J. Automation & Systems Engineering 13-1 (2019): 18-28

Regular Paper

Analysis of maximum power tracking technique for Grid-connected photovoltaic system

Henchiri Abdelhmid, Bahi Tahar and Lekhchine Salima

20 August 1955-Skikda University, Laboratory of Mechanical Engineering and Materials, Skikda, Algeria

JASE

Journal of Automation & Systems Engineering

Abstract- In the last years the utilization of photovoltaic technology is very attractive and popular due to the increasing of power demand. This paper, describes the mathematical model of the photovoltaic's system, maximum power point tracking algorithm, and design of the controller. The dynamic performance of the photovoltaic's generator connected through the inverters to the distribution network; discussed under different climate conditions. The simulation results show the controllers ensures to operate PV panel at its maximum power point, and provide the DC output voltage at its reference whatever is the atmospheric conditions.

Keywords: Renewable energy, Photovoltaic, DC/DC rectifier, MPPT, Simulation.

1. INTRODUCTION

Electric power generation is undergoing significant changes during this decade. This is mainly due to the demand of electricity witch increase drastically, with the development of renewable which is unlimited, non-polluting and whose exploitation causes fewer damages on the environment [1]. The renewable energy (Photo Voltaic (PV) system, wind, biomass etc…) is abundant in nature. Energy can be retrieved easily and economically with the help of those renewable energy resources [2]. The photovoltaic systems offer an advantageous solution as a renewable energy source (RES). Indeed, their use has been particularly accentuated in network-connected applications because of many advantages of using RES in Distributed Generation Systems (DG) [3, 4]. Nowadays, using renewable energy resources as a power supplier in a power generating system instead of conventional ones has been more popular [5]. Furthermore, a sensitivity analysis is also performed considering variations in two important parameters, namely solar irradiation and temperature. These systems have the major advantages over the traditional energy sources (oil and natural gas) but their efficiency and controllability stand as the major drawbacks [6]. However, when system PV is connected the utility network, the power electronic converters are widely adopted and consequently all photovoltaic systems are interfacing the utility grid through a voltage source inverter [7], and a boost converter. The voltage, current and power values, changed according to temperature, solar radiation, and the variation of the load. The PV generators exhibit non-linear current-voltage characteristics. On the other hand, the optimum operating point changes with the solar irradiation, and cell temperature. Therefore, online tracking of the maximum power point of a PV array is an essential part of any successful PV system [8]. So, in order to extract the maximum amount of power from the PV generator, Perturb and Observe (P&O) control method for the MPPT of a PV system and the loop control uses a proportional–integral (PI) controller to obtain a suitable duty cycle the keep the output voltage according to the reference level of DC bus are considered [9-10] .These renewable energy-based electricity production systems require an efficient analysis of the photovoltaic systems connected to the distribution network so as to predict their dynamic performances under different operating conditions in order to make a comprehensive decision on the feasibility of incorporating this technology into the electric utility grid.

In this paper, Maximum Power Point Tracking (MPPT) technology is adapted to optimize the power output. There are many methods applied to MPPT such as hill climbing, peturb and observe, particle swarm optimization, fuzzy logic control, ant colony optimization, neural network, chucko search, and others [11, 12] . With the MPPT algorithm can be used to trace the maximum power that generated electricity can generate. This MPPT method is implemented on a dc-dc converter circuit In this study, we will use the Incremental conductance method to trace the maximum power. Moreover, the important results of numerical simulation obtained from the study is related to the optimal operating under the available conditions, principally, the solar irradiation and temperature variation.

The paper is arranged as follows: in section 2, the configuration of the energy conversion system studied is presented. Modeling of PV array configurations as well as the principle is developed in section 3. The details of Boost converter model and MPPT algorithm based on incremental conductance are presented in the sections 4 and 5, respectively. The performance of grid connected photovoltaic system is shown by the numerical simulation in Section In section 6. Finlay, section 7 summarizes the main conclusions.

2. CONFIGURATION OF STUDIED SYSTEM

The structure of the electric power generation system considered in this work to analyze the performances PV system connected to the grid is represented by the block diagram shown in Fig.1.
The photovoltaic generator (PVG), two level inverter (DC/AC converter) synchronize a sinusoidal current output with a voltage grid and power grid via a step-up DC-DC converter (Boost converter), which carries out the maximum power point tracking MPPT control. There are, three important parts are addressed to ensure that: the PV module is operated at the maximum power point, the regulation of the output voltage of the boost converter, and sinusoidal current to the grid. The models of each part of the overall structure are given by the figure 1.

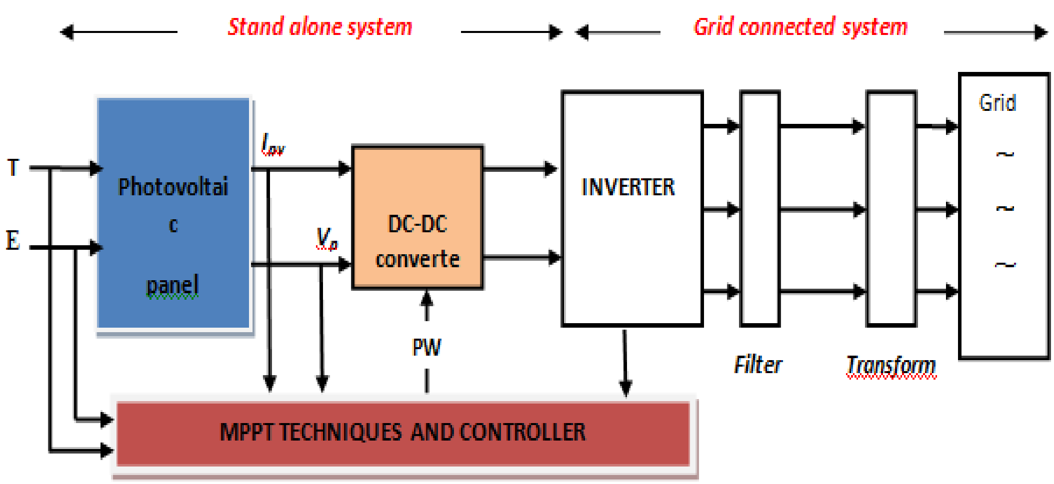

Figure 1. Bloc diagram of studied system

3. PHOTO VOLTAIC SYSTEM

In this part, mathematical model of photovoltaic cell and the principle of control of maximum power point using the incremental conductance algorithm as good as the control of the boost output voltage are developed. The photovoltaic energy production can be directly converts the under exposed solar radiation into DC electric power [13-15]. The photovoltaic cell is a semiconductor diode consisting of the p-n junction. The equivalent circuit of a photovoltaic cell using the single exponential model is shows by Figure 2.

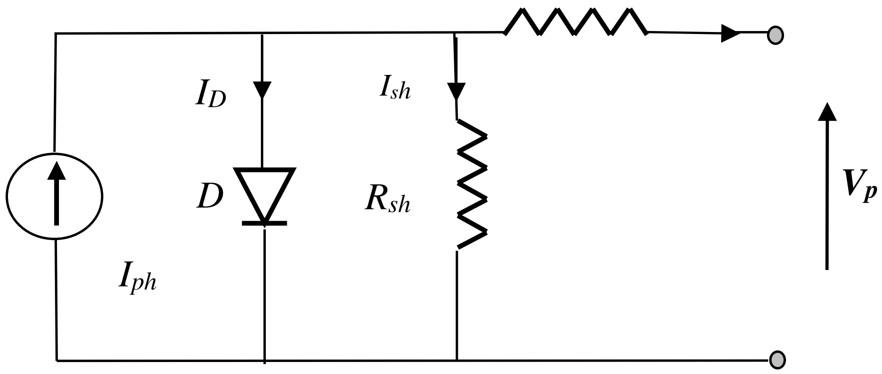

Figure 2. Electrical equivalent circuit of a photovoltaic cell

The equivalent circuit and the basic equations of the PV cell in Standard Test Conditions (STC: Temperature = 25 °C and irradiantes level = 1000 W/m^2) . STC is to measure PV cells nominal output power [16]. The output current and the voltage of the photovoltaic cell are given by the following equations:

$$I_{pv} = I_{ph} - I_D - I_{sh} \tag{1}$$

Where, I_{ph} is the photovoltaic current of PV cell which is strongly related to the solar operating and standard radiation (G_o and G_s) and solar cell operating and standard temperature (T_o and T_s) according to the following relation [17] :

$$I_{ph} = \frac{G_o}{G_s}\left[I_{sc} + K(T_o - T_s)\right] \tag{2}$$

With I_{sc} is the cell's short-circuit current at standard temperature T_s=25°C

I_D is modeled using the Shockley equation for an ideal diode [18]:

$$I_D = I_{Ds}\left(\exp\frac{V_{pv} - R_s}{V_T} - 1\right) \tag{3}$$

Where; V_T presents the thermal voltage expressed by:

$$V_T = \frac{n.K.T_o}{q} \tag{4}$$

With *n* is the diode ideality factor, *K* is the Boltzmann constant (K = 1.38 10^{-23} J/K) and *q* is the electron charge (q = 1.6 10^{-19} C). And the shunt resistor current I_{sh} is denoted by the given expression:

$$I_{sh} = \frac{V_{pv} + R_s\, I_{pv}}{R_{sh}} \tag{5}$$

To form a photovoltaic panel, the cells must be assembled in series and parallel where, connecting cells in series increases the output voltage, however the parallel connection increases the output current. The mathematical model presenting the produced power of the photovoltaic panel becomes a simple algebraic model defined by the current-voltage relation [19, 20]:

$$I_{pv} = N_{sh} I_{ph} - N_{sh} I_{RS} e^{\frac{x}{A V_{Th}} - 1} - \frac{N_{sh}}{R_{sh}} x \tag{6}$$

With,

$$x = \frac{V_A}{N_s} + \frac{R_s I_{pv}}{N_{sh}} \tag{7}$$

The parameters I_{Ph}, I_{RS}, R_S, R_{sh}, are necessary for to determine the characteristics: Ipv=f(Vpv) and Ppv=f(Vpv), for different operating conditions. Moreover, they depend on the incident solar radiation and the cell temperature. In practice, each PV module is identified by his reference values for the STC: solar radiation (G) of 1000 W/m² and a solar cell temperature (T) of 25 °C and an air mass AM (a measure of the amount of atmosphere the sun rays have to pass through) of 1.5 [21].

3.1. Simulation

The parameters of the photovoltaic used in this work are tabled in table 1 and the Figure 3 and Figure 4 show, respectively, I-V and P-V characteristics on weather condition of the solar radiation irradiation (1000W/m^2 , 800W/m^2 and 500W/m^2) and temperature (25°C, 35°C and 45°C). In this work there is the use of four (4) identical modules.

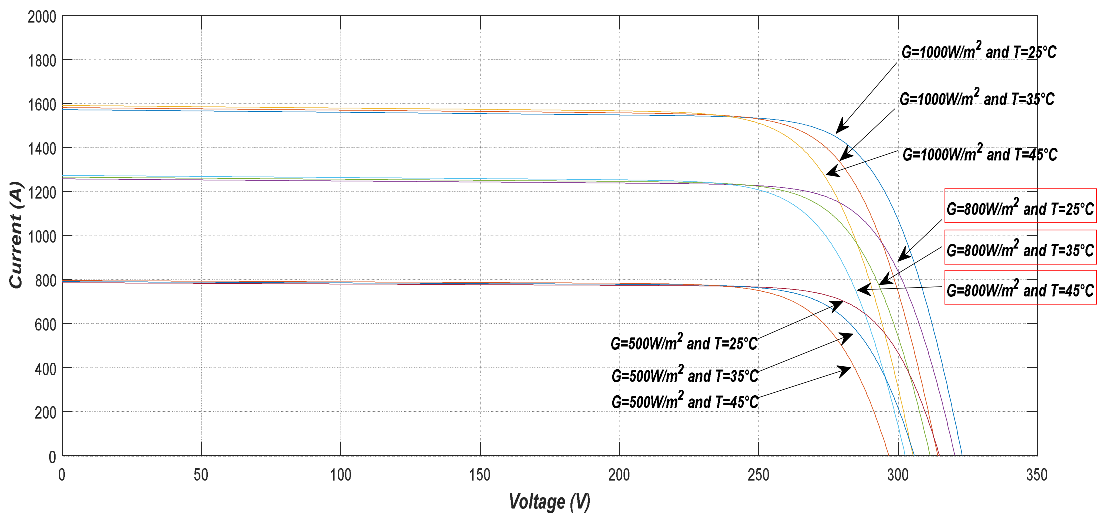

Figure 3. I-V Caracteristics

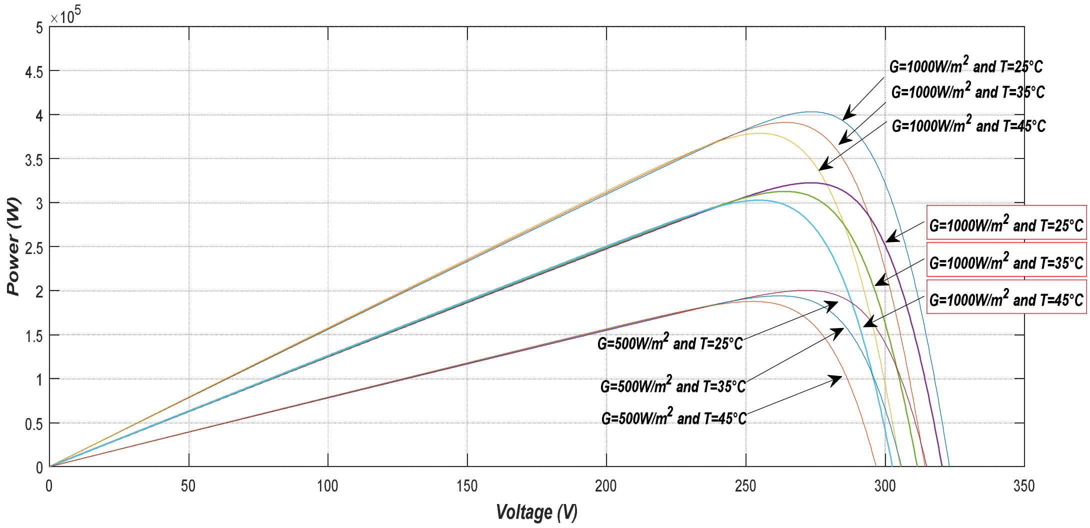

Figure 4. P-V Caracteristics

Moreover, the analysis of the forms of the maximum output powers obtained under different climatic conditions is depicted in Table 2.

Table 2. ***Maximal powers***

	P=1000 W/m²	**P=800** W/m²	**P=600** W/m²
T =**25**°C	4.0330e+05	3.2254e+05	2.0036e+05
T =**35**°C	3.9114e+05	3.1272e+05	1.9409e+05
T =**45**°C	3.7881e+05	3.0276e+05	1.8773e+05

4. CONVERTER MODEL

The Boost converter is installed to increase the photovoltaic array voltage to a level, which ensures correct operation of the inverter and he controlled by the duty ratio d (0 <<1) with which the average values of the output quantities can be expressed with those of the input. The equivalent circuit is illustrated in Figure 5.

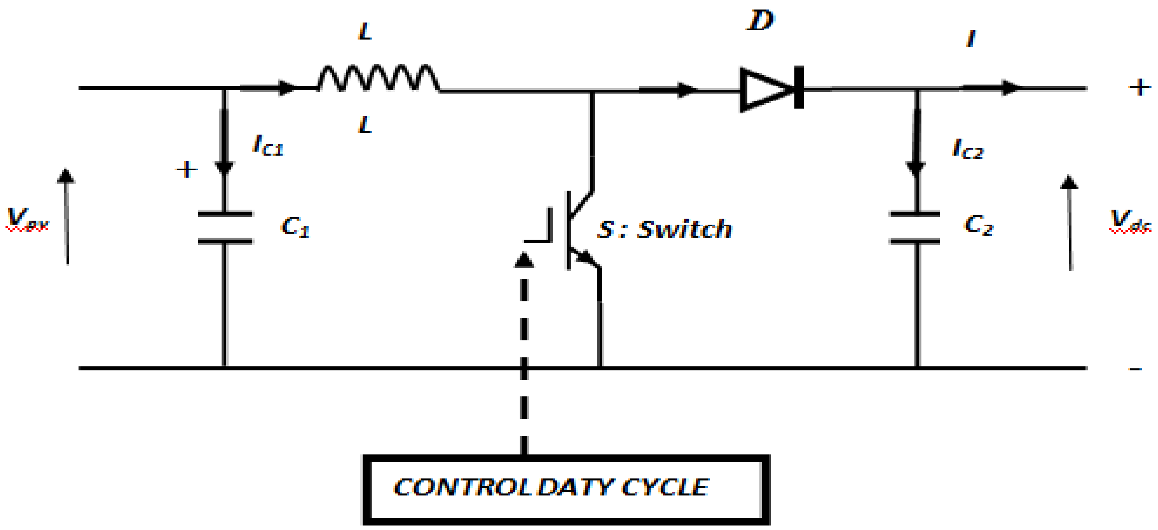

Figure 5. Equivalent circuit of DC/DC converter

At the first cycle (αT), the switch (S) is closed, the current through the inductance increases gradually, it stores energy during the first cycle. Then, (S) is opens the inductance (L) opposing the current decrease, generates a voltage which is added to the source voltage, which is applied to the load (R) through the diode (D). Kirchhoff's laws are applied to the two equivalent electric circuit cases of the chopper. For the first period $\alpha.T_S$: (S) closed:

$$I_{C_1} = C_1 + \frac{dV_g}{dt} = I_g - I_L \tag{8}$$

$$I_{C2} = C_2 + \frac{dV_0}{dt} = -I_0 \tag{9}$$

$$V_L = L\frac{dI_L}{dt} = V_g - R_L I_L \tag{10}$$

Kirchhoff's laws are applied to the two electric circuits of the chopper. For the second period α.Ts: (S) open:

$$I_{C_1} = C_1 + \frac{dV_g}{dt} = I_g - I_L \tag{11}$$

$$I_{C2} = C_2\frac{dV_0}{dt} = I_L - I_0 \tag{12}$$

$$V_L = L\frac{dI_L}{dt} = V_g - V_0 - R_L I_L \tag{13}$$

5. INCREMENTAL CONDUCTANCE METHOD

The boost converters are used to transfers maximum power from the solar array to the DC bus, in a coordinated way and at a voltage always greater than the input magnitude. Photovoltaic array is charged at the Maximum Power Point (MPPT) near operating point and had done with MPP Tracking Algorithm [22-24]. In order to extract the maximum amount of power from the PV generator, incremental conductance (INC) control method for the MPPT of a PV system under variable temperature and insulation conditions, is considered. The voltage and current supplied by the photovoltaic network are affected by unstable climatic conditions [25]. In order to ensure the proper functioning of the PV module at its maximum power point, we use the algorithm, incremental conductance [26]. INC was designed based on an observation of P-V characteristic curve. From the derivative of the PV module, power is zero at MPP, positive at the left of MPP and Negative at the right of the MPP. The flowchart of the incremental conductance algorithm is show by the Figure 6. The MPP can be calculated by using the relation between di/dv and –I/V if dp/dv is negative then MPPT is lies on the right side of recent position and if the MPP is positive the MPPT is on left side the equations of IC method is:

$$\frac{dp}{dv} = \frac{d(V.I)}{dv} = I\frac{dV}{dv} + V\frac{dI}{dv} \tag{14}$$

$$= I + V\frac{dI}{dv} \tag{15}$$

MPP is reached when dp/dv=0 and

$$\frac{dI}{dv} = -\frac{dI}{dv} \tag{16}$$

$$\frac{dp}{dv} > 0 \text{ then } V_P < V_{mpp} \tag{17}$$

$$\frac{dp}{dv} = 0 \text{ then } V_P = V_{mpp} \tag{18}$$

$$\frac{dp}{dv} < 0 \text{ then } V_P > V_{mpp} \tag{19}$$

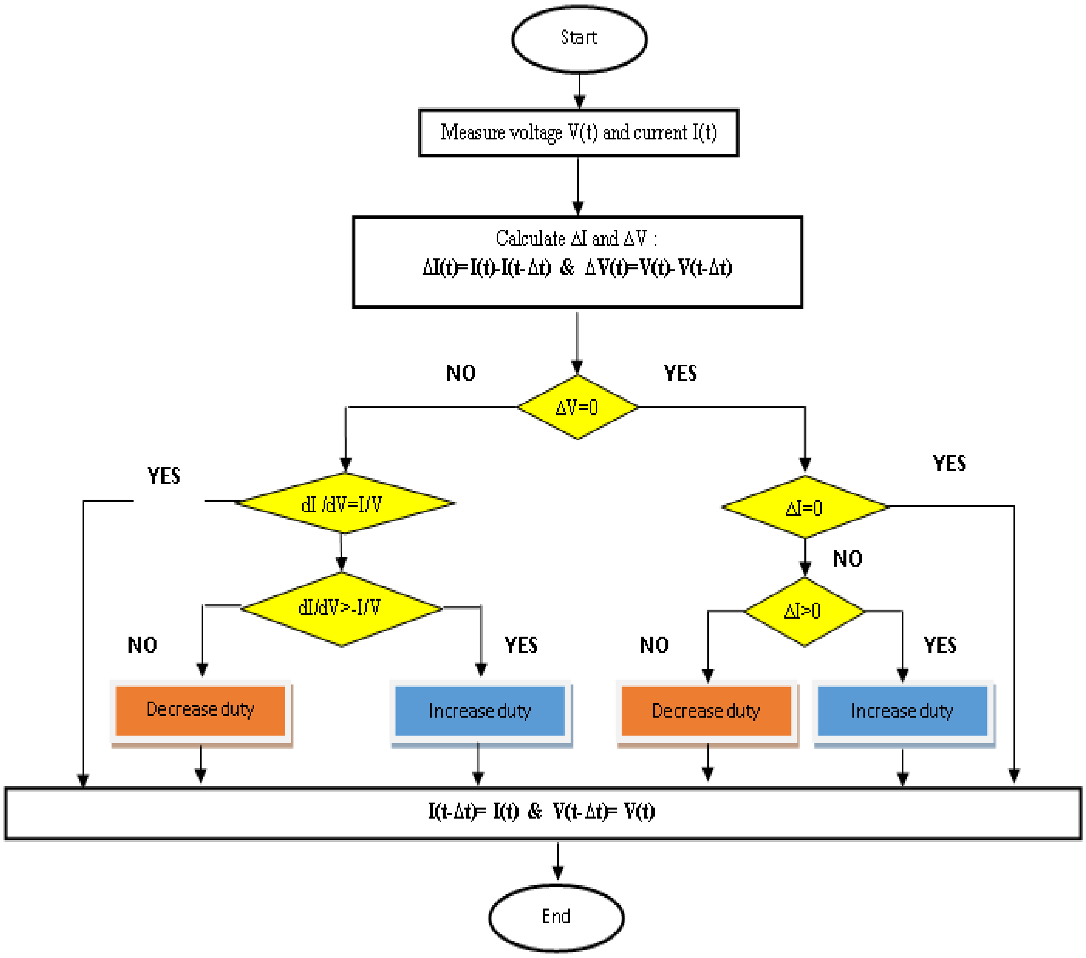

Figure 6. Flowchart of incremental conductance method

6. SIMULATION RESULTS AND DISCUSSION

In this section, two main tests of simulations were carried out to evaluate the performances of the considered system. At the beginning, the system is considered to operate with its standard conditions (G= 100W / m^2 and T = 25 ° C) but the reference of the output voltage of the Boost is variable.

Figure 7 presents the solar radiation, temperature and V_{dc} conditions imposed for first test, notes that the voltage at the output of the Boost converter follows correctly the reference value imposed, the voltage and the current (V_g and I_g) of the network are synchronized, and finally whatever the variations, the reactive power is zero; therefore the power factor is unitary. Concerning, the second test, it is realized under the conditions where irradiance and the temperature are changes but the V_{dc} reference is kept constant as shown in Figure 8. The corresponding simulation results are shown in Figure 9, where, we chose to represent the zooms of three zones: (G=1000W/m^2, T=25°C (Standard conditions); 800W/m^2 ,T=35°C and 500W/m^2, T=45°C. All these last forms show that the evolutions correspond perfectly to the imposed conditions and that the synchronization is assured. In this case too, the system has good performances despite the imposed tests.

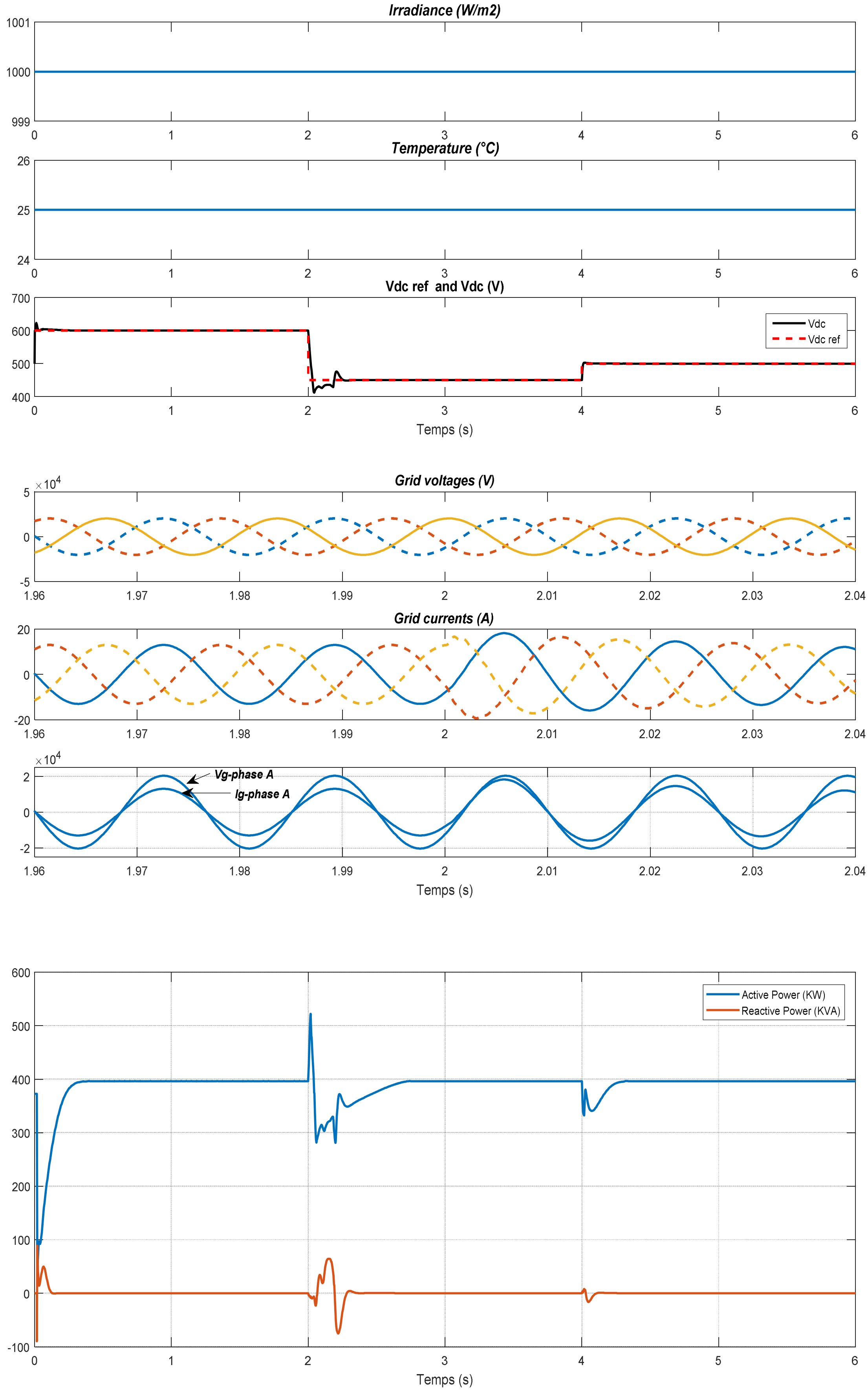

Figure 7. Characteristics: E and T = constants; Vref= Variable

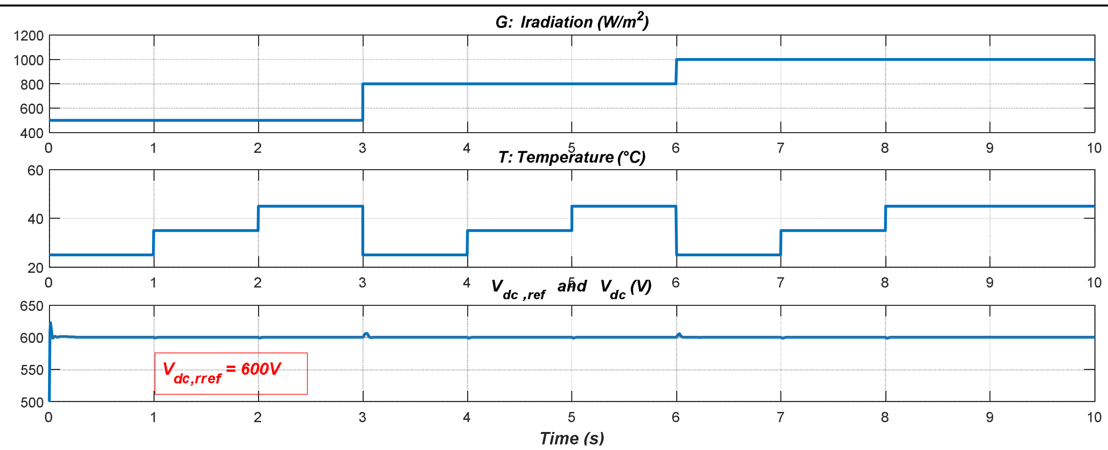

Figure 8. Solar radiation, temperature and Vdc reference

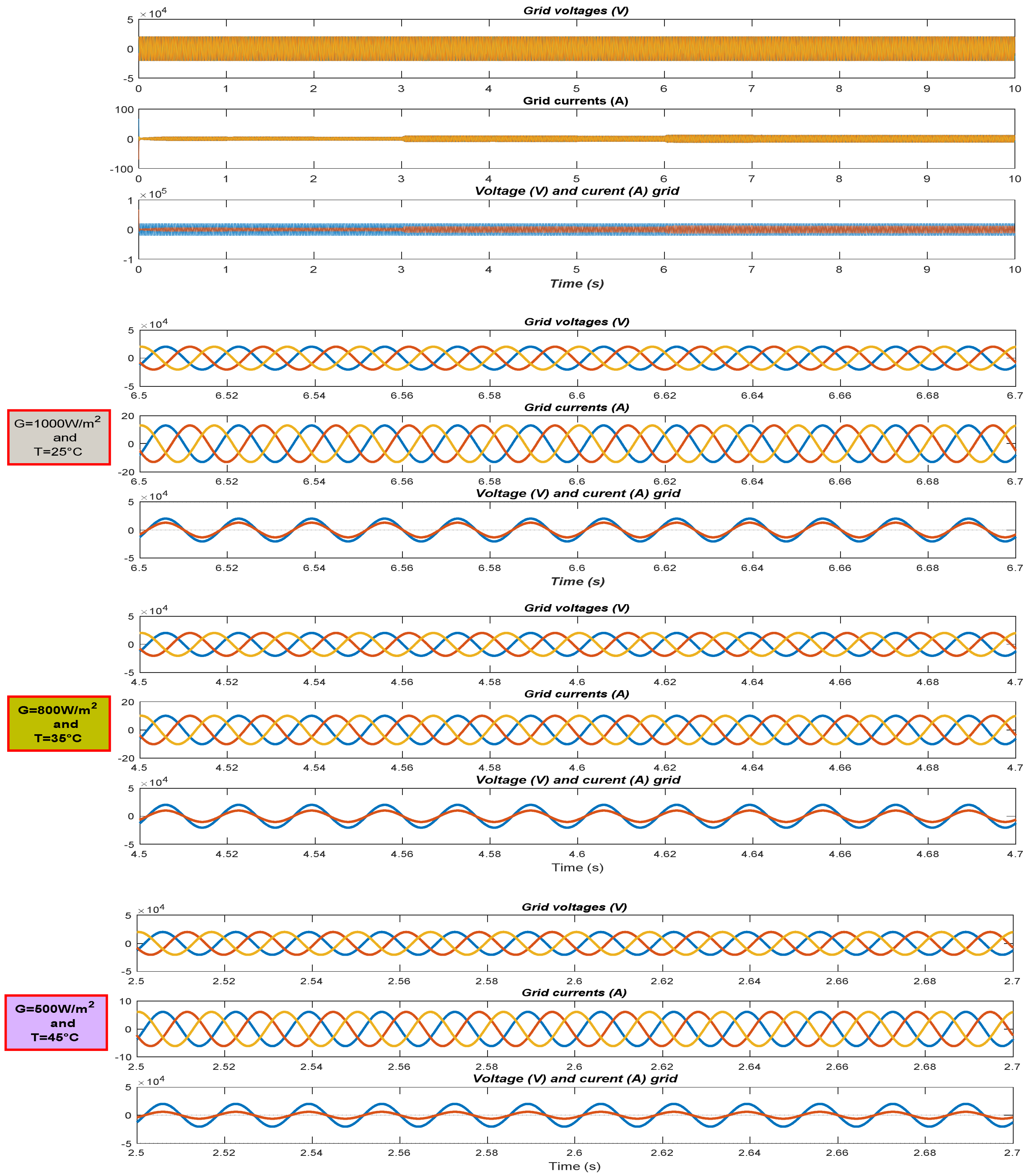

Figure 9 Grid voltages and grid currents

Figure 10 shows the evolutions of the active and reactive powers obtained under the imposed conditions (see Figure 8). The active power (solid line) follows correctly the imposed evolution and also, the reactive power (discontinuous line) is forced to zero thanks to the command.

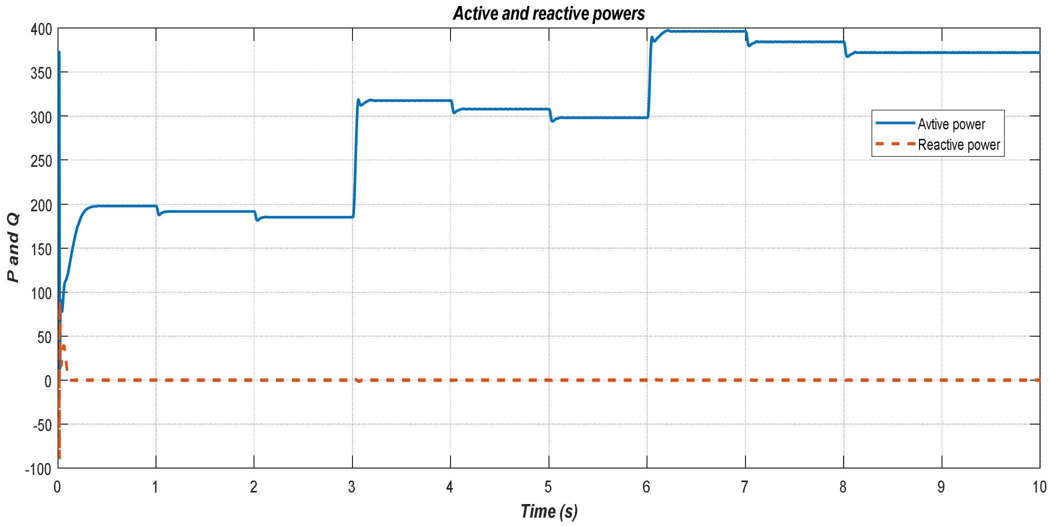

Figure 10. Active and reactive powers

7. CONCLUSION

The most important requirements for the systems to produce electric energy based on renewable energies are presented. The DC voltage controller and incremental conductance algorithm MPPT technique and control of a grid connected photovoltaic system, fully detailed, mathematical model of a three-phase grid-connected photovoltaic generator, including the PV array and the electronic power conditioning system. The simulation results, obtained for standard operating conditions and under other possible conditions, shows that the performances of the grid connected photovoltaic are encouraging.

8. REFERECES

[1] Karami, N, Moubayed, N, Outbib, R. General review and classification of different {MPPT} Techniques.Renew. Sustain. Energy Rev 2017; 68: 1–18.

[2] Daniel Gonzalez, D, Carlos Andrés Ramos Paja, Andrés Julián Saavedra Montes, Eliana Isabel Arango Zuluaga1, Carlos Eduardo Carrejo. Modeling and control of grid connected photovoltaic systems. Rev. Fac. Ing. Univ. Antioquia 2012; 62 : 145-156.

[3] Hamrouni, N, Chérif, A. Modelling and control of a grid connected photovoltaic system . Revue des Energies Renouvelables 2007; Vol, 10 N°3 : 335 – 344]

[4] Siddiquia, M.U, Arifa, A.F.M., Biltonb, A.M., Dubowskyb, S., Elshafeic ,M..An improved electric circuit model forphotovoltaic modules based on sensitivity analysis. Solar Energy 2013; 90: 29-42.

[5] Henchiri ,A, Bahi , T, Khochemane, L, Lekhchine,S. Control of the DC Voltage Output Photovoltaic System, 5th International Conference on Green Energy and Environmental Engineering , 28 - 30 April 2018 , Sousse, Tunisia.

[6] Rakesh, R, Kannan, S. A, Jomy, J, Kamala, D. VJayaraju, , M. Modelling and analysis of MPPT techniques for grid connected PV systems. International journal of innovative research in electrical, electronics, instrumentation and control engineering. 2014; 2: 1031-1037 .

[7] Esram,T, Chapman,P.L. Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques. IEEE Transactions on Energy Conversion, 2007;22(2), 5 : 439-450.

[8] Mule, S.M, Sankeshwari, S. S. Sliding Mode Control based Maximum Power Point Tracking of PV System. IOSR Journal of Electrical and Electronics Engineering. 2015; 10: 58-63 .

[9] Henchiri. A , Bahi. T, Khochemane. L, Performances of solar photovoltaic under different climatic conditions , CIMSI, November 2017, Mecanical Deparment, Skikda University, Algeria

[10] Siddiquia M.U, Arifa A.F.M., Biltonb A.M., Dubowskyb S., Elshafeic M.: An improved electric circuit model forphotovoltaic modules based on sensitivity analysis. Solar Energy, 2013; 90: 29-42.

[11] Duffie. J and Beckman, W.A. Solar Engineering of Thermal Processes. Second ed. New York John Wiley & Sons Inc.1991.

[12] El Shahat A.: PV Cell Module Modeling & Ann Simulation For Smart Grid Applications. Journal of Theoretical and Applied Information Technology; 2010 , 16(1): 9-20.

[13] King. D.L, Kratochvil. J, Oyson. W.E. and Ower. WI. Field Experience with a New Performance Characterization Procedure for Photovoltaic “rrays. 2nd World Conference on Photovoltaic Solar Energy Conversion 1998; 6-10.

[14] Duffie. J, and Eckman. W. Solar Engineering of Thermal Processes. Second edition. New York : John Wiley & Sons Inc.1991.

[15] Acharya, Y.B . Effect of Temperature Dependence of Band Gap and Device Constant on I-V Characteristics of Junction Diode. Solid-State Electronics 2001; 45: 1115-1119.

[16] Lyden. S , Haque. M. E , Gargoom,. A, Negnevitsky. M and P. I. Muoka. P.I. Modelling and Parameter Estimation of Photovoltaic Cell, Universities Power Engineering Conference (AUPEC), 22nd Australasian,2012;1–6.

[17] Amoozadeh, S. A. Gholamian. Active and Reactive Power Control of Photovoltaic Systems Connected to the Network for Maximum Power Point Tracking. International Journal of Mechatronics, Electrical and Computer Technology. 2014. Vol 4. pp 857-885.

[18] Gow J. A, C. D. Manning. Development of a photovoltaic array model for use in power electronics simulation studies, IEEE Proceedings on Electric Power Applications 1999, 146(2):193–200.

[19] .Rakesh. R, Kannan. S. A., Jomy. J, Kamala. D. V, Jayaraju. M. Modelling and analysis of MPPT techniques for grid connected PV systems. International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering. 2014; 2: 1031-1037 .

[20] Nagarajan. R, Chandramohan. J, Sathishkumar. S, Anantharaj. S, Jayakumar. G, Visnukumar. M, Viswanathan. R, Implementation of PI Controller for Boost Converter in PV System, International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE) 2016 ; 2(7) : 6-10.

[21] A. Henchiri, T. Bahi, S. Lekhchine, Performance analysis of a network connected photovoltaic system, *Proceedings of the International Conference on Recent Advances in Electrical Systems, Hammamet, Tunisia, 2018.*

[22] Karami, N, Moubayed, N, Outbib, R. General review and classification of different {MPPT} Techniques.Renew. Sustain. Energy Rev 2017; 68: 1–18.

[23] A. Henchiri, T. Bahi, S. Lekhchine, Modeling grid-connected solar PV system with maximum power point tracking Controller, *The 7th International Conference on Control Engineering &Information Technology (CEIT-2019), Tetouan, Maroc, 24-26 August 2019.*

[24] Rakesh, R, Kannan, S. A, Jomy, J, Kamala, D. VJayaraju, , M. Modelling and analysis of MPPT techniques for grid connected PV systems. International journal of innovative research in electrical, electronics, instrumentation and control engineering. 2014; 2: 1031-1037.