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Simulation Design of Photovoltaic Array Variable Electronic Load

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Abstract

With global energy depletion and environmental pollution becoming more and more serious today, energy issues have become the primary issue that humans need to face. As the world's second largest energy source, solar energy has developed rapidly due to its many advantages such as safety, greenness, and environmental protection. How to increase the conversion rate of solar energy and thus reduce the cost, so that the photovoltaic array can provide electric energy to the load with the highest efficiency or store electricity to the battery is the primary issue of reducing costs and improving efficiency. In the photovoltaic field, due to issues such as equipment aging and installation errors, the output power of the photovoltaic array is far less than the ideal output power. The use of variable electronic loads can test the I-U and P-U output curves of the photovoltaic array on the spot to obtain the maximum output power point, so as to evaluate the power generation of the photovoltaic field to make it more efficient and safe. It is a necessary measuring instrument for photovoltaic arrays at the practical level.

Keywords

Photovoltaic array; Variable electronic load; Variable duty cycle.

1. Introduction

This paper mainly studies the use of variable electronic load to scan the output curve of the photovoltaic array, obtains the output P-U and P-I characteristics of the photovoltaic array under different conditions, and determines the maximum output power of the photovoltaic array under different conditions. The first chapter of the article introduces the basic principles of photovoltaic cells and the current status of photovoltaic power generation at home and abroad; the second chapter introduces the working principles and mathematical expressions of photovoltaic arrays, use matlab software to establish a photovoltaic array model, and draws The IU curve and PU curve of the photovoltaic array when the ambient temperature is constant and the light intensity changes; the IU curve and the PU curve of the photovoltaic array when the ambient temperature changes and the light intensity does not change; Chapter 3 first uses rectangular wave drive MOSFET, and set the duty cycle of the rectangular wave to 20%, 50%, and 70% respectively, verifying the feasibility of using a rectangular wave to drive the mosfet to change the load impedance. Chapter 4 compares the ramp function generation module with the triangular wave function generation module to obtain a rectangular wave with variable duty cycle and incorporate it into the load of the photovoltaic array. By changing the ambient temperature under the same light intensity, in the same environment The IU output characteristic curve and the PU output characteristic curve of the photovoltaic array are obtained by changing the light intensity under temperature. The accuracy of this scheme is verified by comparing with the maximum output power under the same conditions, the current through the load, and the voltage across the load. Chapter 4 uses AD software to give a basic introduction to the hardware circuit.

2. Overview of Photovoltaic Power Generation and Model Establishment

2.1. Work Principle of Solar Cells

The principle of solar photovoltaic power generation is the photovoltaic effect. Solar radiation is converted into electrical energy by photovoltaic cells. The "photovoltaic effect" is used to generate a potential difference between uneven semiconductors or different parts of the semiconductor and metal. Wires are used to connect the two ends of the negative and positive charges to form a voltage and electrical circuit. Compared with traditional power generation methods, solar power generation has the advantages of zero emissions, zero pollution, long service life, and relative safety. However, the power generation efficiency is affected by altitude, sunshine intensity, sunshine duration and ambient temperature. The general off-grid photovoltaic system is composed of photovoltaic array, solar controller, inverter, battery pack, load, etc., as shown in Figure 1.

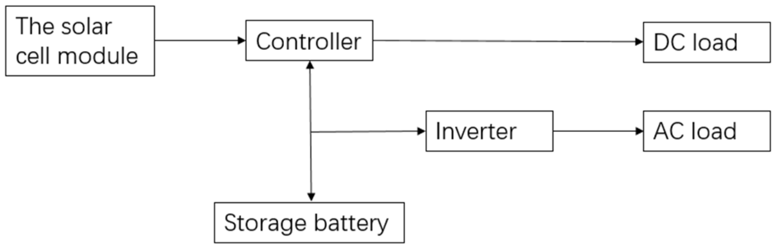

Fig 1. The principle of solar photovoltaic power generation

The solar photovoltaic cells currently put into production in large numbers are silicon photovoltaic cells, and elements such as phosphorus, arsenic, and antimony are likely to lose the outermost electrons. These elements, which are relatively easy to lose the outermost electrons, are incorporated into silicon crystals. The process of combining the outermost electrons lost by these elements with the holes of the silicon crystal can generate free electrons. When it is doped with trivalent elements such as aluminum and boron, the outermost single electrons of these elements will trap the outermost single electrons of the outermost layer of silicon crystals, thereby causing the silicon crystal to generate excess holes. This process enables the formation of hole semiconductors, which we call P-type semiconductors for short. As shown in Figure 2.

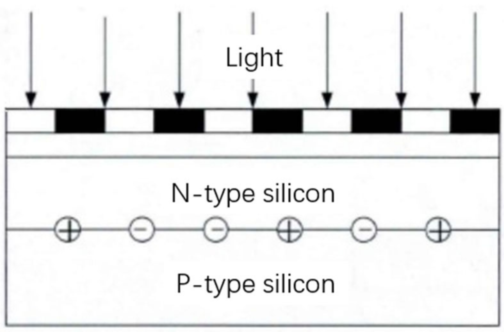

Fig 2. The schematic view of P-N junction

2.2. Photovoltaic Cell Model Establishment

Based on the above content, a solar photovoltaic power generation model can be established as shown in Figure 3.

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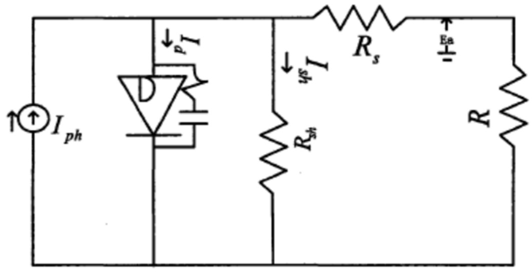

Fig 3. Solar photovoltaic power generation circuit

Then the U/I characteristic of the photovoltaic cell is:

$$I = Iph - I_d - Ish \tag{1}$$

Among

$$I_{ph} = I_{sc}\left(\frac{S}{1000}\right) + C_T\left(T - T_{ref}\right) \tag{2}$$

$$I_d = I_{d0}\{exp\,\frac{q(U+IR_S)}{AKT} - 1\} \tag{3}$$

$$I_0 = I_{d0}\left(\frac{T}{T_{ref}}\right)^3 e^{[\frac{qEg}{nk}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)]} \tag{4}$$

$$I_{sh} = \frac{U+IR_S}{R_{sh}} \tag{5}$$

In an ideal situation: R_s≈0, R_{sh}→∞, The above formula can be simplified to:

$$I = I_{sc}\left(\frac{S}{1000}\right) + C_T\left(T - T_{ref}\right)\text{-}I_{d0}\left(\frac{T}{T_{ref}}\right)^3 e^{[\frac{qEg}{nk}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)]}\ I_{d0}\{exp\,\frac{q(U+IR_S)}{AKT} - 1\} \tag{6}$$

In formula (6):

I	The current flowing through the load
Iph	Photocurrent
S	Light intensity
T	Ambient temperature
T_{ref}	Reference temperature (25°C)
I_d	Current flowing through the diode
q	Electronic charge
E_g	Bandwidth of silicon (45.12V)
n	Diode emission factor (47.69)
K	Boltzmann constant
A	P-N junction ideal factor
I_{sc}	Photovoltaic cell short-circuit current
I_{d0}	Diode reverse saturation current

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2.3. Equivalent Model and Output Characteristics of Photovoltaic Cells

Use the simpower system in matlab to simulate the photovoltaic array, the simulation model is shown in Figure 4.

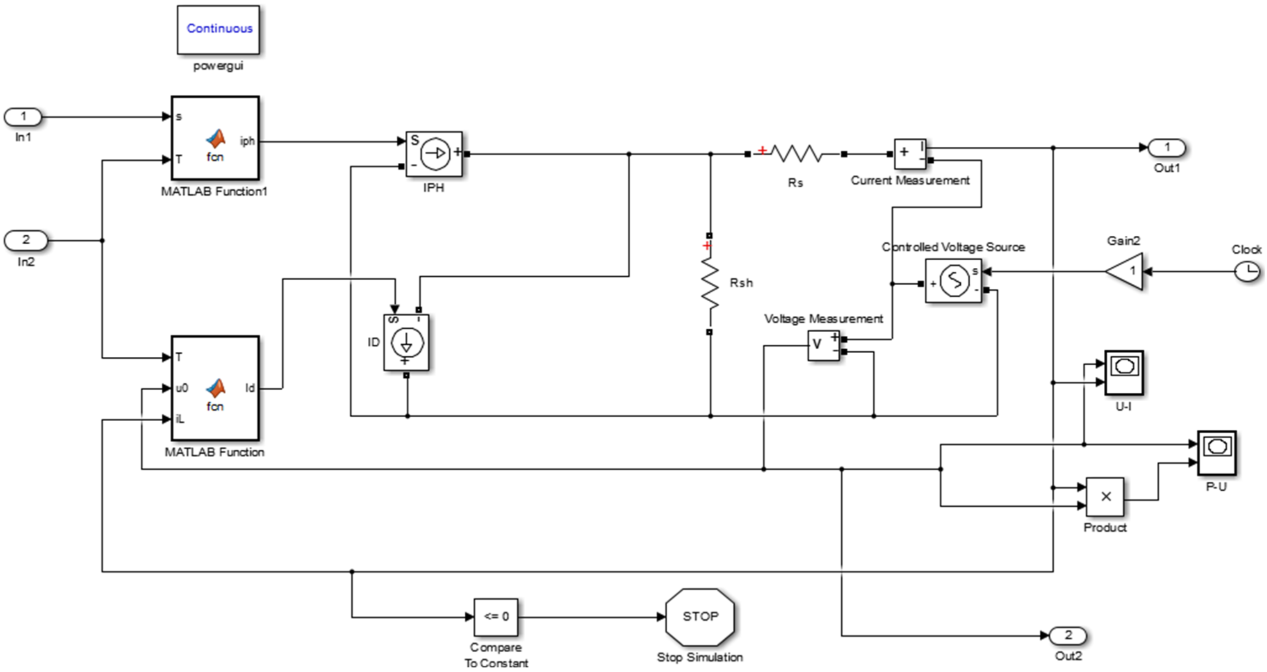

Fig 4. Simulation model building

3. Design of Variable Electronic Load

3.1. Feasibility Analysis

Through the analysis in the previous section, it can be found that the solar photovoltaic array is a non-linear power source, and its output will show a non-linear change with changes in light intensity and temperature. In the case of the same external environment such as light intensity and temperature conditions, different working voltages will produce different currents. If the impedance of the load is changed, the output of the photovoltaic array can be made under the same temperature and the same light intensity. The voltage and current change regularly. When the load impedance value changes more, the output curve of the photovoltaic array can be roughly described. When the impedance of the load changes linearly, a continuous photovoltaic array output characteristic curve can be obtained.

First, use the Pulse Generator module in the Simulink module to generate a rectangular wave, and drive the MOSFET unit, connect it in parallel in the load loop, change the duty cycle of the square wave and analyze it (the solar module is a photovoltaic module package). The simulation diagram is shown in 5.

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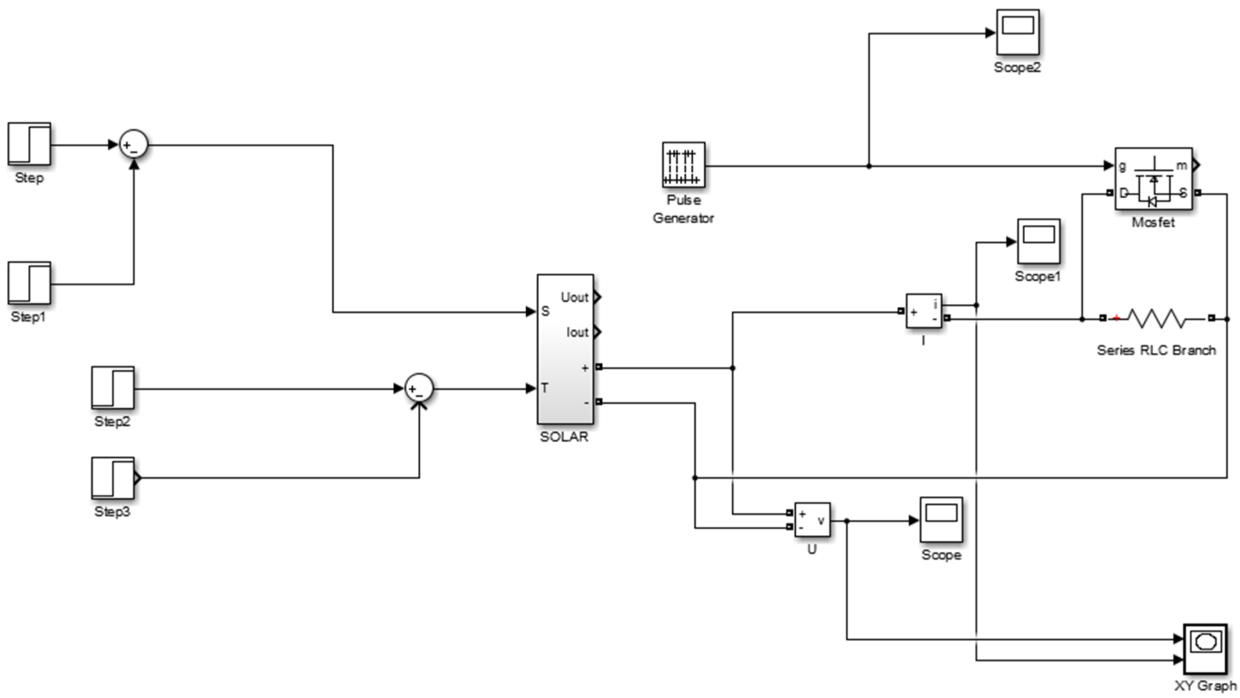

Fig 5. Variable duty cycle simulation design

When the temperature is 25°C, the light intensity is 1200W/m^2, and the load resistance is 10Ω, the duty cycle of the rectangular wave is changed, and the voltage value, current value and effective value changes at both ends of the load are analyzed. After analysis, it is found that when the rectangular wave generator changes the duty cycle, although the maximum and minimum values of the current passing through the load and the voltage across the load do not change, the effective value will change. The current passing through the load will increase as the duty cycle of the rectangular wave increases, and the voltage across the load will decrease with the increase of the duty cycle of the rectangular wave. That is, changing the duty cycle of the rectangular wave to drive the mosfet can make The impedance of the load changes, so it is feasible to use a rectangular wave as a driving circuit to drive the mosfet and obtain the output characteristics of the photovoltaic array.

3.2. Formation of Variable Duty Cycle Rectangular Wave

In the Simulink module, a triangular wave generator and ramp function generator are used to generate a rectangular wave that can change the duty cycle, so as to drive the MOSFET to change the impedance, so as to obtain the IU curve and the PU curve at different load impedances, so you can get different The IU curve and PU curve of the load impedance are shown in Figure 6.

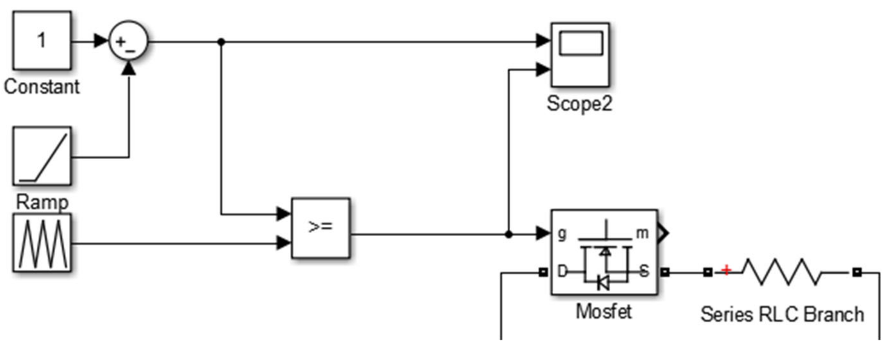

Fig 6. Variable duty cycle rectangular wave model

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When the ambient temperature is 25°C, the light intensity is 1200W/m^2, and the load is 10Ω, this simulation model can get the P-U output characteristic curve and U-I output characteristic curve of the photovoltaic array. The P-U output characteristic curve of the photovoltaic array is shown in Figure 7.

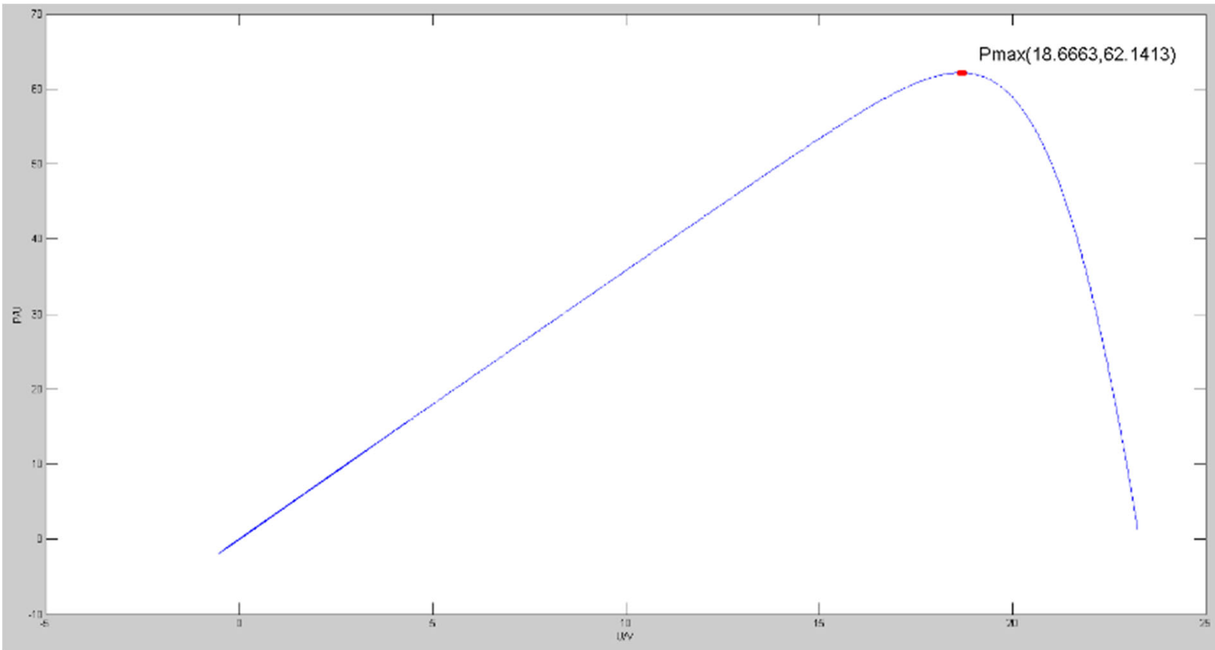

Fig 7. P-U characteristic diagram

The U-I output curve of the photovoltaic array is shown in Figure 8.

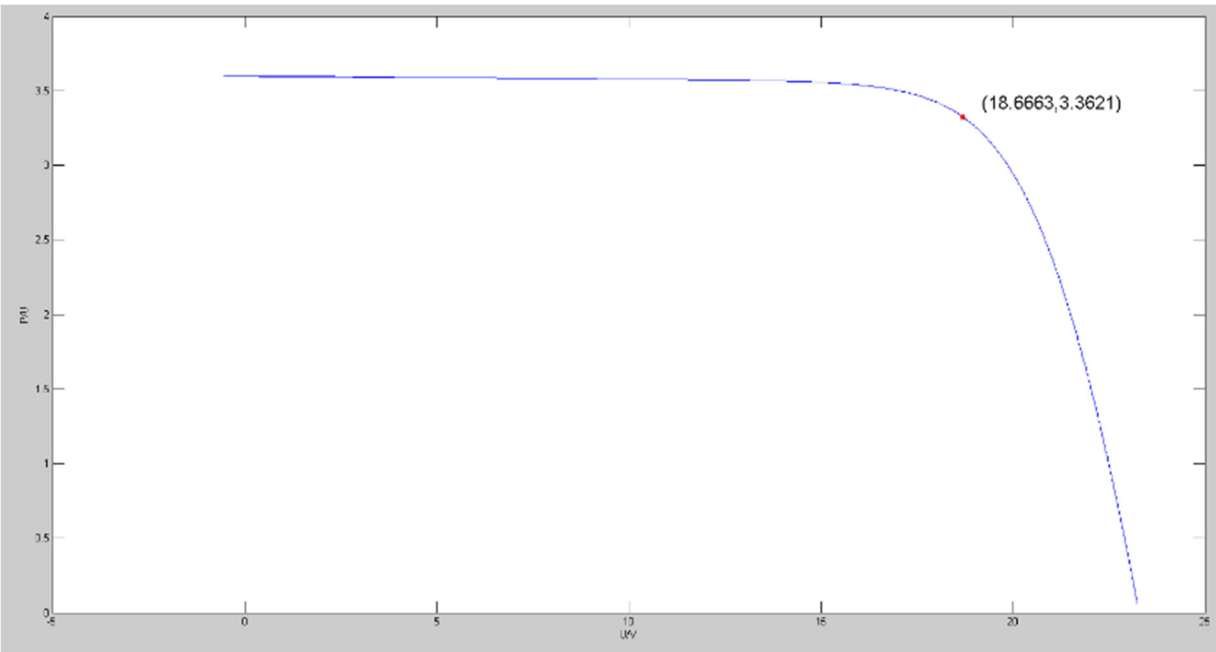

Fig 8. U-I characteristic diagram

It can be concluded that when the ambient temperature is 25°C and the light intensity is 1200W/m^2, the current passing through the load is 3.3621A, the voltage across the load is 18.6663V, and the maximum output power of the photovoltaic array is 62.1413W.

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After mathematical calculation, when the ambient temperature is 25°C and the light intensity is 1200W/m^2, the current passing through the load under the same load (500 ohms) is 3.2539A, the voltage across the load is 19.0069V, and the maximum output power of the photovoltaic array is 61.8672W . The maximum output power error is 0.443%, indicating that the error is small. This model can be used for photovoltaic array variable electronic loads to identify the output characteristic curve and maximum power operating point of the photovoltaic array.

4. Change the Output Characteristics of Environmental Conditions

The ambient temperature and light intensity are always changing. A qualified variable electronic load must obtain the PV array PU output characteristic curve and IU output characteristic curve in the shortest time while the ambient temperature and light intensity change. Therefore, the light intensity and environmental The temperature is changed, and the PU output characteristic curve and IU output characteristic curve of the photovoltaic array are analyzed.

4.1. Fixed Temperature Output Characteristics

When the ambient temperature is 25°C, change the light intensity to obtain the photovoltaic array P-U output curve as shown in Figure 9. (The light intensity is 1200 W/m^2, 1100 W/m^2, 1000 W/m^2, 900 W/m^2, 800 W/m^2)

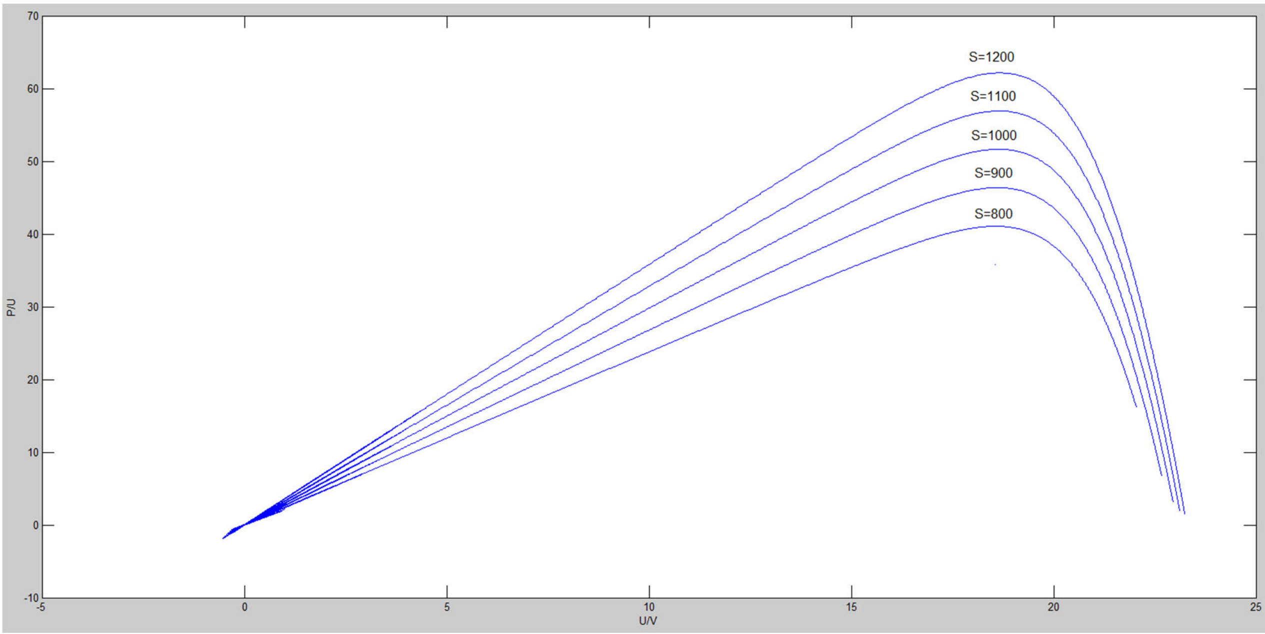

Figure 9. P-U output curve

Light intensity(W/m^2)	Output Power(U)
800	40
900	45
1000	50
1100	55
1200	60

4.2. Output Characteristics of Fixed Light Intensity

When the light intensity remains unchanged at 1200M/m^2, change the ambient temperature to get the photovoltaic array P-U output curve as shown in Figure 10. (Ambient temperature is 0°C, 10°C, 20°C, 30°C, 40°C)

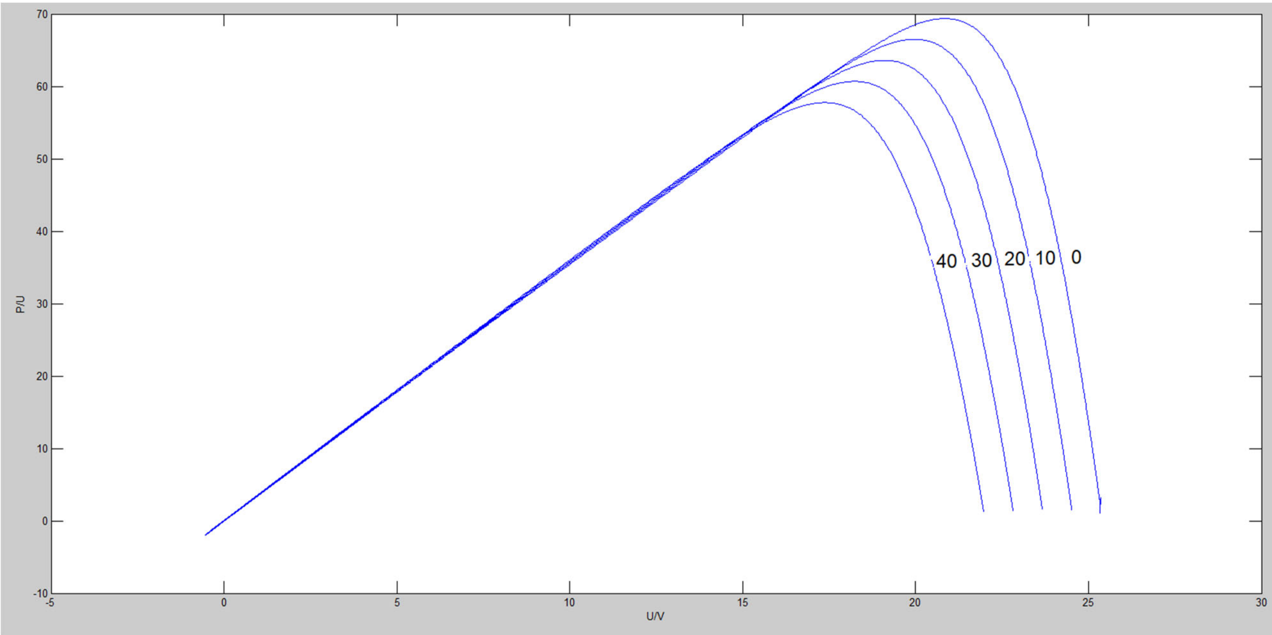

Figure 10. P-U output curve

Ambient temperature(°C)	Output Power(U)
0	55
10	60
20	65
30	70
40	75

5. Summary

It can be seen that when the ambient temperature remains unchanged and the light intensity gradually increases, the maximum output power obviously increases. When the light intensity remains unchanged, the ambient temperature gradually increases, and the maximum output power will gradually decrease. This model can be used to identify the characteristics of photovoltaic arrays.

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