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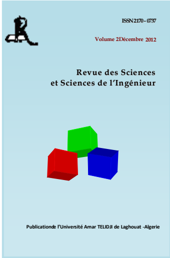

Modeling and Control of a Photovoltaic Generator Using MPPT Regulator

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Abstract: In this paper, we study the performance of photovoltaic generators (PVG) controlled by Maximum Power Point Tracking (MPPT) algorithm, using a DC/DC converter (Boost) and batteries. We develop the mathematical model of the photovoltaic cell and of the photovoltaic generator and their electrical models. Also, we present the new battery model which we used in our simulation. We present the electrical model of the DC/DC convertor, and introduce the MPPT control algorithm PO (Perturbation and Observation). The simulation results obtained with this algorithm has shown good performances of our PVG regarding to its easy implementation and the low cost, and provide also a permanent supply.

Keywords: PVG, MPPT, DC/DC converter, PO.

I. INTRODUCTION

Today, the photovoltaic technology is controlled and managed enough to make great steps in the field of energy applications and consumption, and optimizing photovoltaic systems surely leads to a better exploitation of solar energy.

The major drawback of this energy is the low conversion efficiency of this energy, as well as the high cost which is currently higher than the cost of other forms of energy.

The second major problem is that the PVGs, which behave as nonlinear generators, have an optimum operating point called the Maximum Power Point (MPP) depends on the temperature, the solar radiation and the load variations.

In order to transfer the maximum energy delivered by the photovoltaic generator to the load, a Maximum Power Point Tracker (MPPT) is used. Most of the MPPT are based on a DC-DC converter. In this paper we used the Boost type which has as task to track the maximum power point when the PV system is exposed to the change of weather and load.

Because the system is not connected to the network (Figure 1), we need a storage device to feed the load in a permanent way.

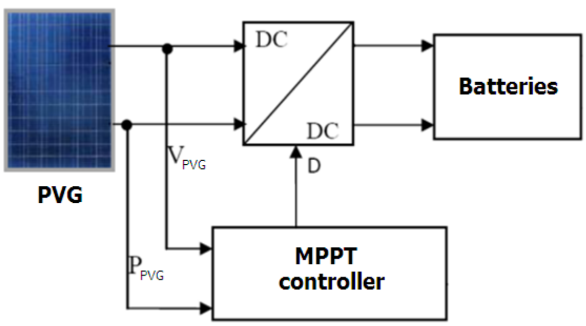


Fig.1. Cascade PVG-Boost- Batteries

II. MODELING OF A PHOTOVOLTAIC GENERATOR

There are different types of solar cells, and each type has its own efficiency and coast.

In this paper, we study the model of two diodes (double exponential), where the solar cell is presented as an electrical current generator shunted by two diodes in parallel [1]-[2]. To take into account the physical phenomena in the cell, the model is supplemented by a serial resistance Rs and a parallel or shunt resistance Rp. The equivalent circuit diagram of the cell is given in Figure 2.

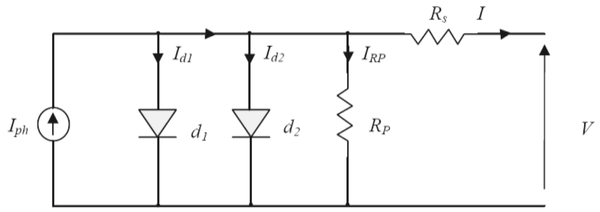


Fig.2. Equivalent two-diode circuit model of a photovoltaic cell

The equation of the current-voltage characteristic of one solar cell is as follows [1]-[2]:

$$I = I_{ph} - I_{s1}.\left[e^{\frac{q\,(V+R_s.I)}{n_1.K.T}} - 1\right] - I_{s2}.\left[e^{\frac{q\,(V+R_s.I)}{n_2.K.T}} - 1\right] - \frac{V+R_s.I}{R_p} \quad (1)$$

With n1 and n2: Ideality factors of the two diodes.

Thus the equivalent circuit of a photovoltaic generator (PVG) is given by Figure 3.

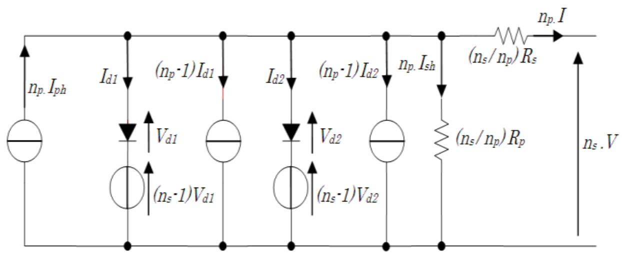


Fig. 3. Equivalent circuit of a photovoltaic generator.

The equation of the current-voltage characteristic of a PVG can be written as follows:

$$I_g = I_{ph.g} - I_{s1.g}.\left[e^{\frac{q\,(V_g+R_{s.g}.I_g)}{n_s.n_1.K.T}} - 1\right] - I_{s2.g}.\left[e^{\frac{q\,(V_g+R_{s.g}.I_g)}{n_s.n_2.K.T}} - 1\right] - \frac{V_g+R_{s.g}.I_g}{R_{p.g}.I_g} \quad (2)$$

In this paper, we used a PVG composed of 288 cells in series and 8 columns in parallel.

Figures 4 and 5 represent respectively the current versus voltage and power versus voltage characteristics with T=298K and E = 1000W/m^2.

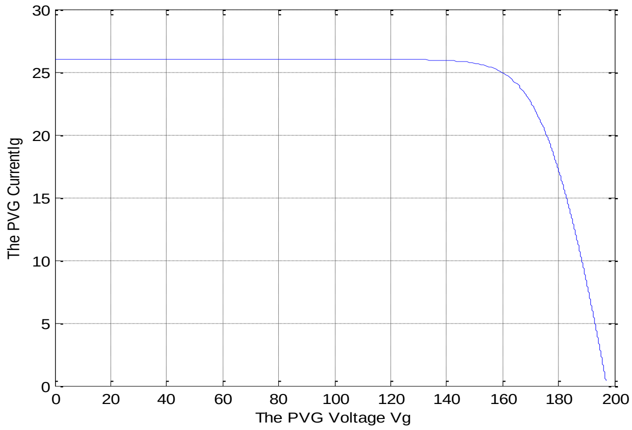


Fig. 4. Current-voltage characteristic of PVG

We obtained this characteristic by varying the load (resistance) over the entire range in a very short time [3]. We observe the progress of the electrical current and voltage.

The I-V Characteristic Curve and the Three Points of Interest

A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current, abbreviated I(sc).

Conversely, the maximum voltage is produced when there is a break in the circuit. This is called the open circuit voltage, abbreviated V(oc). Under this condition the resistance is infinitely high and there is no current, since the circuit is incomplete.

There is another point on the "knee" of the curve, where the maximum power output is located. This point is called the Maximum Power Point.

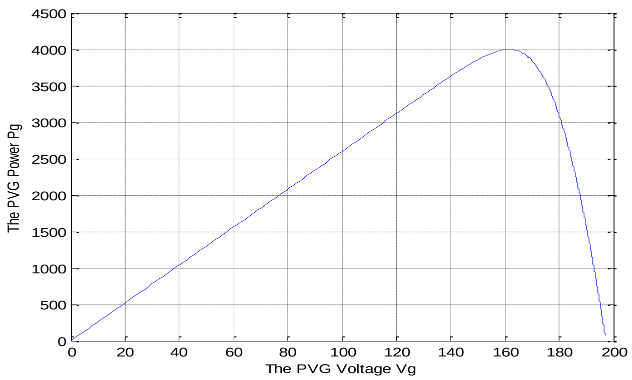


Fig. 5. Power-voltage characteristic of PVG

This characteristic shows us the progress of the power relating to the voltage. The point (MPP) we talked about above is very clear to recognize in this characteristic. This point is situated on the “knee” of this curve too.

III. BATTERY BANK MODEL

One of the major disadvantages of the photovoltaic systems is the ongoing shortages of solar energy which are due to various reasons: periodic input of solar energy (alternating day / night, summer / winter) and random weather effect, sunshine duration which is subject to seasonal conditions (position of the sun by the zenith) ... etc.

Accordingly, whenever the demand of energy changes through time vis-à-vis the contribution of solar, the storage of electricity is necessary. The most commonly used for PV systems is the electrochemical storage battery.

The Battery model used in our simulation is based on the kinetic model developed by the University of Massachusetts [4]. It has been divided into the following components:

- Capacity model
- Voltage model
- State of Charge(SOC) model
- Gassing current loss model

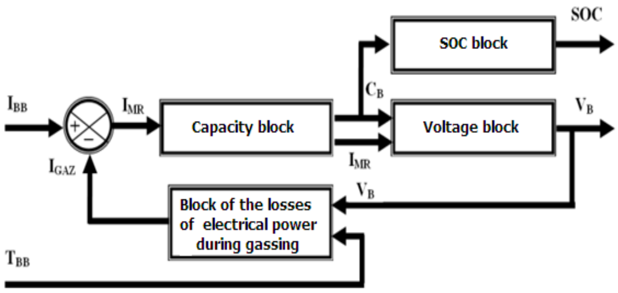


Fig.6. Battery bank model diagram

The capacity of battery is determined by integrating the main reaction I_{MR}:

$$I_{MR}(t) = I_{BB}(t) - I_{GAZ}(t) \quad (3)$$

I_{MR} : *Main battery reaction current* (A)
I_{BB} : *External battery current* (A)
I_{GAZ} : *Battery gassing current* (A)

The actual battery capacity can be determined as:

$$C_B(t) = \int_{t=0}^{t} I_{MR}(t)dt + C_{B,i}$$

C_B : *Actual battery capacity* (Ah)
$C_{B,i}$: *Initial battery capacity* (Ah)

IV. BOOST CONVERTER MODEL

The power produced by the solar panel depends on two factors which are irradiation and temperature [5]. As irradiation and temperature change through time, the produced voltage fluctuates and becomes unstable. A converter is therefore inserted to produce a constant voltage and ensure the transfer of the maximum power from the solar panel to the load.

The boost converter, or set-up converter, we have used consists of an inductor, a switch, a diode, and tow capacitors as shown in Figure7.

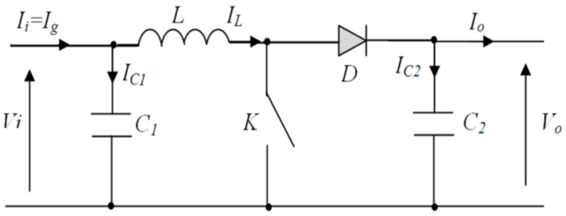
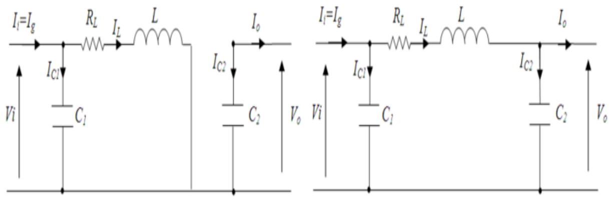


Fig.7. Electrical circuit of a boost converter.

Boost converter circuit can be divided into two modes. Mode 1 begins when the switch *K* is turned on at *0<t<DTs* as shown in Figure 8.a. The input current which rises flows through inductor *L* and switch *K*. During this mode, energy is stored in the inductor.



a) K closed b) K open

Fig.8. Equivalent circuit models of a boost converter.

Mode 2 begins when the switch is turned off at *DTs<t<Ts*. The current that was flowing through the switch would now flow through inductor *L*, diode *D*, capacitor C_2, and load as shown in figure 8.b. The inductor current falls until the switch is turned on again in the next cycle. Energy stored in the inductor is then transferred to the load. Therefore, the output voltage is greater than the input voltage [5]

A. Mathematical model of a Boost converter

The application of Kirchhoff's laws on the two equivalent circuits of the two phases of operation is given by [1]-[2] and [5]-[6]-[7]:

$$0 < t < DTs$$

$$\begin{cases} i_{C1} = C_1 \dfrac{dv_i}{dt} = i_i - i_L \\ i_{C2} = C_2 \dfrac{dv_o}{dt} = -i_o \\ v_L = L \dfrac{di_L}{dt} = v_i - R_L\, i_L \end{cases} \quad (4)$$

$$DTs < t < Ts$$

$$\begin{cases} i_{C1} = C_1 \dfrac{dv_i}{dt} = i_i - i_L \\ i_{C2} = C_2 \dfrac{dv_o}{dt} = i_L - i_o \\ v_L = L \dfrac{di_L}{dt} = v_i - v_o - R_L\, i_L \end{cases} \quad (5)$$

B. Approximated model of Boost converter

By applying on the system of equations (4) and (5) the following equation:

$$< \frac{dx}{dt} > T_s = \frac{dx}{dt_{(DT_s)}} . DT_s + \frac{dx}{dt_{((D+1)T_s)}} . (D-1) T_s \quad (6)$$

We obtain these equations which describe the operation of the DC-DC converter during the two phases (one period):

$$\begin{cases} C_1 \dfrac{dv_i}{dt} T_s = DT_s\,(i_i - i_L) + (1-D)T_s\,(i_i - i_L) \\ C_2 \dfrac{dv_o}{dt} T_s = -DT_s\; i_o + (1-D)T_s\,(i_L - i_o) \\ L \dfrac{di_L}{dt} T_s = DT_s\,(v_i - R_L\, i_L) + (1-D)T_s\,(v_i - v_o - R_L\, i_L) \end{cases} \quad (7)$$

We arrange this system of equations in order to simplify the connection of the Boost with the other blocks. We obtain the dynamic model of the Boost converter:

$$\begin{cases} i_L = i_i - C_1 \dfrac{dv_i}{dt} \\ i_o = (1-D)\, i_L - C_2 \dfrac{dv_o}{dt} \\ v_i = (1-D)\, v_o + R_L\, i_L + L \dfrac{di_L}{dt} \end{cases} \quad (8)$$

C. Steady-State study

Replacing the derivatives of signals with zeros, and the converter signals with their average quantities, we obtain:

$$\begin{cases} I_i - I_L = 0 \\ I_o - (1-D) I_L = 0 \\ V_i - (1-D) V_o - R_L I_L = 0 \end{cases} \quad (9)$$

D. Conversion Ratio

Using the relations (9), we can calculate the conversion ratio V_O / V_i

$$M(D) = \frac{V_o}{V_i} = \frac{1}{(1-D) + \frac{R_L I_L}{V_o}} = \frac{1}{1 + \frac{R_L I_o}{(1-D)^2 V_o}} \frac{1}{(1-D)} = \eta \frac{1}{(1-D)} \quad (10)$$

During the operation of a PV generator, the maximum power point MPP can be changed due to changes of weather or load, hence a controller is needed to follow the MPP. In fact, the research of this MPP must be done automatically.

This is quite possible by using one of the approaches known as Maximum Power Point Tracking MPPT.

V. PO MPPT METHOD

In this section, we present the PO algorithm, which track the maximum power point delivered by the photovoltaic generator [1][2] and [5].

It's a simple control technique. It uses power-feedback control technique where the output power of the PVG is tracked continuously and compared with the previous power.

The power difference is then used as a parameter for the microcontroller to produce a PWM signal with a set of duty cycle. PWM signal is used to control the switch K in the boost converter.

Figure 9 shows the flow chart of the power-feedback control technique. With this control technique, our photovoltaic generator, will produce a constant output voltage at the end of the converter, and ensure the transfer of the maximum power can the PVG delivers.

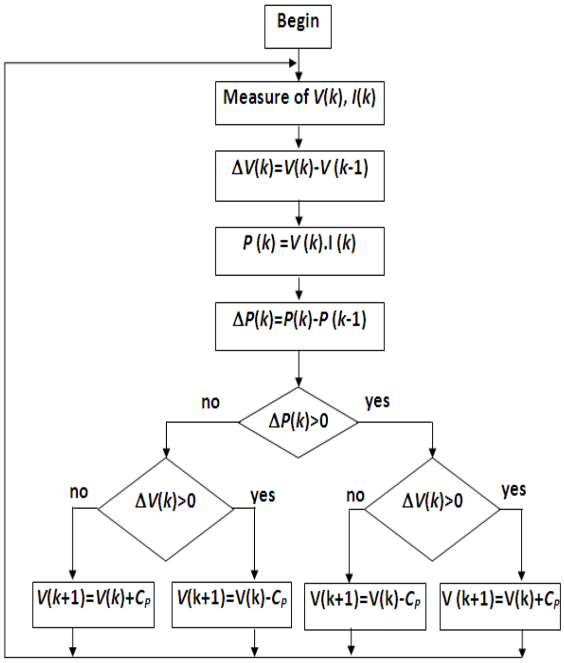


Fig. 9. The P&O flow chart.

VI. SIMULATION RESULTS

The figures that follow represent the performances of our photovoltaic generator. The simulation results are obtained using Matlab / Simulink. All the characteristics are to be obtained using a fast varying load

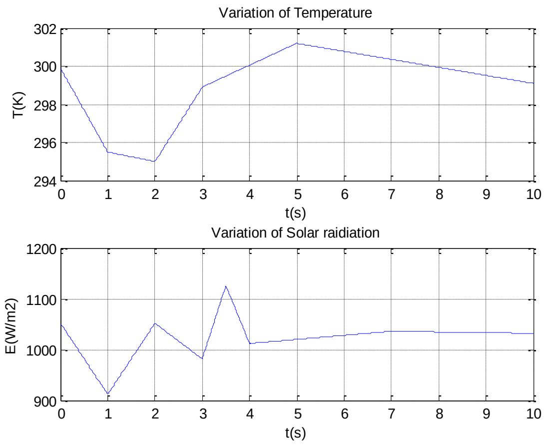


Fig.10. Variations of solar irradiation and temperature

The figure 10 shows the variation of the meteorological factors, Temperature and Radiation, through time.

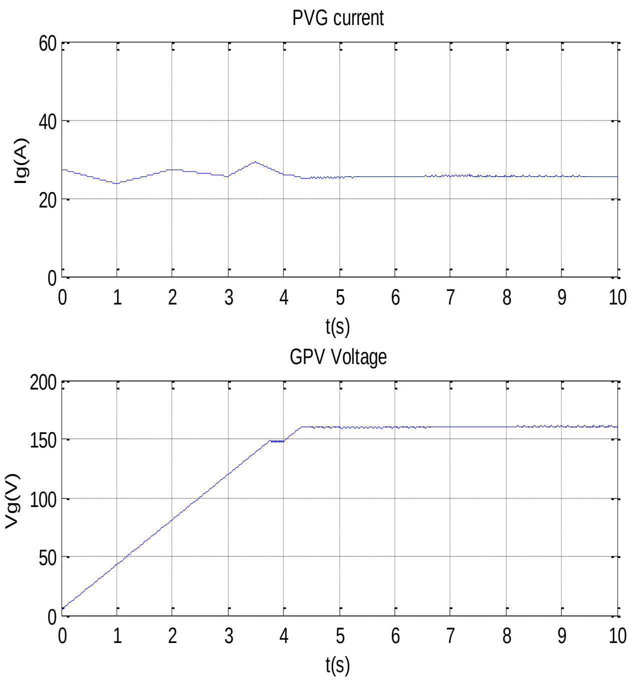


Fig.11. Optimal current and voltage of the PVG.

The figure 11 represents both steady and start-up states of the output voltage and current of the PVG. The steady state takes place after 4.3 sec, knowing that we have used fast varying load to get both states.

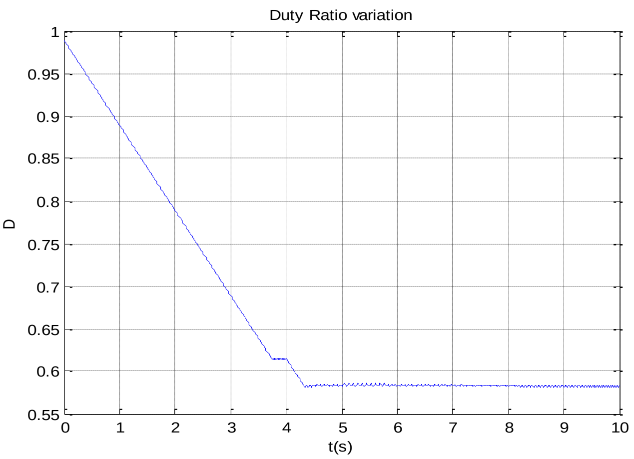


Fig.12. Duty Ratio Variation

The figure 12 shows the variation of the Duty Ration during the start-up and steady states. It starts by an initial value (0.99) then decreases till around 0.58 which meet the steady states.

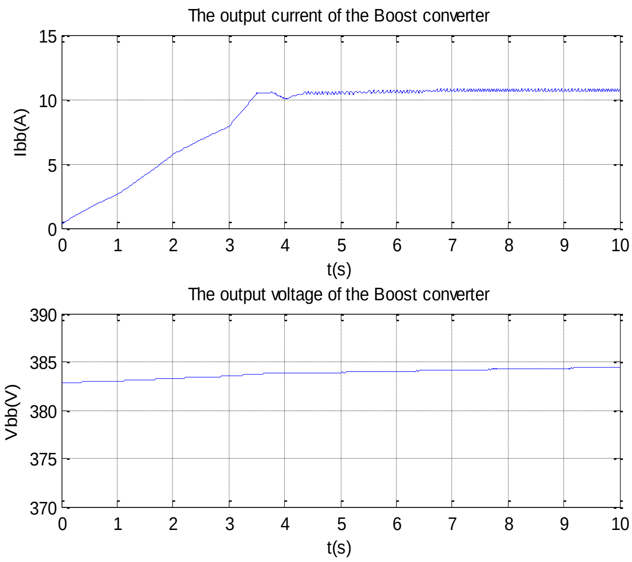


Fig.13. Charging current and voltage of batteries

The curves shown in the figure 13 show the output voltage and current of the boost converter. We notice that there is no clear start-up state in the output voltage curve which comes back to the use of the batteries.

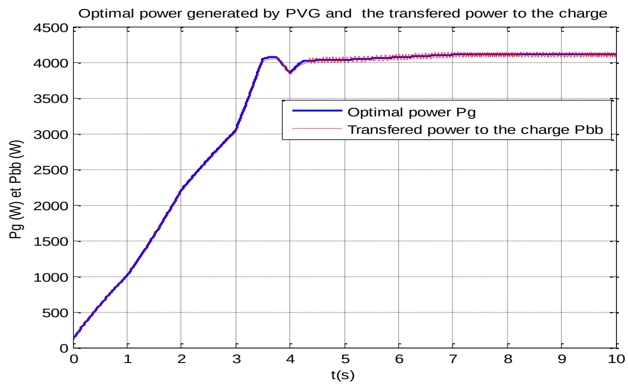


Fig.14. Variations of the optimal power of PVG and of the power transferred to the batteries according to the variations of solar radiation and temperature.

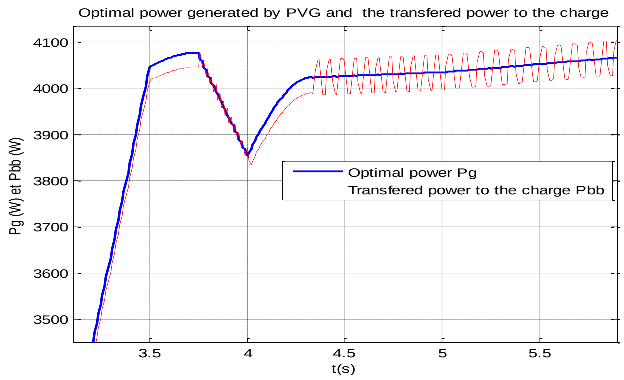


Fig.15. Zoom on the previous curves of electrical power

We observe that despite the fast variations and the sudden changes in temperature and solar radiation, our tracker (controller) has reached its goal to transfer the maximum power from the photovoltaic generator to the load.

VII. CONCLUSION

In this paper, we proceeded to modeling a photovoltaic generator using the double exponential model.

The obtained results show that the characteristics of the PVG model are close to those of the real PVG, which allowed us to validate our model.

Since the characteristics of PVG depends heavily on meteorological parameters, it has seemed necessary to find methods for tracking the maximum power point of the generator at any moment whatever the variations of meteorological parameters are (temperature and / or solar radiation).

For this purpose we have used a method called P&O to control the boost converter. The P&O method has given satisfying results, because despite the different variations of the solar radiation and temperature, the generator works at its optimal power. And to ensure the supply of receivers permanently, a storage device is added.

Finally we conclude that the PO method is one of the best MPPT methods regarding its low cost, and easy implementation.

ABRIVIATIONS

PV : *Photovoltaic*
GPV : *Photovoltaic Generator*
DC-DC : *Direct current/Direct Current.*
SOC : *State Of Charge*
MPPT : *Maximal Power Point Tracking.*
PPM : *Maximal Power Point*

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