Model Building of Photovoltaic Array with MPPT Function and Research on Single Phase Grid Connected

Li Zhengzhou

North China Electric Power University, School of Electrical and Electronic Engineering, 2nd Beinong Road, Huilongguan, Changping District, Beijing, China

Abstract. With the continued development of solar photovoltaic technology, research on distributed grid connected photovoltaic system has become a research focus in the field of photovoltaic grid power plant and the computer simulation technology is an effective technology means in the study. On the basis of the photovoltaic array output characteristic equation, the photovoltaic array maximum power control simulation model based on M function is established by using MATLAB/Simulink and the simulation model of single phase grid connected photovoltaic array is proposed. It overcomes the shortcomings of the process of building the model of the PV array by using Simulink component library and provides the basic guarantee for the realization of system simulation, guiding theory research and system design.

1 Introduction

With the world's energy shortage and environmental pollution becoming more and more serious, the energy and the environment become a major problem faced by mankind in the 21st century. The development and application of clean renewable energy have received more and more attention from all over the world. In the last twenty or thirty years, the solar photovoltaic (PV) technology has been developed continuously and photovoltaic has become one of the main ways of using solar energy. The development of solar photovoltaic generation system is of great theoretical and practical significance for the mitigation of energy and environmental issues, developing a broad photovoltaic power generation market and mastering the advanced technology related fields[1].

In the previous research on photovoltaic power generation system simulation, most of them are based on the quasi steady state theory to model the system components, to calculate the system power flow and to evaluate the long-term performance of the system. But in the study of the dynamic performance of photovoltaic grid-connected system, the model cannot reflect the transient change of the running state of the photovoltaic power station and the influence of the change on the power grid when the solar radiation intensity and environmental temperature changed. This needs to establish the dynamic simulation model of PV array.

PV array is the key component of distributed photovoltaic grid connected power system and its *I-V* characteristics are the nonlinear function of solar radiation intensity, ambient temperature and PV module parameters. To realize the dynamic simulation of PV power generation system, the first step is to solve the problem of how to simulate the *I-V* characteristics of PV array. Once established, the model can be used to simulate the input power of the system. But the model cannot follow the solar radiation intensity, the environment temperature and the PV array parameters in real time, so the system simulation cannot reflect the influence of the above parameters on the whole system performance. At present, the relevant work in this area has not been published in the literature. Although there are public literatures in this area abroad but the model is mainly aimed at specific PV modules and thus lack of general[2].

Based on the PV array output characteristic equation, a general simulation model of PV array maximum power control based on M function is established by using MATLAB/Simulink. The model can reflect the influence of environment temperature and solar radiation intensity on *I-V* characteristics in real time and consider the influence of PV module parameters on the output of the general model. The application example of the model in the simulation of single phase PV grid connected system is presented in this paper. The results show that it has a strong versatility and exhibits good dynamic characteristics.

2 Mathematical Model of PV array and Characteristics Analysis

PV array is the key component of the PV power generation system, and its output characteristics are greatly influenced by the external environment. In order

to study the influence of the external environment change on its output characteristics, we need to establish a mathematical model. And In the MATLAB environment, the characteristics of the output under different environmental parameters need to be analyzed.

2.1 Establishment of Mathematical Model of PV Array

In practical applications, the PV modules are usually connected in series and parallel to a M×N PV array(M and N are the number of PV modules in series and parallel)[3].

In this paper, the mathematical model of the PV array for MATLAB modeling is as follows.

Under the condition of any solar radiation intensity R(W/m^2) and ambient temperature Ta(℃), the temperature Tc(℃) of solar cell is as follows:

$$T_C = T_a + t_C \times R \qquad (1)$$

R is the total solar radiation on the inclined plane of the PV array and t_c is the temperature coefficient of the PV array module.

Under the reference condition, I_{sc} is short circuit current; V_{oc} is open circuit voltage; V_m and I_m are the current and voltage of peak point. When the voltage of the PV array is V, the corresponding point current is I.

$$I = I_{SC}\left(1 - C_1(e^{\frac{V}{C_2 V_{OC}}} - 1)\right) \qquad (2)$$

$$C_1 = \left(1 - \frac{I_m}{I_{SC}}\right)e^{-\frac{V_m}{C_2 V_{OC}}} \qquad (3)$$

$$C_2 = \frac{\left(\frac{V_m}{V_{OC}} - 1\right)}{\ln\left(1 - \frac{I_m}{I_{SC}}\right)} \qquad (4)$$

Considering the change of solar radiation and temperature:

$$I = I_{SC}\left(1 - C_1(e^{\frac{V - DV}{C_2 V_{OC}}} - 1)\right) + DI \qquad (5)$$

$$DI = \alpha \cdot \frac{R}{R_{ref}} \cdot DT + \left(\frac{R}{R_{ref}} - 1\right) \cdot I_{SC} \qquad (6)$$

$$DV = -\beta \cdot DT - R_s \cdot DI \qquad (7)$$

$$DT = T_C - T_{ref} \qquad (8)$$

In the above formula, R_{ref} and T_{ref} are the reference values for the solar radiation and the PV array temperature and they are generally taken as 1kW/m^2 and 25℃.

α—the current variation of temperature coefficient under the reference sunlight (A/℃);

β—the temperature coefficient of voltage variation under the reference of the sunshine(V/℃);

R_s—series resistance of PV module (Ω)。

2.2 Characteristic Analysis of PV Array

PV array is the basic component of the solar PV power generation system. The characteristics of *I-V* and *I-P* are influenced by the sun light intensity, ambient temperature and parameters of PN junction photocell which presents a non-linear relationship. On the basis of the mathematical model of the PV array mentioned above, the simulation results are as follows by using the MATLAB environment to analyze the characteristics of the PV array[4].

The typical characteristics of PV arrays are shown in Figure 1, Figure 2. Figure 1 and Figure 2 show that *P-V* and *I-V* change with the change of the solar radiation. Figure 3 shows the law of *P-V* with the change of environment temperature.
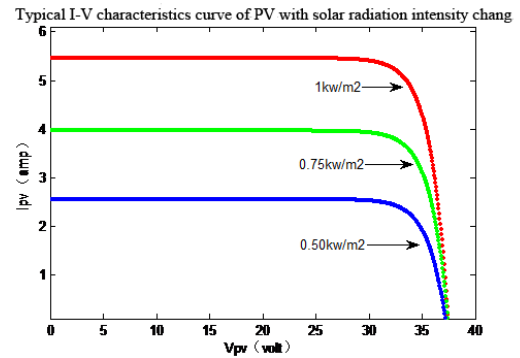

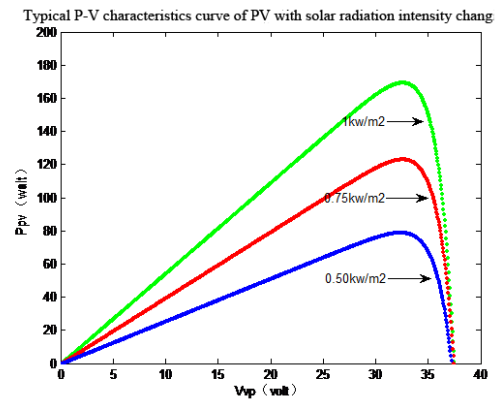**Figure 1** *I-V* Characteristics of Typical PV Arrays with the Variation of Solar Radiation Intensity

Figure 2 *P-V* Characteristics of Typical PV Arrays with the Variation of Solar Radiation Intensity
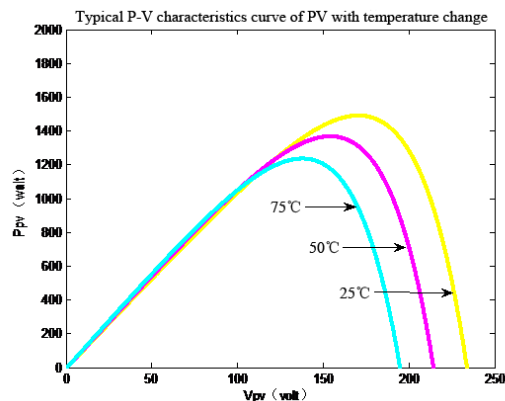

Figure 3 *P-V* Characteristics of Typical PV Arrays with the Variation of Temperature

3 Research on Maximum Power Tracking Control of PV Array

To improve the efficiency of PV power generation system and make full use of the energy generated by the PV array is the basic requirements of PV power generation system. Now the PV power generation system usually requires the output power of the PV array has always been the largest. It is that the system should be able to track the maximum power point of the PV array[5].

The output characteristic of PV array is nonlinear and its output is influenced by the intensity of solar radiation and ambient temperature and load. In the solar radiation intensity and environment temperature, PV array can work in different output voltage. But only in a given output voltage, the output power of PV array can reach the maximum and then the working point of PV array reaches the highest output power voltage curve which is known as maximum power point. Therefore, to improve the overall efficiency in the PV power generation system, an important way is to adjust the working point of the PV array in real time so that it always works in the vicinity of the maximum power point. This process is referred to as the maximum power point tracking (MPPT).

In this paper, a mathematical model of the maximum power point tracking of PV array is established based on the Newton iteration method for solving MPPT points.

The power of PV array in any solar radiation intensity and ambient temperature is as follows:

$$P = IV = \left(I_{sc} \left(1 - C_1 \left(e^{\frac{V-DV}{C_2 V_{oc}}} - 1 \right) \right) + DI \right) V \quad (9)$$

By the extreme conditions of $dP/dV=0$, we can know:

$$I_{sc} \left(1 - C_1 \left(e^{\frac{V-DV}{C_2 V_{oc}}} - 1 \right) \right) + DI - V I_{sc} e^{\frac{V-DV}{C_2 V_{oc}}} / \left(C_2 V_{oc} \right) = 0 \quad (10)$$

The formula above is a transcendental equation and we can use Newton method to iterative solution of the corresponding maximum power point of the voltage V_{max}.

$$V_{k+1} = V_k - \frac{P'(V_k)}{P''(V_k)} \quad (11)$$

$$= V_k - \frac{1 + V_k \left(-I_{sc} \frac{C_1}{C_2 V_{oc}} e^{\frac{V_k - DI}{C_2 V_{oc}}} \right)}{\left(2 + \frac{V_k}{C_2 V_{oc}} \right) \left(-I_{sc} \frac{C_1}{C_2 V_{oc}} e^{\frac{V_k - DI}{C_2 V_{oc}}} \right)} \quad (12)$$

When $|V_{k+1} - V_k| < \varepsilon_1$, $V_{max} = V_{k+1}$.

In the above formula, V_{k+1} and V_k are the iteration values of $k+1$ and k respectively. ε_1 is iterative precision. $P'(V_k)$ and $P''(V_k)$ are the first and second order derivatives of V under the iteration of the k. Putting all the V_{max} into the equation (5), we can get I_{max}. Thus the maximum power P_{max} can be obtained by the following formula:

$$P_{max} = V_{max} \cdot I_{max} \quad (13)$$

The simulation results show that it is able to track the maximum power point of the PV array stably and efficiently under the control of this method and quickly find a new job, keep the system stable, exhibit good

dynamic characteristics at the same time in sunshine intensity, environment temperature and other parameters of the system disturbance.

4 General MATLAB Simulation Model of PV Array

A general simulation module of PV array with MPPT is established based on the above specific algorithm and simulation model in the MATLAB environment by using Simulink tools and combined with the preparation of the M function. The M function is used to solve the voltage and current of the maximum power point of the PV array in the corresponding arbitrary solar radiation intensity.

Figure 4 is the realization of the voltage of any PV cell by MATLAB Function to obtain the maximum power control voltage and to obtain the maximum current by using the $f(u)$ function in the MATLAB/Simulink and the formula (5) in the previous mathematical model.
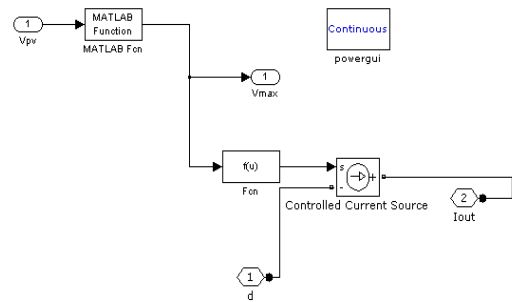

Figure 4 The Internal Structure of the General Simulation Model of PV Array

After the common simulation module of the PV array being written, it will be packaged. Figure 5 shows the appearance of the model and its internal package a number of parameters. The user can get the user interface which is shown in Figure 6 by clicking the icon in Figure 5 to facilitate the setting of the parameters thereby forming a PV array under different parameters.
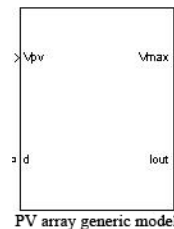

Figure 5 General Simulation Package Model of PV Array

The general simulation model of PV array with MPPT is the key component of the PV power generation system. The establishment of the model provides a basic guarantee for the research of the maximum power point tracking, guiding theory and system design of PV system.
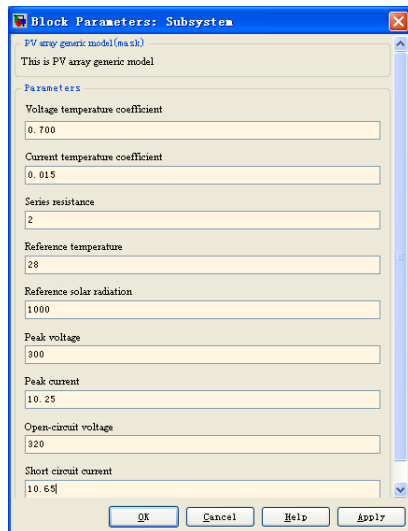
Figure 6 User Interface of General Simulation Model of PV Array

5 Application of General Simulation Model of PV Array in Grid Connected System

A general simulation model of the PV array is obtained which is used in the single phase PV grid connected system. The basic idea is to put the maximum current output of the PV array to the positive end of the inverter bridge. And the inverter bridge is triggered by the pulse trigger and the DC power is changed into AC so as to realize the grid connection with the single phase 220V. The single phase AC voltage and current and voltage amplitude after grid connection are measured by the measuring element and as the simulation results. The PV array is respectively provided with the simulation results when the solar radiation intensity is reduced from 1000W/m^2 to 800W/m^2 and 600W/m^2. DC-AC inverter

module is the universal inverter bridge in MATLAB. MATLAB model of single-phase grid-connected system is shown in the following figure[6][7].

Based on the research above, we obtain the grid-connected voltage fundamental amplitude, single-phase grid connected voltage, grid connected current, voltage of the input terminal of the inverter and the output current of the PV array of PV grid connected system when solar radiation intensity is reduced from 1000W/m^2 to 800W/m^2 and 600W/m^2. We can see from the simulation results that the simulation model has the change of the PV array in real time simulation of different solar radiation intensity and the simulation results are as follows.

It can be seen from the simulation results that the inverter input voltage has been dropped from 268V to 265.6V and 264V and the drop range is within the range of 4V because of the control strategy adopted for the fixed modulation ratio when the solar radiation intensity is decreased from 1000 W/m^2 to 800 W/m^2 and 600 W/m^2 and t=1s, t=2s. The simulation result is shown in Figure 8. As can be seen from Figure 9, the PV array output current is reduced from 10.65A to 8.45A and 6.25A respectively. Figure 10 shows the change of grid connected voltage and current with the change of solar radiation. As can be seen from the figure that the grid connected voltage amplitude is constant and the grid connected current decreases with the decrease of the solar radiation intensity when the solar radiation changes. And the current is gradually reduced from the 22A to 12A.

The simulation results show that the the Matlab simulation model of single-phase PV grid-connected system in this paper can output current and voltage quickly and accurately and with the changes in the intensity of solar radiation, the output current of inverter can also change correspondingly.
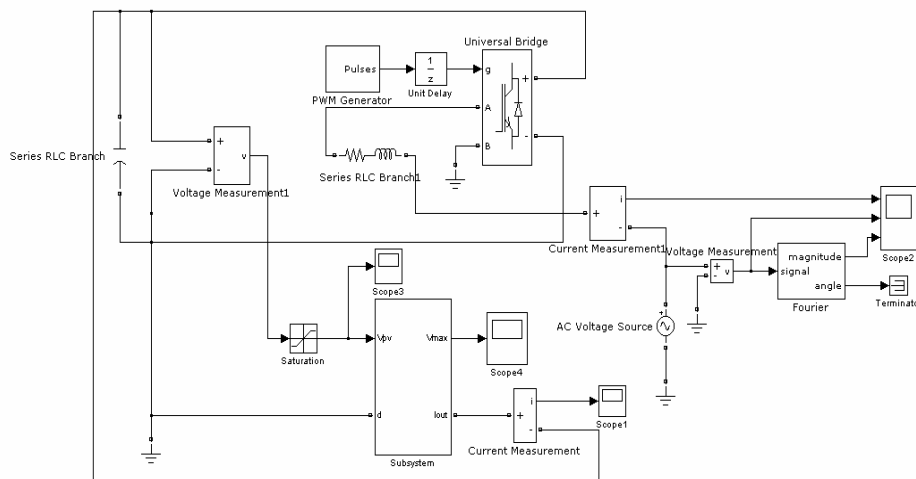

Figure 7 MATLAB Simulation Model of Single Phase PV Grid-connected System
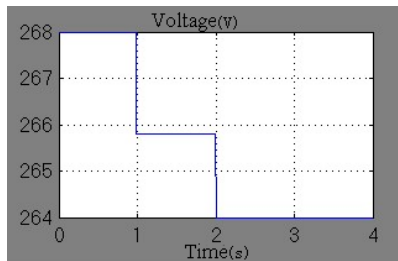
Figure 8 Relationship Between the Output Voltage of PV Array and the Solar Radiation Intensity
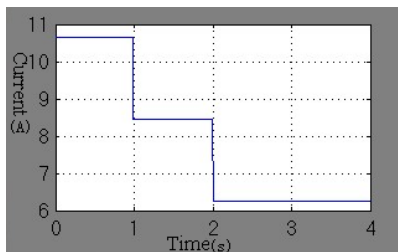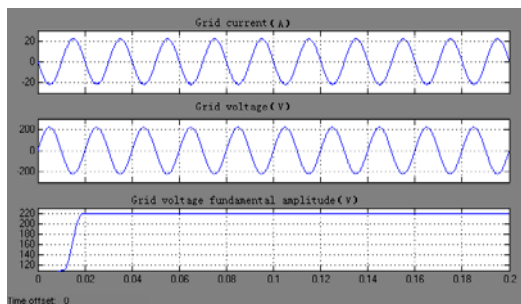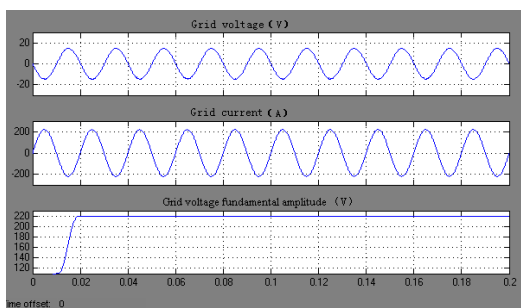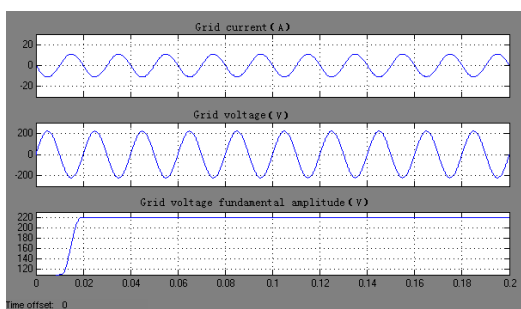

Figure 9 Relationship Between the Output Current of PV Array and the Solar Radiation Intensity

a) The Grid-connected Voltage and Current Curve of the Inverter When R=1000 W/m^2

b) The Grid-connected Voltage and Current Curve of the Inverter When R=800 W/m^2

c) The Grid-connected Voltage and Current Curve of the Inverter When R=600 W/m^2

Figure 10 The Change of Grid Connected Voltage and Current with the Change of Solar Radiation

6 Conclusions

In this paper, the MATLAB is used to establish the PV array simulation model which is based on the existing mathematical model of PV array. The theoretical analysis of simulation results shows that the simulation model can accurately reflect the output characteristics of PV array. Based on the theoretical research, the general simulation model of PV array with MPPT function is established by using Matlab/ Simulink. This model can realize the maximum power tracking control using the M function in Simulink and can simulate the maximum voltage and current output of PV array quickly and accurately under different solar radiation intensity and ambient temperature. The Matlab simulation model of single-phase PV grid-connected in this paper can output current and voltage of grid-connected system quickly and accurately and with the changes in the intensity of solar radiation, the output current of inverter can also change correspondingly. It has important theoretical effect and practical value to understand and get the characteristics of PV arrays and to guide the design of practical systems.

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