RESEARCH ON MAXIMUM POWER POINT TRACKING'S ALGORITHM OF PHOTO-VOLTAIC CELL ARRAY FOR GREENHOUSE
/
用于农业大棚的光伏阵列最大功率点跟踪算法研究

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ABSTRACT

In order to enhance the utilization of solar energy in photovoltaic greenhouse, this paper takes the optimization strategy of photovoltaic array's maximum power point tracking algorithm as research object. According to the changing rule of the slope of photovoltaic array's output P-U curve, this paper proposes a new variable-step conductance increment method to track the maximum power point. When the working point is located on the left side of maximum power point, the logarithmic function value of curve's slope is adopted as the voltage step to adjust the position of working point. When the working point is located on the right side of maximum power point, the exponential function value of curve's slope is adopted as the voltage step to adjust the position of working point. Through the MPPT modelling and simulation in MATLAB/Simulink and the corresponding circuit test, the result shows that comparing with the traditional variable-step conductance increment method, the proposed algorithm can find the maximum power point faster, and it can effectively reduce the power loss caused by step oscillation in the searching process, which achieves the goal of enhancing conversion efficiency of photovoltaic power generation.

摘要

为了提高光伏农业大棚对太阳能的利用率，本文对光伏阵列最大功率点跟踪算法的优化策略进行了深入研究。根据光伏阵列输出 P-U 曲线斜率的变化规律，文章提出一种新型的变步长电导增量法对 MPP 点进行追踪，当工作点位于 MPP 点左侧时，采用曲线斜率的对数函数值作为电压步长调整工作点的位置，当工作点位于 MPP 点右侧时，采用曲线斜率的指数函数值作为电压步长调整工作点的位置。通过在 MATLAB/Simulink 中进行 MPPT 建模与仿真，并对相应的电路进行测试，结果表明该算法相较于传统的变步长电导增量法，能够更快地寻找到 MPP 点，且有效降低了寻找过程中由步长振荡造成的功率损失，提高了光伏发电转换效率。

INTRODUCTION

Greenhouse with solar energy system has been world widely developed in recent years. These greenhouses are integrated with solar cell array, digital control system, power-conversion module and data communication system to perform sustainable development functions *(Aznar-Sánchez et al., 2020; Riahi et al., 2020; Zialo et al., 2019)*. For instance, solar cell array has been fixed on the top of greenhouse that leads to the result of land saving. In addition, the solar panels have numerous levels of transmittance and they can be used as a part of the luminous system for different plants. The generated electrical power can be consumed by the intelligent greenhouse including the irrigation system, ventilation system and heating system *(Chen et al., 2013; Wang et al., 2011; Zhang et al., 2020)*. The extra energy generated during the high luminous period can be sold to the state grid for further financial benefit. The utilization of solar energy system for greenhouse has been studied by many researchers *(Azaizia et al., 2019; Cuce et al., 2016; Ravishankar et al., 2020)*.

However, the efficiency of the solar energy system for greenhouse has been a challenge due to the fluctuation of luminous intensity, temperature and other environmental factors *(Gil et al., 2019; Loik et al., 2017; Tiwari et al., 2017; Thaker et al., 2019; Zhang et al., 2019)*.

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The solar panels are impacted by these factors and the output power cannot meet the maximum power point. This not only results in energy loss but also leads to the instability of the system.

Therefore, corresponding algorithm is required to deploy on the solar systems to track the maximum power point *(Carbone, 2017; He et al., 2015; Liu, 2015; Radjai et al., 2015; Tajuddin et al., 2015)*.

In this paper, an incremental conductance with variable step size MPPT control method has been proposed. This improved algorithm is superior to the traditional method for better stability and fast response. Its fundamental principle is to adopt logarithmic function and exponential function to modulate the output voltage for achieving higher tracking efficiency. Compared to our previous algorithm based on the fuzzy control theory *(Wei et al., 2019)*, this proposed method has much faster response time which can result in less power loss in the solar energy systems. Experimental tests have been performed by using MATLAB Simulink to evaluate the performance of the proposed algorithm and results suggest good tracking efficiency.

SYSTEM STRUCTURE AND THEORY

System structure

The functional block diagram of the MPPT system for greenhouse is shown in Figure 1. The solar cell panel array system has been mounted on the greenhouse for electricity generation. The output voltage is detected by the main control board through ADC module. The proposed algorithm is processed by the high-performance processor, which is TMS320F28335 in this system, and the output PWM is adjusted according to the detected working point. A boost circuit is deployed in the system to perform DC-DC voltage modulation. Then, the stabilized DC power will be converted to be AC power by the inverter system. The output AC power has been consumed by the electrical devices in the greenhouse and the extra power will be sent to the national grid for further commercial benefit. During the process, modulation of the fluctuated voltage is crucial not only for the system's stability but also results in less power waste. In this way, the performance of the voltage detection and modulation has been researched and optimized in different ways. The improved algorithm based on variable-step incremental conductance principle has been adopted and experiments have been carried out to optimize the system.

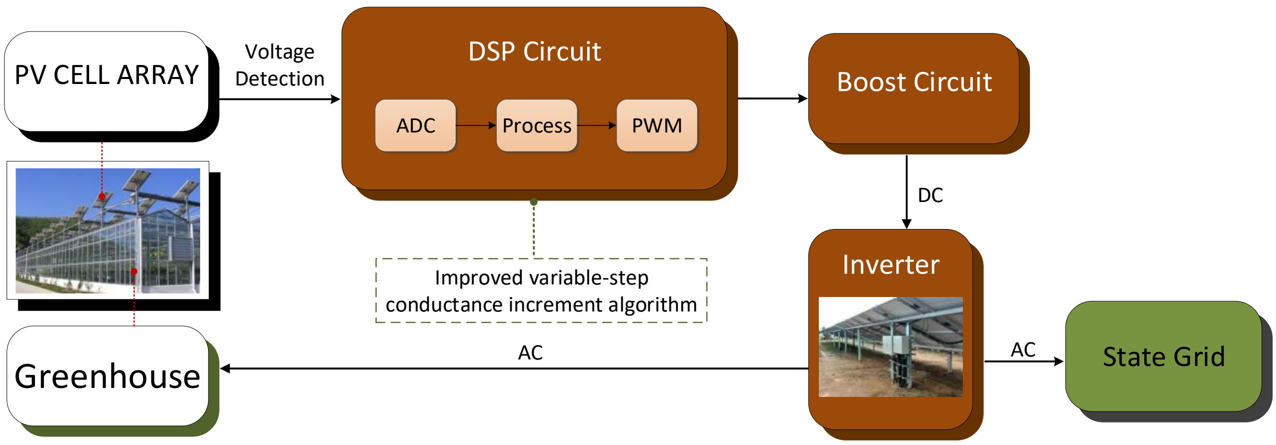

Fig. 1 - Block diagram of the MPPT adopted solar cell array system for greenhouse

MPPT control method of incremental conductance with variable step size

The fundamental of MPPT control theory is briefly summarized here to guide audience. The MPPT control method of incremental conductance with variable step size, which is similar to the fuzzy control method proposed in our previous research paper, is also required to detect real-time voltage and current of solar cell. Then, calculation is performed to obtain the opposite number of the output conductance and the instantaneous conductance. The results are compared in order to evaluate the MPPT location. Meanwhile, the slope of P-U can be adopted as reference step size coefficient to adjust the output voltage. The equation below shows the derivation expansion of solar cell output power towards voltage.

$$\frac{dP}{dU} = \frac{d(UI)}{dU} = I + U\frac{dI}{dU} \tag{1}$$

As shown in Equation (1), the working point located at the left side of maximum power point when $I+U(dI/dU)>0$, which can also be expressed as $dI/dU>-I/U$. In this way, the output voltage should be modulated from the positive direction. On the contrast, the output voltage should be modulated from the negative direction if the working point located at the right side of the maximum power point when $I+U(dI/dU)<0$, which can also be expressed as $dI/dU<-I/U$. The last situation is $I+U(dI/dU)=0$, which is $dI/dU=-I/U$ when the working point is exactly located at the maximum power point. Under this situation, the solar cell is at its maximum power point.

The incremental conductance with variable step size equation can be expressed as Equation (2).

The output voltage can be shown as Equation (3).

$$d = \frac{dP}{dU} \tag{2}$$

$$U(k) = U(k-1) + d \tag{3}$$

In order to establish models for analysis, parameters of solar cells are applied in this paper. These parameters include short current I_{sc}, short voltage V_{oc}, optimum operating voltage V_m, optimum operating current I_m and are provided by project companies. In this way, the model of solar cell can be expressed in Equations (4) – (6).

$$I = I_{sc}\{1 - C_1\left[exp\left(\frac{V}{V_{oc}C_2}\right) - 1\right]\} \tag{4}$$

$$C_1 = exp\left[-\frac{V_m}{V_{oc}C_2}\right](1 - \frac{I_m}{I_{sc}}) \tag{5}$$

$$C_2 = \left(\frac{V_m}{V_{oc}} - 1\right)[In\left(1 - \frac{I_m}{I_{sc}}\right)]^{-1} \tag{6}$$

As shown in Equations (4) – (6), C1 and C2 are project variables that can be obtained considering two situations. The first situation is that the output voltage is located at the maximum power point. The second situation is that the output is under short condition. The two situations can also be expressed as shown in Equations (7) and (8) respectively.

$$V = V_m, I = I_m \tag{7}$$

$$V = V_{oc}, I = 0 \tag{8}$$

By using this MPPT control method, the output voltage can be adjusted to achieve optimum output power. However, this method can also be improved to reduce the fluctuation of output power and to minimize response time. Therefore, the improved MPPT control method of incremental conductance with variable step size is adopted in this paper. In contrast with the traditional method, which adopts P-U slope to adjust output voltage, the improved method adopts the asymmetry of P-U curve with modulation strategy for the left side and right side of the maximum power point in order to achieve better tracking performance.

MATERIALS AND METHODS

Improved simulation of Incremental conductance with variable step size MPPT control method

The proposed algorithm model of improved incremental conductance with variable step size MPPT control method is shown in Figure 2. In this figure, there are two input ports which are the output voltage and current of the solar cell system. The output of the model is the voltage step which is adopted to modulate the working voltage at the most efficient value. In this way, the maximum power generation of the solar system can be achieved. The model can be divided into three parts. Firstly, the output voltage of the solar cell system is measured and compared with zero and then suitable modulation strategy will be selected by the switch block. Secondly, if the instantaneous voltage is zero, fixed step will be applied to modulate the output voltage and the instantaneous current will be measured and its direction will be adjusted by using the sign block. Finally, if the instantaneous voltage is not zero, its working point will be compared with the maximum power point and corresponding algorithm will be adopted to modulate the output voltage.

In contrast with the original algorithm model, there are two additional approaches implemented in this improved model. The P-U slope is determined and suitable calculations are performed by using logarithmic function and exponential function accordingly.

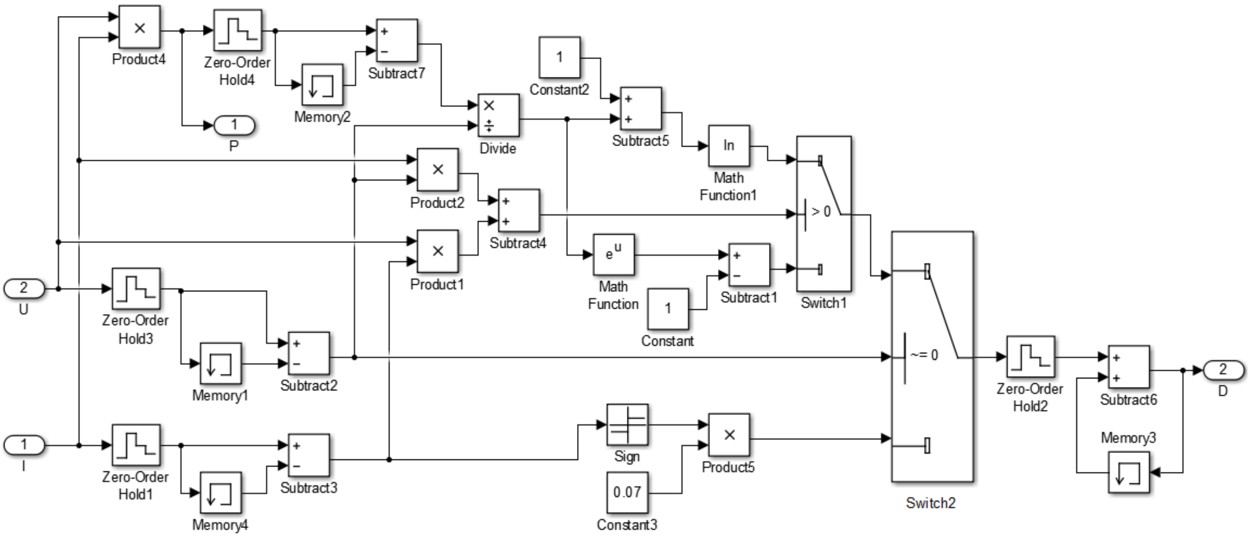

Fig. 2 – Diagram of improved MPPT control method with incremental conductance with variable step size

Optimized algorithm

The P-U curve can be obtained by using MATLAB simulation with equations and algorithm proposed in the theory part. The simulated curve is shown in Figure 3. In this figure, the parameters are provided as V_{oc} =21.8V, V_m =17.6V, I_{sc} =4.23A and I_m=4.05A. As shown in the figure, the P-U curve of solar cell presents unipolar asymmetry feature. The left side of the curve is linearly increased and the right side of the curve drops sharply. This feature leads to further analysis of two conditions. On the one hand, when the output voltage is zero, dP/dU is positive and the absolute value is relatively small. It increases slowly at the left side of the maximum power point. On the other hand, when the output voltage is short, dP/dU is negative and the absolute value is relatively big. It decreases sharply at the right side of the maximum power point. Therefore, further modulation can be performed based on this feature.

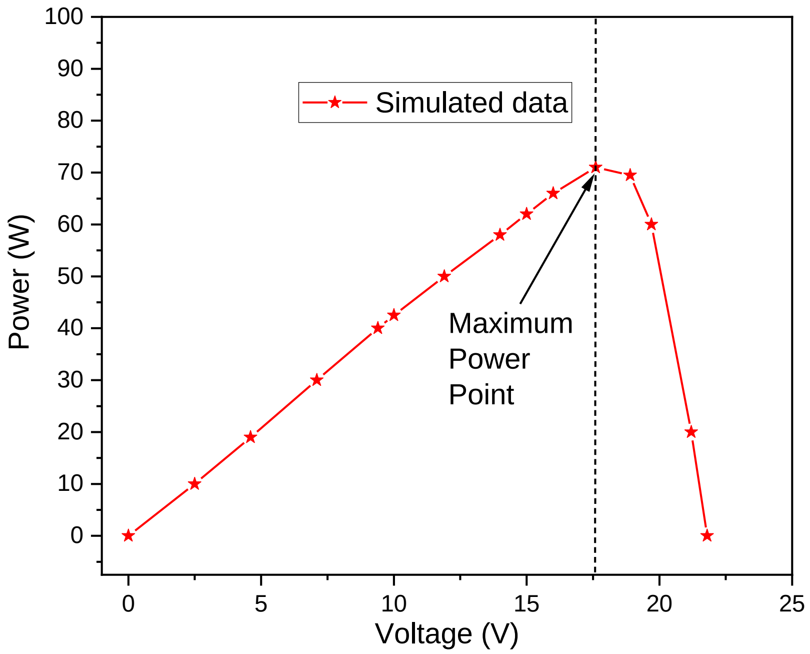

Fig. 3 – Variation curve of the P/U data by using MATLAB simulation

According to the features proposed above, the variations features of logarithmic function $In(x+1)$ within the scope (0, +∞) and exponential function $exp(x)-1$ within the scope (-∞, 0) are combined to optimize the traditional incremental conductance with variable step size MPPT control method in two ways. Firstly, if the P-U slope is positive, which is $dP/dU>0$, the output voltage is modulated by using $In[(dP/dU)+1]$ as its reference step. Then, if the P-U slope is negative, which is $dP/dU<0$, the output voltage is modulated by using $exp(dP/dU)-1$ as its reference step. The plotted curve is shown in Figure 4. In this figure, the relationship between the step and slope are shown for traditional method and improved method in Figure 4 (a) and Figure 4 (b) respectively.

As shown in Figure 4 (a), the P-U curve has a steep slope by adopting the traditional method. The advantage is fast response for region far away from the maximum power point. However, the asymmetry of the curve is not considered by using this method. Therefore, the improved method divides the whole scope into two regions to achieve better tracking performance and the advantage of the traditional method can be kept as well. Relatively big step and small step are applied for working point located at the left side and right side of the maximum power point respectively.

In this paper, the instantaneous PV output voltage is measured and calculated firstly. Then, if the measured voltage has positive or negative value, the output voltage will be adjusted accordingly. If $dI/dU>-I/U$, the output voltage will be increased with the step of $k1In[(dP/dU)+1]$. Otherwise the output voltage will be decreased with the step of $k2[exp(dP/dU)-1]$. In addition, the output voltage remains its value without adjustment if $dI/dU=-I/U$. The coefficient $k1$ and $k2$ are valued as 2 and 1 respectively in the experiments. In this way, accurate detection of output voltage is crucial for obtaining precision calculations and results for carrying out experiments.

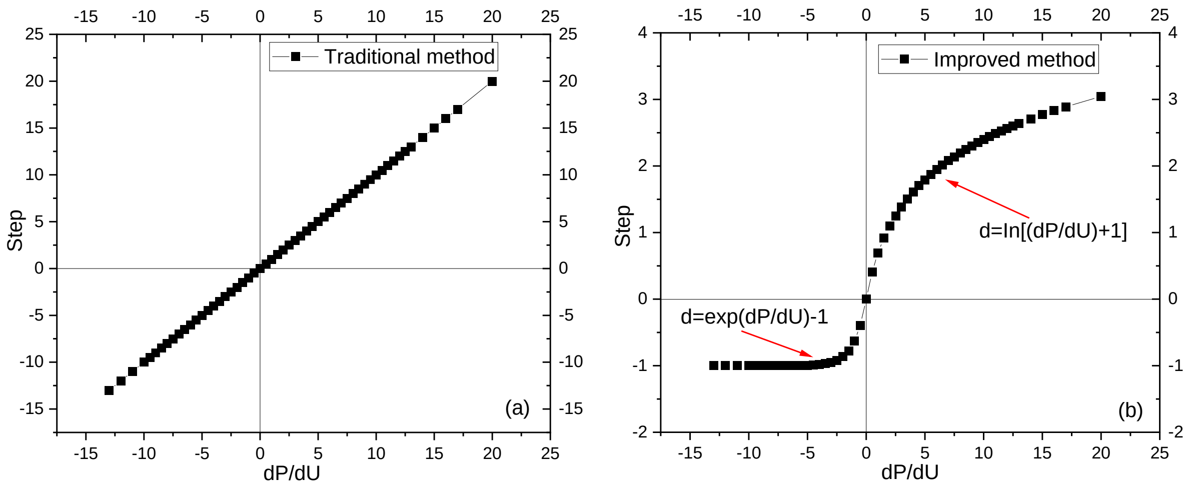

Fig. 4 – Traditional incremental conductance with variable step size MPPT control method (a) and the improved method (b)

Optimized Circuits

In order to accurately measure the output voltage of solar cell system, the main control circuit has been optimized and the schematic diagram is shown in Figure 5 (a). Compared to our previous circuit, the boost circuit remain the same but the main controlling chip has been replaced as TMS320F28335 which is shorten as DSP28335 (Digital Signal Processing). The photo of the main control board is shown in Figure 5 (b).

The output voltage is measured by the DSP28335 chip with its own analog-to-digital converter (ADC). There are 16 ADC channels available for voltage measurement. The conversion accuracy is 12 bit which is suitable for applications including solar system. The on-chip ROM of DSP28335 is 256K 16-bit and there is an extensional FLASH chip embedded on the board for data storing as well. This processor has powerful computing ability so that the floating computing speed is 150 MHz. The board is able to detect multiple channels of output voltage and then perform the calculations for generating PMW to control the MOSFET circuit. Meanwhile, there is also a serial port on the board for communicating with computer. In this way, the voltage measurement can be performed accurately by using the high-performance hardware based on DSP circuit and further simulation experiments can be performed to evaluate the algorithm proposed previously.

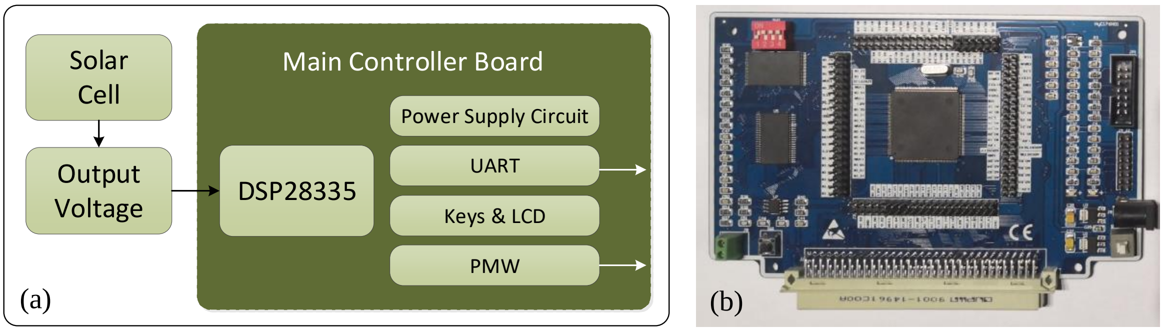

Fig. 5 – Schematic diagram of voltage measurement by using DSP28335 (a) and the photo of DSP board (b)

RESTULTS AND DISCUSSIONS

Simulation circuit

The simulated circuit is shown in Figure 6 for evaluating the performance of the proposed algorithm. In this model, a typical boost circuit has been established with solar cell module, MPPT module, PWM generator, MOSFET, resistor, capacitor, inductance and I/O ports. According to the simulation demonstrated in the last section, the PWM module can be adjusted by the proposed algorithm to modulate the charge-discharge status of the boost inductance. Based on the principle of conservation of energy, the average output current of solar cell is equal to the current flowed through the boost inductance. In this model, the inductance is set as 11 μH. Considering the impact of ripple and the stability of the circuit, the ripple is set as 1%, which is relatively big enough compare to the realistic applications, and the corresponding filter capacitors have been deployed to minimize the impact. There are two filter capacitors, C1 and C2, deployed to stable the circuit and set as 300 μF and 100 μF respectively. The PWM frequency is set as 30 kHz and is adjustable.

The MOSFET, IRF640 type, is applied to perform the on-off functions for this high-frequency and low-voltage application. In addition, the maximum power capacity of solar cell is 70 W and the environmental luminous intensity, temperature and load resistor are 100 W/m^2, 25^{o}C and 50Ω respectively. Experiments have been carried out to evaluate the performance of the circuit with the corresponding parameters.

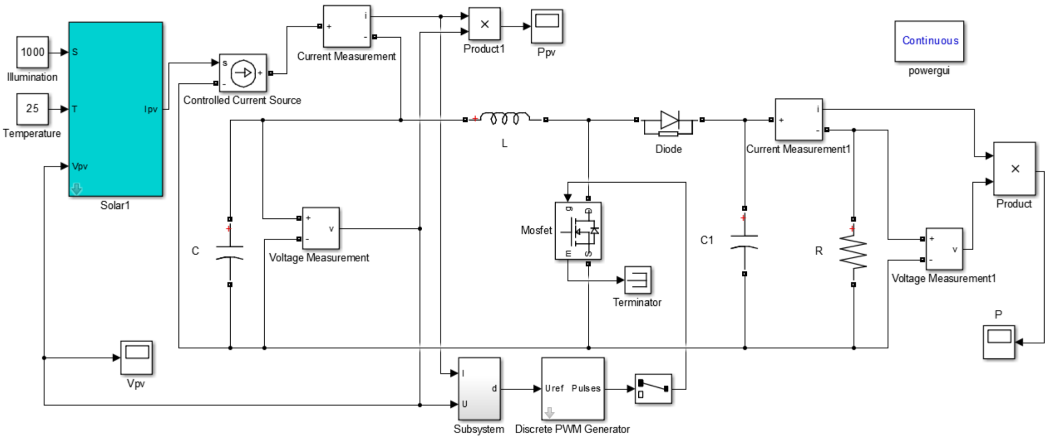

Fig. 6 – Circuit of improved MPPT control algorithm by using MATLAB Simulink

Comparison between the improved method and the traditional method

The performance between the traditional method and the improved method of incremental conductance with variable step size has been separately executed and the results are shown in Figure 7. The parameters were set according to the circuit and simulation solver was set as ODE45. The period, environmental temperature and luminous was set as 0.1 s, 25^{o}C and 1000 W/m^2. The result of the traditional and improved method are shown in Figure 7 (a) and Figure 7 (b) respectively. As shown in Figure 7 (a), it can be seen that the curve reaches the maximum power point at 70 W very quickly but it keeps rising until the peak point around 80 W. Then it drops and maintains at 70 W. The total process takes about 0.04 s from the begging to the stable status. This result demonstrates that the output voltage varies rapidly and there is a fluctuation in the system until the output becomes stable.

On the other hand, the curve in Figure 7 (b) which adopts the improved method has a less vibration than the first one. Also, it costs about 0.03 s from the begging to the stable status at the maximum power point. This experiment demonstrates that the proposed method has a quicker response time and more stable performance during the begging period of the system.

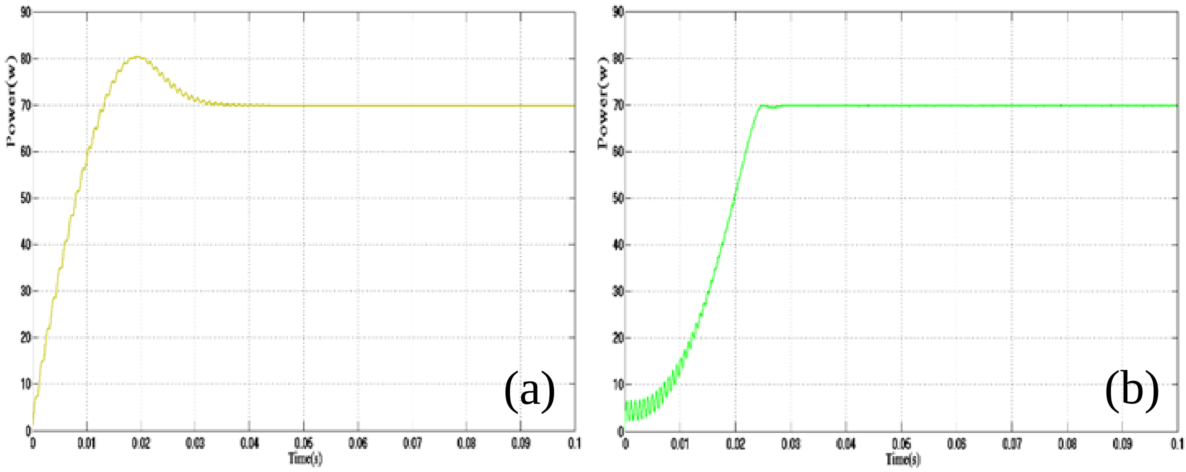

Fig. 7 –Response test of the traditional method (a) and the improved method (b)

The performance of the two algorithms was evaluated by using a robust test as shown in Figure 8. The intensity of luminance and temperature drops from 1000 W/m^2 and 25^{o}C to 900 W/m^2 and 15^{o}C at 0.06 s respectively. As shown in Figure 8 (a), the curve drops deeply and there is a regain process. On the other hand, the curve in Figure 8 (b) drops quickly and there is no fluctuation between the two steady statuses.

In this way, it can be seen that the proposed method has a better robust performance. The system that adopts this algorithm will be more stable and less energy loss will be achieved.

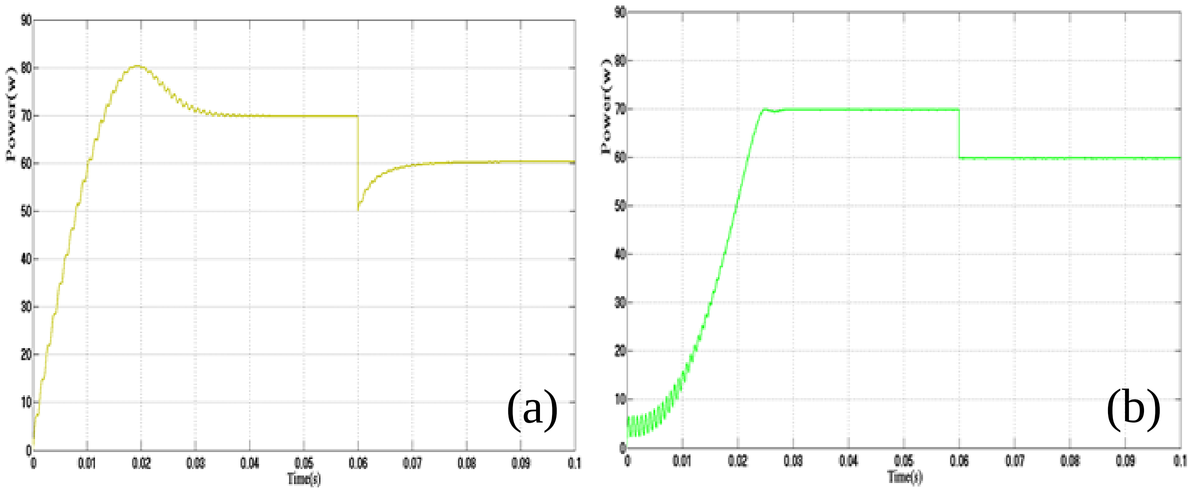

Fig. 8 – Robust test of the traditional method (a) and the improved method (b)

The tracking performance was evaluated by carrying out comparison experiments as shown in Figure 9. The target output power has been set as 70 W as well, but other environmental factors have been changed to see the general tracking performance between the two algorithms. In Figure 9 (a), it can be seen that the output power can be adjusted to the maximum power point after a period of fluctuation. On the other hand, the curve in Figure 9 (b) still present faster response and more stable status than the first one. This general tracking test suggests good efficiency of the proposed method.

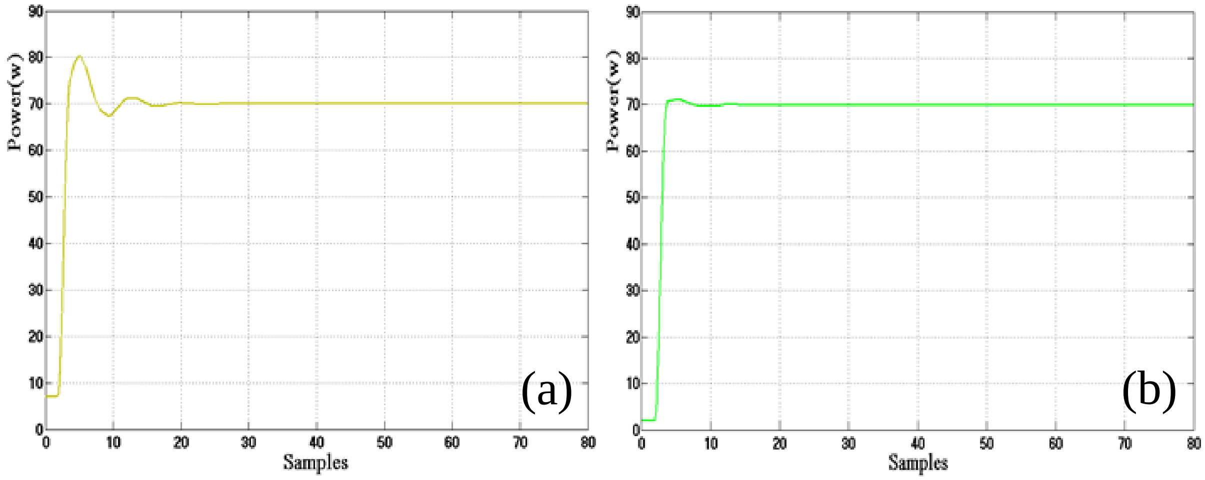

Fig. 9 – Tracking performance test of the traditional method (a) and the improved method (b)

Comparison between the proposed method and the fuzzy control method

The comparison experiment was carried out between the proposed method and the fuzzy control method which was demonstrated in our previous paper. The result of the experiment is shown in Figure 10. It can be seen that the two methods are both capable to track the maximum power point which is at 64 W. The fuzzy control curve fluctuated in the begging stage and reached the target point after about 0.04 s. The response time was slower than the second one which was about 0.02 s.

The advantage of the fuzzy control method is that there is no oscillation zone when it reaches the target point. The curve in Figure 10 (b) apparently has a very fast response time compared to the first one. This not only results in good stability of the system but also saves much energy for the solar systems. Therefore, the result of the comparison test demonstrates that the proposed method is superior to the fuzzy control method for its fast response time and system stability.

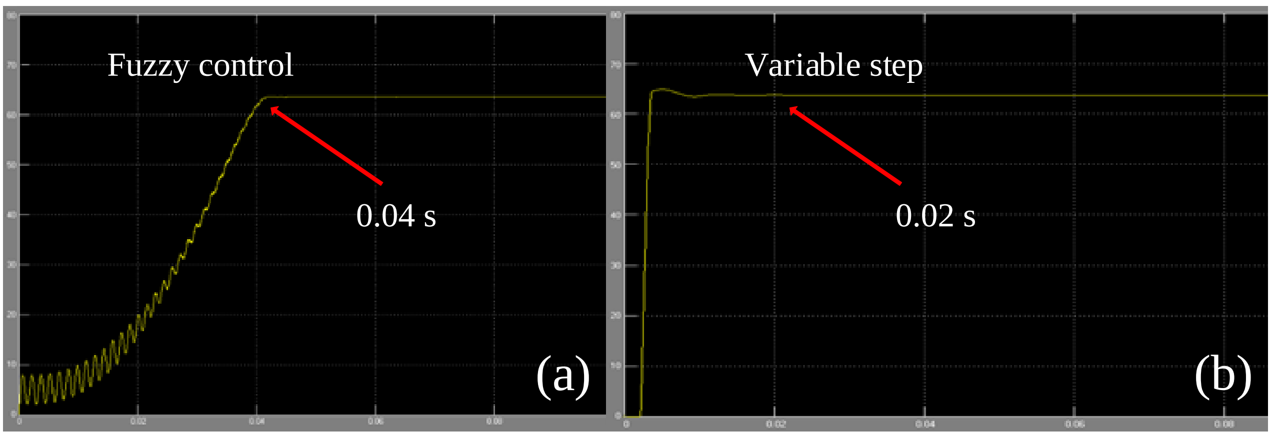

Fig. 10 – Performance comparison between the fuzzy control method (a) and the proposed method (b)

CONCLUSIONS

In this paper, an improved MPPT tracking algorithm based on the variation step method has been proposed. This algorithm has been tested and has been compared with the traditional variation step algorithm. In this process, models have been established and relative parameters have been obtained experimentally. The working point and output voltage of the system are measured firstly and then corresponding strategy are deployed. Logarithmic function and exponential function are adopted to achieve better response time for MPP tracking. The PWM signal can be modified according to the environmental change based on the proposed method. The output power can reach its peak value quicker than traditional method and the power loss can also be minimized. In this way, the solar energy system can be optimized to generate more electricity for greenhouse. In the future, further experiments will be conducted to evaluate the performance in the greenhouse to optimize the system.

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