European Journal of Electrical Engineering
Vol. 24, No. 4, August, 2022, pp. 195-200
Journal homepage: http://iieta.org/journals/ejee

Battery Storage System Design Using PWM Current and Voltage Controllers

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https://doi.org/10.18280/ejee.240404

Received: 19 June 2022
Accepted: 1 August 2022

Keywords:
photovoltaic system, lithium-ion battery, boost chopper, bidirectional DC-DC converter, PWM controller

ABSTRACT

Today, energy storage systems are strongly present both in industry and for individual applications, especially in on-board systems where an autonomous source of energy is required for power. Energy needs as well as the search for efficient means for its storage have become a very important research axis. Solar battery storage allows to store electricity generated from the sun via solar panels to ensure power supply in all circumstances (day or night, clear or overcast sky). This work focuses on modeling and dynamic simulation of a photovoltaic system with a Lithium Ion battery storage system (LI-BSS). Battery charge and discharge is performed using PWM current and voltage controllers using DC/DC bidirectional management converter BMC.

1. INTRODUCTION

Due to population growth, urbanization and development global energy demand continues to rise. Non-renewable energy defines resources that are depleted faster than they are replenished. However renewable resources are permanently available to us. Renewable resources have the disadvantage of being sparsely concentrated, and their intermittency poses some problems for isolated applications [1].

Solar energy is particularly suitable for generating electricity in isolated sites, or in micro-grids. It is then often associated with batteries, which make it possible to ensure the storage of energy in case of excess production, or to compensate for the temporary lack of power during peak consumption [2].

A storage element is then required to supply the customer. There are several methods of storing energy. The most important are batteries, super capacitors and fuel cells. Adding a solar battery system is a great way to use renewable energy to increase independence from the grid [3, 4].

This work focuses on modeling, dynamic simulation and integration of a lithium ion battery storage system (LI-BSS). Modelling and simulation of the basic characteristics of photovoltaic (PV) modules controlled by adaptive P&O maximum power point tracking (MPPT) method and connected to a DC-DC boost converter is done in the first section. An energy storage module (battery) connected to a bidirectional DC-DC with charge and discharge PWM controller has been studied, implemented and discussed in the last section.

2. PV MODULE MATHEMATICAL MODEL

As presented in Figure 1, the PV module is basically modeled by using a current source, a diode and two series and parallel resistors [5].

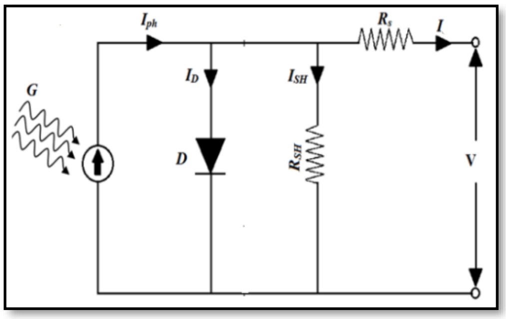


Figure 1. Equivalent circuit of PV module

Photonic generated current basically depends on irradiance and temperature.

$$I_{ph} = I_{sc} + k_i(T - T_{ref})(\frac{G}{1000}) \quad (1)$$

The short-circuit current I_{sc} is defined by:

$$I_{sc=}I_{s=}I_{ph}$$

The module-reverse saturation current I_{rs} and I_0 which varies with cell temperature are given by:

$$I_{rs} = I_{sc}/[\exp\left(\frac{qV_{oc}}{N_s knT}\right) - 1] \quad (2)$$

$$I_o = I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{qE_g}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right] \quad (3)$$

The current voltage characteristics will be:

$$I = I_{ph} - I_s\left(e^{\frac{q(V+IR_s)}{nKT_c}} - 1\right) - \frac{V + IR_s}{R_{sh}} \quad (4)$$

The PV cell output voltage and power depend on the generated current value which again depends on the solar irradiance and temperature. Figure 2 shows P-V and I-V characteristics for irradiation and temperature variations. The PV array type simulated in Matlab/Simulink software is: 1Soltech 1STH-215-P with 2 series modules and 2 parallel strings. Each module is composed by 96 series cells. The various parameters of PV module are listed in Table 1.

Table 1. Parameters of the solar module

Open circuit voltage (Voc)	**36.3 V**
Short-circuit current (I_{sc})	7.84 A
Voltage at MPP (V_{mp})	29 V
Current at MPP (I_{mp})	7.35
Maximum Power (P_m)	213.15 w
N_s	96

This panel in standard conditions STC (G =1KW/m^2, T= 25°C) can provide a power P_{mp} of 852 (W) which corresponds to a terminal voltage V_{pvm} of 58 (V). It is clear that current and power increase with increasing solar irradiation. Voltage and power decrease in the case of temperature rise.

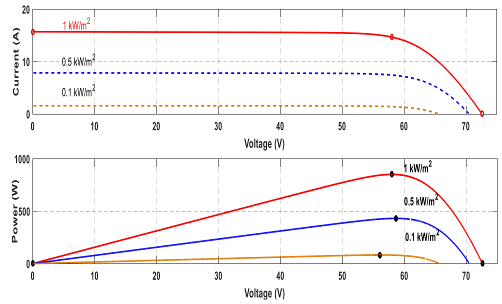


Figure 2. a. P-V and I-V characteristics for irradiation variation

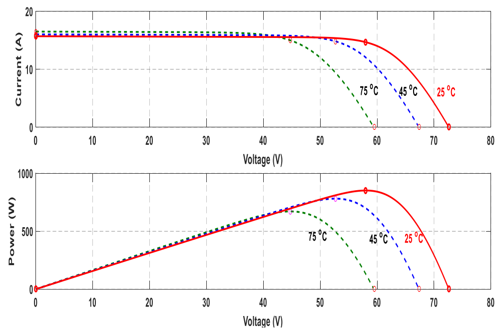


Figure 2. b. P-V and I-V characteristics for temperature variation

3. ADAPTIVE P&O MPPT CONTROL

An MPPT control associated with an adaptation static converter, makes a GPV to operate and to permanently produce the maximum of its power. Thus, whatever the meteorological conditions (temperature and irradiation). The control of the converter places the system at the maximum operating point (V_{mp} and I_{mp}). The variable perturbation step size which depends on power changes can reduce the most drawbacks of the conventional P&O method and track quickly the MPP under fast varying atmospheric conditions [6, 7]. Flowchart of the adaptive P&O MPPT algorithm is presented on Figure 3.

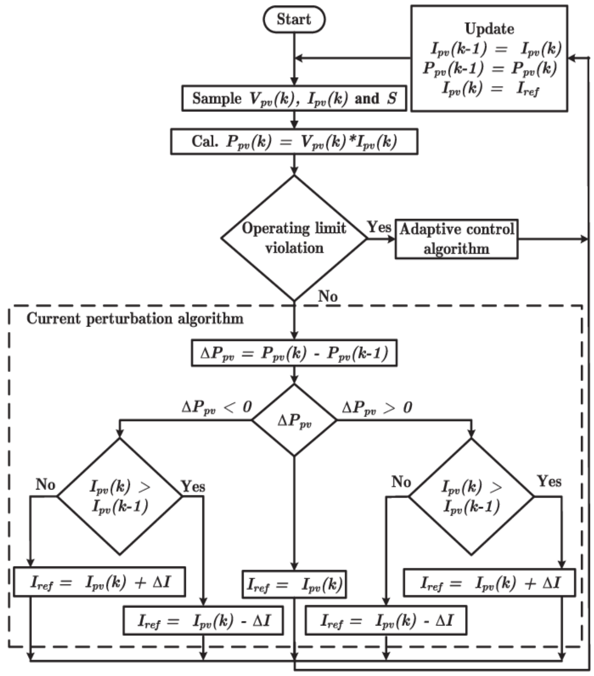
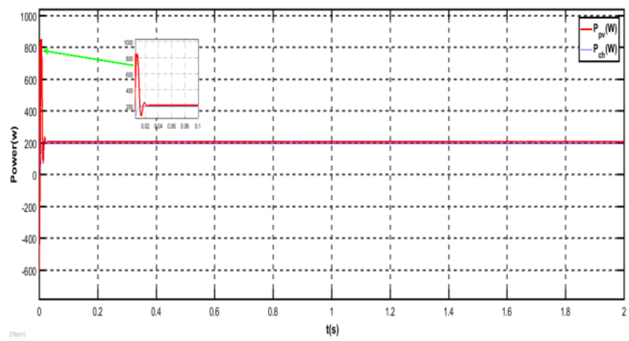


Figure 3. Flowchart of the adaptive P&O MPPT algorithm

First various simulations are carried out for a PV system implemented in Matlab/Simulink software which is built mainly of a PV panel, a resistive load and a Boost chopper controlled by the proposed adaptive P&O MPPT algorithm. Figure 4 shows PV and load power with and without MPPT. Figure 5 illustrates power and voltage of the PV panel for fast irradiation variation. Simulation results clearly show the effectiveness of the applied control.



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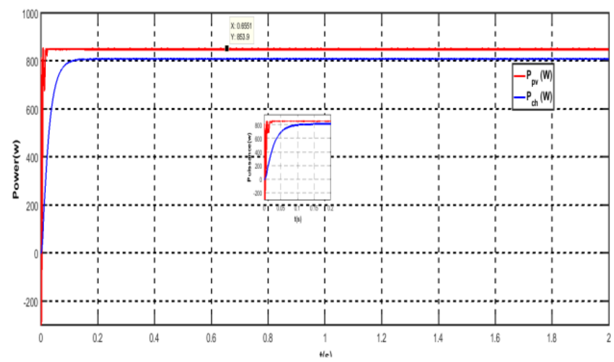

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Figure 4. PV and load power. a- without MPPT, b- with adaptive P&O MPPT

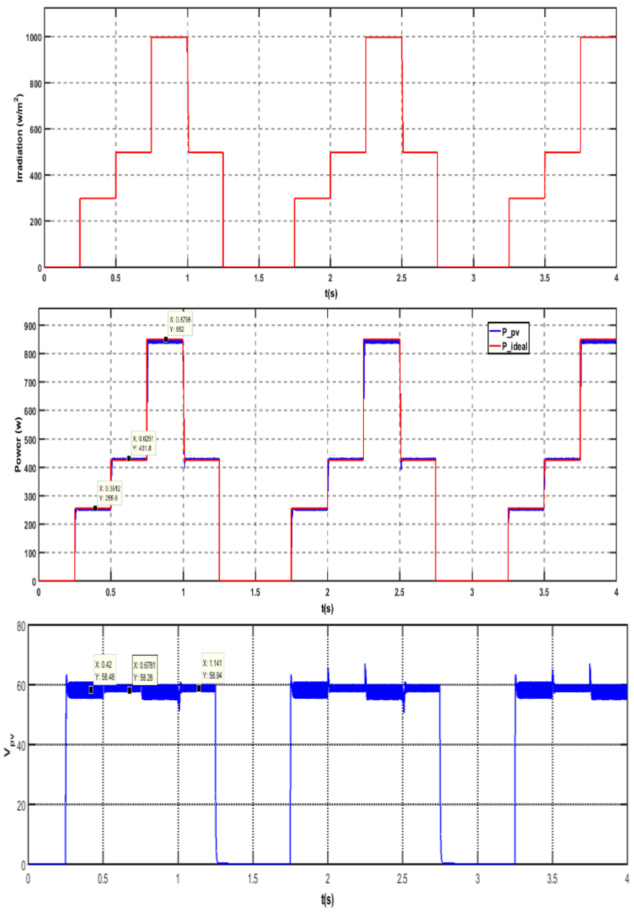


Figure 5. Power and voltage of PV panel for irradiation variation

Table 2 shows comparison of MPPT technique used in this paper with conventional ones to track the MPP [6, 7].

Table 2. Comparaison of different MPPT techniques

Performance criteria	P&O	INC	Adaptive P&O
Number of sensing parameters	1 Vpv	2 Vpv,Ipv	2 Vpv,Ipv
complexity	less	more	less
Accuracy to track MPP	Less time but high oscillations	more time but low oscillations	Fast with little oscillations

4. DYNAMIC SIMULATION AND INTEGRATION OF A LITHIUM ION BATTERY STORAGE SYSTEM (LI-BSS)

The battery-operated photovoltaic system designed in this work includes a solar panel that ensures the power supply of the load and the charging of the battery in the period of sunlight. An accumulator battery which ensures the storage (daily/seasonal) of electrical energy and the supply of the load in periods of darkness or when the energy required by the load is greater than that which can be supplied by the panel (Figure 7).

A DC/DC bidirectional management converter **BMC** which is designed and implemented for the Lithium Ion battery storage system (**LI-BSS**) using PWM current and voltage controllers. Solar regulator used in photovoltaic systems is used to protect the battery against overcharge and deep discharge phenomena to guarantee the storage device's safety, reliability, and long life [8, 9].

5. TYPICAL DISCHARGE PATTERN OF THE LI-BSS

The considered model **LI-BSS** mathematical model can be generalized by two main equations:

Discharge mode (i* > 0):

$$f_1(it, i*, i) = E_0 - K \cdot \frac{Q}{Q-it} \cdot i* - K \cdot \frac{Q}{Q-it} \cdot it + A \cdot \exp(-B \cdot it) \qquad (5)$$

Charge mode (i* < 0):

$$f_2(it, i*, i) = E_0 - K \cdot \frac{Q}{it + 0.1 \cdot Q} \cdot i* - K \cdot \frac{Q}{Q-it} \cdot it + A\exp(-B \cdot it) \qquad (6)$$

The Battery block used is taken from Simulink library. It is a generic dynamic model parameterized to represent most popular types of rechargeable batteries. The equivalent circuit is shown in Figure 6.

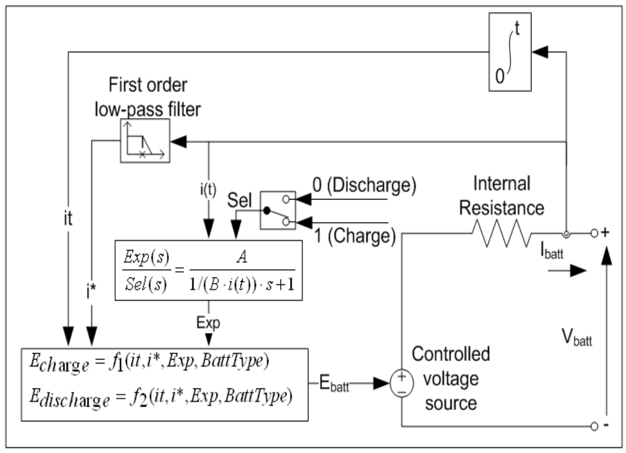


Figure 6. Dynamic model of the battery

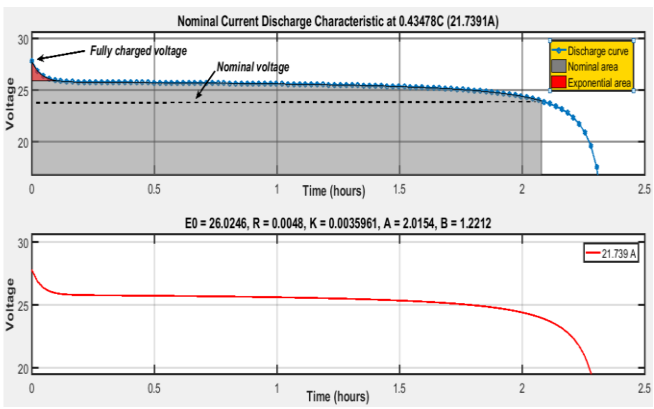
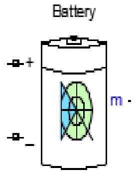


Figure 7. Nominal current discharge characteristic

The purpose of the simulations is to charge and then discharge the battery at constant current considering the accumulator data given in Table 3.

Table 3. Parameters of a lithium ion battery



Nominal Voltage (V)	24
Rated Capacity (Ah)	50
Initial State-Of-Charge (%)	45
Fully charged Voltage (V)	27.93
Nominal discharge current (A)	21.7

A typical discharge curve is composed of three sections, as shown in Figure 7 The first section represents the exponential voltage drop when the battery is charged. Depending on the battery type, this area is more or less wide. The second section represents the charge that can be extracted from the battery until the voltage drops below the battery nominal voltage. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

Simulink model of Photovoltaic system with the Lithium Ion Battery storage using Bidirectional DC-DC converter is shown in Figure 8.

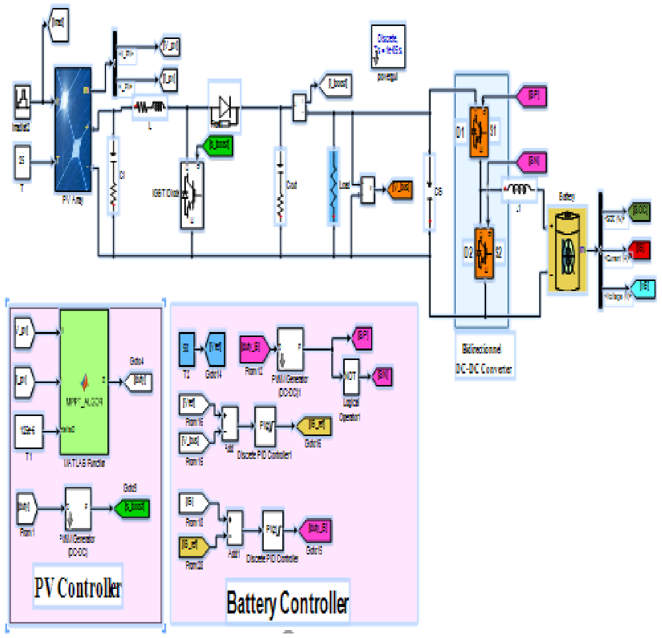


Figure 8. Simulink model of photovoltaic system with the lithium ion battery storage using bidirectional DC-DC converter

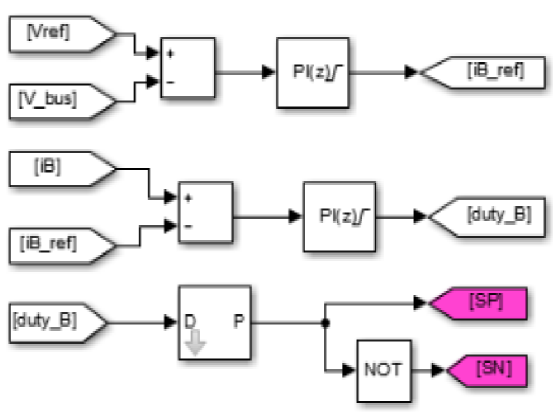


Figure 9. PWM controllers design for bidirectional DC-DC converter

Two PI controllers are used to manage battery charging and discharging (Figure 9). The first provides reference current from voltage load control. The second controls discharge current of the battery and generates pulses for switches of the bidirectional DC-DC converter for Buck operation (charge mode) and for Boost operation (discharge mode) [10, 11].

Figure 10 shows evolution of state of charge SOC, voltage, current of the Lithium Ion battery and power generated by PV panel for irradiation variation. It can be seen that when the irradiation of the PV array is able to generate enough voltage, the PV array will charge the battery through the bidirectional DC-DC converter and also supply power to the load during this time.

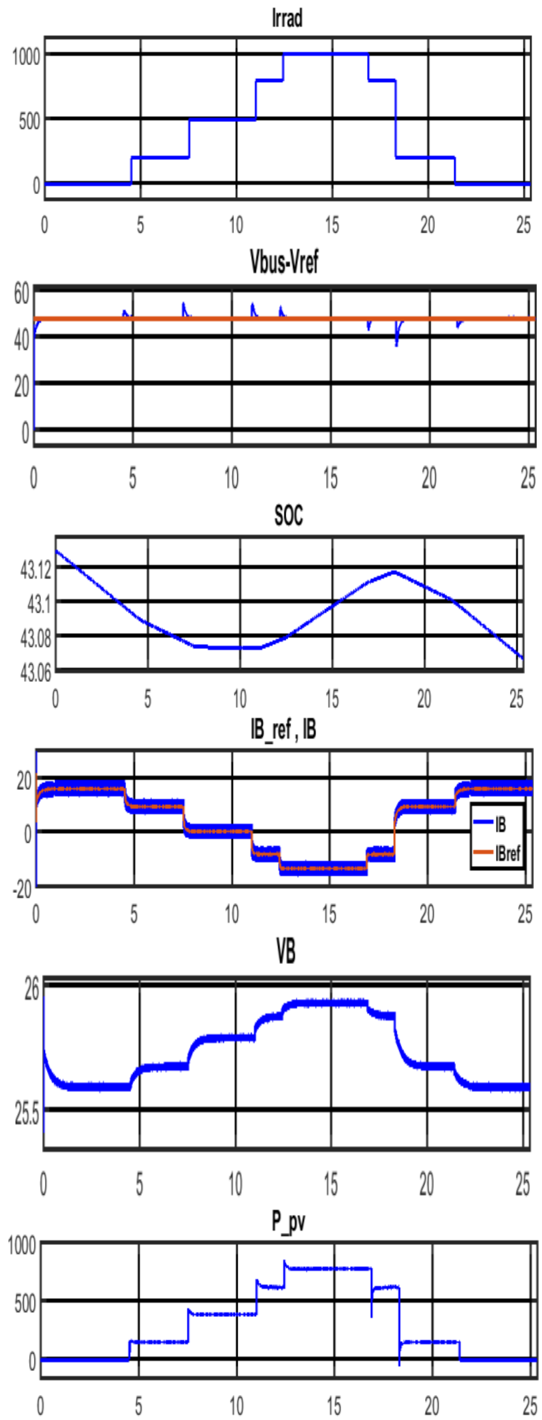


Figure 10. Evolution of battery voltage, current, state of charge SOC and PV output power during Irradiation variation

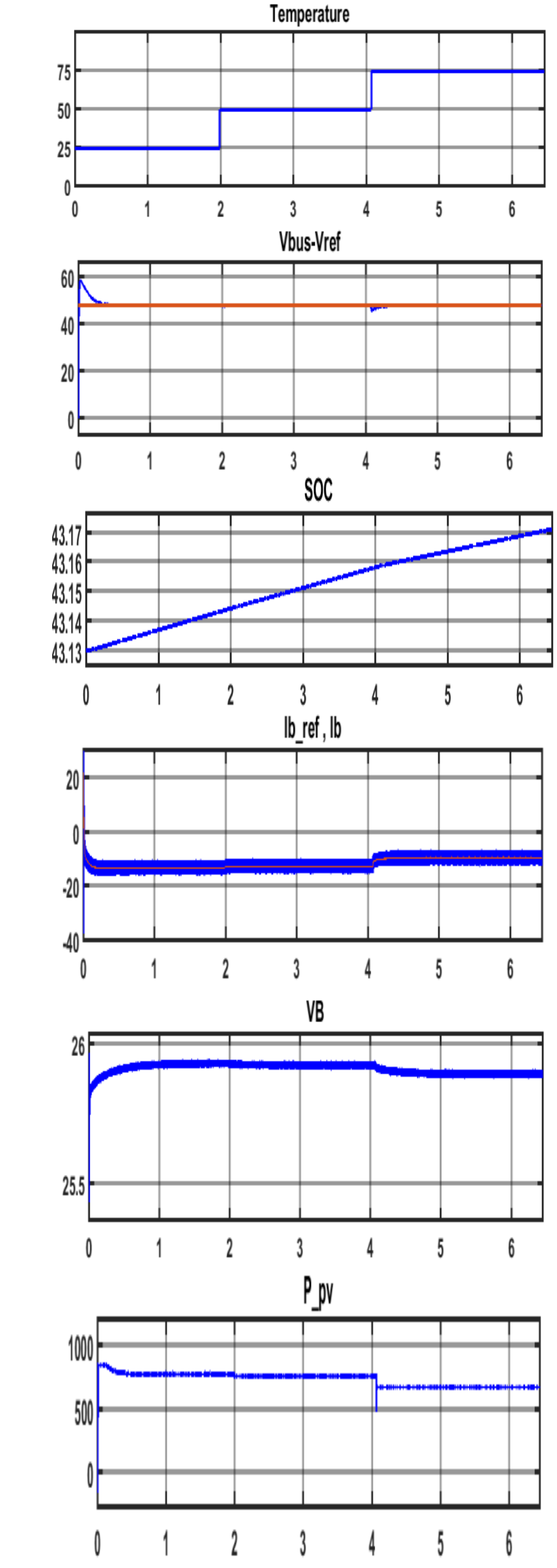


Figure 11. Evolution of battery voltage, current, state of charge SOC and PV output power during Irradiation variation

For irradiation G=1000 w/m^2 and G=800 w/m^2 P_{pv} is greater than $P_{battery}$, so PV panel supply the load and charge the battery. At night (G=0 w/m^2) or for G=500 w/m^2 and G=300 w/m^2 P_{pv} is less than $P_{battery}$, in this case the load is supplied by the battery. When the irradiation cannot generate sufficient voltage, the battery will power the load through the same bidirectional DC-DC converter, it will discharge through it. While the battery is charging, the battery voltage V_B will increase. Because of this, charge current I_B should decrease. When battery is in discharge mode the SOC is decreasing and the battery current is positive. Load voltage is around 48V.

Figure 11 shows dynamic performances of the solar storage system for temperature variation. It is clear that for this case there is one working mode it is the charge mode. The increase in temperature does not alter the working of the system too much, contrary the variation in irradiation.

6. CONCLUSION

The work presented in this article deals with the study of a photovoltaic system energetically coupled to storage batteries ensuring continuous energy availability. This system operates at its optimum power with the use of an adaptive P&O MPPT algorithm applied to the step up Boost converter. The maximum power point is being successfully tracked. Simulation and analysis of closed loop control of bidirectional DC-DC buck-boost converter using two PWM current and voltage regulators was performed in both charge and discharge modes.

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NOMENCLATURE

G	solar irradiance
T	cell *p-n junction* temperature
Rsh	equivalent shunt resistance
Rs	equivalent series resistance
I	output current
V	output voltage
Iph	photo generated electric current
Isc	short circuit current
Id	current at diode *D*
K	Boltzman's constant
Q	electron charge
*I*s	diode reverse bias saturation current
n	diode ideality factor
Ns	Number of series cells
Eg	Band gap energy of the semi conductor
E_0	Constant battery voltage (V)
i	Battery current (A)
i^*	Low frequency current dynamics (A)
i_t	Extracted capacity (Ah)
Q	Maximum battery capacity (Ah)
A	Exponential voltage (V)
B	Exponential capacity $(Ah)^{-1}$
K	Polarization resistance (Ohms)