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The Impact and the Need for the DC/DC Converter to Adapt the Energy Produced by the Photovoltaic Generator

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ABSTRACT

Considering the environmental effects and the shortage of fossil fuels, research encourages us towards the development and use of more and more renewable energies such as the autonomous photovoltaic system which is very much used for rural applications such as solar lighting, battery charging, etc. The beginning of our study describes the photovoltaic effect and the current-voltage and power-voltage characteristics of a mathematical model of a cell with a single diode. This allows us to model a solar panel and get an idea of the behavior of the field and the photovoltaic generator. The model predicts the behavior and characteristics of the PV model using the Matlab/Simulink platform. Connected to a basic circuit, the constant DC source voltage step-up converter first and to the PV system last, allows us to conclude that the presence of power electronics is essential in the photovoltaic system in order to adapt and d Ensuring its proper functioning and satisfactory results suggest the effectiveness of this model.

1. INTRODUCTION

Solar energy is by nature widely available everywhere in the world, even if the countries located in certain zones are privileged because the solar radiation is very intense there. Solar is for the moment only an ultra-minority in the global energy mix (1%), but it is experiencing rapid development which, according to forecasts by the IEA (the International Energy Agency), is expected to continue over the next few years [1].

The main solar power generation capacities are currently installed in China, the United States, Germany, Japan and Italy. India could also quickly catch up with these countries.

Renewable energies such as wind energy, solar energy, biomass energy, are promising solutions to compete with mass energy sources such as fossil and nuclear energies [2].

By renewable energy, we mean energy from the sun, wind, heat from the earth, water or biomass. Unlike fossil fuels, renewable energies are energies with unlimited resources. If we look at solar energy in particular, we will notice that solar radiation is distributed over the entire surface of the earth. No country will have to sell the resource, it will rather sell the technology [3].

The photovoltaic effect manifests itself in the form of a potential difference between the two sides of a semiconductor P-N junction when this junction receives solar radiation of adequate wavelength and connected at the end with a load, the material most used industrially is based on silicon [4].

Such a system consists of a field of modules and a set of components which adapt the electricity produced by the modules to the specifications of the receivers.

The photovoltaic generator is the only direct converter to transform solar radiation into electrical energy, but it is not capable of generating energy suitable for charging or connecting to the electrical grid. One or two adaptation steps should always be used. This is the role of power converters which are as important as they are indispensable in photovoltaic systems [5].

Most household appliances operate with a voltage of 220V, 50Hz. However, energy sources available in isolated environments such as batteries or solar panels provide DC voltages between 12 and 24V. In order to use these energy sources to operate 220V, 50Hz appliances, it is necessary to use inverters that convert direct current to alternating current. Generally, two converters are required to adapt the energy produced by the photovoltaic generator; a DC/DC converter, object of our paper, to raise or lower the voltage to the desired value and an inverter to obtain the AC form from the DC form delivered by the photovoltaic generator [6].

This paper deals with the modelling and the study of a PV module connected to a boost converter which supplies a resistive load that can be a lamp or another receiver for domestic use.

2. PV GENERATOR MODEL

There are mathematical models of the characteristic current-voltage of the photovoltaic cell. However, the most practical by their relative simplicity in the calculation are the single exponential model (a single diode), in which, the obscurity current (diode current), representing uniquely the saturation current resulting of the diffusion phenomenon and the two exponential model (two diodes) representing both the components, diffusion and recombination [7].
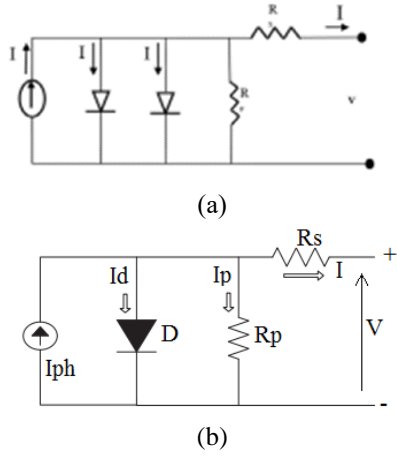
(a)

(b)

Figure 1. Two and one Diode model of PV cell

The model of one diode (Figure 1), has the advantage of being simple, it allows to obtain the static behavior of a PV cell under polarization

$$I = I_{ph} - I_d - I_p \qquad (1)$$

I: The current of the PV cell,

I_{ph}: The, photon current it is proportional to the irradiance,

I_d: The current flowing in the ideal diode D (diode in parallel models the junction),

I_p: The current flowing through the shunt resistor.

There are several ways to present and calculate the current of a PV cell (1). For this, we chose a simplified and improved mathematical model [8], and the I-V characteristic can be written as follows:

$$I_p = \frac{V + R_s I}{R_p} \qquad (2)$$

R_p: The shunt resistance (parallel).

The photocurrent is given by:

$$I_{ph} = \left(\frac{G}{G_{ref}}\right)(I_{ph,ref} + \mu cc(T_c - T_{c,ref})) \qquad (3)$$

G: Irradiance,

G_{ref}: Irradiance in standard conditions=1000W / m²,

$T_{c,ref}$: The temperature of the cell under standard conditions=25°C,

T_c: The temperature of the cell (°C),

μ_{cc}: Temperature Coefficient of the DC current (A / °C),

$I_{ph,ref}$: The photocurrent.

Latter can easily be measured from the manufacturer's characteristic (I-V) to standard conditions.

The diode current is given by Shockley's equation:

$$I_d = I_0 \left[exp\left(\frac{e(V + IR_s)}{\lambda K T_c}\right) - 1\right] \qquad (4)$$

V : The voltage,

R_s : Series resistance,

λ : is a coefficient characterizing the power variation as a function of temperature,

K : The Boltzmann constant,

e : The charge of the electron,

I_0 : The saturation current.

We have:

$$I_0 = DT_c^3 \, exp\left(\frac{-e\varepsilon_G}{nKT_c}\right) \qquad (5)$$

D : The diffusion factor of the diode,

ε_G : The width of the forbidden band (eV).

To eliminate the term D, the two equations are divided into parts:

$$I_0 = I_{0,ref}\left(\frac{T_c}{T_{c,ref}}\right)^3 exp\left[\left(\frac{e\varepsilon_G}{nK}\right)\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right] \qquad (6)$$

It is necessary to write the characteristic equation I (V):

$$I = I_{ph} - I_0\left[exp\left(\frac{e(V + R_s I)}{\lambda K T_c}\right) - 1\right] - \frac{V + R_s I}{R_p} \qquad (7)$$

We can write the following three relations:

$$I_{cc,ref} = I_{ph,ref} - I_{0,ref}\left[exp\left(\frac{eI_{cc,ref}R_s}{\lambda K T_{c,ref}}\right) - 1\right] \qquad (8)$$

$$0 = I_{ph,ref} - I_{0,ref}\left[exp\left(\frac{eV_{co,ref}}{\lambda K T_{c,ef}}\right) - 1\right] \qquad (9)$$

$$I_{pm,ref} = I_{ph,ref}$$
$$-I_{0,ref}\left[exp\left(\frac{e(V_{pm,ref} + I_{pm,ref}R_s)}{\lambda K T_{c,ref}}\right) - 1\right] \qquad (10)$$

So it can be deduced that [1-6]:

$$I_{cc,ref} \approx I_{ph,ref} \qquad (11)$$

By replacing $I_{ph,ref}$ with $I_{cc,ref}$ in Eq. (9):

$$0 \approx I_{cc,ref} - I_{0,ref} \, exp\left(\frac{eV_{co,ref}}{\lambda K T_{c,ref}}\right) \qquad (12)$$

$$I_{0,ref} = I_{cc,ref} \, exp\left(\frac{-eV_{co,ref}}{\lambda K T_{c,ref}}\right) \qquad (13)$$

For the calculation of I_0, we replace in Eq. (6), and for I_{ph} in Eq. (3).

For a photovoltaic generator composed of N_s modules in series and N_p modules in parallel, there will be:

$$V_{pv} = N_s V \qquad (14)$$

$$I_{pv} = N_p I \qquad (15)$$

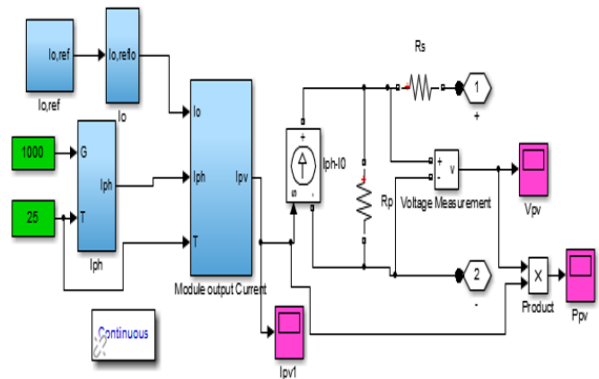The Figure 2 gives the PV module Matlab/SIMULINK model.

Figure 2. PV model under Simulink

The evolution of the I−V characteristic as a function of temperature shows that the current increases very rapidly when the temperature rises and generates a less pronounced decrease in the open circuit voltage (Figure 3).
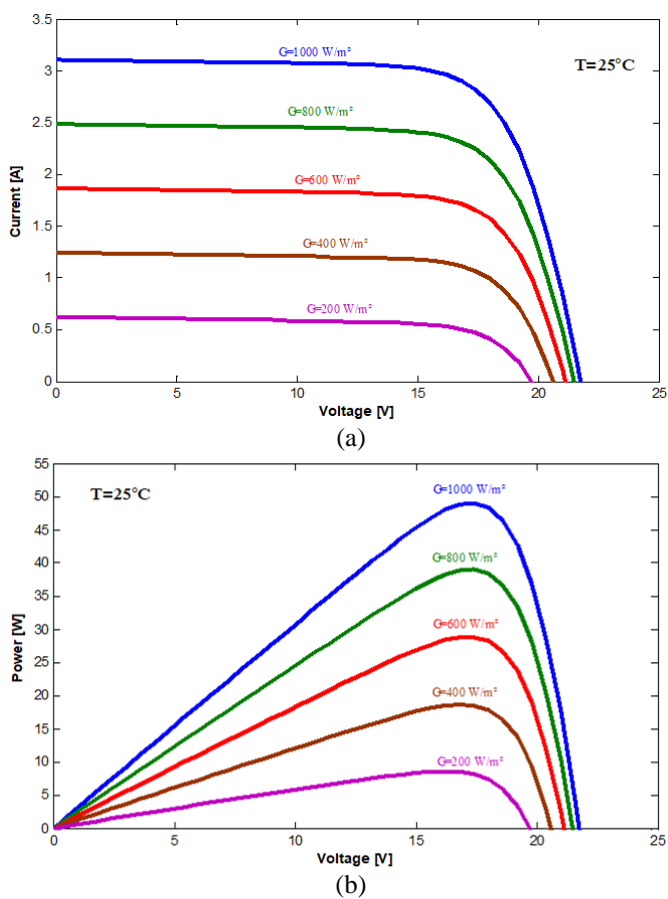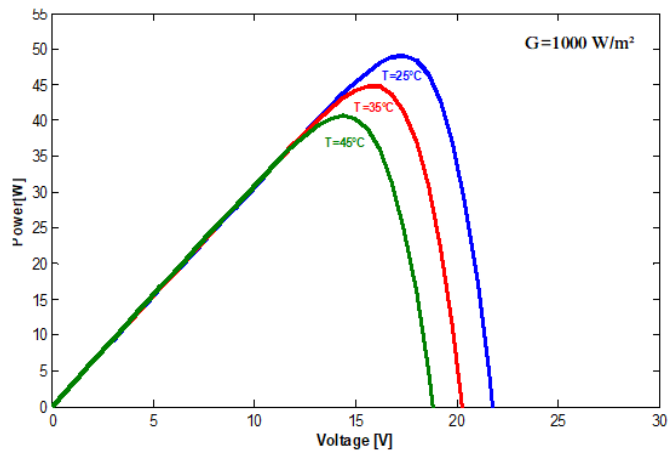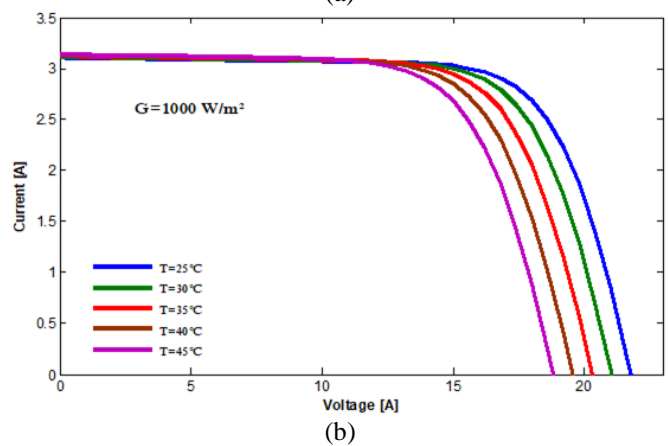

(a)

(b)

Figure 3. (a) I (V) curves and (b) P (V) curves of a panel at various irradiances at T=25°C

The high temperature lowers the open circuit voltage for fixed sunlight; therefore, the maximum power drops (Figure 4).

(a)

(b)

Figure 4. The influence of temperature on the (a) I(V) curves at G=1000 W/m^2 and on the (b) P(V)

3. DC/DC CONVERTER IN PV SYSTEMS

Like inverters, converters are essential for integrating PV electricity into the grid. Indeed, the fluctuation of this energy constitutes a real problem of adaptation. It is constantly necessary to stabilize, reduce or often raise the tension. Several topologies are proposed in the literature, we present the most appropriate and the most studied: Boost, Buck, Buck-boost and Cuk. Figure 5 presents four possible topologies of non-isolated DC/DC converters suitable for PV panels [9].

3.1 Buck converter

A chain connection of series of buck modules, as in Figure 5.b, allows total independence with respect to the output voltage and therefore the power, while the output currents are necessarily equal because of the connection in series. In addition, the internal freewheeling diode of the Buck converter allows the inactive module to which it is associated to be kept automatically on without causing a short-circuit of the DC source.

3.2 Buck-boost converter

They are choppers capable of operating in two ways (Buck-Boost) where the average output voltage is lower or higher than that of the input [10, 11].
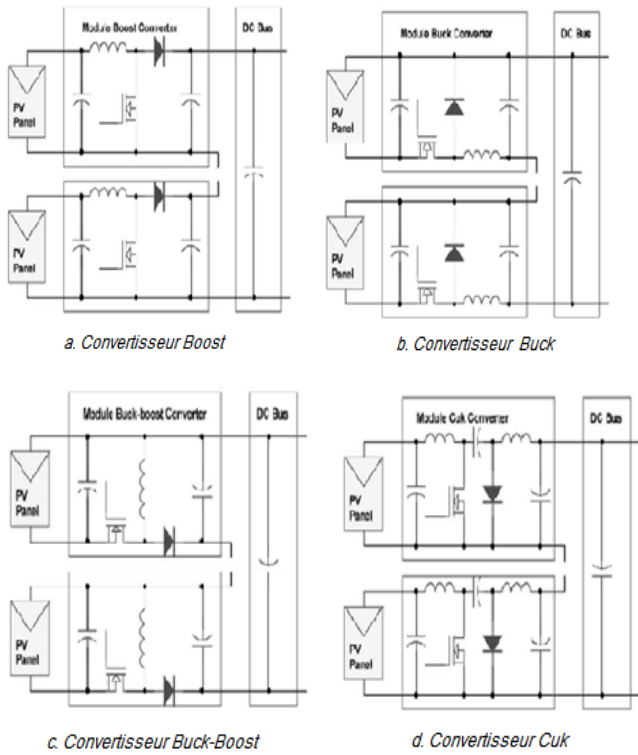
Figure 5. Diagrams of the different converter topologies DC/DC for PV connected to a power grid

3.3 Ćuk converter

Unlike other types of converters, which use an inductor, a Ćuk converter uses a capacitor to store energy [12].

3.4 Boost converter

It is very suitable for boosting the direct voltage generated by the PV installation to the value necessary to convert it into alternating voltage and therefore frees up the use of the transformer (Figure 6). The characteristic of the Boost is that it allows with the minimum required voltage of 340V of the direct bus to reach the alternating voltage of 240 V for a connection to the network without a transformer and above all, with the fewest possible photovoltaic panels [13-15].
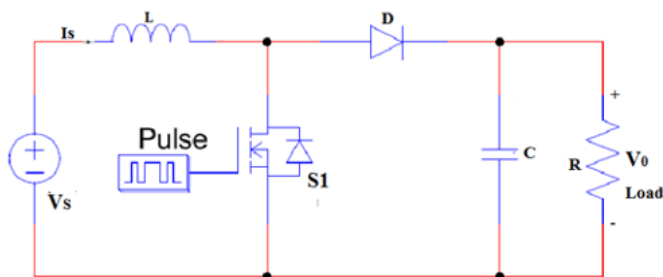
4. SYSTEM FOR STUDY

Figure 6. Circuit diagram of the Boost converter

At the beginning of this work, we took the simple example of a continuous source which feeds a boost converter and we proceeded to calculate the various parameters, to to reach the desired output, we removed the continuous source and we had it replaced with the photovoltaic system proposed in the model .In both cases, the service pulses are supplied by the PWM pulse generator [16, 17].

4.1 System data

For our case study:
- The switching is ensured by mosfets with a resistance of 0.01Ω its snubber with a value of $100k\Omega$.
- Resistance of the Diode 0.001Ω and snubber resistance as 500Ω.

4.2 Determination of parameters

In this study example, we take:
the output voltage Vo =100 volt
Vs =70 volt
switching frequency Fs=1kHz,
R load =50Ω
r=0.5%.

4.2.1 Duty cycle (D)

$$D = 1 - \frac{Vs}{Vo} \tag{16}$$

$$D = 1 - \frac{70}{100} = 0.3 \tag{17}$$

4.2.2 Value of inductor (L)
Calculate minimum inductance

$$L_{min} = \frac{D(1-D)^2 R}{2*f} \tag{18}$$

$$L_{min} = \frac{0.3(1-0.3)^2 * 50}{2*1000} = 3675\ \mu H \tag{19}$$

Calculate 25% larger than minimum inductance

$$L = 1.25 * L_{min} \tag{20}$$

$$L = 1.25(3675) = 4593.75\ \mu H$$

4.2.3 Calculate minimum capacitance

$$C = \frac{D}{Rrf} \tag{21}$$

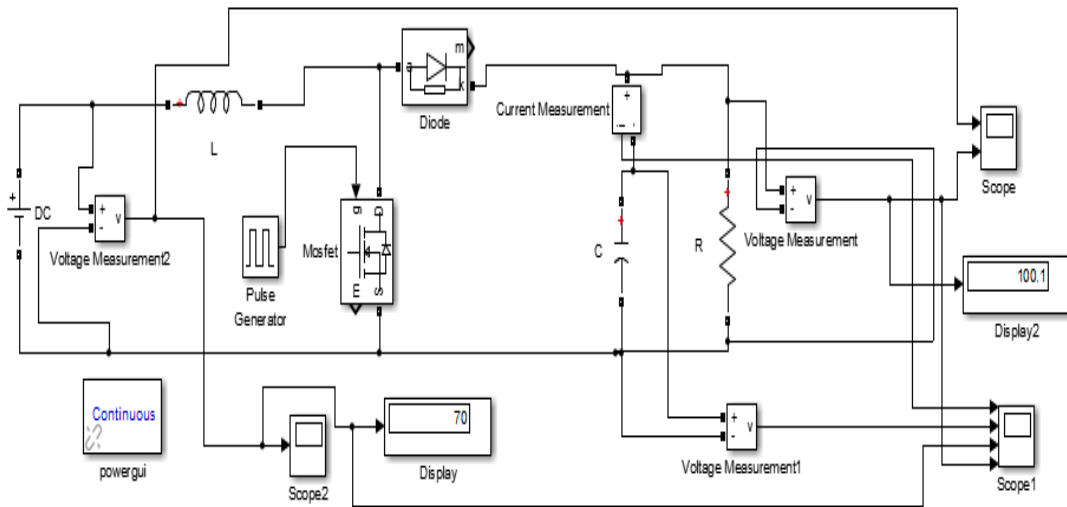$$C = \frac{0.3}{50*0.005*1000} = 1200\mu F \tag{22}$$

Figure 7. Equivalent circuit of the boost converter

5. MODELLING AND SIMULATION

Under MATLAB / Simulink and using different blocks of the library, we have connected the diagram of the Figure 7, which is an example of a resistive load, supplied by a continuous source using a step-up converter (Boost) [18-21].

The gate pulse needed to trigger the circuit is supplied by the pulse generator.

Figure 8 represents the outputs of the converter.

6. PV SYSTEM

We take the PV module shown in Figure 7 and we connect the boost DC-DC converter for main to have a boost input voltage of 70 volts and a voltage boost output of 100 volts or load voltage for our case we took a resistive load of 50 ohms.

After simulation ,the results are given by Figure 10 for constant irradiance at a value of 1000W/m² and Figure 11 by varying the irradiances.

Figure 10 represents the output current, voltage and power waves form.

For a constant irradiance, we note the reliability of our proposed model, since the goal is to have a voltage at the output of the boost higher than that given by the photovoltaic generator which the values have been defined beforehand ($V_{0=}$100 Volts and Vs=70 Volts).

By varying the irradiances with the bloc of Simulink Repeating Sequence Stair at Vector of output values: [600 1000 800 200] in Figure 11, the current, voltage and the power in the load vary with the irradiances.
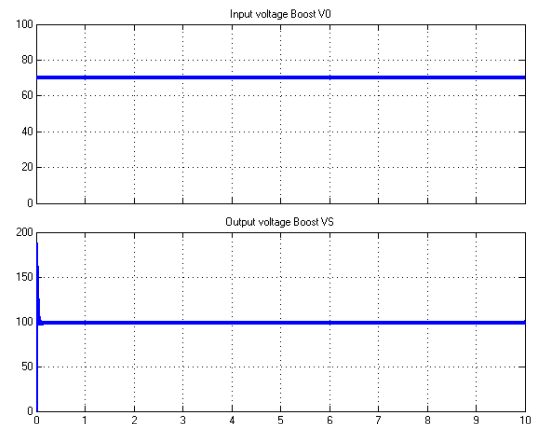

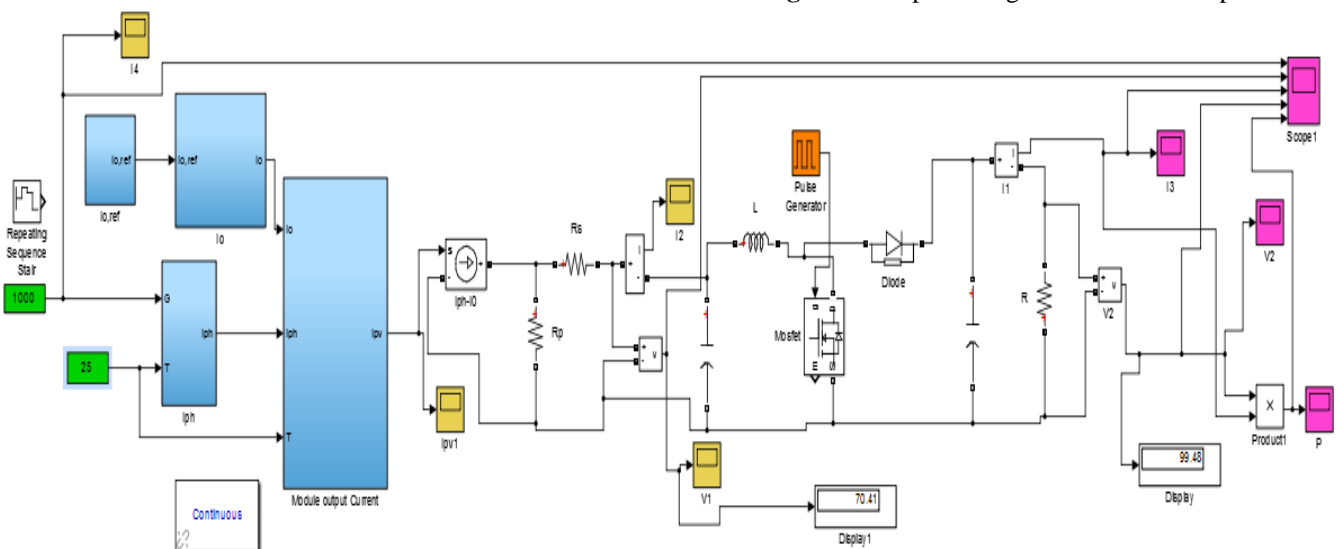**Figure 8.** Output voltage waveform of simple boost

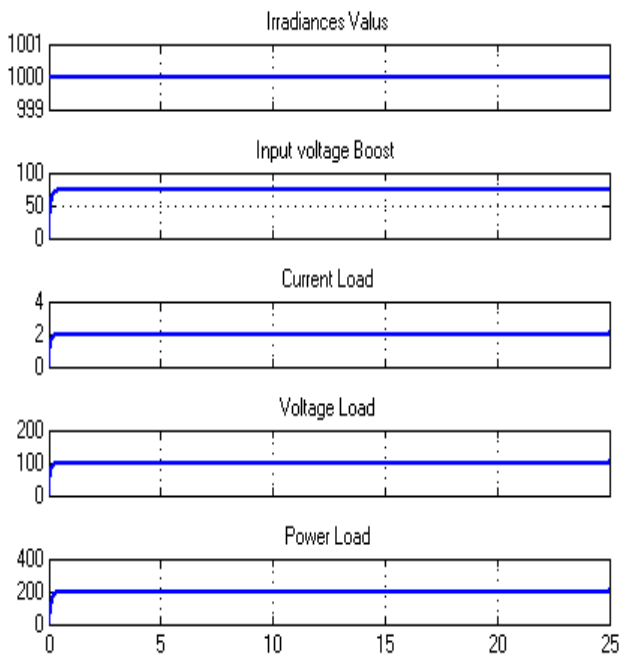**Figure 9.** PV and boost converter with impulsion generator

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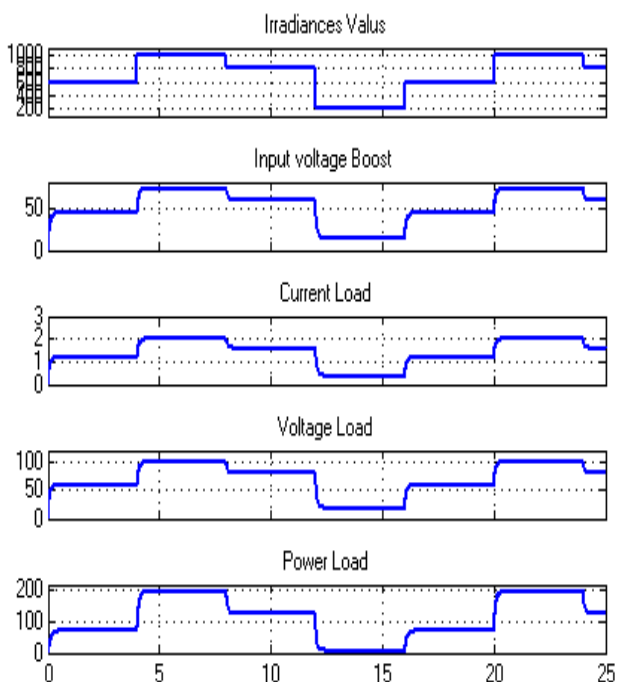**Figure 10.** Output voltage waveform of PV system connected boost converter with impulsion generator

Figure 11. Output voltage waveform of PV system

7. CONCLUSION

The work summarizes, modeling of system elements and simulation for variations in temperature and irradiance, the performance of a PV generator is strongly influenced by these two parameters.

The one-diode model is the most classic and the most used in the literature, it takes physical phenomena into account, it involves a current generator for modeling the luminous flux, a diode for the junction polarization phenomena and two resistors (series and shunt) for losses.

The strength of this work is the design of the model with the contribution of the boost converter, which is answered in the use of systems aimed at increasing the input voltages and supplying loads with desired outputs.

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