} \end{cases} \tag{12}$$

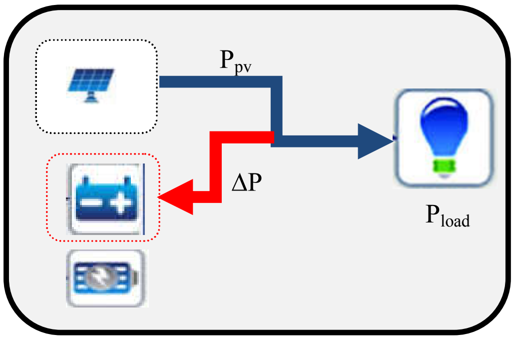


Fig.7. Scenario 3

- **Senario 5**: the photovoltaic power is higher than the power required by the load, so the supercapacitor will be charged by the excess power ΔP, in this case the load will be supplied by the generated photovoltaic power (Fig.9).

$$\begin{cases} \Delta P > 0 \\ P_{Load} = P_{pv} \\ SOC_{SC} \leq SOC_{SC-min} \end{cases} \quad (13)$$

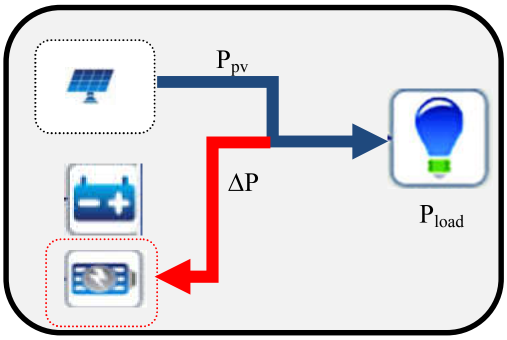


Fig.9. Scenario 4 in mode3

4. **Mode 4**

Scenario 5: The photovoltaic power is less than the power of the load, and the batteries are charged, the photovoltaic power will be compensated with the power of the batteries to provide the load power (Fig.10).

$$\begin{cases} \Delta P < 0 \\ P_{PV} \neq 0 \\ SOC_{batt} > SOC_{batt-min} \end{cases} \quad (14)$$

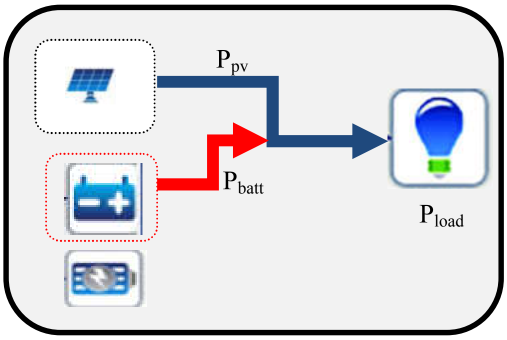


Fig.10. Scenario 5 in mode4

Senario 6: The photovoltaic power is less than the power of the load, the photovoltaic power is zero and the batteries are charged and supplied the load (Fig.11).

$$\begin{cases} \Delta P < 0 \\ P_{PV} = 0 \\ SOC_{batt} > SOC_{batt-min} \end{cases} \quad (15)$$

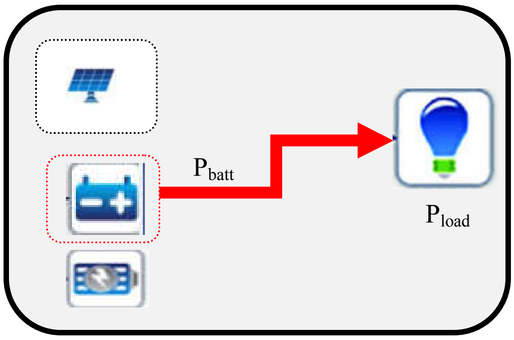


Fig.11. Scenario 6 in mode4

5. **Mode5**

- **Scenario 7:** the load is supplied by the generated photovoltaic power the batteries and supercapacitor are discharged so we disconnect them (Fig.12)..

$$\begin{cases} \Delta P = 0 \\ P_{Load} = P_{pv} \\ SOC_{batt} < SOC_{batt-min} \\ SOC_{SC} < SOC_{SC-min} \end{cases} \quad (16)$$

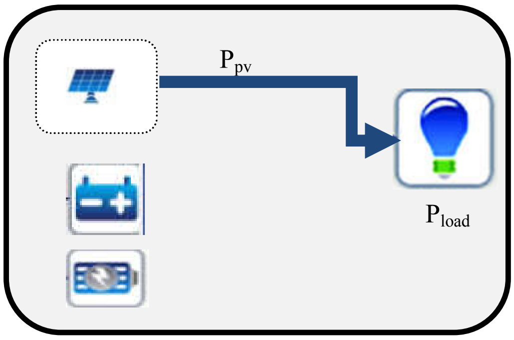


Fig.12. Scenario 7 in mode5

- **Scenario 8:** the photovoltaic power is less than the load power, the batteries and SCs are discharged, so we disconnected them and the photovoltaic power is not sufficient to supply the load (Fig.13).

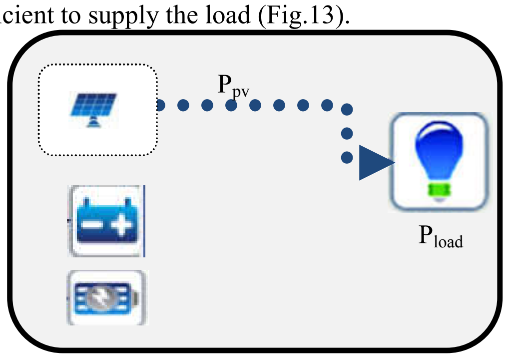


Fig.13. Scenario 8 in mode5

6. Mode 6

-Senario 9: the photovoltaic power is higher than the power required by the load, the batteries and supercapacitor are charged, so the excess power ΔP can be sent to a dump load (Fig.14).

$$\begin{cases} \Delta P > 0 \\ P_{Load} = P_{pv} \\ 0 \leq SOC_{batt} \leq SOC_{batt-min} \\ 0 \leq SOC_{SC} \leq SOC_{SC-min} \end{cases} \quad (17)$$

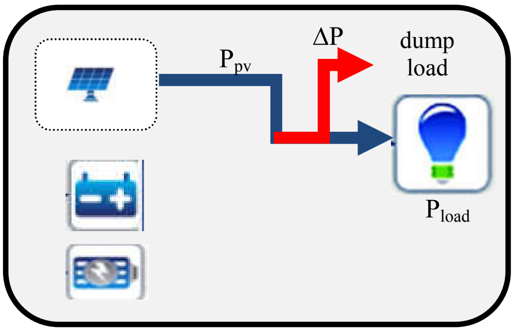


Fig.14. Scenario 9 in mode6

7. Mode 7

- **Scenario 10:** the photovoltaic power is less than the power of the load, the SCs are charged and the photovoltaic power is zero, in this case the load is supplied by SCs (Fig.15).

$$\begin{cases} \Delta P \langle 0 \\ P_{PV} = 0 \\ SOC_{batt} \rangle SOC_{batt-min} \end{cases} \quad (18)$$

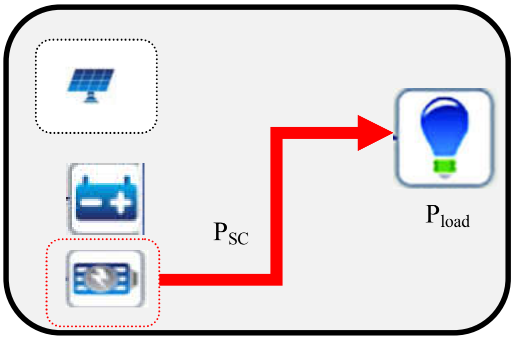


Fig.15. Scenario 10 in mode7

- **Scenario 11:** the photovoltaic power is less than the power of the load, the SCs are charged and the photovoltaic power is not null, so the load is supplied by SCs and PV power (Fig.16).

$$\begin{cases} \Delta P \langle 0 \\ P_{PV} \neq 0 \\ SOC_{SC} \rangle SOC_{SOC-min} \end{cases} \quad (19)$$

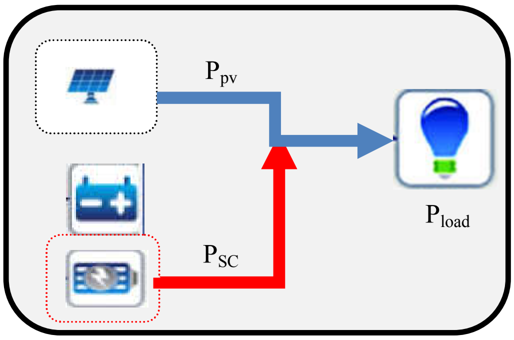


Fig.16. Scenario 11 in mode7

4. Simulation results:

To confirm the validity of the proposed control and energy management strategy, the studied system depicted in Fig.1 is simulated using the MATLAB/Simulink. The results of the simulation are obtained and presented. The measured profiles of solar irradiation (Fig.19) and ambient temperature (Fig.20) of a profile day have been introduced.

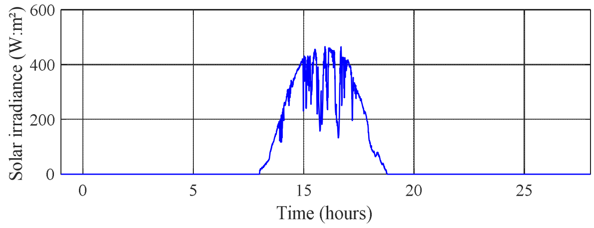


Fig.19. Solar irradiance

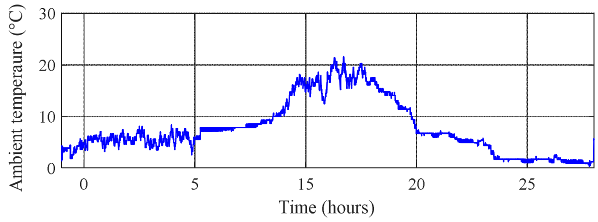


Fig.20 Ambient tempertaure

The DC voltage is well controlled whatever solar irradiation (Fig.21).

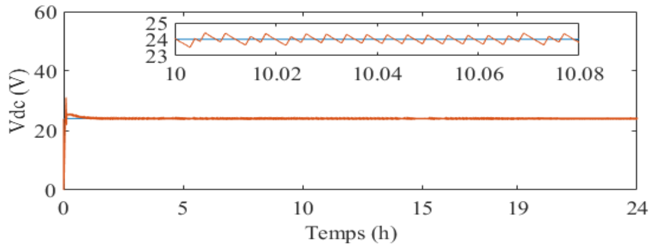


Fig.21. DC voltage

Battery voltage and battery state of charge are shown respectively in Fig.22 and 23. The SOC is maintained between 30% and 90%.

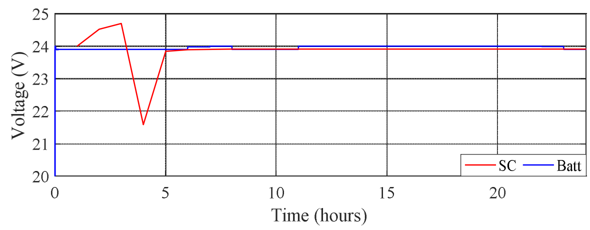


Fig.22. Voltage battery and supercapacitor

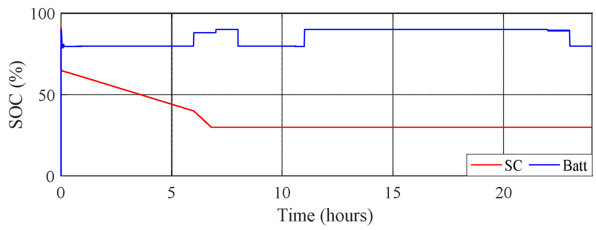


Fig.23 Battery and supercapacitor state of charge

The different powers are represented in Fig.24.

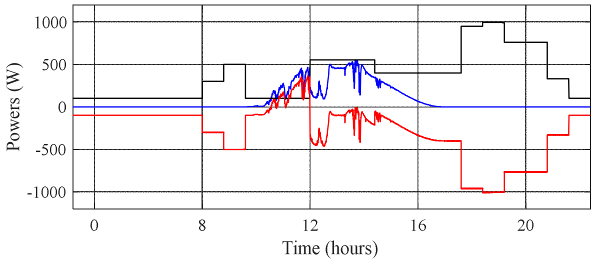


Fig.24. The different powers

5. Conclusion

This study presents a photovoltaic system power management with hybrid storage. The major components' properties and the system setup are provided. Results from simulations have been used to confirm the proposed system. The findings obtained confirm the effectiveness of the chosen control method. Regardless of the weather, the suggested power management enables us to operate the system as efficiently as possible with high photovoltaic system performance. This fact ensures that the suggested application will work as intended.

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