Study on Maximum Power Point Tracking Technology for PV System using Pattern Search Algorithm

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Abstract. In order to improve the efficiency of the Photovoltaic (PV) system. Firstly, Solar Cell Array (SCA) model was established, and the simulation analysis of which was conducted through MATLAB/Simulink, then, the output characteristic curves of PV system with different external environment condition were obtained; Secondly, the Maximum Power Point Tracking (MPPT) technology based on the Pattern Search Algorithm (PSA) was proposed and the MPPT simulation model based on DC/DC converter was built; Finally, the simulation results show that dynamic output of the model and the theoretical calculation values are match each other very well, which proves that the proposed technology can achieve maximum power point effectively.

Introduction

Solar energy has become the most widely used clean energy, Photovoltaic (PV) solar energy technology stands out in lots of solar energy application technologies [1]. However, PV solar battery has very strong nonlinear in the process of power generation, and it is easily affected by many environment factors, so that it is hard to operate in the maximum power point stably. Therefore, how to make the PV system operate in the maximum power point accurately under the changeable environment becomes the key of energy efficient use, and it appears to be of essence to Maximum Power Point Tracking (MPPT).

In order to improve the efficiency of the PV system, and to get electricity as much as possible, a wide range of research about MPPT control algorithm of PV power generation system was conducted both at home and abroad, putting forward a variety of control algorithms[2-4] including Constant Voltage Tracking, Perturb & Observe algorithms[5], Incremental Conductance[6] etc... However, traditional MPPT methods easily appear some problems, for example, tracking speed is slow and oscillate at the maximum power point, which causes energy loss of output power of PV power generation system. In this paper, the SCA model based on MATLAB/Simulink was established, and optimal control values was to be searched based on the PSA, and then, the maximum power point was be tracked through controlling the boost circuit.

The model of PV system

Mathematical model of SCA. Under the reference conditions, Assumed that I_{sc} is the short-circuit current, U_{oc} is the open-circuit voltage, and I_m, U_m is the current and voltage at maximum power point, respectively. If the voltage of SCA is U, considering the change of solar radiation and the influence of temperature, the current I can be obtained as

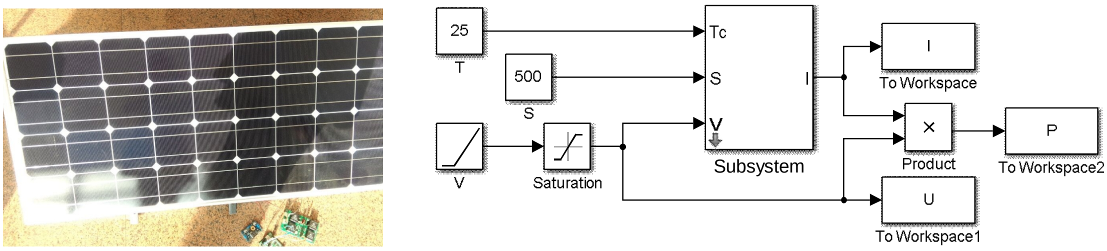
$$I = I_{sc}(1-\Psi_1(e^{\frac{U-\Delta U}{\Psi_2 U_{oc}}}-1))+\Delta I \tag{1}$$

where $\Psi_1=(1-I_m/I_{sc})\mathrm{e}^{-\frac{U_m}{\Psi_2 U_{oc}}}$, $\Psi_2=(U_m/U_{oc}-1)/\ln(1-I_m/I_{sc})$, ΔU, ΔI can be shown by the following:

$$\begin{cases}\Delta U=-b\cdot\Delta T-R_s\cdot\Delta I\\ \Delta I=a\cdot R/R_{ref}\cdot\Delta T+(R/R_{ref}-1)\cdot I_{sc}\end{cases}\tag{2}$$

where R is the total solar radiation on the surface of the inclined plane of SCA (W/m^2); R_{ref} is the reference value of solar radiation, generally whose value is $1kW/m^2$; a is the temperature coefficient of current changes (A/℃) under the reference condition; b is the temperature coefficient of voltage changes (V/℃) under the reference condition; $\Delta T=T_c-T_{ref}$, $T_c=T_a+t_c\cdot R$, T_{ref} is the reference value of temperature, generally whose value is 25℃; T_a is environment temperature (℃), T_c is temperature of solar battery (℃), t_c ($\mathrm{degw}^{-1}\cdot m^2$) is the temperature coefficient of battery module; R_s is the series resistance of PV module.

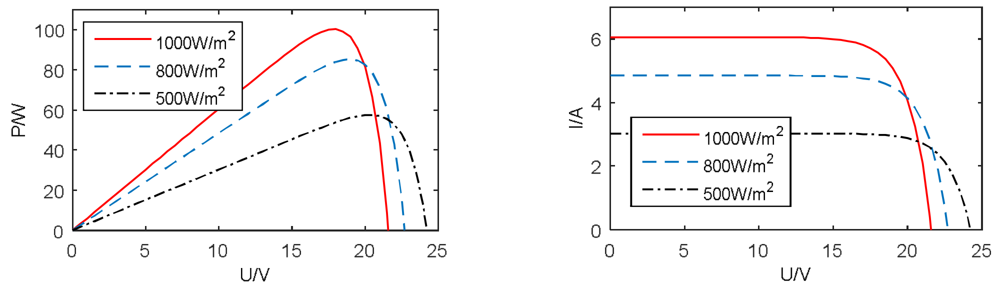
The simulation analysis of SCA. A variety of external factors, such as the solar radiation and the environment temperature, will have an effect on performance of SCA. Hence, the typical U-I curves and U-P curves of SCA should be analyzed. The basic parameters of the chosen SCA tested in the standard test condition ($1kW/m^2$, 25℃) are as follows, $I_m=5.51A$, $V_m=18.17V$, $V_{oc}=21.6V$, $I_{sc}=6.06A$, $a=7.3\times10^{-3}A/℃$, $b=0.108V/℃$. According to the Eq.(1), a SCA simulation model can be build based on MATLAB/Simulink, the encapsulation of the model is shown as Fig.1.



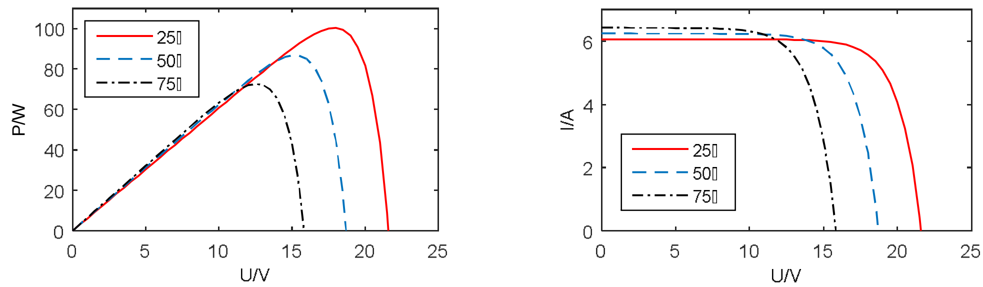
(a) Testing platform of SCA (b) Encapsulation SCA model

Figure1 Testing platform and simulation model of SCA

Then, the characteristic curves of SCA can be obtained after running the model, and simulation results are shown as Fig.2.



(a) U-P curves under 25℃ (b) U-I curves under 25℃



(c) U-P curves under $1000W/m^2$ (d) U-I curves under $1000W/m^2$

Figure 2 The characteristic curves along with the change of environment

As shown in Fig.2, when the temperature is constant, the voltage at maximum power point only changes in small scope, but the maximum output power will increase with light intensity increasing. When the light intensity is constant, the voltage at maximum power point will reduce with temperature increasing, as well as the maximum power point will decrease. At the same time, The simulation result shows that the maximum power is 100.29W under $1kW/m^2$ and 25℃, in accordance with the real parameters of SCA as shown in Fig.1(a), which verified the accuracy of this model.

Optimal control of maximum power point

The control strategy of maximum power point. When both degree of solar radiation and environment temperature are constant, the SCA working or not working in the maximum power point is decided by the value of the load impedance of SCA[7]. When external factors changes , the output of the SCA curves will produce a corresponding change. Therefore, in the different environment, the value of the load impedance require to be changed according to the demand of the maximum power output to achieve the control of maximum power point tracking.

If set the DC/DC converter behind the PV system model as a tracker to achieve maximum power point tracking, then the duty-ratio of converter can be adjusted in the real time to meet requirements, realizing dynamic matching between the internal resistance of PV battery and the equivalent load, to make the tracking maximum power point come true.

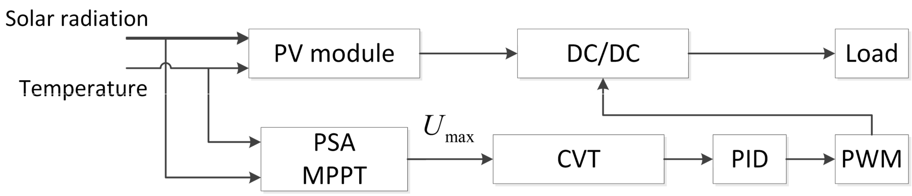


Figure 3 Structural drawing of MPPT based on PSA

Traditional MPPT methods ignore a lot of changes in external conditions, which lead to poor accuracy. Therefore, PSA is adopted to get optimal control data. As shown in Fig.3, system parameter is converted to PWM pulse by using the control algorithms and control procedures in the controller, and then, the PWM pulse is carried on the converter which can control the system directly.

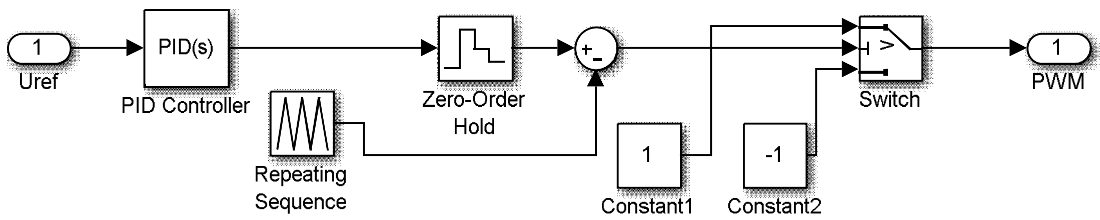


Figure 4 PWM generated module

PWM pulse generated module is shown in Fig.4, where U_{ref} is the difference value between optimized voltage value and reference voltage value, through the PID control and triangular carrier adjust, exporting PWM to control boost circuit.

Optimal solving of maximum power point. Pattern Search Algorithm[8, 9] (PSA) is a direct search algorithm to solve optimization problems ,which can be divided into two patterns, detection move and mode move. Former of which the main purpose is to detect the search direction, the latter is employed for detecting the the search speed based on the search detection, which can accelerate the convergence rate. The basic idea of PSA is looking for valley in a smaller function value using the objective function, and try to make iterative sequence generated along the valley to approach the minimum point, which has strong local search ability. According to the Eq. (1), the power of SCA in any solar radiation and the ambient temperature can be obtained as

$$P = IU = (I_{sc}(1-\Psi_1(e^{\frac{U-\Delta U}{\Psi_2 U_{oc}}}-1))+\Delta I)U \tag{3}$$

When PV arrays achieve the maximum power point, $dP/dU=0$, thus the optimization objective function can be achieved:

$$F_{obj} = \min\left(dP/dU\right)$$
$$= \min\left(I_{sc}(1-\Psi_1(e^{\frac{U-\Delta U}{\Psi_2 U_{oc}}}-1))+\Delta I - UI_{sc}\Psi_1 e^{\frac{U-\Delta U}{\Psi_2 U_{oc}}}/(\Psi_2 U_{oc}) \right) \tag{4}$$

In view of the optimization goal previously mentioned F_{obj}, bringing in variable $x=U_{opt}$, Coordinate direction:

$$e_j = (0,..,0,1,0,...,0)^T, \quad j=1,2,...,n \tag{5}$$

Coordinate direction $e=[1,-1]^T$, the initial step length $d=U_{OC}/50$, allowable error $e=10^{-3}$, accelerated factor $a=1.95>1$, scalage $b=0.458\in(0,1)$. The step of PSA can be described simplicity as follows:

Step1: If $F(x_i+m_j d)<F(x_i)$, then $x_i^*=x_i+m_j d$. Otherwise $x_i^*=x_i$.

Step2: If $F(x_i^*)<F(U_i^{(k)})$ and $d>e$, then $U_i^{(k+1)}=x_i^*$, $x_i=U_i^{(k+1)}+c_1\left(U_i^{(k+1)}-U_i^{(k)}\right)$, undate the boundary condition, and continue the iteration process.

The improved CVT_MPPT simulation model based on pattern search method is shown as Fig.5.

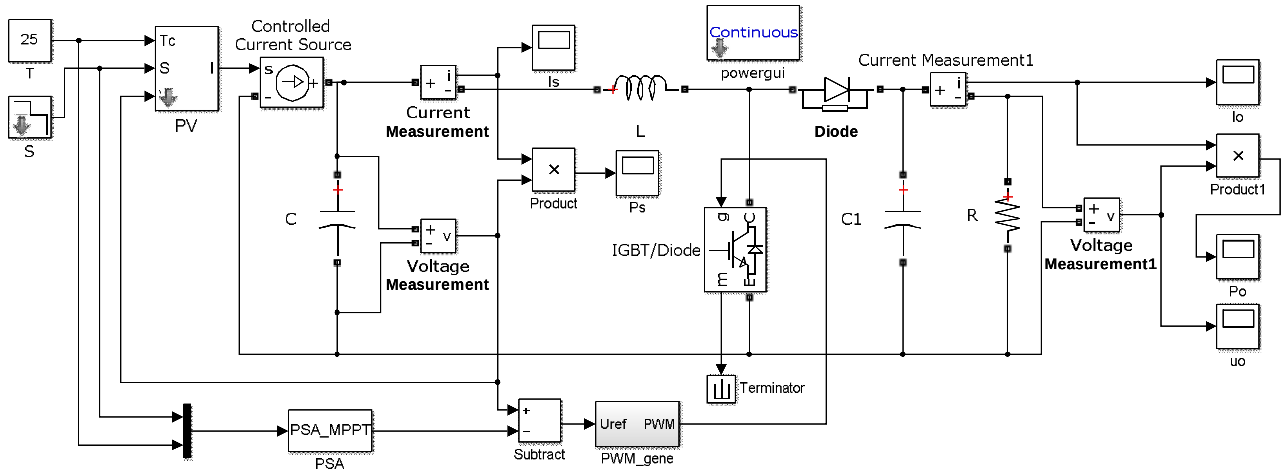


Figure 5 Improved MPPT simulation model based on PSA

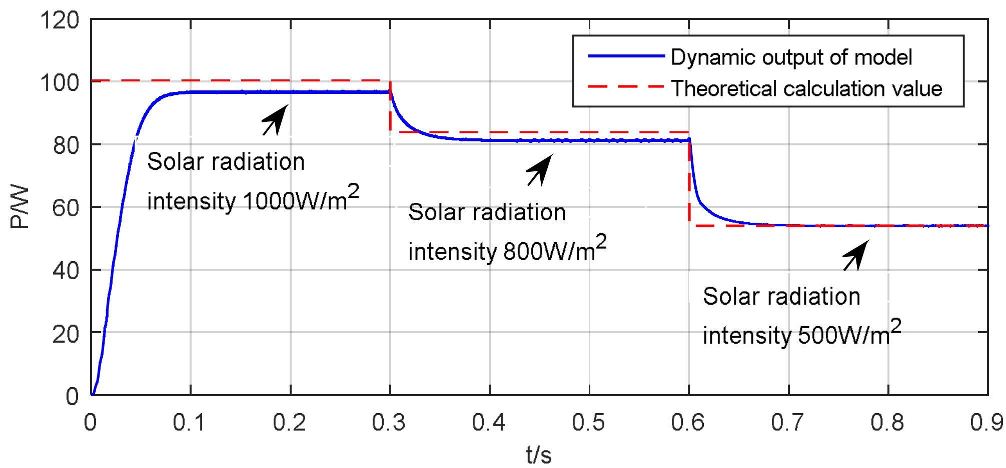


Figure 6 Comparison between dynamic output of model and the theoretical calculation value

Fig.6 shows that when the light intensity changes, the system can adjust to the the maximum power point with rapid response and good stability. The defect of the traditional constant voltage control method, which can not track the maximum power point during significant changes of environmental condition, is overcomed very well by this proposed method.

Conclusions

In order to improve the efficiency of the PV system, and to get electricity as much as possible, in this article, an maximum power point tracking technology for PV system using PSA has been proposed. The main contributions are as follows:

1. Based on the simulation model of PV array, output characteristic curves along with the changes of environment were obtained, which verified the rationality of the model;
2. The MPPT technology based on the PSA was put forward and the MPPT simulation model based on DC/DC converter was built; dynamic output results of the model and the theoretical calculation values match each other very well;
3. Under the change of environmental temperature and solar radiation, the MPPT technology applied in the text can realize better tracking of maximum power point, improving efficiency of the system.

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