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On-Line Maximum Power Tracking In A Stand Alone Photovoltaic System

تتبع أقصى قدرة كهربية أثناء التشغيل لنظام فوتوفولتى منفرد

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ملخص البحث

تتوقف القدرة المتولدة من الخلايا الشمسية على الظروف المحيطة والتى من أهمها درجة حرارة الخلية و الإشعاع الشمسى .ونظرا لارتفاع تكلفة الخلايا وانخفاض كفاءتها يلزم تعظيم العائد منها وذلك بتشغيلها عند نقطة التشغيل المقابلة لأقصى قدرة ومن ثم تتبع هذه النقطة عند تغير الظروف المؤثرة.وقد تناولت العديد من الأبحاث هذه المشكلة وتم طرح اكثر من طريقة لتتبع نقطة التشغيل المقابلة لأقصى قدرة.ومعظم هذه الطرق تعتمد على قياس الظروف المحيطة من إشعاع شمسى ودرجة حرارة لتحديد نقطة التشغيل المناسبة إما باستخدام النموذج الرياضى للخلية أو التحديد المسبق للجهود والتيارات المناظرة لأقصى قدرة عند ظروف التشغيل المختلفة .و يعرض هذا البحث طريقة جديدة لتتبع أقصى قدرة كهربية لنظام فوتوفولتى وذلك من خلال القياس أثناء التشغيل لكل من جهد وتيار الخلية وحساب معدل تغير القدرة المتولدة بالنسبة للجهد حيث يتم استنتاج الجهد الواجب تشغيل الخلية عنده والمناظر لأقصى قدرة يمكن الحصول عليها من الخلية .وترجع سهولة الطريقة المقترحة إلى أنها لا تعتمد على نموذج رياضى للخلية المستخدمة ولا تحتاج لقياس أى من الإشعاع الشمسى أو درجة الحرارة ، وكذلك لا تعتمد على التحديد المسبق للجهود والتيارات المقابلة لأقصى قدرة. وقد تم اختبار الطريقة المقترحة على نظام فوتوفولتى منفرد. ومن خلال المحاكاة قد أظهرت النتائج كفاءة الطريقة فى تتبع نقطة أقصى قدرة سواء عند تغير الظروف المحيطة أو تغير الأحمال.

Abstract

This paper presents an on-line maximum power point tracking (MPPT) algorithm for a stand-alone photovoltaic system. The proposed algorithm determines approximately the maximum power point of a PV array for any temperature and solar radiation level. The proposed algorithm is so simple that it needs only an on line values of PV array output current and voltage which can be obtain easily by using just current and voltage transducers. The algorithm does not require the measurement of temperature and solar radiation or a PV array model that is most used in look up table based algorithm. The proposed algorithm has simple structure and provides acceptable results.

1-Introduction

As the conventional source of energy is decreasing fast while the cost of the energy is increasing, the photovoltaic energy becomes a promising alternative source .It has the following advantages:

1.Pollution free.　2.Disributed throughout the earth.　3.Recyclable. [1]

The only drawback is that the initial installation cost is considerably high.

PV is, by nature, nonlinear power source that has only one operating point (V_p, I_p) corresponding to maximum power .The maximum power from PV system depends on the environmental factors such as solar insolation and operating cell temperature. In order to achieve the most reliable and economical operation from the PV system more attention is paid to their design and optimum utilization because of the relatively high cost of a PV generator The power of a PV array varies as functions of radiation level, temperature and load current. It is important to operate PV array near the maximum power point to increase the efficiency of a PV arrays. To overcome the undesired effects of the temperature and solar radiation variation on the output power of a PV system, two different control strategies have usually been applied: 1) controlling the sun input to the PV array, and: 2) controlling the power output from the PV array .The combination of these two groups also may be considered For the second

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strategy, many techniques have been developed to provide maximum PV power. For example, Rahman used a neural network to estimate maximum power operating point [5], and some systems use an online maximum power point tracking algorithm to obtain the maximum power point [4,13]

2- On-Line MPPT Search Algorithm

From the P-V characteristic of PV arrays, it is known that for each specific atmospheric condition there is a voltage value (V_{max}) at which the PV array delivers maximum power (P_{max}). MPPT is used to adjust the array operating point voltage so that maximum power production is achieved for the given atmospheric condition. There are various methods to find maximum power reference voltage of the PV arrays. They can be classified as follows:

1. Using look-up tables representing the previously determined maximum power point data for different temperature and solar irradiation levels. [3]
2. Simulating the PV array characteristic equations to search for the new maximum power point if any change occurs in temperature and solar irradiation level. [12]
3. Fix an operating point near to the optimum value for each value of radiation, by choosing the working voltage as 80% of the unloaded value
4. Using on-line search techniques for maximum power point regardless of the variation in temperature and solar radiation level. [4,8,9]

The first three methods require

- A PV array model and the measurement of temperature and solar irradiation levels.
- These methods need long measuring data to identify the look-up tables.
- Close match between the reference cell and the array must be satisfied. In practice, this close matching may be difficult to achieve. Good initial performance may be severely degraded by differences in shadowing, dust, or even damage to the array or reference cell.

Some systems use an online maximum power-tracking (MPPT) algorithm to obtain the maximum power point [4,7,8,9,14]. An online MPPT algorithm often used is the perturbation and observation method [8,9]. The perturbation and observation method operates by periodically incrementing or decrementing the array reference voltage with a fixed step (ΔV). If a given perturbation leads to an increase (decrease) in array power, the subsequent perturbation is made in the same (opposite) direction.

Some of online algorithms use dP/dV=0 to obtain the maximum output power point. The perturbation and observation method measures ΔP and ΔV to judge the momentary operating region, then according to the region, the reference voltage is increased or decreased such that the system operates close to the maximum power point. The system will therefore work in oscillation between two points on either side of maximum power. The presented algorithm is used to continually maximize the true PV array output power rather than maximizing the current or voltage at either the PV array or load. That is done by increasing (decreasing) the array reference voltage with variable step based on the rate of change of PV power versus its voltage. The algorithm can be developed as follows.

The output power of the PV array is expressed as

$$P=VI. \tag{1}$$

At the maximum power point

$$dP/dV=0 \tag{2}$$

From (1) and (2), the differential of P to V can be expressed as

$$\frac{dP}{dV} = I + \frac{dI}{dV}V \tag{3}$$

$$\frac{dP}{dV} \cong I + \frac{\Delta I}{\Delta V}V \tag{4}$$

Where ΔI and ΔV are the increments of output voltage and current, respectively.

At the maximum power point the Equation (4) become

$$\frac{dP}{dV} \cong I + \frac{\Delta I}{\Delta V}V = 0 \qquad (5)$$

Equation (6) describes the reference voltage.

$$V_{ref}(t) = \begin{cases} V_{ref}(t-1) + \Delta V_{ref} & if\ {dP}/{dV} > 0 \\ V_{ref}(t-1) & if\ {dP}/{dV} = 0 \\ V_{ref}(t-1) - \Delta V_{ref} & if\ {dP}/{dV} < 0 \end{cases} \qquad (6)$$

Where: $V_{ref}(t)$ the reference voltage

$V_{ref}(t-1)$ the previous reference voltage

ΔV_{ref} the increment of reference voltage that proportional with the slope of the power.

If dP/dV <0 then the algorithm decreases the array reference voltage with a step proportional to dP/dV to force dP/dV to approach zero; if dP/dV >0 then the algorithm increases the array reference voltage with a step proportional to dP/dV to force dP/dV to approach zero, if dP/dV =0 then the array reference voltage does not need any change.

V and I are the voltage and the current of PV array that can be obtained directly from the online values of the PV array. ΔI and ΔV are the increments of output voltage and current that can be obtained approximately by using the difference between two points on the I-V curve. When $dP/dV=0$ the reference voltage does not need any change, and thus oscillation is reduced. Configuration of maximum power tracking system is shown in Fig. 1.

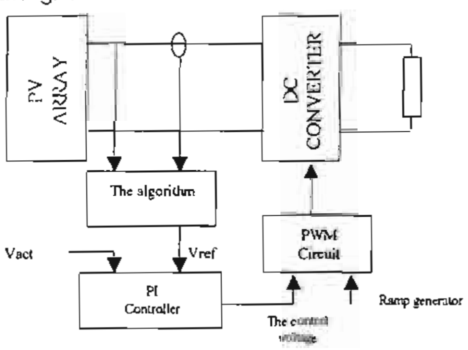

Fig. 1 Configuration of Maximum Power Tracking System

Fig.2 shows the flow chart of the on line search algorithm that does not require the measurement of temperature and solar radiation. Initially, initial power, Pm, and initail current, Im, are set to zero While, the initail voltage, V_m, is set to the open circuit voltage, the tolarable power error, P_{tol}, is set to suitable value. At each sampling instant, the difference, dP, between the reference initial value of P_m and operating power, $P_{op}= V_{op} I_{op}$, is calculated and compared with the P_{tol} .If the difference is smaller than the P_{tol}, which is not possible for first sample, do not change the reference voltage If else calculate $dP/dV = V\frac{\Delta I}{\Delta V} + I$. For the first sample, the error will be $dP/dV = V_{op}\frac{I_{op} - I_m}{V_{op} - V_m} + I_{op}$ Where V_{op}, I_{op} are the operating voltage and current of the PV array. For the next sampling these operating quantities (P_{op}, V_{op}, I_{op}) are assigned to be the reference quantities (P_m, V_m, I_m)

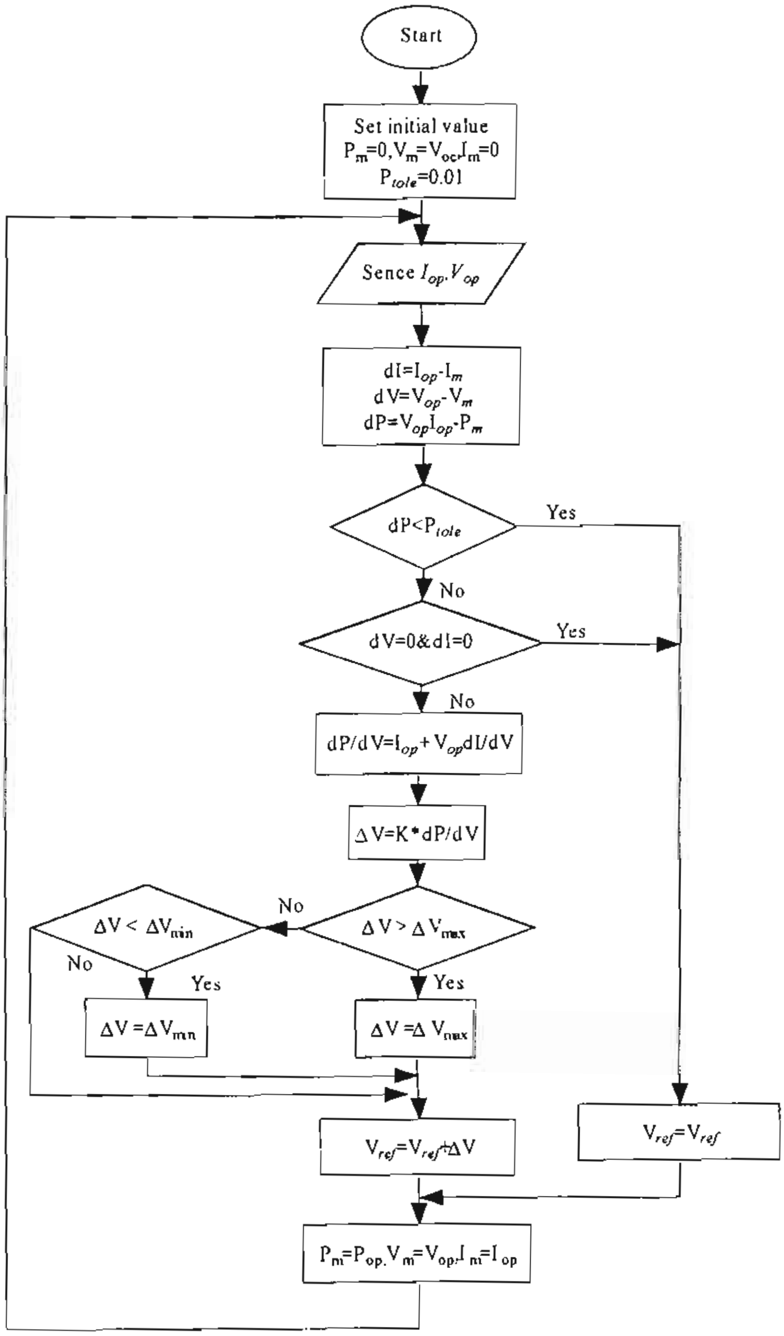

Fig.2 Flowchart of the on-line search algorithm

3-System Configurations

A stand-alone PV system consists of PV array, step down dc/dc converter, resistive load, PI controller, and MPPT algorithm. The arrangement of the stand-alone PV system shown in Fig (3) is described in the following. The solar array model relating voltage and current is given by the equation (A.1). The generated PV voltage is related to the load voltage as follows

$$I_{pv}=C\frac{dV_{pv}}{dt}+I_{dc} \tag{7}$$

Where C is the DC link smoothing capacitor

From the characteristic of the step down dc/dc converter

$$I_{dc}=D\,I_L \tag{8}$$

$$V_{pv}=V_L/D \tag{9}$$

$$I_L=V_L/R_L \tag{10}$$

Where:

- I_{dc} is the input current to the converter,
- V_L is the voltage drop across the load resistance R_L
- D is the duty cycle of the converter

Using equations (A.1) in appendix A, 8,9&10, equation 7 is written as

$$\frac{dV_{pv}}{dt}=1/C\left[\left[I_{ph}-I_{sat}\left[\exp(B(V_{pv}+I_{pv}R_s))-1\right]\right]-\frac{V_{pv}D^2}{R_l}\right] \tag{11}$$

Due to the large value of the shunt resistance, it is neglected. The shape of P-V characteristic is slightly affected by the shunt resistance. The proposed algorithm search for maximum power point regardless the state of the cell.

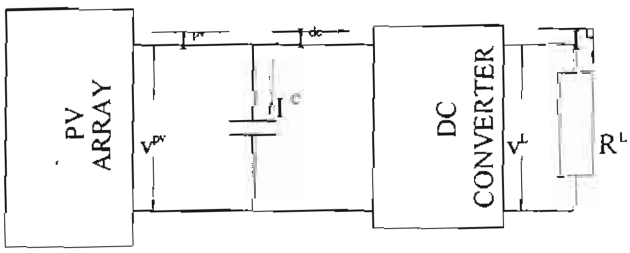

Fig.3 Basic construction of the stand-alone PV system

4-The Digital PI Controller

The discrete type PI control loops are described by using the following difference equations on the computer simulation

$$V_{con}(k) = U_P(k) + U_I(k) \tag{12}$$

$$U_P(k) = K_P e(k) \tag{13}$$

$$U_I(k) = U_I(k-1) + K_I(e(k) + e(k-1)) \tag{14}$$

$$e(k) = V_{ref} - V_{pv} \tag{15}$$

The proportional gain, K_P, and the integral gain K_I were tured in order to achieve the quick tracking ability also to prevent the overshoot and undershoot during the transient. By trail and error method, the tuned parameters are as follows: K_P=0.05, K_I=0.025

5- Simulation Results

Simulation program using MATLAB program, is designed to investigate the performance of the presented algorithm. Figure 4 shows the maximum power tracking at constant radiation, 1000 w/m^2 and constant load 50 ohm using the presented algorithm, where Figure 4.a shows the PV array voltage, and the PV array power is shown in Figure 4.b. Figure 5.a shows the response of the PV voltage for insolation decreases from 1000 to 600 w/m^2 at constant load resistance. Figure 5.b shows the direct coupling power transferred (dashed line) and the power transferred from the PV using the proposed algorithm (solid line). Using the proposed algorithm, the power increases 40% compared to the direct coupling at the insolation 1000 w/m^2 and 117% at insolation 600w/m^2. Figure 6 shows the performance of the search algorithm for maximum power tracking for step change in the load resistance R_L from 50 to 70 Ohm then from 70 Ohm to 40 Ohm.

In order to see the performance of the on-line algorithm, based on the slope of PV power with variable step, the results are compared with those of perturb and observe method with fixed increment in the reference voltage. Figure 7.a illustrate the number of iterations taken by the algorithm to find maximum power point (V_m). Figure 7.b and Figure 7.c illustrate the number of iterations taken by the perturb and observe method with increment 2 and 4 volt in reference voltage to find maximum power point (V_m) when the radiation is 1000 then varies to 600 w/m^2.

With a greater step size voltage, as in Figure 7.c, there is less delay in reaching V_m (an average of 15 iterations), but once maximum power point is reached, the array voltage exhibits pronounced oscillation above and below V_m. This in turn lowers the peak efficiency of the tracker. Using a smaller step size voltage, as shown in Figure 7.b reduces the amplitude of the oscillation, but results in a longer delay in reaching V_m (an average of 25 iterations).

6-Conclusions

The purpose of maximum power tracking is to deliver the highest possible power to the load from the solar arrays. In this paper an online algorithm for maximum power tracking for a stand-alone load is presented. The algorithm only requires the sensing of PV array output current and voltage. The measurements of solar radiation and temperature, that increases the number and the cost of equipment as well as the design complexity, are not required. With the online algorithm, the number of iteration is reduced as compared with those of perturb and observe method with fixed increment in the reference voltage. Also the algorithm keeps the reference voltage a constant value, and thus oscillation is reduced as compared with perturb and observe method.

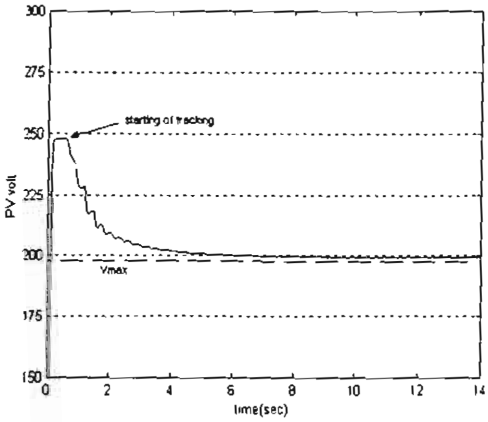

Fig.4.a

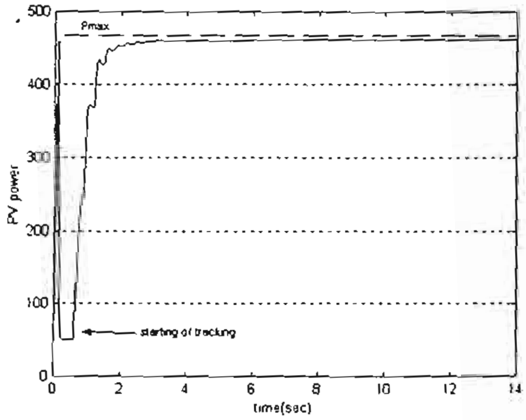

Fig.4.b

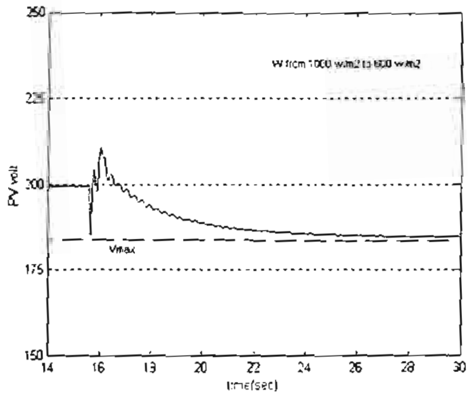

Fig.5.a

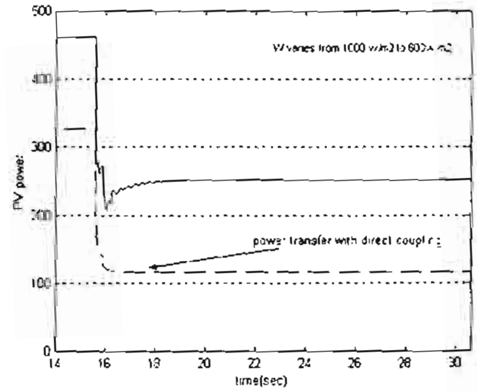

Fig.5.b

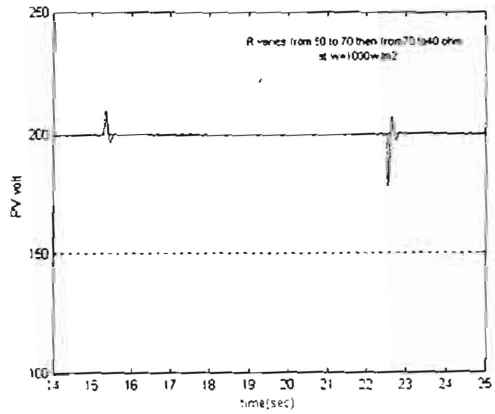

Fig.6 a

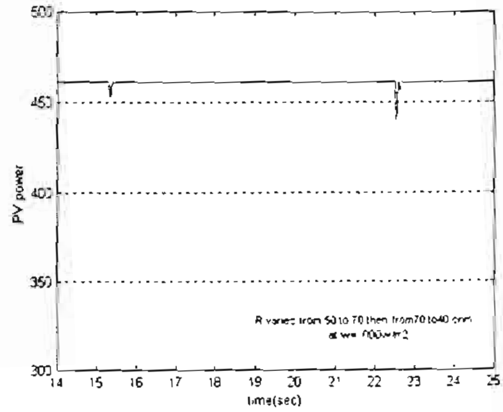

Fig.6 b

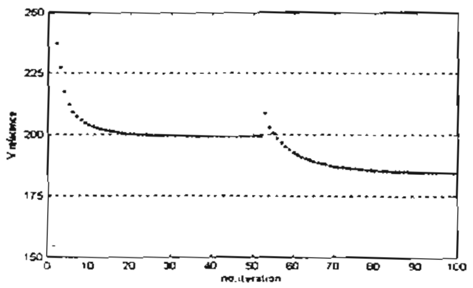

Fig.7.a

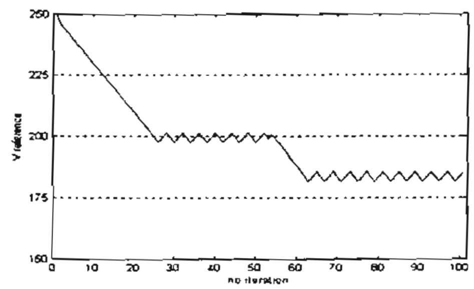

Fig.7.b

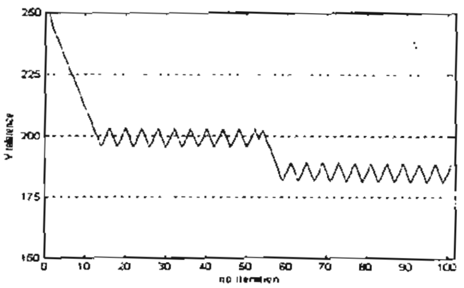

Fig.7.c

7-Appendix A. Model Of A PV Array

The characteristics of a solar cell relating the cell's voltage to current are expressed by following equations

$$I_{pv} = I_{ph} - I_{sat}\left[\exp(B(V_{pv} + I_{pv}R_s)) - 1\right] \quad \text{(A.1)}$$

$$I_{ph} = \left[I_{scr} + K_i(T - 298)\right]\left[w/1000\right] \quad \text{(A.2)}$$

$$B = {}^{q}\!/_{KT} \quad \text{(A.3)}$$

I_{pv} The output current of a solar array (A)
V_{pv} The output voltage of a solar array (V)
I_{ph} The generated current under a given insolation:
I_{scr} The short circuit current at T=298
I_0 The saturation current of a solar array;
q The charge of an electron;
K Boltzmann's constant ($1.3805*10^{-23}$Nm/^{0}K)
T The temperature of a solar array (^{o}K)
R_s The series resistance of a solar array, the value is very small usually.
K_i The short circuit current coefficient

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