Chapter

Operation of Photovoltaic Panels in Stand-alone Applications

Ali Lamkaddem, Hajar Chadli, Khalid Salmi, Rachid Malek, Olivier Deblecker, Khalil Kassmi and Najib Bachiri

Abstract

In this chapter, we propose the analysis of the maximum power point (MPP) of photovoltaic panels (PV) in a renewable energy application. From the current–voltage characteristics, we deduced the MPP of a PV panel and specified the use of a power block (DC/DC converter) controlled by an MPPT control. In the case of an MPPT control of type perturb and observe, we realized the photovoltaic system that heats a photovoltaic solar cooker, taking into account this MPPT command. The experimentation of this application, during a sunny day, shows that the MPPT control carries out its role correctly, such as optimal operation of the PV panels and heating of the cooker by the maximum power supplied by the PV panels. The analysis of all the results shows an excellent agreement between the experiment and the simulation of the operation of the photovoltaic system which made it possible to operate the photovoltaic panels around their MPP, over the course of the sun. Under these conditions, the efficiency of the proposed DC/DC converter, with a power of 500 Wp, is of the order of 97%.

Keywords: energy, photovoltaic panels, maximum power point, MPPT command, DC/DC converter, efficiency

1. Introduction

Solar photovoltaic is the most widely used renewable energy source with relatively high accessibility in many parts of the world [1–4]. In recent years, the development of the solar PV market and the use of this technology worldwide has been increasing at annual rates of 35–40%. This rapid expansion has developed rapidly due to a sharp decline in PV prices and increased attention to the importance of sustainable energy [4–8].

In addition, the market development of solar photovoltaic (PV) applications is increasing, due to their contributions to environmental protection, and use as an alternative sustainable solution to the energy crisis. In the short and long term, PV technology is considered the main source of electricity generation in various applications such as [9–16] solar desalination, solar cookers, solar cooling, and air conditioning. In PV technology, the problem that arises is the operation of PV panels around their maximum power points (MPP). Regardless of the applications used, stand-alone or grid-connected, the design of a power matching system (DC/DC converter) of the PV panels with its MPPT control (maximum power point tracking) [17, 18] is necessary to produce the maximum electrical energy during the operation of these applications [19]. In the literature, several MPPT controls are proposed [20, 21]. Each method has its advantages and disadvantages. Currently, in the context of PV energy applications that we are developing in the framework of national and international projects, we use the perturb and observe control [21–24], due to its ease of implementation and accuracy of convergence to the maximum power point of the PV panels.

In this chapter, we analyze the maximum power point (MPP) of PV panels and the PV systems that maximize this power during the operation of an application. Particular attention is paid to the description of the MPPT control, the perturb and observe type, and its application in PV solar cookers, with a power of 600 Wp.

2. Optimization of the operation of photovoltaic (PV) panels

2.1 Electrical model of a PV panel cell

Figure 1 shows the equivalent electrical circuit of a cell (Junction P/N) of a PV panel, illuminated by radiation of intensity "Le" [25]. This circuit is formed by a diode (D), a current source (I_{CC}), a contact series resistance (R_s), and a parallel resistance (R_{sh}), which represents the leakage current of the cell. From this diagram, the current of the PV cell (I) is expressed as a function of the voltage V according to the expression [25–29]:

$$I = I_{CC} - I_s \left\{ \exp\left[\frac{q(V + IR_s)}{A \cdot K \cdot T}\right] - 1 \right\} - \left(\frac{V + IR_s}{R_{sh}}\right) \tag{1}$$

where

I_s: Reverse saturation current of the diode (A),

q: Electric charge of an electron = 1602×10^{-19} Coulomb,

A: The diode ideality factor,

K: Boltzmann constant 1.381×10^{-23} J/K,

T: Cell temperature (°C).

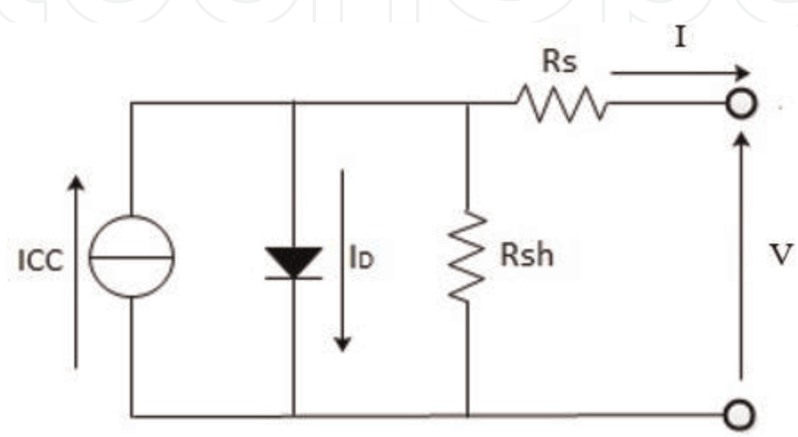

Figure 1.
The diagram of the electrical circuit of a cell of a PV panel.

In this expression, the current I_{CC} depends very little on the temperature and varies with the intensity of the illumination according to the equation [30, 31]:

$$I_{CC} = A.Le + B \quad (2)$$

where

A and B are two constant factors [30, 31].

As part of our application, we used PV panels that have cells, where A = 0.00932; B = 0.0055; very low contact resistance and very high parallel resistance. Under these conditions, the current I is written as a function of the voltage V according to the expression:

$$I = A.Le + B - I_s\left\{\exp\left[\frac{q(V)}{A \cdot K \cdot T}\right] - 1\right\} \quad (3)$$

2.2 Electrical characteristics of PV panels

As part of our experiment, we used PV panels (**Figure 2**), 300 Wp, formed by $N_s = 80$ identical cells in series. The expression of the current of the I_{PV} panels is written according to the intensity of the illumination (L_e) and the voltage V_{PV} according to the equations:

$$I_{PV} = 0.00932 * L_e + 0.0055 - I_s\left\{\exp\left[\frac{q(V_{PV})}{80.A \cdot K \cdot T}\right] - 1\right\} \quad (4)$$

The typical experimental electrical characteristics (current–voltage and power—voltage) of the PV panels (**Figure 2**), each with a power of 300 Wp, for illuminations ranging from 300 W/m^2 to 900 W/m^2, are shown in **Figure 3**. From these characteristics, we have determined and represented in **Table 1** the optimal electrical values:

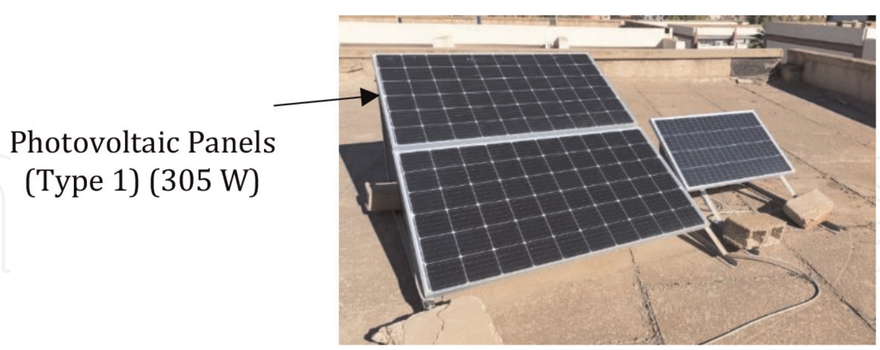

Figure 2.
Photos of 600 Wp photovoltaic panels (Type 1) installed in the laboratory.

	Le (W/m^2)	Vopt (V)	Iopt (A)	Ropt (Ω)	Popt (W)
Panel PV (305 W):Type 1	300	25.4	2.87	8.85	72.9
	500	25.5	4.78	5.33	121.9
	900	25.4	8.61	2.95	218.7

Table 1.
*Optimal electrical values of a PV panel, from **Figure 2**, as a function of illuminations. Temperature = 25°C.*

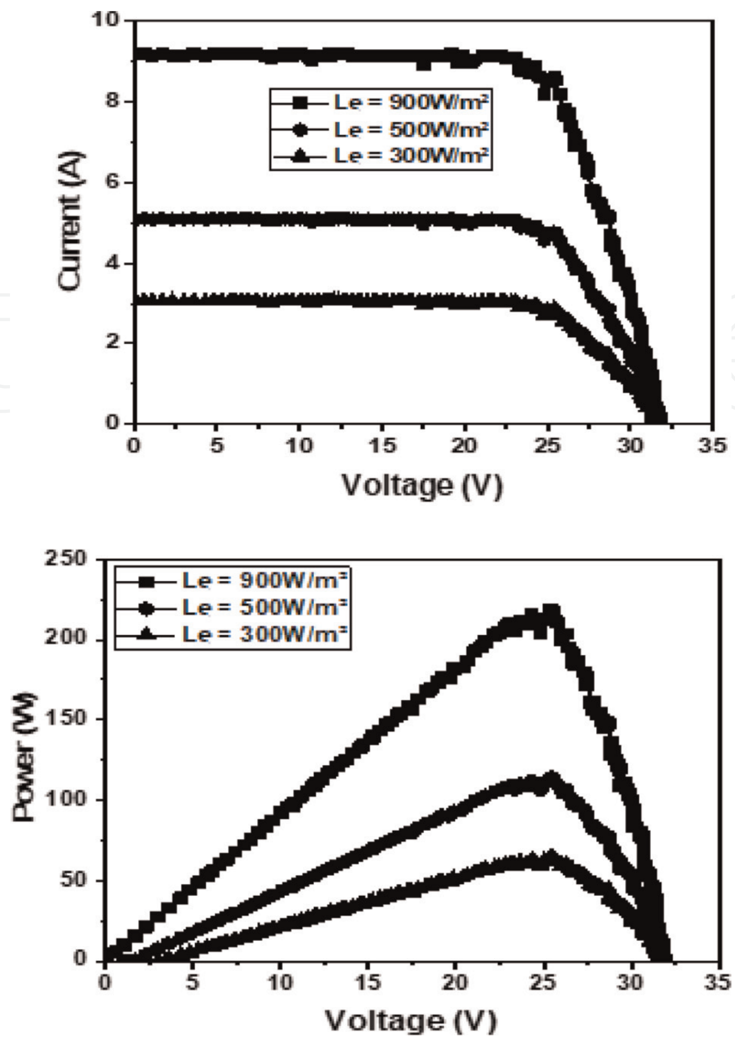

Figure 3.
Current–voltage-power characteristics of the photovoltaic panel used (Type 1), for three illuminations (300, 500, and 900 W/m²). Ambient temperature = 25°C.

voltage, current, maximum power point (MPP), and optimal resistance. Therefore, we can deduce, when the illuminance varies from 300 to 900 W/m^2, the optimal power and resistance vary from 72.9 to 218.7 W and from 8.85 to 95 Ω, respectively. In a PV application, to ensure the production of optimal electrical energy and reduce the cost of kWh, the operation of PV panels, over the sun, must follow these variations.

Moreover, in the design of PV system blocks, these optimal values allow for determining the size of each electrical component of the power, and the nature of the MPPT control that optimizes the operation of the PV panels, during the operation of the applications throughout the day.

2.3 MPPT command: perturb and observe

In this section, we describe the basic functioning of the MPPT command type perturb and observe that we used in all the applications developed in the laboratory. To do this, the PV panel adaptation block (**Figure 3**) generates a PWM signal of frequency f and duty cycle α, following the execution of an MPPT algorithm (**Figure 4**), which controls the DC/DC converters. The basic principle of the P&O method consists in disturbing the voltage of the PV panels (Vpv) and observing its impact on the variation of the output power of the PV panel, following the steps:

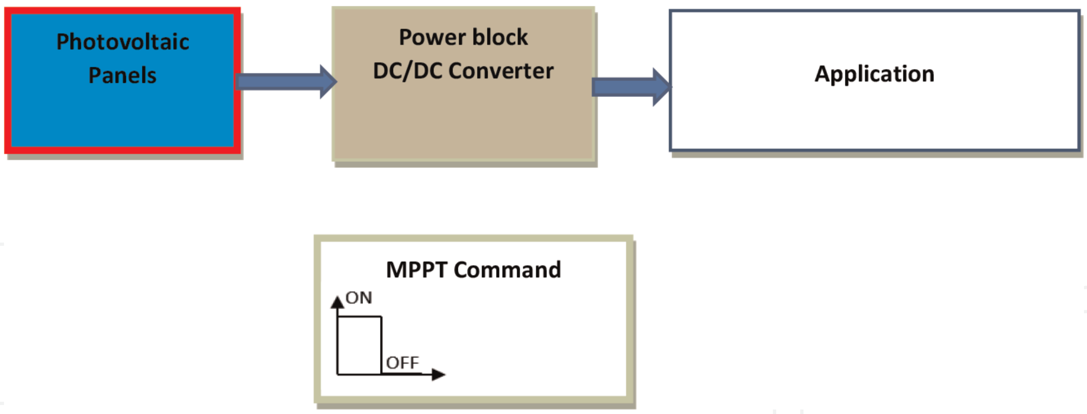

Figure 4.
PV panel adaptation system.

- Acquire and store the electrical quantities of the converter: voltages, currents, powers, efficiency, and duty cycle.
- Once all the quantities have been acquired, the microcontroller generates the PWM signals with a variable duty cycle α.
- At each cycle, Vpv and Ipv are measured to calculate Ppv (k). This value of Ppv (k) is compared to the value of Ppv (k-1) calculated in the previous cycle. When the output power has increased, Vpv is adjusted in the same direction as in the previous cycle. If the output power has decreased, Vpv is adjusted in the opposite direction as in the previous cycle. When the maximum power point is reached, this means that Vpv is around the optimal value.

3. Application: Photovoltaic solar cooker

In this section, we have analyzed the optimization of the PV panels by the system of **Figure 4** powered by two PV panels of **Figure 2** in series. The PV application consists of heating a cooker with 600 Wp PV energy. In the following sections, we present the model and the optimization of the PV panels used, then the operation and the validation of the PV system of **Figure 4** in the case of a cooker with PV energy.

3.1 Model of PV panels

In the case of our 600 Wp application, the expression of the current Igene as a function of the voltage Vgene of the PV generator, formed by two panels of **Figure 2** in series, is written for a given illumination according to the expression:

$$I_{PV} = 0.00932 * L_e + 0.0055 - I_s \left\{ \exp\left[\frac{q(V_{PV})}{160.A \cdot K \cdot T} \right] - 1 \right\} \tag{5}$$

As previously (Section 2.2) mentioned, experimentation with this generator when the intensity of the illumination varies from 300 to 900 W shows optimal voltages, currents, resistances, and powers, which vary from 50.8 to 51.0 V; 2.87 to 8.61 A; 17.7 to 25.8 Ω, and 145.8 to 437.4 W.

3.2 Operation of the cooker

We experimented, during 1 day, the PV system of **Figure 3** in the case of the heating of 1 liter of water of a photovoltaic solar cooker. The principle of operation of this cooker is the supply of thermal resistance by optimal energy supplied by the PV panels, *via* a DC/DC converter, controlled by an MPPT command "perturb and observe" (**Figure 4**). We recorded the meteorological electrical quantities (intensity of illumination and ambient temperature), the electrical quantities (voltage, current, and power) at the input and output of the DC/DC converter, and the heating temperatures of the water and thermal resistance (**Figure 5**). The results obtained show:

- Intensity of illumination and ambient temperature, respectively, reach maximum values of around 998 W/m^2 and 22°C.
- The voltages and currents at the input of the converter are, respectively, around 52.4 V and 9.1 A and at the output around 96.9 V and 4.8 A.
- The powers at the input and there at the output of the converter are, respectively, of the order of 476.8 W and 465.1 W, that is, an efficiency of 97%.
- The temperature of the thermal resistance reaches the value of 300°C after 5 seconds of heating (i.e., 60°C/s), and the maximum value reached 660°C after 20 seconds.

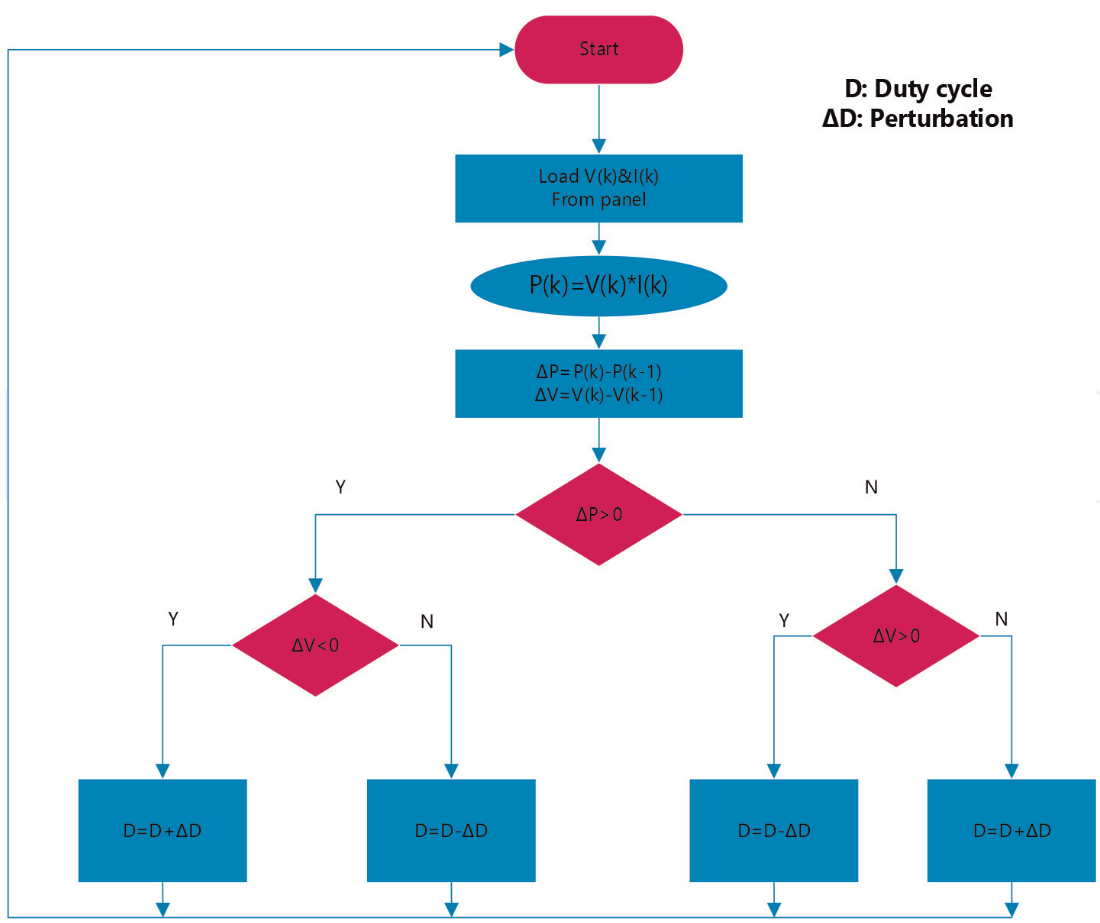

Figure 5.
MPPT command flowchart Perturb and Observe.

- During 5 minutes of heating, the water temperature varies from 24–49°C, that is, 3.8°C/min. In this case, the thermal efficiency is around 75%.
- After 18 minutes of heating, the water reaches the maximum boiling temperature, which is 98°C.

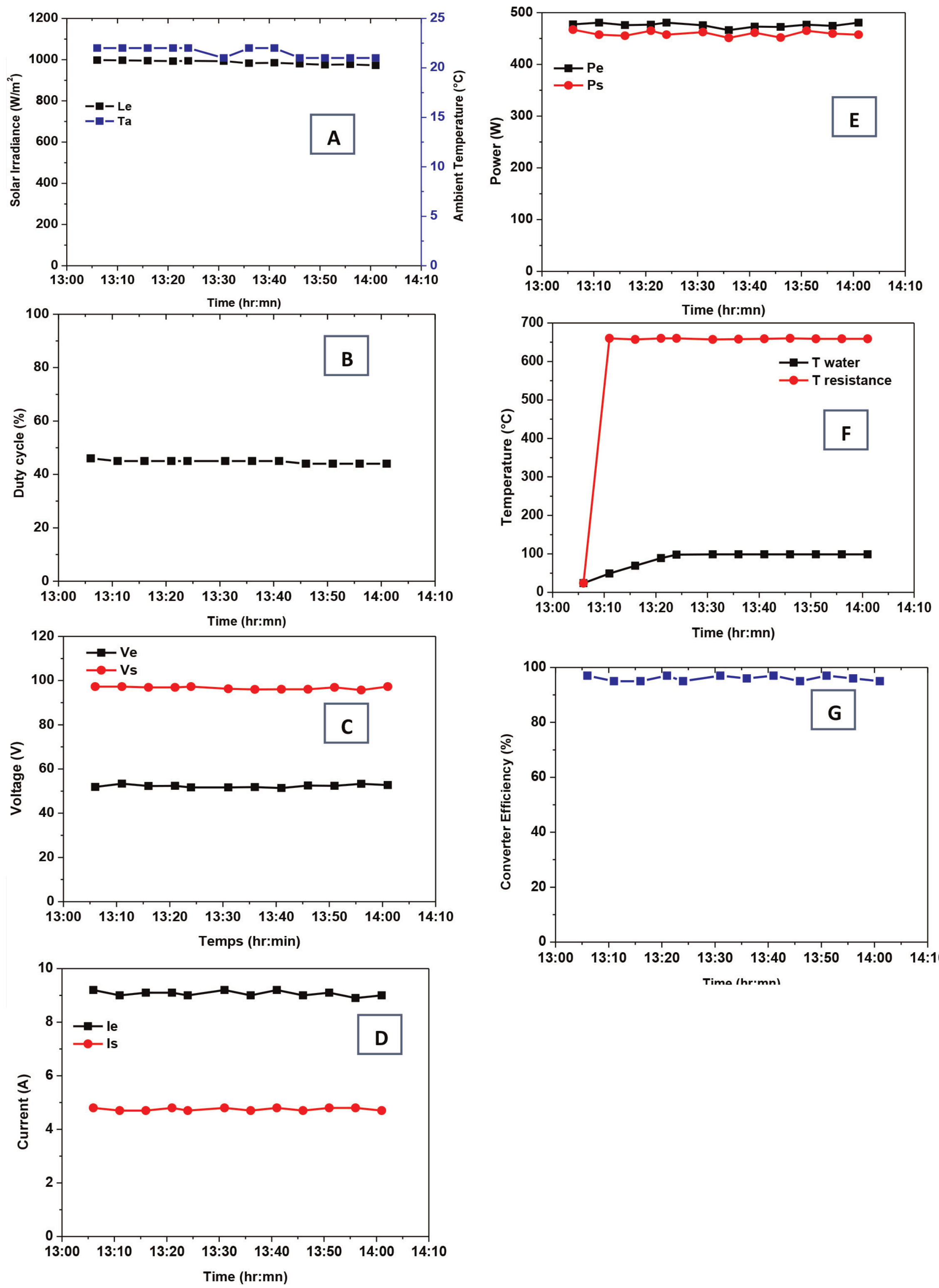

Figure 6.
*Experimentation of the cooker (hot plate) (**Figure 3**) during the heating of 1 liter of water. A: Illumination and external temperature. B: Duty cycle of the DC/DC converter. C: Input and output voltage of the DC/DC converter. D: Input and output current of the DC/DC converter. E: Power of Photovoltaic generator and heating resistor. F: Efficiency of the DC/DC converter. G: Temperature of the heating resistor and water.*

All the results obtained on the PV system, controlled by the MPPT command, show that the proposed MPPT command plays its role correctly, and the solar cooker is heated by the maximum power provided by the PV panels (**Figure 6**).

4. Conclusion

In this chapter, we have analyzed the operation of photovoltaic (PV) panels around their maximum power points (MPP). We recalled the equations and electrical models that govern the operation of these panels and showed that knowledge of their electrical quantities, over the sun, is essential to design the different blocks of the PV system, which control their operation in a PV application. As part of our experiment, when the intensity of the illumination varies from 300 to 900 W, the optimum voltages, currents, powers, and resistances of a PV panel (300 Wp), vary, respectively, from 25.4 to 25, 5 V; 2.87 to 8.61 A; 72.9 to 218.7 W and 8.85 to 2.95 Ω. Then, we showed that these electrical quantities are fixed through a power block (DC/DC converter), controlled by an MPPT command, which generates a variable duty cycle PWM signal. We specified that the most established MPPT command is that of perturb and observe since it presents the stability and the precision of convergence toward the MPP. In the case of a solar photovoltaic application (solar cooker), we have followed the role of this control in the optimization of the operation of the 600 Wp PV panels (two PV panels in series). We have shown that, during a sunny day, where the intensity of the illumination varies from 950 to 1000 W/m^2, the duty cycle of the PWM signal varies from 0.42 to 0.45, and the operation of the PV panels converges toward their optimum electrical quantities (voltage, current, optimum resistance, and power of the order of: 51.17 V, 9.2 A, 5.56 Ω, and 470 W), and the temperature of a liter of water has reached the boiling temperature of 90°C after 23 min of heating. All the results obtained show the role of the power unit and its perturb and observe type command to optimize the operation of PV panels, in a PV application, over the sun.

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