A comparison of two MPPT techniques for PV system

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Abstract: - In the context of renewable energy, this study treats the case of the conversion of solar energy, which is one part of non pollutant energy, to electrical one. In this paper, two different methods are used to maximize the generated power. Thus, a comparison between the ‘perturb and observe’ control method and the ‘incremental conductance’ control method are given, analyzed and discussed.

Key-Words: - Renewable energy, solar panel, photovoltaic cell, modeling and control.

1 Introduction

In general, the Earth has two global movements that affect the reception of the solar energy to its surface: the rotation that it does once on itself per day and the yearly revolution that it does around the sun. The combination of these movements implies daily changes in the receipt of the solar light to particular places [1],[2],[3],[4]. The reason for which the energizing flux received to soil hardly passes 1000 W/m^2 is that the atmosphere modifies in an important way the direct radiance of the sun [5],[6].

The phenomenon named "photovoltaic effect" consists mainly in transforming the solar light in electric energy by means of the semiconductor devices named photovoltaic cells. The solar panel, or photovoltaic generator, is itself constituted of an association of series and parallel of the necessary number of modules to assure the requisite energy [7],[8].

Maximum Power Point Trackers (MPPTs) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT can minimize the overall system cost. MPPTs find and maintain operation at the maximum power point, using an MPPT algorithm. Many such algorithms have been proposed [9],[10],[11]. However, one particular algorithm, the perturb-and-observe (P&O) method, continues to be by far the most widely used method in commercial PV MPPTs. Part of the reason for this is that the published MPPT methods do not include comparisons between multiple existing algorithms.

In this paper, we are interested in different method of modeling and control of a solar panel used in a solar production system. For this, the paper is organized as follows. Section 2 is devoted to present the system under considerations. Section 3 defines the model of a photovoltaic cell and a solar panel. In the fourth section, an analysis of the output power and condition of its maximizing value is given. Then, two MPPTs algorithms are discussed in section 5 and section 6, and then compared in section 7. Finally, conclusions are given in section 8.

2 System under consideration

Our system is achieved in the Faculty of Engineering of the Lebanese University in Lebanon. It is constituted of two solar panels (50 W each one), the first stationary and the second mobile. The control of this last took place so that its surface is always perpendicular to the solar rays. The accumulators are placed in order to stock the received solar energy. An anti-return diode and a load voltage regulator are installed (Figure 1). The using of a microcontroller on the whole system has permitted the interconnection between the two solar panels and the computer in order to archive the values of the produced powers. Another role was to turn the electric motor of the support carrying the mobile panel. In addition, our system contains a weather station in order to manage better the produced power. In this paper, we are interested in the modeling and control of the solar panel in order to maximize the produced power.

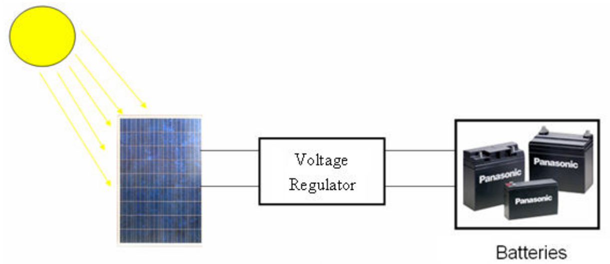

Fig. 1: The solar conversion system.

3 Modeling of the solar generator

3.1 Modeling of an ideal photovoltaic cell

In the obscurity, a semiconductor presents a high resistance. When it is strongly illuminated, its resistance decreases. If the energy of the photons that constitutes the luminous ray is sufficient, these photons will be able to excite the electrons blocked in the valence layer to jump to the conduction layer. It is the phenomenon of photo conductibility. The characteristic of an ideal photovoltaic cell is represented in figure 2.

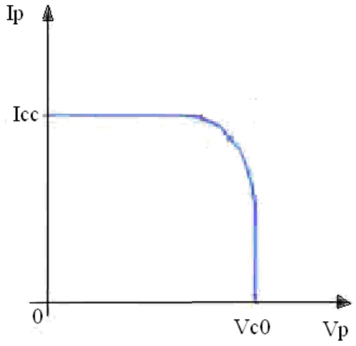

Fig. 2: Photovoltaic Cell characteristic.

The expression of the diode current is described by the following equation:

$$I_p = I_{cc} - I_d = I_{cc} - I_s(\exp\frac{eV_p}{kT} - 1) \quad (1)$$

with:

- I_p and V_p are the current and voltage of this photovoltaic cell,
- I_s is the saturation current,
- I_{CC} and I_d are the short-circuit and the direct currents,
- k is the Boltzmann constant which is equal to $8{,}62.10^{-5}$ eV/°K,
- T is the absolute temperature,
- e is the electron charge.

This equation corresponds to a current generator, which models the sunshine, and a diode in parallel, which represents the PN junction.
The equivalent circuit of the ideal photovoltaic is given in figure 3.

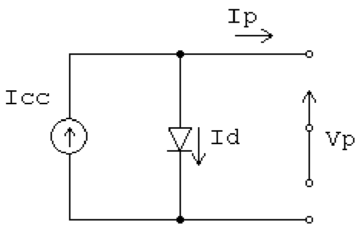

Fig. 3: Equivalent ideal model of photovoltaic cell.

3.2 Modeling of a real photovoltaic cell

To draw the real model of photovoltaic cell, it is necessary to take in account the losses due to the manufacture. Therefore, two resistances should be added to the ideal model, one placed in series and the other in parallel (figure 4). In fact, the resistance R_s represents the losses dues to the contacts and the connections. The parallel resistance R_{sh} represents the leakage currents in the diode. The characteristic equation becomes then:

$$I_p = I_{cc} - I_d - \frac{V}{R_{sh}} \quad (2)$$

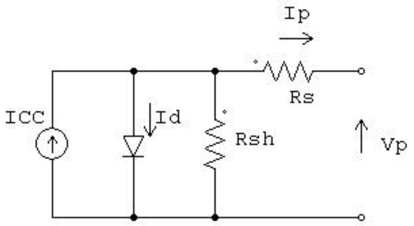

Fig. 4: Equivalent real model of photovoltaic cell.

3.3 Modeling of a solar panel

A solar panel is an association of several cells in parallel (n_p) and in series (n_s), (figure 5).

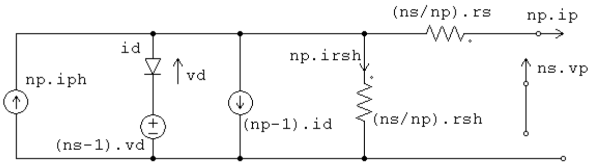

Fig. 5: Model of a real solar panel (n_s x n_p cells).

With:

$$I_{ph} = n_p i_{ph} \quad ; \quad I_d = n_p i_d \quad ; \quad I_G = n_p i_p \quad ; \quad I_{rsh} = n_p i_{rsh} \tag{3}$$

$$V_d = n_s v_d \quad ; \quad V_G = n_s v_p \quad ; \quad R_{sh} = \frac{n_s}{n_p} r_{sh} \quad ; \quad R_s = \frac{n_s}{n_p} r_s \tag{4}$$

The characters in capital letter correspond to the panel model, whereas those in lower-case letter are those of an elementary photovoltaic cell. The equivalent model of the solar panel is given in figure 6.

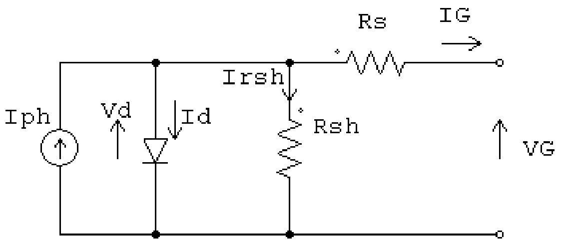

Fig. 6: Equivalent model of the solar panel.

The expression of the output current I_G of the solar panel is [12]:

$$I_G = P_1 E_s [1 + P_2 (E_s - E_{sref}) + P_3 (T_j - T_{jref})] - P_4 T_j^3 \exp(-\frac{E_g}{kT_j})[\exp(\frac{e(V_G + R_s I_G)}{K n_s T_j}) - 1] - \frac{V_G}{R_{sh}} \tag{5}$$

where:

- T_j is the temperature and $T_{j\ ref}$ = 25°C is the temperature reference,
- E_s is the sunshine and $E_{s\ ref}$ = 1000 W /m^2 is the sunshine reference,
- E_g is the gap energy,
- P_1 to P_4, R_s and R_{sh} are constant parameters.

Therefore, this model contains two inputs, the sunshine and the temperature (E_s and T_j), and two outputs, I_G and V_G [13].

4 Output power

4.1 Output power characteristics

For any solar panel, the output power is function of the temperature and the sunshine values of the site where the panel is placed. This power can decrease or increase as result of any temperature and/or shining variations.

In Tripoli, the second city of Lebanon, the temperature varied between 0°C to 40°C, and the sunshine changed from zero to 900 W/m^2. For these extremities, the output power versus voltage for different values of temperature is given in figure 7, and that versus voltage for different values of shining is shown in figure 8. In these figures, the output power is not constant. To maximize this power and maintain it constant at high values, it is necessary to define the Maximum Power Point Tracking (MPPT) methods, and apply these methods to the controlled dc-dc converters [14].

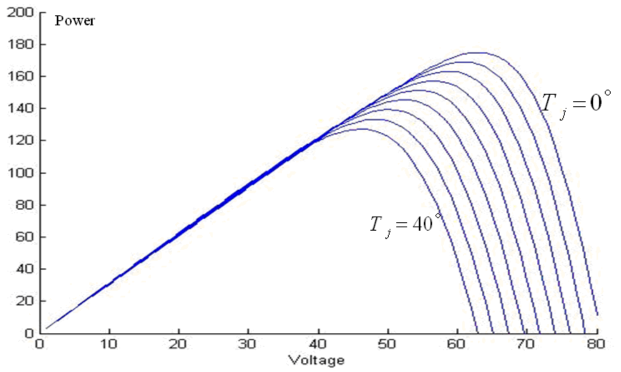

Fig. 7: Output power curve at different temperature values.

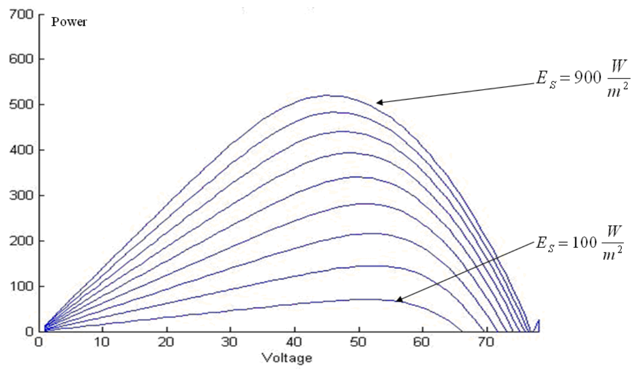

Fig. 8: Output power curve at different sunshine values.

4.2 Maximizing the output power

The output power of a solar panel is a function of the temperature, the sunshine and the position of the panel. It is also function of the product of the voltage by the current. By varying one of these two parameters, voltage or current, the power can be maximized. Several MPPT methods exist in order to maximize this output power and to fix its value, in steady-state, at its high level as shown in figure 9. In this figure, the temperature and the sunshine values are constants.

The existing methods are:
1. Perturb and observe,
2. Incremental Conductance,
3. Parasitic Capacitance,
4. Voltage Based Peak Power Tracking,
5. Current Based peak power Tracking.

The first two methods, which are the most used from these five methods, are studied and compared in this paper.

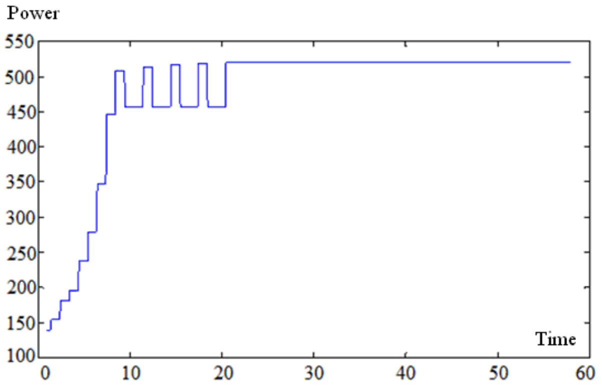

Fig. 9: Output power using one of the MPPT methods.

5 Perturb and Observe

5.1 Principle of the Perturb and observe method

Applying a variation on the voltage (or on the current) toward the biggest or the smallest value, its influence appears on the power value. If the power increases, one continues varying the voltage (or the current) in the same direction, if not, one continues in the inverse direction (figure 10).

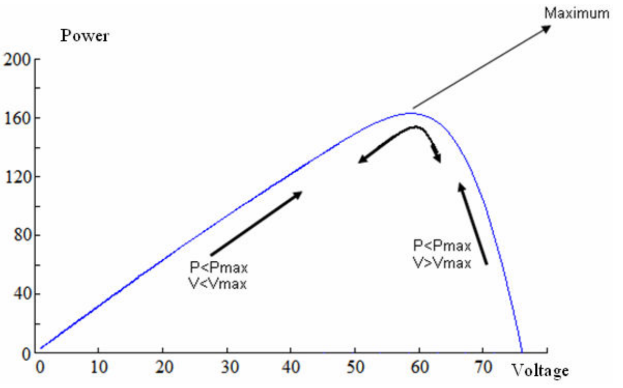

Fig. 10: Output power using the MPPT method, Perturb and Observe.

Figure 11 shows the block diagram of this MPPT method. In this figure, the duty cycle (α_n) of the used chopper (or dc-dc converter) is calculated by the following expression:

$$\alpha_n = \alpha_{n-1} \pm \Delta\alpha \qquad (6)$$

where $\Delta\alpha$ is the duty cycle step.

The different steps of the 'Perturb and Observe' method are:
1. Take current and voltage measurements, power calculation,
2. If the power is constant, return to take new measurements,
3. If the power decreased or increased, test the voltage variation,
4. According to the direction of the voltage variation, modify the current.

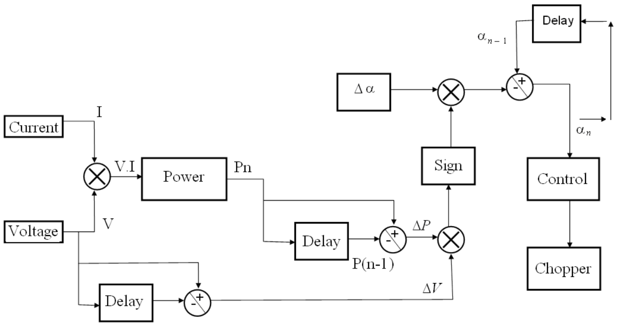

Fig. 11: Block diagram of the MPPT method, Perturb and Observe.

5.2 The used chopper

By using the MPPT method, perturb and observe, the output voltage can take values lower or bigger than V_{max}, therefore, a step down and step up chopper should be used. The presented chopper in figure 12, which is with inductive storage, is used in the solar system.

The expression of the output voltage is:

$$V_s = \frac{\alpha.E}{1-\alpha} \qquad (7)$$

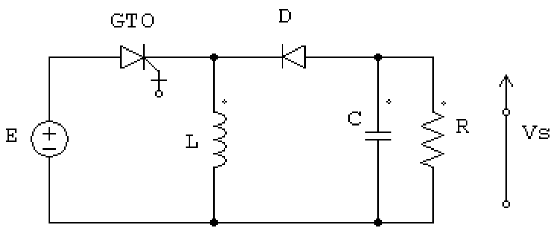

Fig. 12: Step down and step up chopper.

5.3 The battery model

In this paper, the used battery model is the third order model (figure 13). With:

- R2 is the resistance of diffusion polarization,
- R0 is the resistance of the connectors,
- R1 is the resistance of load transfer,
- C1 is the capacity of double layer,
- Em is the no load voltage,
- the parasitic branch represents the phenomenon of degassing in the case of the load.

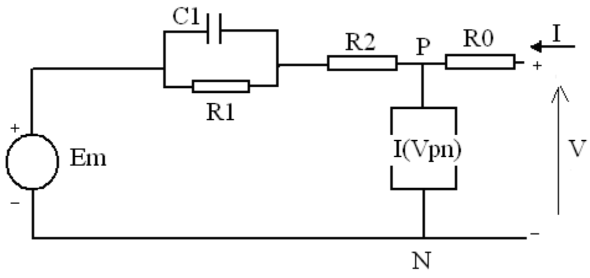

Fig. 13: Battery model.

5.4 Simulation results:

The studied system is represented in figure 14. Its implementation in the Matlab / Simulink software is given in figure 15.

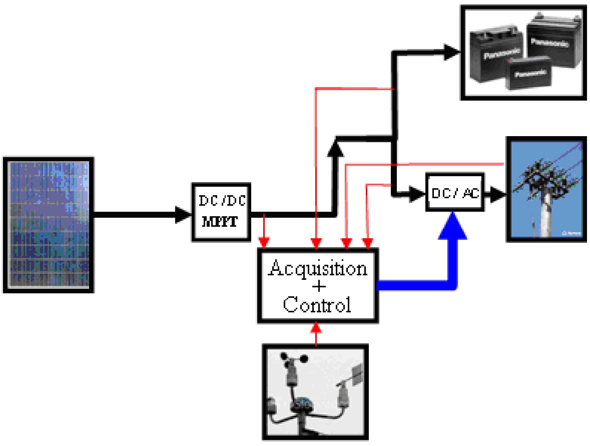

Fig. 14: The studied system.

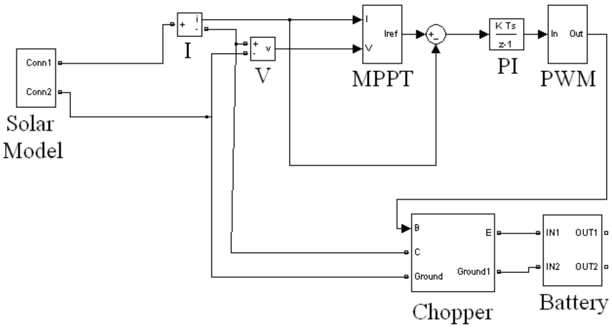

Fig. 15: The studied system in Matlab / Simulink.

For uncertain values of temperature and sunshine (T_{JA} and E_{sA} with small variations), by using the 'perturb and observe' method which is already explained in the previous section, the curve of the output power versus time is presented in the figure 16. This figure shows that the power transient state becomes very small, and this power remains constant, with small variation, in permanent state (zone A). After 80 seconds, big variations of temperature and/or sunshine followed by small ones (T_{JB} and E_{sB} with small variations) appear in the power curve as decreasing in the average value (Zone B).

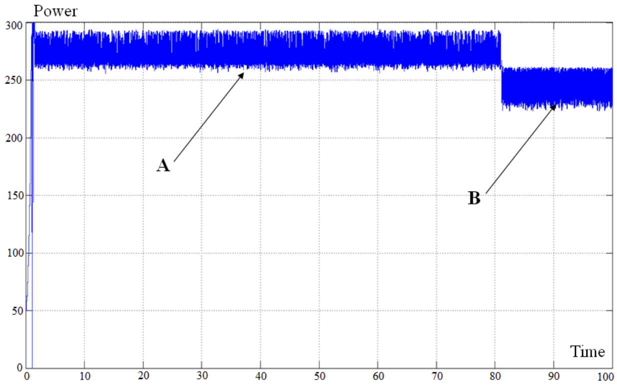

Fig. 16: Output power using the MPPT method.

In zone A and in zone B, the power ripples amplitudes are equal to 30 W. From zone A to zone B, the power decreases by 50 W.

The characteristic of the output power versus voltage, for different values of temperature and sunshine, is shown in figure 17. These values are uncertain. Therefore, for a voltage greater than 40 V, the power versus voltage characteristic is uncontrolled. Also, the maximum power is not reached at reasonable power.

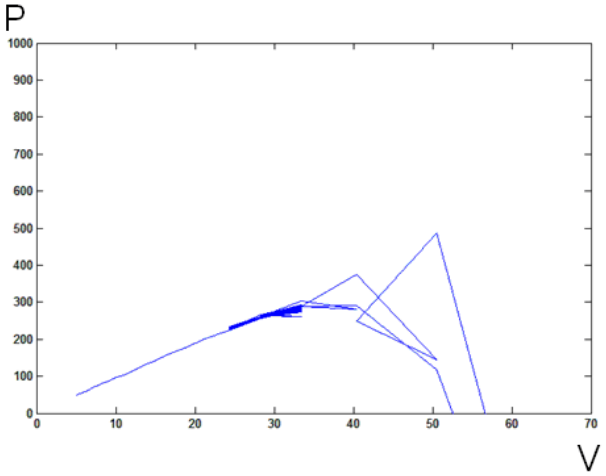

Fig. 17: Output power versus voltage.

5.5 Improving the MPPT 'Perturb and observe' method

To improve the studied MPPT method, it is proposed to make change on the duty cycle. The new one takes the value of:

$$\alpha = \frac{\alpha_n + \alpha_{n-1}}{2} \tag{8}$$

For uncertain values of temperature and sunshine, the power waveform (figure 18) is not constant as it is shown by figure 16. But, it takes more important values. The power versus voltage characteristic (figure 19) is more significant than that obtained in figure 17. In spite of the using of uncertain values for the temperature and the sunshine, this characteristic represents more stability. The power is maximized for voltage less then 45 V. Therefore, by using this original method and certain values for temperature and sunshine, the output power can be maximized. The disadvantage of this method is the high amplitude of the ripples which appear on the power and which can be dangerous in charging and discharging the battery.

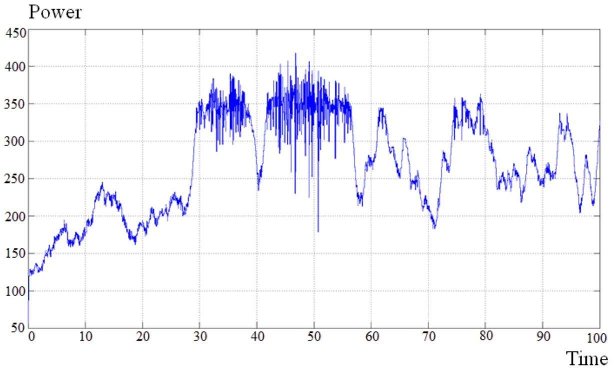

Fig. 18: Output power after improving the 'perturb and observe' method.

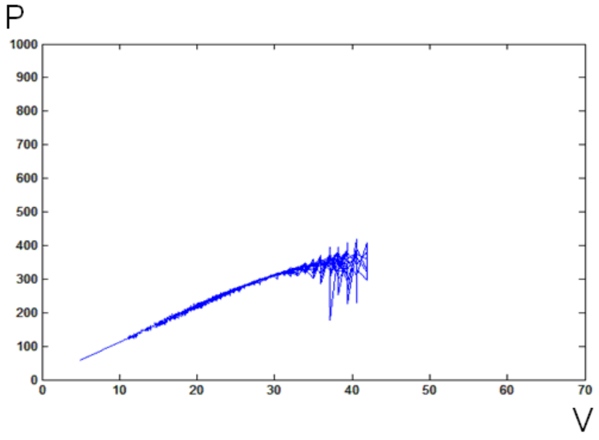

Fig. 19: Output power versus voltage using the improved MPPT method.

5.6 The Delta-adaptive method

By using the previous control strategies, the output power waveform was not constant and had ripples of different magnitudes. To maximize the output power and minimize its ripples, the duty cycle step $\Delta\alpha$ should be less then 0.05. In this case, the convergence becomes slow. To avoid this disadvantage, the delta-adaptive method can be used.

In fact, the duty cycle step starts at $\Delta\alpha = 0.01$. After each complete operation, the output power is analyzed. If this power needs to be increased in the same direction, the duty cycle should be increased by 0.01. If this power needs to be decreased, which implies in changing the direction, the counter of the duty cycle should be reset.

By using this method, the output power rises rapidly to the maximum. At this maximum value, the duty cycle step regains its old value which is equal to 0.01.

The output power waveform is given in figure 20. The power ripples amplitudes are equal to 0.2 watts in steady state. This value is very small if it should be compared to that obtained with the 'Perturb and observe' method and which was equal to 30 W.

Figure 21 shows the output power variation with the change of the duty cycle step (from 0.01 to 0.05).

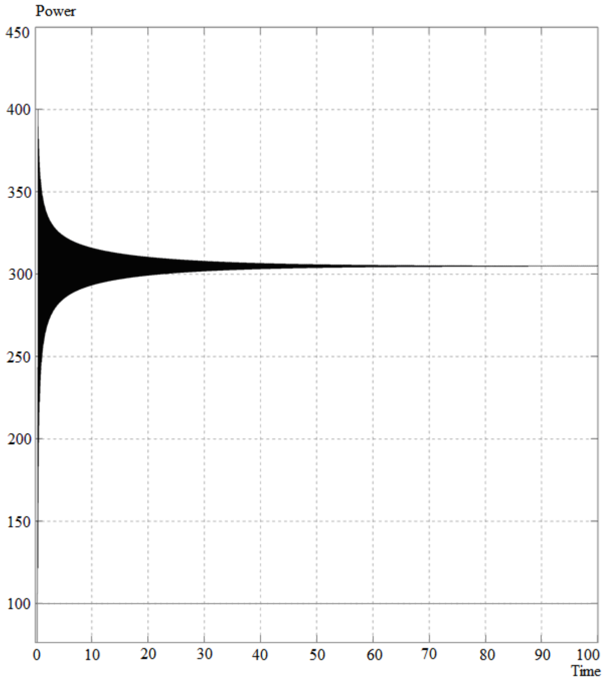

Fig. 20: Output power versus the time using the delta-adaptive method.

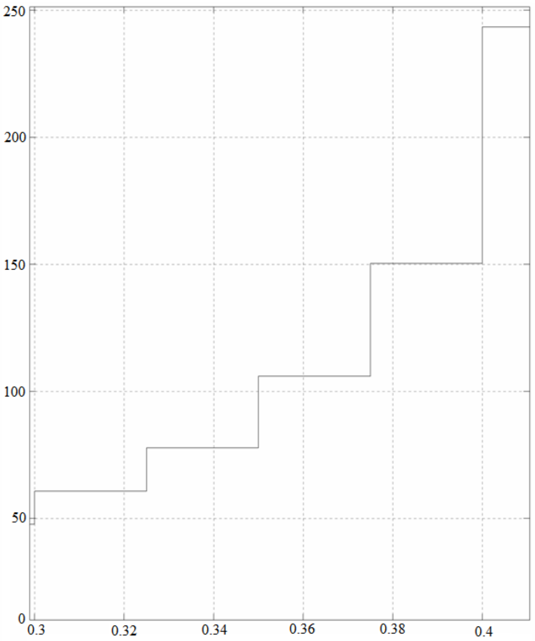

Fig. 21: Zoom on the output power in transient state by using the delta-adaptive method.

5.7 Simulation using real values of temperature and sunshine

In the following simulations, the temperature values vary between 5°C and 30°C and the sunshine values vary between 400 W/m^2 and 700 W/m^2.

By using the improved ‘Perturb and observe’ method, the output power reaches the steady state in 3 seconds (figure 22). At this time, the power amplitude is about 300 W.

With the delta adaptative method, the transient state is reduced to 0.5 seconds (figure 23) and the magnitude of the output power is maximized to 370 W. The ripples shown in circle A of figure 23 are due to the changing in temperature and in shining (for example changing of shining from 450 to 475 W/m^2).

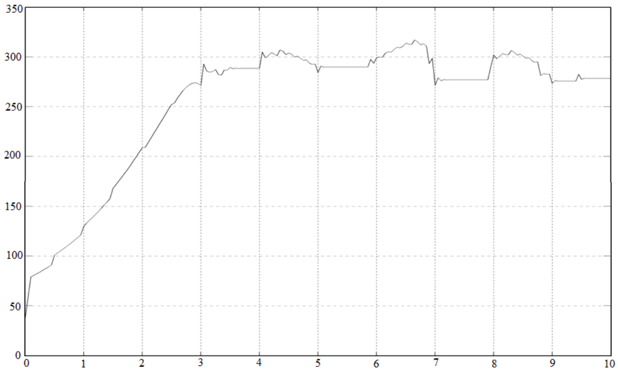

Fig. 22: Output power versus time using the improved ‘Perturb and Observe’ method.

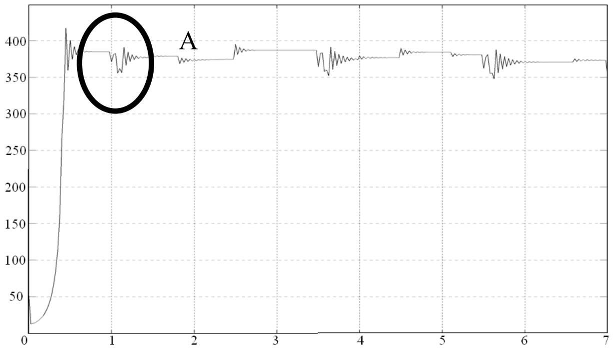

Fig. 23: Output power versus time using the delta adaptative method.

6 Incremental conductance method

6.1 Principle of the incremental conductance

This method consists in using the slope of the derivative of the current with respect to the voltage in order to reach the maximum power point. To obtain this point, dI/dV must be equal to –I/V (Figure 24).

In fact, applying a variation on the voltage toward the biggest or the smallest value, its influence appears on the power value. If the power increases, one continues varying the voltage in the same direction, if not, one continues in the inverse direction. The simplified flow chart of this method is given in figure 25.

In addition, by using the power formula, P=V.I, its derivative becomes:

$$dP = V.dI + I.dV \tag{9}$$

In general, the duty cycle (α_n) of the used chopper (dc-dc converter) is calculated by the following expression:

$$\alpha_n = \alpha_{n-1} \pm \Delta\alpha \tag{10}$$

where $\Delta\alpha$ is the duty cycle step.

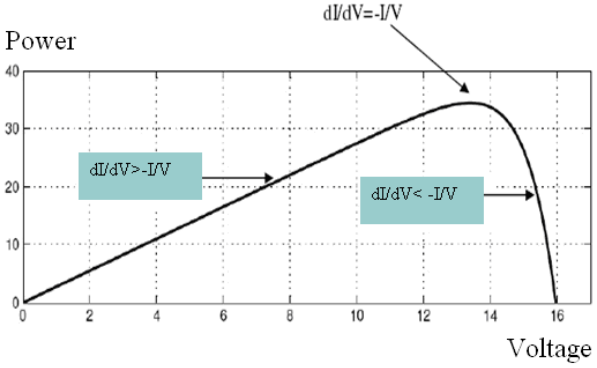

Fig. 24: Output power using the MPPT method, Incremental conductance.

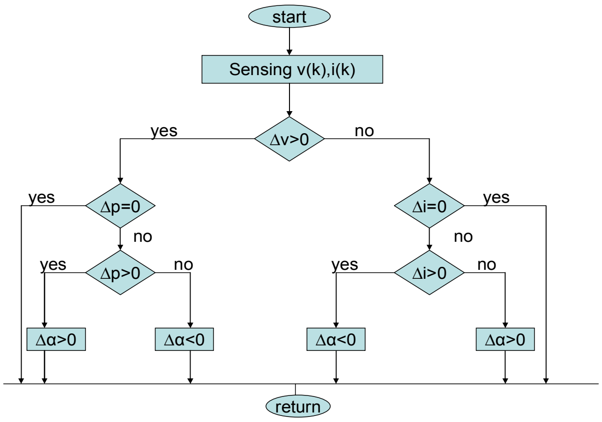

Fig. 25: Incremental conductance method flowchart.

6.2 Simulation Results

The temperature average value is taken equal to 25°C with variation of ±15°C applied by using the Matlab random function. The sunshine average value is fixed to 600 W/m^2, with variation of ±200 W/m^2 applied by using the Matlab random function. With the 'Incremental conductance' method, the curve of the output power is illustrated in figure 26. This figure shows that the power value remains approximately constant, with small ripples.

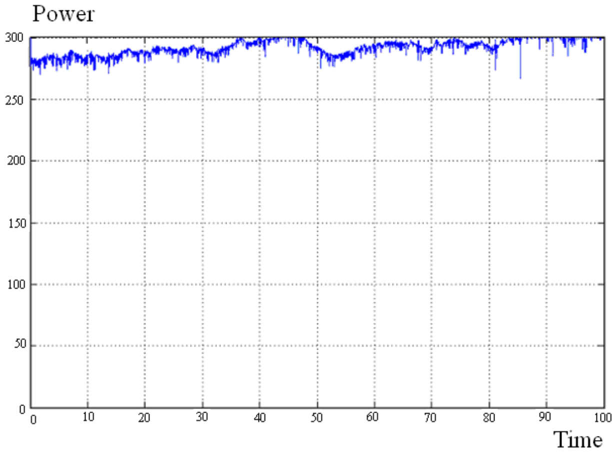

Fig. 26. Power waveform by using the incremental conductance MPPT method.

6.3 Improving the MPPT 'Incremental conductance' method

To improve the studied MPPT method, it is proposed to make change on the chopper duty cycle. The new one takes the value of:

$$\alpha = \frac{\alpha_n + \alpha_{n-1}}{2} \qquad (7)$$

The obtained power amplitude (Figure 27) takes more important amplitude values than that illustrated in figure 26. The time response is smaller. The power is maximized by using this original method. Its disadvantage is the presence of ripples which can be dangerous for batteries functioning.

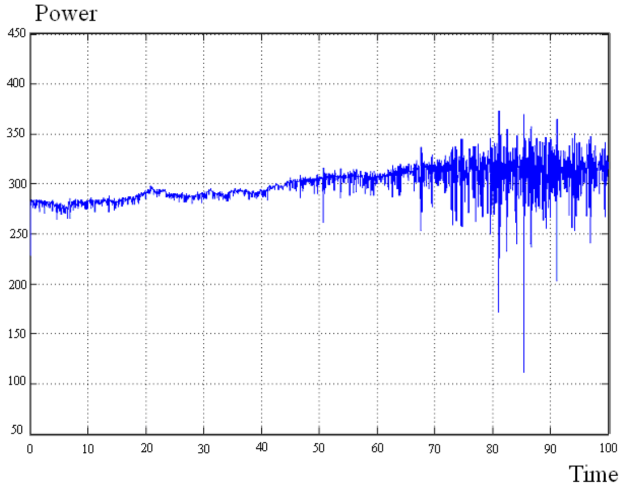

Fig. 27. Power after improving the used method.

6.4 The Delta-adaptive method

To maintain the output power at its maximum value and to minimize its ripples, the delta-adaptive method can be applied on the MPPT incremental conductance method. The remarkable thing in this method is that the duty cycle(α) is not added by Δα or subtracted by Δα in a constant way. In other words, Δα is not constant. The duty cycle changes with respect to the form of the curve in use. In delta adaptative method, there are two basic algorithms that can be used: the space shuttle and the song algorithm. By using the space shuttle algorithm, the time response of the output power becomes smaller, and, in steady state, the power ripples are attenuated. The output power waveform is given in figure 28.

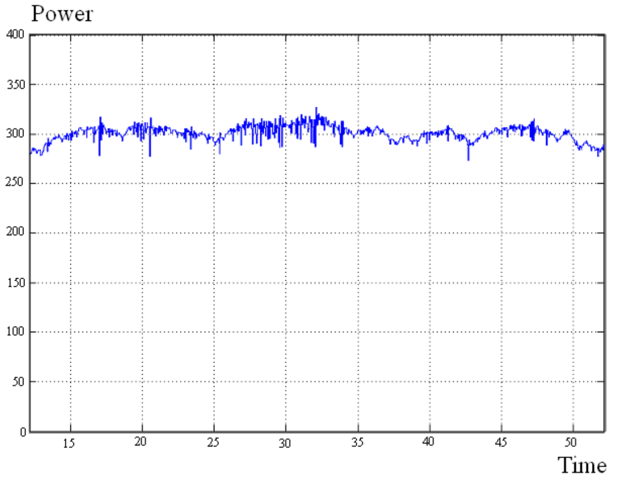

Fig. 28. Power after applying the delta-adaptive method.

7 Between the ‘Perturb and observe’ and the ‘Incremental conductance’ methods

The temperature average value is taken equal to 25°C with variation of ±15°C applied by using the Matlab random function. The sunshine average value is fixed to 600 W/m^2, with variation of ±200 W/m^2 applied by using the Matlab random function.

For uncertain values of temperature and sunshine with small variations and by using the ‘perturb and observe’ method, the curve of the output power versus time is presented in figure 29. This figure shows that the power transient state is fast, and this power remains constant, with small variation, in permanent state. The power ripples amplitudes are equal to 30 W.

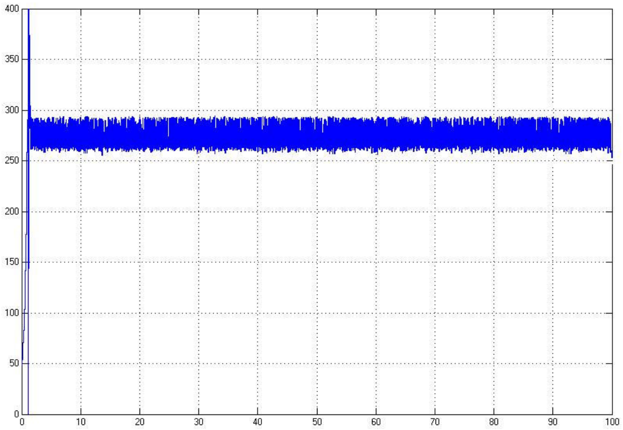

Fig. 29: Power versus time using the ‘perturb and observe’ method.

By using the ‘Incremental conductance’ method, the curve of the output power versus time is illustrated in figure 30.

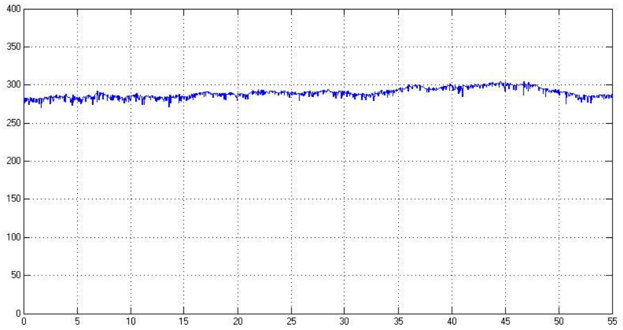

Fig. 30. Power versus time using the incremental conductance method.

Figure 30 shows that the power value remains approximately constant, with small ripples. In addition, the time response is negligible.

The time response, the average power and the ripples amplitude of the output power corresponding to the two treated MPPT controlled methods are given in table 1.

Table 1. Comparison results.

	Time response	Average power	Ripples amplitude
Perturb and Observe	1.8 µs	275 Watt	50 Watt
Incremental Conductance	0.5 µs	290 Watt	40 Watt

In general, the advantages of the ‘incremental conductance’ method over the ‘perturb and observe’ method are:

- Incremental method can calculate the direction, for which the array’s point changed in order to reach the MPP,
- Incremental method can determine precisely when the MPP is reached,
- Incremental method should not oscillate about the MPP once it reaches it,
- Incremental method does not go on the wrong direction when conditions in the system changed rapidly.

8 Conclusion

The sun is at the origin of the quasi-totality of the sources of energies used by the humanity for its food, domestic and industrial needs. The solar energy is important because it is non pollutant energy.

In this paper, after presentation of the studied system, the conversion from solar energy to electrical one is treated. In this case, the model of a photocell and a solar panel are presented.

The ‘Perturb and observe’ and the ‘incremental conductance’ methods are used to maximize the output power. The flow chart of each method had been explained and discussed. With the incremental conductance method, compared to the perturb and observe method, simulation results underline that the time response is small, the existing ripples have low amplitude and the average power is more important.

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