

Implementation of Maximum Power Point Tracking Controller for Photovoltaic Systems

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ABSTRACT

In order to increase the output overall conversion efficiency of the photovoltaic(PV) arrays it is used maximum power point tracker (MPPT) control to increase the PV arrays output power. The approach uses a novel controlling scheme to combine perturbation and observation (P&O) method together with three-point weighting comparison (TPWC) method for tracking maximum power points of PV arrays. The advantage of this approach is that it is a simple algorithm conducting on a microprocessor without redundant circuit components and thus the maximum power point of the PV systems will be obtained quickly and stably. According to the practical experiment, the system will produce fast and effective tracking results.

Keywords: photovoltaic arrays, maximum power point tracker, perturbation and observation, three-point weighting comparison

研製新型太陽電池發電系統最大功率追蹤控制器

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摘 要

使太陽電池模組發揮最大輸出功率使其提高整體光電轉換效率，研製新型最大功率追蹤控制器。本文結合擾動觀測法與三點加權比較法的優點，提出一種新的控制方法使太陽電池陣列追蹤最大功率。由於本研究所提出的新型最大功率追蹤控制器沒有冗餘的電路組件在微處理器上，因此可以使演算法簡單化，而讓太陽電池系統快速穩定的得到最大功率輸出。根據實驗結果發現，本文所提出的控制器能產生快速有效的追蹤結果。

關鍵詞：太陽電池，最大功率追蹤，擾動和觀察法，三點加權比較法

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I. INTRODUCTION

Solar cell is a kind of optoelectronics converting energy. It converts optics into electricity after being illuminated by sunlight [1-4]. The solar cell arrays are normally designed to extract maximum electrical power from varying irradiation levels. However, the photovoltaic (PV) power generation have a nonlinear current voltage (I -V) characteristic as their power output depends on the weather conditions [5, 6]. In order to achieve the maximum power from the PV arrays, the control unit needs to have an appropriate strategy for maximum power point tracking (MPPT). Several techniques for MPPT have been used in recent years in which the Perturb & Observe (P&O) algorithm is very popular used in PV industry [7, 8]. A typical disadvantage of this technique is that the slow response speed, oscillations in power output [9, 10], tracking failures in rapid environmental changes, and required parameters less. Several enhanced the P&O algorithm have been proposed [11-13], however they have a higher computational cost, slow down the response speed and increased oscillations which results in weather change conditions. In the tradition P&O algorithm measured power of two points is used to determine movement to the next operating point. Based on the experiments, there are difference in the output power the controller increases or decrease the PV module array output voltage.

This paper proposes implementation of a novel controlling scheme to combine P&O method together with Three-Point Weighting Comparison (TPWC) method [14-17] for tracking maximum power points of PV systems. The basic concept of this approach is that the variation of solar irradiation conditions changes suddenly, the P&O method will be applied for fast tracking of the maximum power point. In the other cases with the solar irradiation is comparatively stable, the TPWC is applied to avoid the perturbation problem around the maximum power point. Therefore, considerable optimal solution is being carried out to implement a microprocessor by combine P&O and TPWC methods for PV systems. The advantage of this approach is that it is a simple algorithm conducting on a microprocessor

without redundant circuit components and also the maximum power point of the PV systems will be obtained quickly and stably. As a result, the PV arrays control is a real time detecting output power and adapting the control algorithm to make the system operate under the optimum work.

II. MATHEMATICAL MODEL

The basic structure of semiconductor solar cell is a p-n junction diode. When the p-type and n-type semiconductor contact to form the p-n junction, the minority carrier of n-type semiconductor will diffuse to the p-type semiconductor to fill the holes. On the p-n junction, electrons and holes combine and form a depletion region, which results in a built-in electric field. An ideal solar cell, without light exposure, can be regarded as the diode, the current-voltage (I-V) characteristics is [1,18-19]:

$$I = I_s (e^{\frac{V}{V_T}} - 1) \quad (1)$$

Where I is current, V is voltage, I_s is the saturation current,

$$V_T = \frac{kT}{q} \quad (2)$$

Where kB is the Boltzmann constant (1.38×10^{-23} J/K). q_0 is denotes the charges of an electron (1.6×10^{-19} coulomb), temperature of the PV arrays (K). At room temperature, V_T is about 0.026V. When the sunlight shines on the solar cells, the built-in electric field direction of the p-n junction is from the n-type to p-type, electrons run to n-type side, and holes to the p-type side, while the photo current flows from n-type to p-type [1,18-19].

$$I = I_s \left[e^{\frac{(V - IR_s)}{V_T}} - 1 \right] + \frac{(V - IR_s)}{R_{sh}} - I_L \quad (3)$$

Where R_s and R_{sh} represent the series and shunt resistance, I_L is negative photo current of the solar cell. Figure 1 shows the solar cell voltage and current (or power) characteristic curve. When load is in short-circuit, the voltage difference is 0 and current is maximum that is called short-circuit current (I_{sc}). When the load

is open circuit, the current is 0 and voltage difference is in maximum that is called the open circuit voltage (V_{oc}). In load changing process from 0 to infinity, there is a particular load which is the highest state of power generation. The power generation at this time is the module's maximum power. The voltage at the maximum power point is called the maximum power voltage (V_{max}), and the current is called the maximum power current (I_{max}). The rectangular area formed by V_{max} and I_{max} at the Maximum power point is the maximum power value. Dotted lines in Figure 1 are the ideal solar cell I-V characteristic, the ideal solar cell hasn't internal resistance and leakage current.

Figure 1 shows a MATLAB/Simulink model of the PV circuit built to obtain the I-V characteristics according to equation (3). This I-V characteristics of solar cell shows that the output curves are non-linear. In addition to that output power influenced by weather changing condition, temperature and load status. Each power voltage (P - V) characteristic curve has a maximum power point, at which the solar cell operates most efficiently.

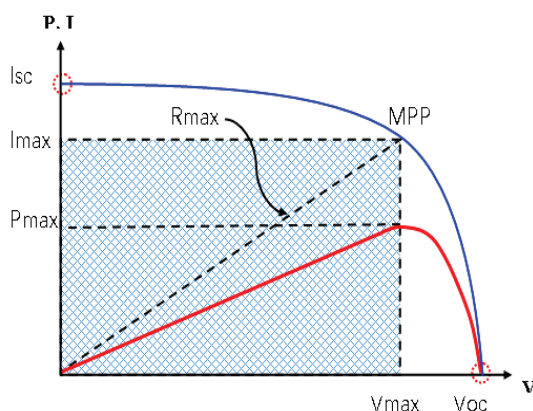


Fig.1. The I-V characteristic relationship of solar cell

III. MPPT System Configuration

The PV system produced output power which is the maximum power that depends on the path of incoming light. In order to achieve the energy generated from PV system during significantly on weather changing condition, the system needs to have a suitable algorithm for

MPPT.

3.1 Perturb and Observe (P&O) Method

The diagram of P&O operation is shown in Figure 2. The operating voltage is sampled and the algorithm changes the operating voltage in the required direction and samples $\Delta P/\Delta V$. The P-V curve can be divided into two characteristic areas. If the operating point lies in left side ($\Delta P/\Delta V > 0$), then the increase of voltage will raise up the perturbed power. However, if operating point lies in the right side ($\Delta P/\Delta V < 0$), then the increase of voltage will decrease the PV system output power. The principle of P&O method will compare one perturbation point to the next, and determine which one is the maximum power point.

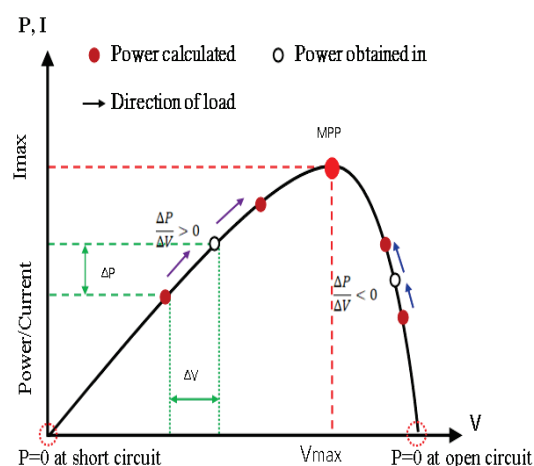


Fig.2. I-V characteristic of PV arrays by operating P&O method

3.2 Three-Point Weighting Comparison (TPWC) Method

TPWC method works similarly to compare the variation of the output power, but with one additional power point to make final determination of maximum power point. The possible states of three perturbation points may be depicted in nine cases which are shown in Figure 3 (with proper weightage '+' or '-' sign). In this method, the voltage and power of the PV systems are adjusted according to the cycle of increasing or decreasing load. At the same time, it will determine the next increasing or

decreasing step of working load by comparing the changed load value of output voltage and power. The three points are the current operation point A, a point, B, perturbed from point A, and a point, C, with doubly perturbed in the opposite direction from point B. The comparison method is weighted by two parts. In these cases one, if point $C > B$, or $C = B$, a positive weight is given, and if $C < B$, then a negative weight is given. Second, if $A > B$ or $A = B$, a negative weight is given, and if $A < B$, then a positive weight is given.

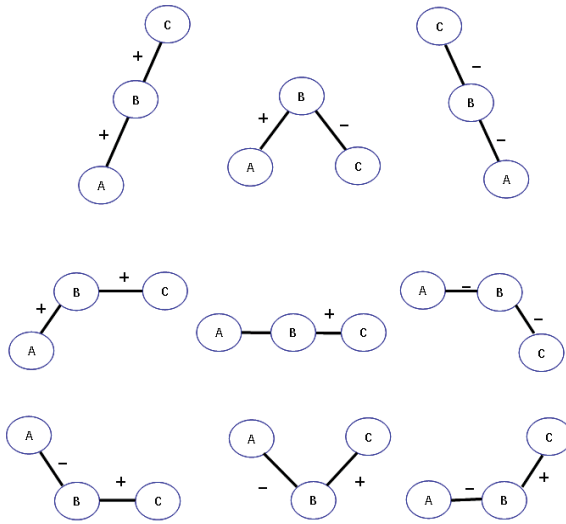


Fig.3. Possible patterns in the direction of step-size in TPWC method

3.3 The Proposed MPPT Method

The P&O method will cause the loss of power and the reduction of the efficiency of the PV arrays. The outcomes of MPPT using classical P&O algorithms are caused by oscillations in power output. Unfortunately, a number of studies to prevent the oscillation problem require complex computational power, which results in unnecessary power loss of the PV system. In the P&O algorithm, only two points, which are the current operation and the subsequent perturbation point, are used to observe their changes in power. Therefore, this work incorporates the TPWC method to improve the drawback of the P&O method. The P-V characteristics for the proposed MPPT method under different conditions are shown in Figure 4. When the slope value of power is larger than

absolute value $1/3$, which means the variation of solar irradiation is rapid. The current and voltage of PV arrays change during a voltage perturbation and $\Delta P/\Delta V > 1/3$, the operating voltage of PV arrays is located on the left side in the P-V curve. If $\Delta P/\Delta V < 1/3$, the operating voltage of PV arrays will be located on the right side in the P-V curve. On the other hand, when the slope value of power is equal $1/3$, which means the TPWC method is used to avoid having to move rapidly the operation point or when a disturbance or data reading error occurs.

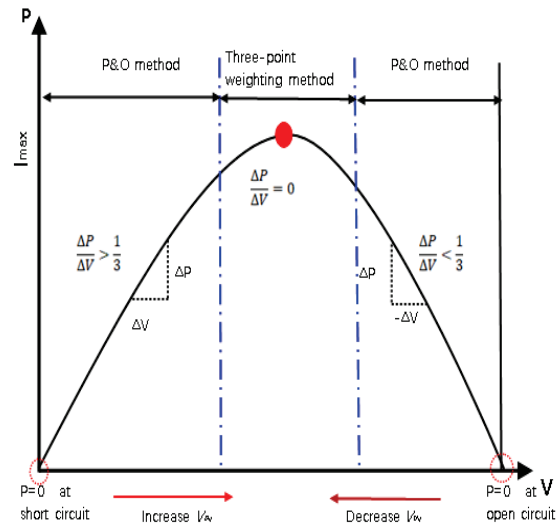


Fig.4. Proposed method sign of $\Delta P/\Delta V$ at different position on the power-voltage characteristic of the PV system

There is unnecessary power loss if only the P&O method is used for tracking the maximum power point. If only the TPWC method is used, the seeking time of the maximum power point will be longer than that of the P&O method when solar irradiation changes rapidly. There are some disadvantages in each method. Therefore, a novel controlling scheme with an adaptive decision mechanism is developed for a PV system to avoid these disadvantages. Figure 5 presents the control flow chart of the proposed control program. The proposed method uses the condition that $\Delta P/\Delta V$ is greater than $1/3$ or not to make the judgment. When the condition $|\Delta P/\Delta V| > 1/3$ is used, the TPWC method is used for tracking the maximum power point. As described in the last paragraph, the P&O method uses the condition $|\Delta P/\Delta V| > 1/3$ to determine whether the maximum power point has been found or not. The proposed method uses the duty cycle of these switching mode

power interface devices as the judging parameter depend on power output.

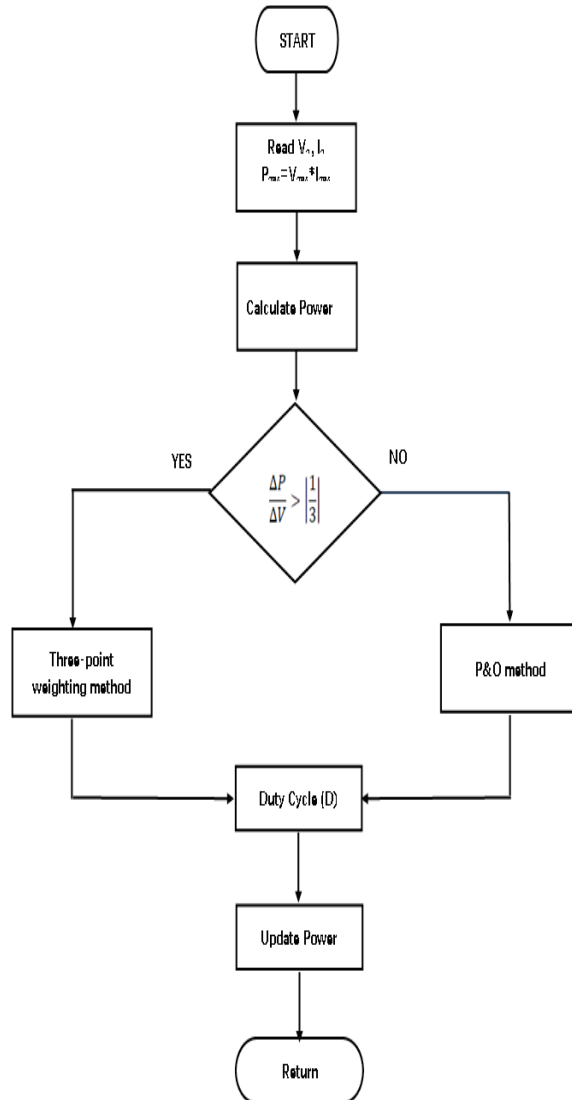


Fig.5. Flowchart of the proposed method

IV. CIRCUIT TOPOLOGY AND OPERATION OF THE BUCK-BOOST DC-DC CONVERTER IN THE PV SYSTEM

From the application of alternating current (AC), voltage control devices are needed to step-up and step-down output voltage. The DC-DC converter can be considered as the DC equivalent to an AC transformer with continuously variable turns-ratio. DC-DC converter is very important in all voltage levels

applications lower power, medium power or high power applications. Many DC-DC converter circuits are considered before design the PV system. Based on this approach, ultimately a buck-boost DC-DC converter was chosen because of this converter an inverting regulator. The buck-boost converter provides an output voltage which may be greater than or less than the input voltage provides an output voltage which may be greater than or less than the input voltage. This converter is a circuit that combines a buck converter topology with a boost converter topology in concatenation. The polarity of input voltage is opposite of the polarity of the output voltage.

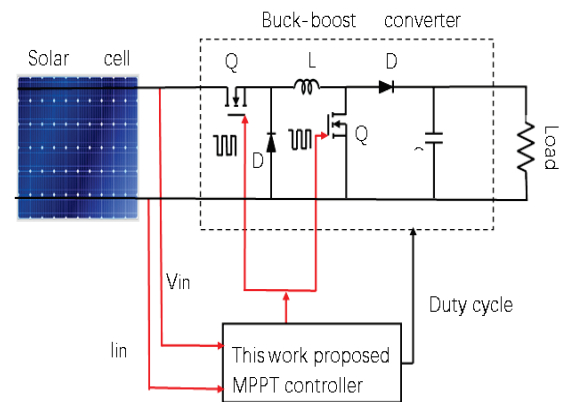


Fig.6. Block diagram of the proposed PV system

Figure 6 shows the topology of the proposed PV system. As shown, the buck-boost DC-DC converter connects the PV modules to the load. The buck-boost converter consists of an inductor (L), two diodes (D1 and D2), capacitor (C) two digital switches (Q1 and Q2) and resistance respectively. The capacitor maintains the load voltage, D2 prevents reverse current, and D1 separates the two modes of operation for this buck-boost topology.

The first mode appears when the transistor is turned on, and diode is reversed biased. During open-switch mode, the input current flows through the transistor and inductor. The second mode appears when the switch is turned off, and the current flows from L through C. The transistor is switched on again in the next cycle when the energy that stored in inductor, the capacitor is added to the converter output to reduce the ripple of its output voltage. Buck converter is a step-down converter that output voltages lower or high than input voltage. The

solar cells load (RL) is connected across PV arrays terminal via buck-boost converter. The buck-boost converter is intended to match the load impedance with source impedance of the PV system to adopted maximum power transfer. The relations between input and output variables of buck-boost converter is given as [20-22]:

$$\frac{V_o}{V_i} = \frac{D}{1-D} = \frac{I_i}{I_o} \quad (4)$$

Where V_o is output voltage, V_i is input voltage of PV system. I_i and I_o are input and output currents, respectively. The power flow is controlled by switch moving during the on/off duty cycle (D). Where duty cycle is the ratio of the on time of the switch to the total switching time. The input/output relation of the voltages can be expressed by equations (5):

$$V_o = \frac{1}{1-D} V_i \quad (5)$$

The buck-boost converter output voltage is controlled by the switch duty-cycle. The duty cycle in terms of the output and the input voltage is given by equation (6). By solving for switch duty cycle:

$$D = \frac{V_o}{V_o + V_i} \quad (6)$$

The algorithm will take this variable as controlled variable for voltage change and then computes the duty cycle from Eq. (5) and (6) as follow:

$$D = \frac{T_o}{T} \quad (7)$$

Where T is switching cycle of power transistor, T_o is turn on period of power transistor. Therefore, we can utilize the buck-boost converter in PV system. During weather conditions change, the PV system will change the duty cycle of power transistor to obtain the maximum power output. In order to maximize the power output of the PV system, a controlling scheme is implemented on a microprocessor to combine with P&O and TPWC methods. There PV system power load output will be regulated to the different weather conditions by controlling the duty cycle of the buck-boost converter.

When controller determines to decrease load, the power transistor's switching duty cycle will gradually decrease the photovoltaic array reaches the maximum power point.

As shown in Figure 6, the proposed MPPT circuit determines an input voltage V_{in} , MPPT corresponding to an atmospheric condition. The PV output voltage is sensed and compared with the V_{in} . Through the proposed controller an appropriate control signal is generated to regulate the PV output voltage so that the buck-boost DC-DC converter draws maximum power from PV arrays. Then, the buck-boost DC-DC converter implant the power into DC bus for DC-distribution applications or into utility via a grid-connection DC-AC inverter. The MPPT controller varies the point of intersection between the load line and I-V curve by varying the duty cycle to achieve an intersection point where maximum power transfer to the load is achieved.

V. SIMULATED AND EXPERIMENTAL RESULTS

5.1 Simulated Results

For implementation purpose a 21V and 4.5A (close circuit current) solar panel is used. It produced 70W at 25°C and 1kW/m2 irradiance. To evaluate the performance of the proposed system, Matlab/Simulink is used to implement the tasks of modeling and simulation. The two most important P-V and I-V curves are carried out simulating to validate the performance of the proposed method. These curves show the relation between temperature, irradiation and power generation.

The developed model of PV system is simulated for different temperatures as shown in Figure 7. In the left-hand side of I-V characteristic curves, it shown the output current is nearly constant as the voltage changed from zero to the voltage at the corner point. In the right hand side of I-V characteristic curves, it shown the output voltage is nearly constant as the current falls to zero. Therefore, it can be seen that the I-V characteristics are dependent on the levels of irradiance and the temperature of PV

arrays.

The P-V curves at various temperatures are plotted, as shown in Figure 7. It is clear that the P-V curve has single peak that could be easily found by P&O method. From the above simulations, it is obvious that the factors, array temperature, will affect the generated PV power significantly. To improve PV system efficiency, the proposed MPPT algorithm has to be adopted to draw maximum power from PV arrays.

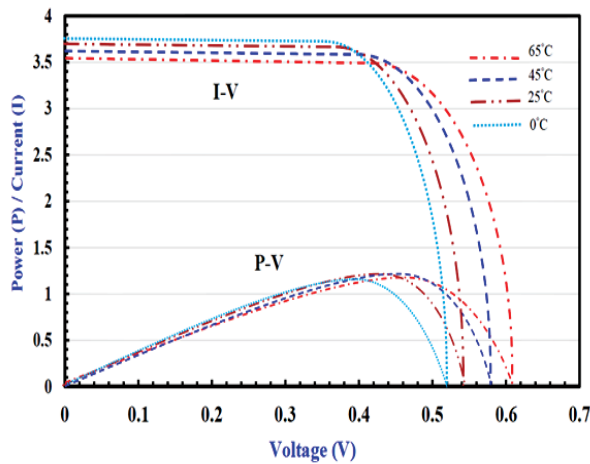


Fig.7. I-V and P-V characteristic curves of a practical photovoltaic device under different temperature (at 1000W/m²)

5.2 Experimental Results

The reliability of power tracking analysis depends primarily on accurate power output data with sufficient time resolution. The data used in this paper are being collected by the DSP laboratory of department of electrical (National Taiwan Ocean University) since 2015 July with 30 days. The available output power of the PV arrays are averaged over several hours, typically AM 09 to PM 05. The sampling time of 30 days assures that all irradiance fluctuations, relevant for different power tracking method, are recorded. There are involve the valid information and useful for tracking evaluation. The cumulative power of PV panel using different methods is shown in Table 1. According to the experiment, it is shown that the proposed method can achieved the best performance by enhancing about 21% efficiency.

The experiment reveals the real variability of power profiles by different methods, as shown in Figure 8. The collection of PV arrays output

power irradiance profiles, shown in this figure, demonstrates the condition of variable-cloudy sunshine, especially in summer. Too small power output is causing by without MPPT, while we proposed method is almost perfect. Power drift is obvious, the irradiance change is the main factor. The deepest fall of power output always occurs for the current and voltage drift at the same time. The quality of PV arrays output power is determined by the terrestrial irradiance. The results represent the energy received by PV arrays, different method tracking efficiency. It is worth noticing, that under highly variable irradiance proposed method can immediate reach steady state.

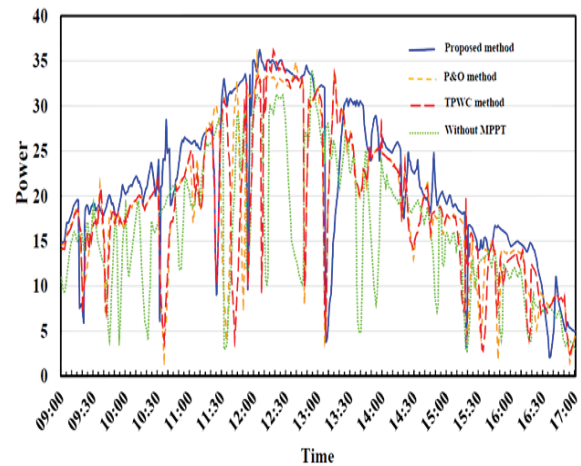


Fig.8. Practical measurement result by different tracking methods. (Remarks: under the condition of irradiance = 850 W/m², temperature = 55°C)

Table.1. Cumulated 30 day's power obtained from different

Method	Cumulated power	Efficiency (%)
Without MPPT	7.21kW	NA
TPWC method	7.9kWf	9.6%
P&O method	7.94kW	10%
Proposed method	8.74kW	21%

VI. CONCLUSION

Maximum power point tracking techniques is always the crucial factor to extract the PV system output power. This paper presents an efficient controlling scheme and developed by

compromising both P&O method and TPWC method for photovoltaic arrays MPPT. This system is implemented in a single chip with a simple algorithm to control these two methods and it will include the advantages of both methods. The experimental results have demonstrated clearly that the proposed method is better than the traditional method, it will track the maximum power point for a PV generation system quickly and stably. The best results are expected for the proposed method can enhance about 21% efficiency. Therefore, we proposed method has the potential in the PV industry application

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