Fuzzy System Based Maximum Power Point Tracking for PV System

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Abstract

Maximum power point tracking for PV systems traditionally uses either perturbation and observation method or incremental conductance method. Both methods require modulation of the output voltage and this leads to significant power loss. In this paper, a method, which senses output circuit voltage and short circuit current and use the above two parameters for optimum control with a fuzzy controller, is introduced. The short circuit current of PV cell represents illumination, and the output circuit voltage carry on information about the temperature.

I. Introduction

With the industrial development, the problem of energy shortage is more and more aggravating. The Photovoltaic (PV) system technologies are rapidly expanding and have increasing roles in electric power technology and regarded as the green energy of the new century. [1-2]

As the power supplied by solar arrays depends on the light illumination intensity, temperature and array voltage. It's necessary to track the maximum power of the solar arrays. [2] Some paper had proposed different maximum power point (MPP) control methods in the past yeas. [3,4,5,6] Two methods are proposed in this paper to track the maximum power point and use the fuzzy system to control the circuit to achieve the maximum power point and increase the efficiency of the PV system.

II. Operation Principle of Solar Cell

Solar array characteristic profoundly influences the converter and control system. A solar cell is a nonlinear device and can be represented as a current source model as shown in Fig.1.

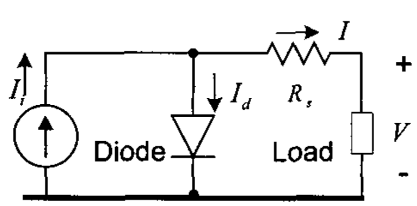

Fig.1 Simplified equivalent circuit of a solar cell

$$I = I_i - I_d \qquad (1)$$

$$I_d = I_s\left(\exp\left(\frac{q(V+R_sI)}{kT}\right)-1\right) \qquad (2)$$

$$I_s = I_{d0}\left(\frac{T}{T_{ref}}\right)^3 \exp\left(\frac{qE_g}{k}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\right) \qquad (3)$$

$$V = \frac{kT}{q}\ln\left(\frac{I_i - I}{I_s}+1\right) - R_sI \qquad (4)$$

$$P = VI \qquad (5)$$

Where I_i is the light generated current, I_s is the diode reverse saturation current, q is the electronic charge, k is the Boltzmann constant, T is the temperature, T_{ref} is the reference temperature, I_{d0} is the diode reversal current, E_g is the bad gap energy of the cell semiconductor, R_s is the series resistance.

The solar cell I-V characteristics are plotted in Fig.2 for different illumination levels. The P-V characteristics are plotted in Fig.3 under different illumination condition, and Fig.4 shows the P-V characteristics for different temperature.

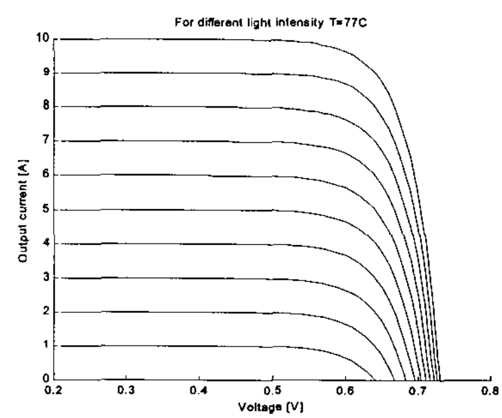

Fig.2 I-V characteristics of PV system

From Fig.3, it is observed that the output characteristic of a solar cell is non-linear and affected by the light intensity, temperature and load condition. Each curve has a maximum power point condition (MPP), which is the optimal operation point for the efficient use of the solar array. As shown in Fig.3, if the real operating point differs

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from the optimum operating point, then power loss should be caused in that circuit. It is necessary that maximum power always would be extracted at any condition in order to eliminate this power loss. [4]

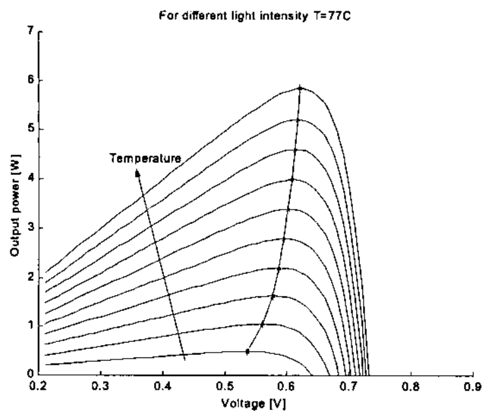

Fig.3 P-V characteristics of PV system at different light intensity

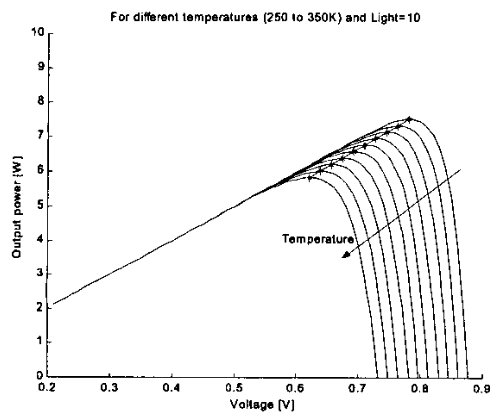

Fig.4 P-V characteristics of PV system at different temperature

From Fig.3, it is observed that when the light intensity increases, the output power will also increase. From Fig.4, it is observed that with the temperature increasing, the open circuit voltage and the maximum power will fall.

III Current Methods to Tracking Maximum Power Point

In order to extract the maximum power from the solar array, it is necessary to operate the solar array at the maximum power point (MPP). Many methods for tracking maximum power point have been proposed. So far, two algorithms often used to achieve the MPPT are: (1) Perturbation and observation method; (2) Incremental conductance method. [2,5,6]

A. Perturbation and observation method

Perturbation and observation (P&O) method [5] has a simple feedback structure and fewer measured parameters. It operates by periodically perturbing (incrementing or decreasing) the array output voltage V(k) and comparing the PV output power P(k) with that of the previous perturbation cycle P(k-1).

$$\Delta P(k) = P(k) - P(k-1) \tag{6}$$

$$\Delta V(k) = V(k) - V(k-1) \tag{7}$$

And Fig.5 shows how the perturbation and observation method works.

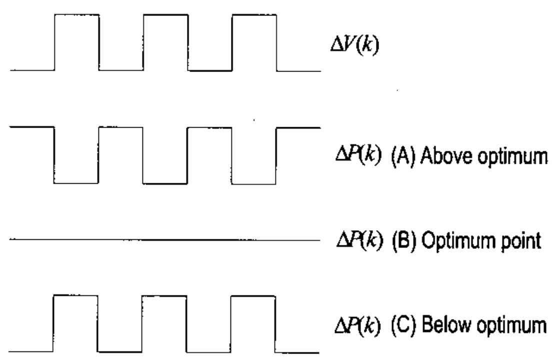

Fig.5 Perturbation and observation diagram

Fig.5 (A) illustrates that the system is working above the optimum power point under the condition that $\Delta P(k)$ and $\Delta V(k)$ have different phases. To make the PV system work at the maximum power point, the duty time should be adjusted to reduce the output voltage, namely, $\Delta V(k+1) < 0$ to increase the PV system output power. Fig.5 (B) shows the PV system works at the maximum power point when $\Delta P(k) = 0$. If $\Delta P(k)$ and $\Delta V(k)$ have the same phase, shown in Fig.5 (C), the PV system works below the maximum power condition. In order to reach the maximum power point, the duty time should be adjusted to increase the output voltage, namely $\Delta V(k+1) > 0$ to increase the output power. In this manner, the peak power tracker continuously seeks the peak power condition.

Fig.6 shows the control loop of the perturbation and observation method.

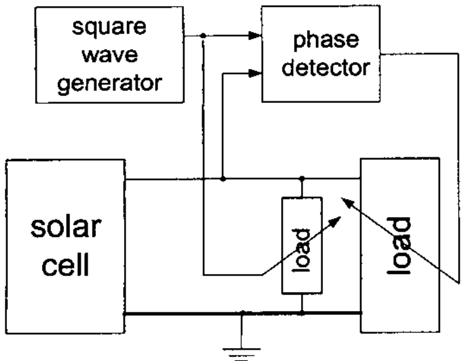

Fig.6 Perturbation and observation control loops

B. *Incremental conductance method*

The incremental conductance method [6] uses the source incremental conductance method as its MPP search algorithm. It is more efficient than perturbation and observation method and independent on device physics. The output voltage and the current from the source are monitored by what the MPPT controller relies on to calculate the ratio of $\frac{I}{V}$ and incremental conductance, and to make its decision (to increase or decrease duty ratio output).

From equation (5), it is trivial to derive equation (8) that can be used to demonstrate the algorithm.

$$\frac{1}{V}\frac{dP}{dV}=\frac{I}{V}+\frac{dI}{dV} \tag{8}$$

Define the source incremental conductance:

$$G=\frac{dI}{dV} \tag{9}$$

In general, the output voltage from a source is positive. Equation (8) explains that the operating voltage is below the voltage at the maximum power point if the ratio of $\frac{I}{V}$ is larger than the incremental conductance, and vise versa. The job of this algorithm is therefore to search the voltage operating point at which the ratio is equal to the incremental conductance. The ideas are expressed by equation (10), and graphically shown in Fig.7.

$$\begin{aligned}&\frac{dP}{dV}>0,\ \text{if}\ \frac{I}{V}>\mathrm{G}\\&\frac{dP}{dV}=0,\ \text{if}\ \frac{I}{V}=\mathrm{G}\\&\frac{dP}{dV}<0,\ \text{if}\ \frac{I}{V}<\mathrm{G}\end{aligned} \tag{10}$$

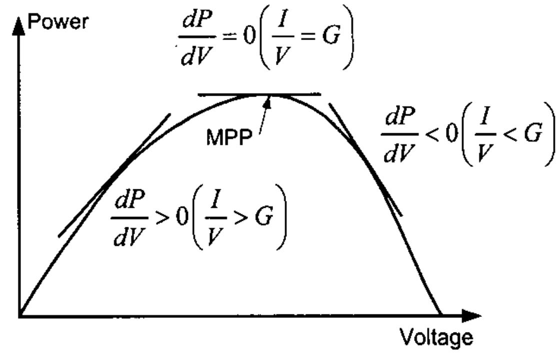

Fig.7 Incremental conductance algorithm P-V characteristics

In both algorithms perturbation and observation method and the incremental conductance method, the AC component must be added to the DC one. In this paper, two methods for maximum power point tacking are proposed.

IV Proposed Methods for Maximum Power Point Tracking

A. *The Current Control Maximum Power Point Tracking*

In order to determine the operating points corresponding to maximum power for different illumination levels, from equation (4) and (5), the partial derivative of power is computed as the following:

$$\frac{dP}{dI}=\frac{d}{dI}\left(\frac{kTI}{q}\ln\left(\frac{I_i-I}{I_s}+1\right)-R_sI^2\right)=0 \tag{11}$$

The solution of equation (11) represents the currents corresponding to the maximum power I_{op} as a function of illumination current of PV system.

$$I_{op}=f_1(I_i) \tag{12}$$

Fig. 8 shows optimum load to illumination current ratio at different temperature and different illumination levels. This means that, at a given temperature and illumination level, the current corresponding to maximum power is the function of illumination current. From Fig.8 it can be observed that at a given temperature, with the light illumination increasing the ratio will increase accordingly; and at a given light intensity level, with the temperature increasing the ratio will drop. At a given temperature, if the illumination current value is measured, then from the Fig. 8, it is not difficult to know the optimum current the PV system should work on.

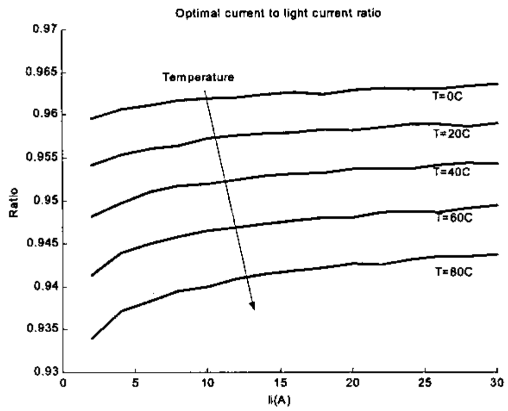

Fig.8 Optimal load to illumination current ratio under different temperature

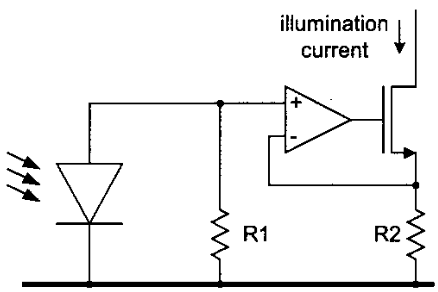

Fig.9 Illumination current measurement diagram

Fig.9 shows the diagram to measure the illumination current. In this diagram, the operational amplifier is used to control the circuit operation and measure the illumination current indirectly, which will reduce the impact of the measurement circuit to the PV system and increase the measurement accuracy.

B. The Voltage Control Maximum Power Point Tracking

Similar to the current control maximum power point tracking method, the voltage control method [7] can also be used. From equation (12) and equation (4), the optimal voltage corresponding to the maximum power point can be drawn, represent as the following:

$$V_{op} = f_2(I_l) \tag{13}$$

At the open circuit condition ($I = 0$) it gives:

$$V_{oc} = \frac{kT}{q}\ln\left(\frac{I_l}{I_s}+1\right) \tag{14}$$

Therefore, the voltage corresponding to maximum power can be expressed as a function of cell open circuit voltage, namely

$$V_{op} = g(V_{oc}) \tag{15}$$

Fig.10 shows the optimum output voltage to the open circuit voltage ratio at different temperature and different light intensity levels, and Fig.11 shows the optimal output voltage to open circuit ratio at different temperature.

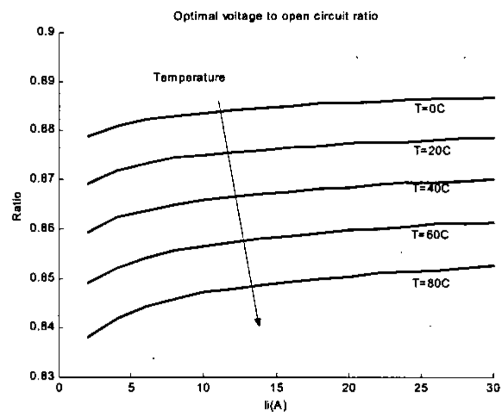

Fig.10 Optimal output voltage to open circuit ratio at different temperature and different light intensity

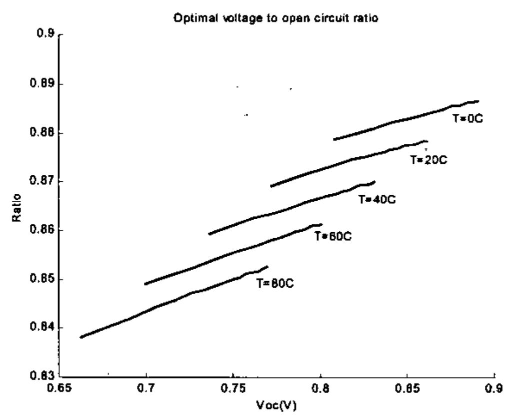

Fig.11 Optimal voltage to open circuit ratio at different temperature

From Fig.10 and Fig.11, it can be observed that at a given light intensity level, with the temperature rising, the voltage corresponding to maximum power point to the open circuit ratio will decrease; and at a given temperature, with the light intensity improving, the ratio will also increase.

Fig.12 shows the open circuit measurement diagram. The operational amplifier can also be introduced to control the measurement circuit

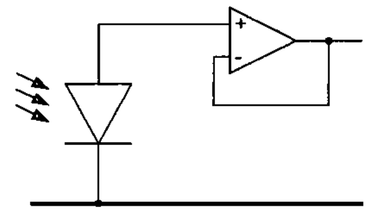

Fig.12 Open circuit measurement diagram

V Fuzzy System Based Maximum Power Point Tracking

Fuzzy controllers are used to provide solutions to control problems that cannot be described by complex mathematical models. Fuzzy systems are relatively easy to design and produce reasonable results. In this paper, the fuzzy system is used to control the PV system to make the PV system work at the maximum power point. In the current approach the fuzzy system was implemented by using Motorola HC11 micro-controller [8]. Fuzzy system provides nonlinear mapping of the function shown in Fig.13.

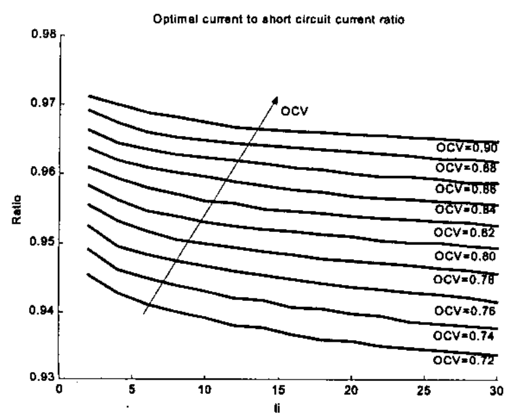

Fig. 13 Optimal current to short circuit ratio at different open circuit voltage

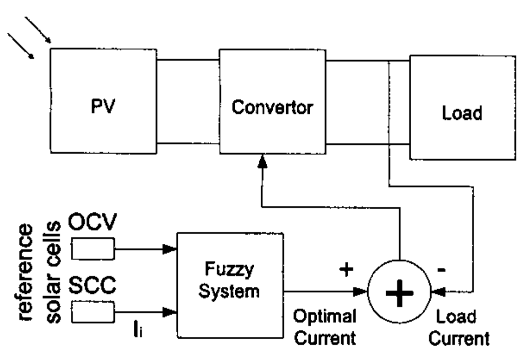

Fig.14 Fuzzy system based current control MPPT diagram

The block diagram, for identifying the optimal operating point and also the maximum power output of the PV system, is shown on Fig.14.

VI Conclusion

A method for maximum power tracking was developed. In contrast to the existing methods there is no need for modulation of the output voltage. The proposed method senses output circuit voltage and short circuit current and uses these two parameters for optimum control using a fuzzy controller. The short circuit current of PV cell represents illumination, and the output circuit voltage carries on information about the temperature.

Acknowledgment
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