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Research Article

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Modeling of solar photovoltaic cells and output characteristic simulation based on Simulink

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ABSTRACT

The simulation model of PV array is presented on the basis of PV array's physical equivalent circuit and its mathematical model by Matlab/Simulink. This simulation model can be used to show the U-I output characteristics of the PV array under various irradiation levels and temperatures condition. Meanwhile, this model can be applied to cases of other powers flexible and used to study array's parallel and serial characteristics. According to the output U-I characteristics, the U-P curve of the PV array is a single peak curve, which means that the PV array has a Maximum Power Point (MPP). Under partially shaded conditions, the U-P curve of PV array has the characteristics of multi-summit. The simulation results show that the irradiation changes mainly affect the PV output current, while the temperature changes mainly affect the PV output voltage.

Key words: Photovoltaic cells; output characteristic; maximum power point (MPP); partially shaded conditions.

INTRODCTION

Photovoltaic (PV) power generation is a reliable and economical source of electricity in rural areas. It is important to operate the PV energy conversion systems near the maximum power point (MPP) to increase the efficiency of the PV system. But the solar energy always varies instantaneously and the current and power of PV array varies non-linearly with the terminal voltage, solar radiation, and temperature. So, the maximum power output cannot be easily obtained.
As solar photovoltaic cells have significant nonlinear output characteristic, the photoelectric conversion efficiency is still very low. Therefore, so far the research of output characteristics of photovoltaic cells is an important topic in the industry.
This paper proposes a mathematical model of PV array based on the principle of photovoltaic cells and establish the simulation model in Simulink. The output characteristic curve of the photovoltaic cells is obtained with different solar radiation and temperature. Thus, it can lay the foundation for in the following research of the maximum power point tracking (MPPT)[1-3].

EXPERIMENTAL SECTION

Photovoltaics cells modeling

Photovoltaics cells characteristics

Output characteristics of photovoltaic cells are represented as volt-ampere characteristic, *U-I* characteristics does change with solar and temperature, namely $I = f(V, S, T)$. Solar cells generate electricity by irradiation and it increases with increasing irradiation. Solar cells can be regarded as constant current power supply which relate to the light intensity [4-5].

The equivalent circuit of photovoltaic cell model is shown in Fig.1[6].

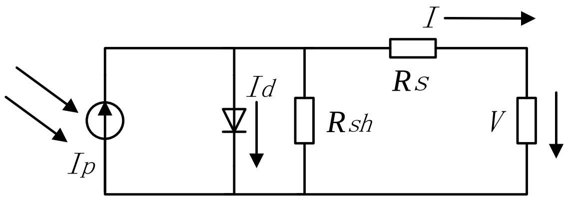


Fig.1 The equivalent circuit of photovoltaic cell

The model can be expressed as

$$I = I_p - I_d \cdot \{\exp[\frac{q(V + IR_s)}{AKT}] - 1\} - \frac{V + IR_s}{R_{sh}} \quad (1)$$

Where:

I_p——photocurrent（A）;
I_d——reverse saturation current（A）;
q——electronic charge(1.6×10^{-19} C);
K——Boltzmann constant(1.38×10^{-23}JPK);
T——absolute temperature（K）;
A——diode factor;
R_s——series resistor（Ω）;
R_{sh}——parallel resistor（Ω）。

Photovoltaic cells components manufacturers usually only provide to users the parameters: short circuit current I_{sc}, open circuit voltage V_{oc}, maximum power point of current I_{mpp}, maximum power point voltage V_{mpp}, maximum power P_{mpp} under the condition of standard test to measure. It is especially important for PV systems technical personnel how to obtain the *U-I* characteristics according to the test data under different solar radiation and temperature.

The engineering mathematics model for Photovoltaic cells[7-9]

The engineering mathematics model for PV is used to in reference radiation intensity and reference ambient temperature that is also called the standard test conditions (S_{ref}=1000W/m^2, T_{ref}=25 ℃), the *I-V* equation of PV is as follows:

$$I = I_{sc}\{1 - C_1[\exp(\frac{V}{C_2 V_{oc}}) - 1]\} \quad (2)$$

Where:

$$C_2 = \frac{V_{mp}/V_{OC} - 1}{\ln(1 - I_{mp}/I_{SC})} \quad (3)$$

$$C_1 = (1 - \frac{I_{mp}}{I_{SC}}) \cdot \exp[-\frac{V_{mp}}{C_2 . V_{OC}}] \quad (4)$$

Therefore, the model can be established only by input the technical parameters of PV, for example, short circuit current I_{sc} and open circuit voltage V_{oc}, maximum power current I_{mpp}, maximum power voltage V_{mpp}, then C_1 and C_2 can be obtained according to the equation (3) and (4).

Based on the above analysis, the model for PV in Simulink is shown in Fig.2

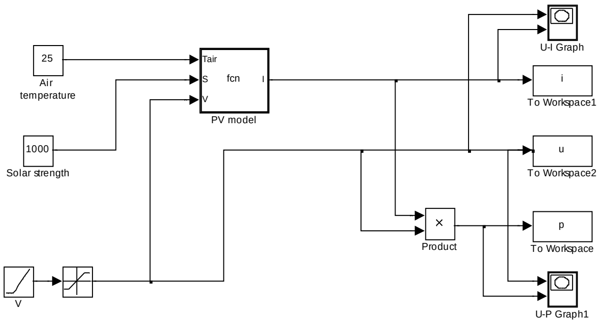


Fig.2 model for PV

RESULTS AND DISCUSSION

The output characteristics of photovoltaic cells under different irradiation conditions

Under standard test condition the temperature *T* is 25℃, select irradiation *S* is 1000 W/m^2, 800W/m^2, 600 W/m^2, 300 W/m^2, in turn. Then *I-U* output characteristics of photovoltaic cells are shown in Fig.3.

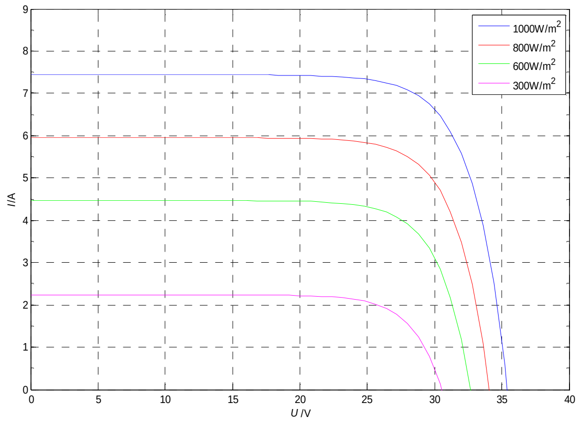


Fig.3 *I-U* curve of photovoltaic cells for four different irradiation levels

From the Fig.3 we can see that in same temperature level, the current *I* is increased significantly with increasing of irradiation level, while the voltage *U* has not changed much. So, the maximum power point also meet the change, namely when irradiation increases, maximum output current I_{mpp} increased obviously and the maximum output voltage U_{mpp} changed small. As a result, the maximum power point $P_{mpp}= I_{mpp}\times U_{mpp}$ also increased with the increase of irradiation.

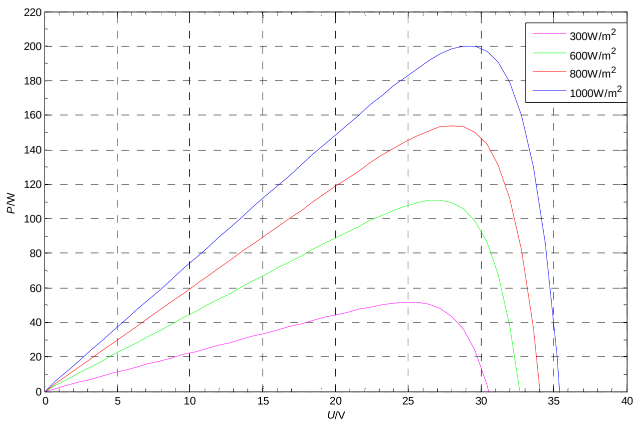


Fig.4 *P-U* photovoltaic characteristic for four different irradiation levels

P-U photovoltaic characteristic for four different irradiation levels is shown in Fig.4. It can be observed that while the irradiation change is increased, the PV output power is also increased. It is consistent with results from Fig. 3. It can be conclude that while the irradiation changes mainly affect the PV output current, therefore the maximum power point is increased.

The output characteristics of photovoltaic cells under different temperature conditions

Under irradiation *S* equal to 1000 W/m^2 constant, set temperature *T* is in turn 50℃ and 25℃, 15℃, 5℃. Then, *P-U* curve of photovoltaic cells for four different temperatures is shown in Fig.5.

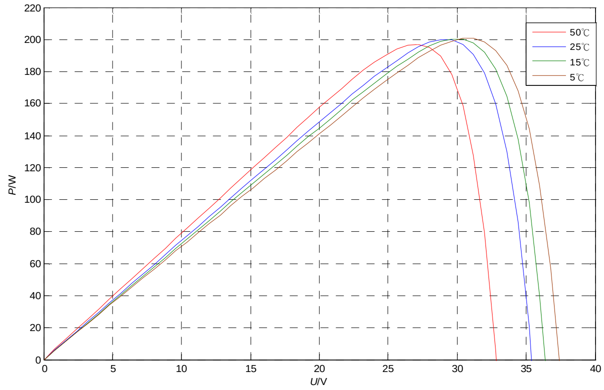


Fig.5 ***P-U*** **curve of photovoltaic cells for four different temperatures**

The curve from left to right is 50℃, 25℃, 15℃, 5℃, respectively. From the Fig.5 can be seen that the temperature changes mainly affect the PV output voltage.

When the temperature rises, the voltage fell sharply. But the temperature rises from 25℃ to 50℃, voltage fell more obviously. As a result, the voltage change is large than the current change as the rise of temperature. The maximum output power meets also the relationship, so its change is very small.

Therefore, it can be conclude that the temperature changes mainly affect the PV output voltage, while the irradiation changes mainly affect the PV output current.

The output characteristics of photovoltaic cells under partially shaded conditions

In case of partially shaded condition, the *I-U* curve of the PV array will have many gradient and multi-extreme features. Series modules of PV array can cause different voltage peak due to sunlight change, while the different modules in parallel group will generate many current peak. The model of PV arrays under partially shaded conditions is shown in Fig. 6.

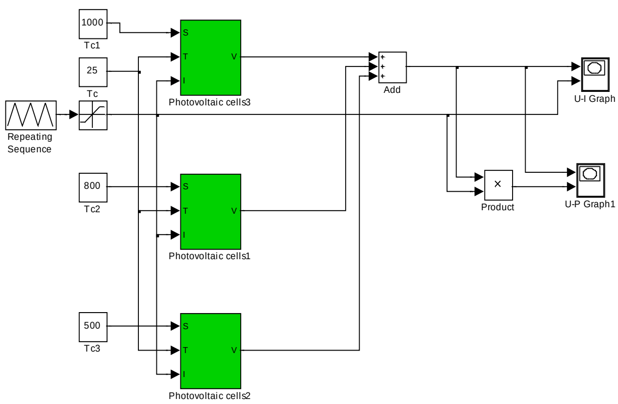
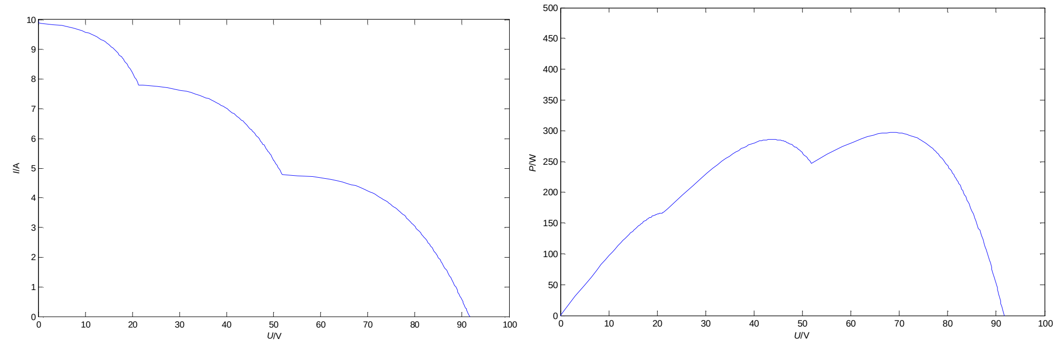


Fig.6 model of PV arrays under partially shaded conditions

Fig. 7 shows *I-U* curve and *P-U* curve for three PV arrays in parallel under partially shaded condition.
The simulation results show clearly that under partially shaded conditions, the *P-U* curve of PV arrays has the characteristics of multi-summit.



(a) *I-U* curve **(b) *P-U* curve**

Fig. 7 *I-U* curve and *P-U* curve for three photovoltaic cells in parallel under partially shaded condition

CONCLUSION

Output characteristic of photovoltaic cells is not only related to its parameters but also associated with the outside irradiation and environment temperature. Based on the engineering mathematical model of PV, the simulation model has been established using the Matlab/Simulink. The simulation results proved the changing rule of output characteristic with irradiation and environment temperature. It can be conclude that the temperature changes mainly affect the PV output voltage, while the irradiation changes mainly affect the PV output current.

In case of partially shaded condition, the *I-U* curve of the PV array will have many gradient and multi-extreme features.

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