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Analysis of the Characteristics of Solar Cell Array Based on MATLAB/Simulink in Solar Unmanned Aerial Vehicle

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ABSTRACT In order to study the solar cell power system of solar unmanned aerial vehicle (UAV), this paper builds a simulation model of solar cell according to the solar cell mathematical model. The characteristic curves of solar cells are obtained by MATLAB/Simulink. The characteristic curves of the solar cells are compared by changing the solar intensity and the external temperature. At the same time, the ground test of the solar cell module is carried out. The corresponding conclusions are obtained by the ground test and simulation analysis. The solar cells have a certain maximum power point at any condition, which is great significant to study the maximum power tracking of solar cells in solar UAVs.

INDEX TERMS Solar cell, mathematical model, UAV, MATLAB/Simulink, characteristic curve

I. INTRODUCTION

The photovoltaic system has become one of the most popular renewable and sustainable energy sources [1]. It features the characteristics of sustainability and environmental-friendliness [2], [3]. Continuous long flight is the most difficult to achieve the goal of UAV applications, but this problem is solved successfully after the application of solar cells to UAV. Sunlight radiant energy is used as energy source for solar unmanned aerial vehicles during the daytime. The solar array is mounted on the surface of the wings, which can convert solar radiation energy into electrical energy to provide the required energy for propulsion systems and airborne equipment, and the excess energy is stored in the battery. The stored energy is used to keep flying at night. When the energy stored in the day is balanced with the energy required for night flight, it can achieve flight for more than 24 hours in theory.

Solar energy is one of the most abundant energy, and solar energy is inexhaustible so that it has aroused people's attention. We use MATLAB/Simulink software to build simulation models for analysis and verification before the completion of UAV entities combined with solar cells. Therefore, it is important to study the output characteristics of solar cell arrays.

Solar cells are important part for unmanned aerial vehicle energy system, the output power of solar cell array determines the efficiency of solar unmanned aerial vehicles. In this paper, the basic principles of solar cells are analyzed and the mathematical simulation model is established by MATLAB/Simulink. Finally, the output characteristics are compared and analyzed by experiments.

Literature 4 described that battery storage effectively stabilizes the electric grid and aids renewable integration by balancing supply and demand in real time [4]. Literature 5 described that Lithium-ion charging management has become an enabling technology towards a paradigm shift of electrified mobility. This paper proposes a novel algorithm to manage battery charging operations using a model-based control approach [5]. Literature 6 seeks to develop a framework for battery model simplification starting from an initial high-order physics-based model that will explicitly detail the assumptions underpinning the development of simplified battery models [6]. The object of this paper is based on crystalline silicon cells. Literature4-6 have a reference value for this study.

This paper presents a model that it can accurately simulate the output characteristics of the battery in any environment. It is necessary to amend the four performance parameters involved in the model according to environmental factors. This paper considers the effect of ambient temperature and the variation of sunlight intensity on the model.

II. THE PRINCIPLE AND MATHEMATICAL MODEL OF SOLAR CELLS

A. WORKING PRINCIPLE OF SOLAR CELL

Solar cells are also called photovoltaic cells. The theoretical basis is the photoelectric volt effect of semiconductor p-n junction [7]. The PV effect refers to a physical phenomenon of the solar radiation in the P-N junction at both ends that it produces induced electromotive force or photocurrent [8], [9]. Figure 1 shows a simple solar cell working principle.

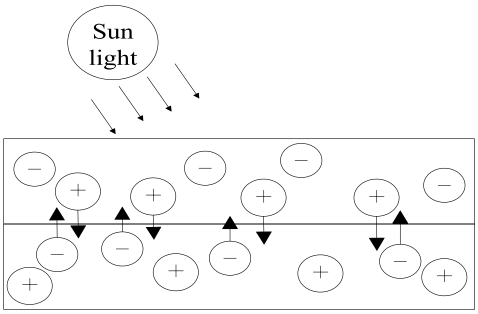


FIGURE 1. Structure diagram of the working principle of solar cells.

When the solar incident light acts on the PN junction, the N-type semiconductor hole in the PN junction moves toward the P-type region, and the P-type region moves toward the N-type region, so that the N-type region and the P-type section can generate potential difference. When the external circuit is turned on, there will be a current flowing through the external circuit to produce a certain output power. This process is that photon energy is converted electrical energy.

NOMENCLATURE

I	photovoltaic battery operating current (A)
I_{ph}	photogenic current (A)
R_S	photovoltaic cell series resistance (Ω)
q	electronic charge (1.6 × 10-19C)
T	absolute temperature (°C)
I_{sc}	short circuit current of solar cells (A)
I_m	maximum power point current (A)
T_{ref}	reference battery temperature (25 °C)
n_s	the number of solar cells in series
I_0	diode Reverse Saturation Current (A)
I_D	PN junction forward current (A)
R_{sh}	photovoltaic cell parallel resistance (Ω)
A	diode quality factor
K	Boltzmann's constant (k = 1.38 × 10-23J / K)
V_{oc}	open circuit voltage of the solar cell(V)
V_m	maximum power point voltage (V)
S_{ref}	reference to solar radiation intensity (1kw/m^2)
n_p	the number of solar cells in parallel

B. MATHEMATICAL MODEL OF SOLAR CELL

Solar cells are a special device that converts solar radiant energy into electrical energy. It is a semiconductor component based on photovoltaic effect. The main factors of its performance are solar light intensity, temperature and raw material properties [10], [11]. Therefore, the working characteristics of this particular solar cells are studied, and it must be converted into an equivalent circuit and an external load to simulate the calculation [12]. The equivalent circuit diagram of the solar cell is shown in Figure 2.

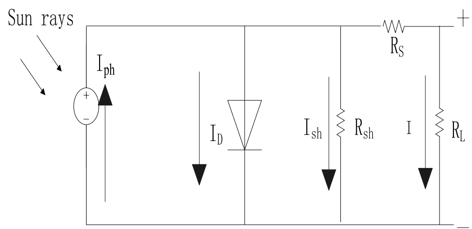


FIGURE 2. Schematic diagram of the equivalent circuit for solar cells.

From the Kirchhoff current law, we obtain the equation [13], [14]:

$$I_{ph} - I_D - I_{sh} - I = 0 \tag{1}$$

$$I = I_{ph} - I_D - I_{sh} \tag{2}$$

$$I_D = I_0 - \{\exp[\frac{q(U + IR_S)}{AKT}] - 1\} \tag{3}$$

$$I_{sh} = \frac{U + IR_s}{R_{sh}} \tag{4}$$

We put the formula (3) and (4) into the formula (2), we can get formula (5) [15], [16].

$$I = I_{ph} - I_0\{\exp[\frac{q(U + IR_S)}{AKT}] - 1\} - \frac{U + IR_S}{R_{sh}} \tag{5}$$

Under normal circumstances, the ideal photovoltaic cell leakage resistance R_{sh} is very large, the series resistance R_s is very small [17]–[20].

The $\frac{U+IR_S}{R_{sh}}$ can be removed, which is $\exp[\frac{q(U+IR_S)}{AKT}] - 1 \approx \exp(\frac{qU}{AKT}) - 1$, and formula (5) can be simplified formula (6).

$$I = I_{ph} - I_0[\exp(\frac{qU}{AKT}) - 1] \tag{6}$$

Also $I_{ph} = I_{sc}$, $\exp(\frac{qU}{AKT}) - 1 > 0$. The characteristic equation of a photovoltaic cell can be simplified formula (7).

$$I = I_{sc}\{1 - C_1[\exp(\frac{U}{C_2V_{oc}})]\} \tag{7}$$

And where is $I = 0$ and $U = V_{oc}$ at the open environment; where is $I = I_m$ and $U = V_m$ at maximum power point.

$$\mathrm{I_{sc}} = \{1 - C_1[\exp(\frac{1}{C_1})]\} = 0 \tag{8}$$

$$\mathrm{I_{sc}} = \{1 - C_1[\exp(\frac{V_m}{C_2V_{oc}})]\} = I_m \tag{9}$$

The formula (7-9) are simplified

$$C_1 = (1 - \frac{I_m}{I_{sc}})\exp(-\frac{V_m}{C_2V_{oc}})$$

$$C_2 = \frac{1}{\ln(\frac{1}{C_1})} \tag{10}$$

C_2 of the formula (10) is putted into C_1

$$C_2 = (\frac{V_m}{V_{oc}} - 1)[\ln(1 - \frac{I_m}{I_{sc}})]^{-1} \tag{11}$$

Therefore, the mathematical model is proposed in this paper, which it needs to enter the solar cell parameters that the results C_1 and C_2 can be obtained.

When the solar radiation intensity and battery ambient temperature changes, we need to recalculate the short circuit current and open circuit voltage, which also need to recalculate the C_1 and C_2 value.

When the change of ambient temperature and sunlight intensity are considered, the equation are as follows.

$$\mathrm{I} = I'_{sc}1 - C_1\left[\exp\left(\frac{U}{C_2V_{oc}}\right)\right] \tag{12}$$

$$C'_1 = (1 - \frac{I'_m}{I'_{sc}})\exp(-\frac{V'_m}{C_2V'_{OC}}) \tag{13}$$

$$C'_2 = \left(\frac{V'_m}{V'_{oc}} - 1\right)/[\ln\left(1 - \frac{I'_m}{I'_{sc}}\right)] \tag{14}$$

$$I'_{sc} = I_{sc}(\frac{S}{S_{ref}})(1 + a\Delta T) \tag{15}$$

$$V'_{oc} = V_{oc}\,(1 - c\Delta T)\,(1 + b\Delta S) \tag{16}$$

$$I'_m = I_m(1 + \Delta S)(1 + a\Delta T) \tag{17}$$

$$V'_m = V_m(1 - c\Delta T)(1 + b\Delta S) \tag{18}$$

$$\Delta \mathrm{T} = \mathrm{T} - T_{ref} \tag{19}$$

$$\Delta \mathrm{S} = \frac{S}{S_{ref}} - 1 \tag{20}$$

Since the panels on the surface of the solar UAV wings are usually connected in series or parallel by several sets of solar cells, the equivalent mathematical model can be expressed as a formula (12).

$$I(1 + \frac{R_s}{R_{sh}}) = \mathrm{n_pI_{ph}} - \mathrm{n_pI_0}[\exp\{\frac{q(V + IR_s)}{AKT}\} - 1] - \frac{(V/n_s + IR_s)}{R_{sh}} \tag{21}$$

Solar photovoltaic cell simulation model taking into account the variation of sunshine intensity and temperature are set up in Matlab/Simulink, which based on the above mathematical model. a is the compensation coefficient current toc temperature, b and c are the compensation coefficient voltage to the outside light radiation intensity and temperature. Typical values of a,b,c in the model are set as follows, a is 0.0025, b is 0.5, and the c is 0.00288.

The output characteristics of photovoltaic cells and environmental factors have a very close relationship, so the parameters of formula 5 can be more accurate simulation of the battery output characteristics in any environment. In this paper, the four performance parameters in the model are modified according to environmental factors, thus the output characteristics of photovoltaic is simulated under any environmental conditions.

III. SIMULATION AND ANALYSIS OF SOLAR CELL BASED ON MATLAB/SIMULINK

The MATLAB/Simulink simulation model is built thought a mathematical model. Simulation model has more modules to facilitate the combination of other modules. So that the simulation interface looks very clear, the module needs to be packaged. The simulation and post-encapsulated model is shown in Figure 3.

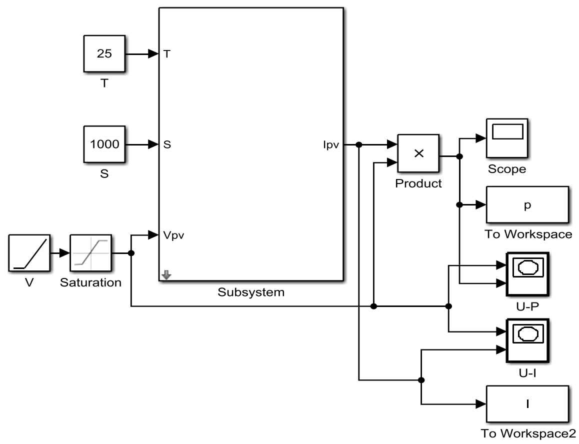


FIGURE 3. Solar cell simulation and package model.

The subsystem is a solar cell package model in the simulation model. The internal package has ambient temperature and solar radiation intensity, and the output is the current, voltage and power in the solar cell model.

The Matlab/Simulink simulation model is used to plot the characteristic curve (with intensity of light varies and solar cell temperature fixed; and intensity of illumination fixed and solar cell temperature varies) in order to better understand the characteristics of solar cell.

It can be obtained from the above Figure 4.

① The change of the light intensity has affected greatly on the current of the solar cell. When light intensity rises from 400W/m^2 to 1000W/m^2, the short-circuit current of the battery increases, and the two are approximately proportional. The intensity of the light has little effect on the open circuit voltage of the solar cell. The open circuit voltage of the solar cell changes slightly with the light intensity increased.

② The light intensity has a great influence on the output power of the solar cell. As the light intensity rises from 400W/m^2 to 1000W/m^2, the output power of the battery increases. The output power of the battery on the left side of the maximum power point has increased with the rise of the output voltage of the solar cell. Yet after the maximum power point is reached, the output power of the battery is decreased with the output voltage goes up.

TABLE 1. Output characteristic equation of PV.

Irrespective of sunshine intensity and temperature effects	Consider sunshine intensity and temperature effects
$I=I_{sc}\{1-C_1[\exp(\frac{U}{C_2V_{oc}})]\}$	$\mathrm{I}=I'_{sc}\{1-C_1\left[\exp\left(\frac{U}{C_2V_{oc}}\right)\right]\}$
$C_1=(1-\frac{I_m}{I_{sc}})\exp(-\frac{V_m}{C_2V_{OC}})$	$C'_1=(1-\frac{I'_m}{I'_{sc}})\exp(-\frac{V'_m}{C_2V'_{OC}})$
$C_2=\left(\frac{V_m}{V_{oc}}-1\right)/[\ln\left(1-\frac{I_m}{I_{sc}}\right)]$	$C'_2=\left(\frac{V'_m}{V'_{oc}}-1\right)/[\ln\left(1-\frac{I'_m}{I'_{sc}}\right)]$
$\Delta\mathrm{S}=\frac{S}{S_{ref}}-1$	$V'_{oc}=V_{oc}(1-c\Delta T)(1+b\Delta S)$
$\Delta\mathrm{T}=\mathrm{T}-T_{ref}$	$I'_{sc}=I_{sc}(\frac{S}{S_{ref}})(1+a\Delta T)$
	$V'_m=V_m(1-c\Delta T)(1+b\Delta S)$
	$I'_m=I_m(1+\Delta S)(1+a\Delta T)$

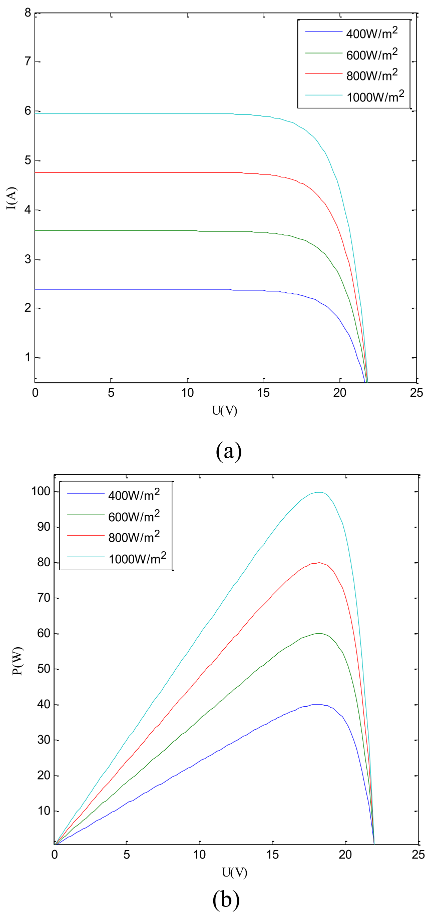


FIGURE 4. Simulation results of solar cell output characteristics under different light intensity. (a) U-I characteristic curve. (b) U-P characteristic curve.

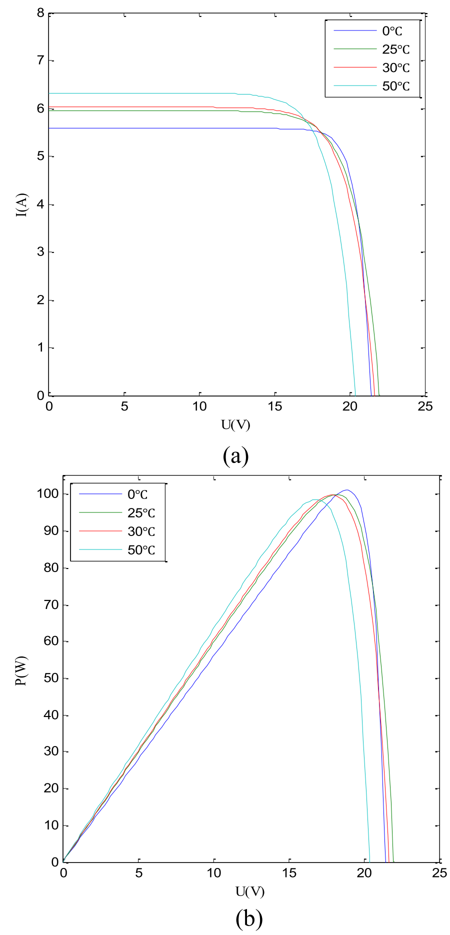


FIGURE 5. Simulation results of solar cell output characteristics under different temperature. (a) U-I characteristic curve. (b) U-P characteristic curve.

③ The U-I characteristic curve shows that the characteristic of the solar cell at the left side of the maximum power point is an approximately constant current source and the right side of the maximum power point near the open circuit voltage is approximated with a constant voltage source.

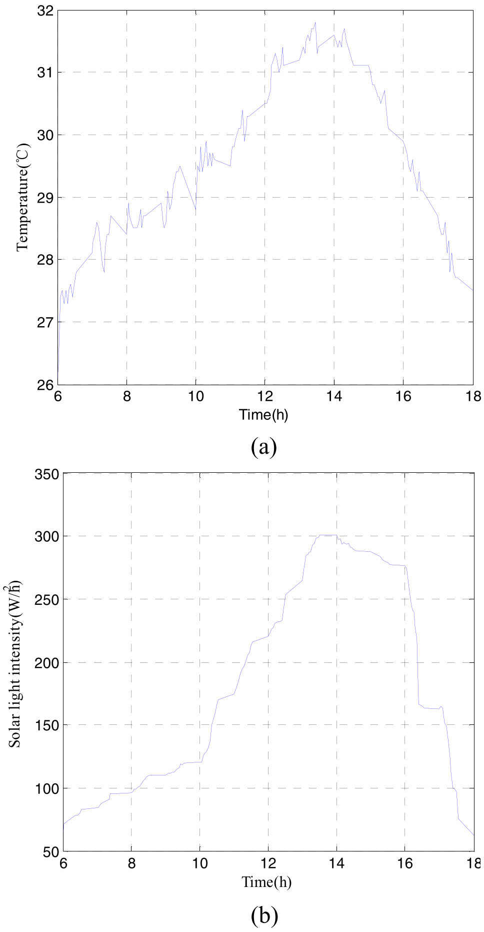


FIGURE 6. **Schematic diagram of time and temperature, light intensity (Light rain day). (a) Schematic diagram of time and temperature. (b) Schematic diagram of time and solar light intensity.**

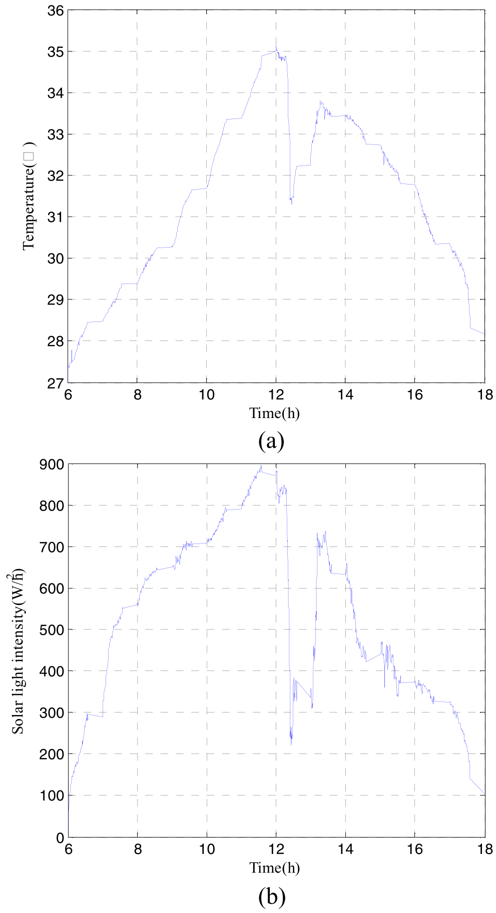


FIGURE 7. **Schematic diagram of time and temperature, light intensity (Sunny day to cloudy day). (a) Schematic diagram of time and temperature. (b) Schematic diagram of time and solar light intensity.**

It can be obtained from the characteristic curve groups of above Figure 5 (with S = 1000W/m^2, from temperature of solar cell at 0°C, 25°C, 30°C, 50°C).

① U-I characteristic curve shows that the output voltage is reduced with the solar cell temperature increases and the light intensity remains unchanged, while the temperature increase impacted little of the output current, which remains at around 6A.

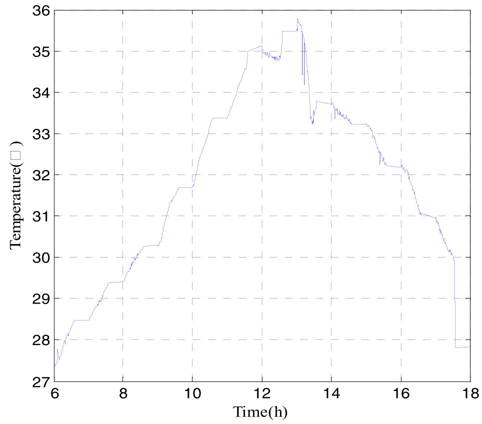
② The U-P characteristic curve shows that the change is similar in solar cell output power when the light intensity remains constant. The maximum output power decreases with the temperature rises, and its corresponding output voltage decreases with the temperature rises.

Analysis of Figure 4 and Figure 5 shows that the output power of the solar cell is closely related to the intensity of the sunlight and the ambient temperature, and the output power of the solar cell varies with the ambient temperature and the intensity of light. Therefore, we must take the corresponding control strategy for solar unmanned aerial vehicles to control the output power, so that it can outputs the maximum power and achieve efficient convert of the solar energy and solar cells.

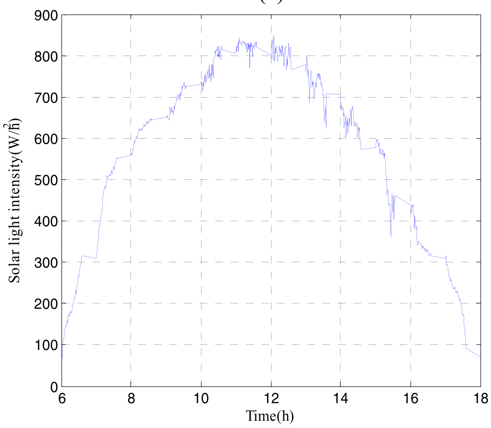
IV. RESEARCH AND VERIFICATION OF SOLAR CELL GROUND TEST

The purpose of the solar cell ground test is that it tests the output characteristics of solar cells. The test equipment are silicon battery components, digital solar light meter and solar cell tester. The solar cell module is made up of 36 monocrystalline silicon cells in series, and the intensity of the solar light is tested using a digital solar light meter. The solar cell tester is designed to test the open circuit voltage, short circuit current, maximum power and conversion of the entire assembly. Solar cell test equipment model is PROVA 210A. It tests the I-V characteristic curve, and finds the maximum power of the solar module operating point. It measures the maximum voltage at maximum power and the maximum current. It can directly display solar cell conversion efficiency η (%) and FF value under the standard light source. Digital solar light model is TES-132. It can choose solar power measurement or transmittance measurement.

In this paper, the actual solar panel output characteristics of the measured temperature and solar radiation intensity was measured in Nanjing, the test site was Nanjing University of Aeronautics and Astronautics (north latitude of about 32°17",



(a)



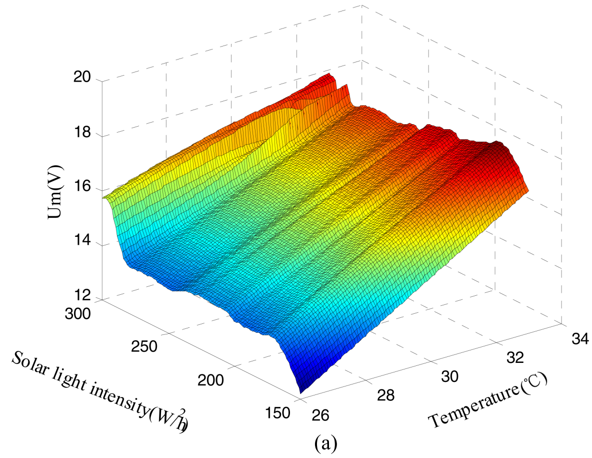
(b)

FIGURE 8. Schematic diagram of time and temperature, light intensity. (a) Schematic diagram of time and temperature. (b) Schematic diagram of time and solar light intensity.

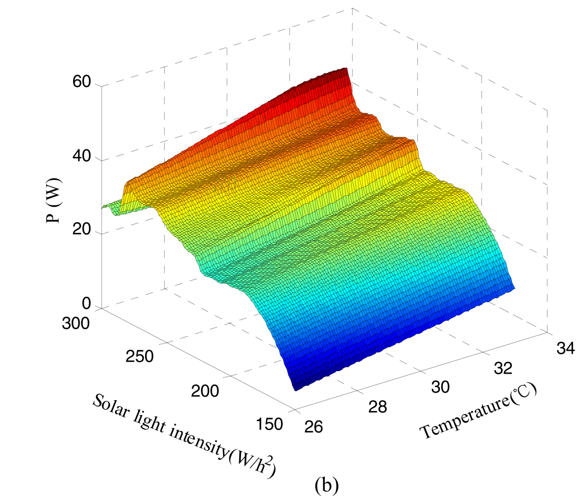
longitude of about 118°42"). The test time was from 6:00 am to 18:00 pm on July 10th to 13th, 2017, with three types weather were tested, including light rain, cloudy and sunny days.

The data of the solar panels measured in the above three weather conditions are shown from Figure 6 to Figure 8. The weather temperature and light intensity are the lowest in the three weathers in light rain, while there is a multi-peak phenomenon in the sunny to cloudy weather. In sunny days, the temperature and light intensity values are larger.

According to the theoretical analysis in the previous section and the experimental test results in this section, it can be concluded that the output curve of a solar cell has a nonlinear characteristic, which is mainly affected by the ambient temperature and light intensity. When the ambient temperature changes or the light intensity changes, the output power of solar cell also changes. In output U-P characteristic curve, it can be found that only one point of the voltage value and the output power achieve the maximum. It can be revealed from Figure 9 that the solar panel output power, voltage, light and temperature curve have a good consistency with light and temperature curve. This conclusion is consistent with the simulation conclusion.



(a)



(b)

FIGURE 9. Schematic diagram of light intensity and temperature with voltage and power. (a) Schematic diagram of solar light intensity and temperature with voltage. (b) Schematic diagram of temperature and solar light intensity with power.

V. CONCLUSION

In this paper, the simulation model of solar cell in solar unmanned aerial vehicle (UAV) is constructed by MATLAB/Simulink software. The characteristic curve of the solar cell is obtained through the operation model. The simulation results are compared with the characteristic curves obtained by the ground test, which concluded that the solar cells have a certain maximum power output point in different solar lighting conditions. In this paper, the output characteristics of solar panels in three kinds of weather conditions are tested. The conclusion of the test data are consistent with the simulation results, which provides an important theoretical basis for the study of the maximum power point tracking of solar cells. It is great significance to study the solar cell system in solar unmanned aerial vehicles.

This paper describes the photovoltaic cells and their characteristics, through the research on the principle and structure of photovoltaic power generation, the equivalent circuit of photovoltaic cell is obtained. According to the output characteristic equation of the battery, a simulation model of engineering application considering the variation of sunshine intensity and temperature conditions is set up in Matlab / Simulink, which the accuracy of the model is verified. By comparing its output characteristic curve, it can be found that the PV cell shows a strong nonlinearity, which is obviously affected by the change of temperature and light conditions. Which temperature changes mainly affect the open circuit voltage, and light intensity changes mainly affect the short-circuit current.

REFERENCES

[1] W. De Soto, S. A. Klein, and W. A. Beckman, "Improvement and validation of a model for photovoltaic array performance," *Sol. Energy*, vol. 80, no. 1, pp. 78–88, 2006.

[2] N. L. Panwar, V. S. Reddy, K. R. Ranjan, M. M. Seepana, and P. Totlani, "Sustainable development with renewable energy resources: A review," *World Rev. Sci., Technol. Sustain. Develop.*, vol. 10, no. 4, pp. 163–184, 2013.

[3] A. Dolara, S. Leva, and G. Manzolini, "Comparison of different physical models for PV power output prediction," *Sol. Energy*, vol. 119, pp. 83–99, Sep. 2015.

[4] X. Hu, C. Zou, C. Zhang, and Y. Li, "Technological developments in batteries: A survey of principal roles, types, and management needs," *IEEE Power Energy Mag.*, vol. 15, no. 5, pp. 20–31, Sep./Oct. 2017.

[5] C. Zou, X. Hu, Z. Wei, and X. Tang, "Electrothermal dynamics-conscious lithium-ion battery cell-level charging management via state-monitored predictive control," *Energy*, vol. 141, pp. 250–259, Dec. 2017.

[6] C. Zou, C. Manzie, and D. Nešić, "A framework for simplification of PDE-based lithium-ion battery models," *IEEE Trans. Control Syst. Technol.*, vol. 24, no. 5, pp. 1594–1609, Sep. 2016.

[7] P. T. Le, H.-L. Tsai, and T. H. Lam, "A wireless visualization monitoring, evaluation system for commercial photovoltaic modules solely in MATLAB/Simulink environment," *Solar Energy*, vol. 140, pp. 1–11, Dec. 2016.

[8] F. Khan, S. N. Singh, and M. Husain, "Effect of illumination intensity on cell parameters of a silicon solar cell," *Sol. Energy Mater. Sol. Cell*, vol. 94, no. 9, pp. 1473–1476, 2010.

[9] A. Bouraiou, M. Hamouda, A. Chaker, M. Sadok, M. Mostefaoui, and S. Lachtar, "Modeling and simulation of photovoltaic module and array based on one and two diode model using MATLAB/Simulink," *Energy Procedia*, vol. 74, pp. 864–877, Aug. 2015.

[10] A. K. Cabrera, H. U. Banna, C. Koch-Ciobotarus, and S. Ghosh, "Optimization of an air conditioning unit according to renewable energy availability and user's comfort," in *Proc. IEEE PES Innov. Smart Grid Technol. Conf. Europe (ISGT-Europe)*, Oct. 2014, pp. 1–7.

[11] J. Kasera, A. Chaplot, and J. K. Maherchandani, "Modeling and simulation of wind-PV hybrid power system using MATLAB/Simulink," in *Proc. IEEE Students' Conferenc Elect., Electron. Comput. Sci.*, 2012, pp. 1–4.

[12] C. Keles, B. B. Alagoz, M. Akcin, A. Kaygusuz, and A. Karabiber, "A photovoltaic system model for MATLAB/Simulink simulations," in *Proc. 4th Int. Conf. Power Eng., Energy Elect. Drives*, May 2013, pp. 1643–1647.

[13] A. Rai, B. Awasthi, A. Dixit, and C. K. Dwivedi, "Modeling of solar photovoltaic module and study parameter variation effect using MATLAB/Simulink," in *Proc. Int. Conf. IEEE Control, Comput., Commun. Mater.*, Oct. 2016, pp. 1–6.

[14] H. Rezk and E.-S. Hasaneen, "A new MATLAB/Simulink model of triple-junction solar cell and MPPT based on artificial neural networks for photovoltaic energy systems," *AIN Shams Eng. J.*, vol. 6, no. 3, pp. 873–881, 2015.

[15] M. S. Hossain, N. K. Roy, and M. O. Ali, "Modeling of solar photovoltaic system using MATLAB/Simulink," in *Proc. Int. Conf. Comput. Inf. Technol.*, Dec. 2016, pp. 128–133.

[16] E. Karatepe and T. Hiyama, "Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions," *IET Renew. Power Generat.*, vol. 3, no. 2, pp. 239–253, 2009.

[17] R. V. Rao and V. J. Savsani, *Mechanical Design Optimization Using Advanced Optimization Techniques*. London, U.K.: Springer-Verlag, 2012.

[18] S. R. Chowdhury and H. Saha, "Maximum power point tracking of partially shaded solar photovoltaic arrays," *Sol. Energy Mater. Sol. Cells*, vol. 94, no. 9, pp. 1441–1447, 2010.

[19] H. E. Perez, X. Hu, S. Dey, and S. J. Moura, "Optimal charging of Li-ion batteries with coupled electro-thermal-aging dynamics," *IEEE Trans. Veh. Technol.*, vol. 66, no. 9, pp. 7761–7770, Sep. 2017.

[20] X. Hu, H. E. Perez, and S. J. Moura, "Battery charge control with an electro-thermal-aging coupling," in *Proc. ASME Dyn. Syst. Control Conf.*, 2015, p. V001T13A002.

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