Hindawi
International Journal of Photoenergy
Volume 2021, Article ID 6648739, 10 pages
https://doi.org/10.1155/2021/6648739

Research Article

Study on the Influence of Light Intensity on the Performance of Solar Cell

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Received 26 November 2020; Revised 29 December 2020; Accepted 20 January 2021; Published 1 February 2021

Academic Editor: Hafiz Muhammad Ali

In order to solve the problem that the influence of light intensity on solar cells is easily affected by the complexity of photovoltaic cell parameters in the past, it is proposed based on the influence of light intensity on the power generation performance of solar cells. By analyzing the electrical performance parameters of photovoltaic cell trough solar energy and determining the influencing factors, discarding other weakly related parameters, and designing targeted research programs, according to the study of the impact of light intensity and temperature on the battery temperature changes, the performance of photovoltaic power generation was understood. The output voltage and current of the maximum power point were obtained. By analyzing its relationship with influencing factors, the impact analysis on the power generation performance of photovoltaic cells was realized. The experimental results show that the open circuit voltage, short-circuit current, and maximum output power of solar cells increase with the increase of light intensity. Therefore, it can be known that the greater the light intensity, the better the power generation performance of the solar cell.

1. Introduction

enewable energy generally includes solar energy, wind energy, water energy, biomass energy, marine energy, tidal energy, and geothermal energy [1, 2]. Among these renewable energy sources, solar energy is rich in resources and can radiate to every corner of the earth. Therefore, solar energy is recognized as one of the most potential energy for large-scale development and utilization in this century. It is proposed in document [3–5] that increasing the development and utilization of solar energy resources can not only alleviate the pressure of economic growth on the environment and ecology to a great extent but also slow down the high-speed consumption of fossil energy, which is of far-reaching significance for the clean and sustainable development of energy [6, 7]; the research on solar energy utilization technology began in the 1960s; after decades of development, photovoltaic and photothermal application technologies have matured and are now in the stage of commercial application [8]. Among them, the commercial solar water heater is widely used, with an efficiency of 60-70%. In some optical devices, solar cells, thermoelectric conversion systems, or spacecraft thermal control systems, radiation is the main heat transfer or energy conversion method. The special radiation characteristics generated when light is incident on the surface of periodic microstructures can effectively meet the industrial needs of this type of system [9].

Traditional fuel energy is declining day by day, and at the same time, there are about 2 billion people in the world who do not have normal energy supply. Searching for new energy has become an urgent issue facing mankind. With its unique advantages, solar energy has become the focus of attention. Because solar power has the advantages of cleanliness, safety, and resource versatility and adequacy that are unmatched by thermal power, hydropower, and nuclear power, solar power is considered to be the most important energy source in the 21st century. At present, there are two main methods to study the performance of solar photovoltaic cells: numerical simulation and finite element analysis. Kohan et al. established a three-dimensional numerical model of photovoltaic modules and TEG devices [10]. The purpose is to study the performance of a hybrid photovoltaic+TEG power generation system with a thermoelectric generator installed on the back of the photovoltaic module. The model ignores the complexity of the internal structure of the device and regards the device as a uniform medium, and the power output is modeled as an internal energy sink. The finite volume method is used to solve the control energy equation. The results show that under certain environmental conditions, a hybrid system can generate more electric energy than pure photovoltaic power generation. However, due to the insufficient temperature difference of the TEG plant, the increase is very small. In addition, the existence of triethylene glycol may have an adverse effect on the cooling of photovoltaic modules. Zandi and Razaghi et al. studied flat perovskite solar cells by a three-dimensional finite element method [11]. In order to fully characterize the proposed device, a hybrid optoelectronic modeling method is used. Compared with the experimental results, the accuracy of the model is verified. In this new structure, when the thickness of $CH_3NH_3SnI_3$ is 200 nm, the power conversion efficiency (PCE) increases from 14.32% to 15.32%. The short-circuit current j (SC) is improved by coating a 40 nm MGF (2) layer on the surface of PSC as an antireflection layer. The influence of periodic corrugated back and reflector on PSC is considered. The PCE of the new two-layer active PSC structure is up to 17.5% because of the periodic corrugation and the reflector replacing the flat back and the reflector, respectively.

In recent years, with the support of industrial policies and financial support, the application of the photovoltaic system has gradually begun to meet the conditions for large-scale commercial development. It can be predicted that the cost of photovoltaic power generation has significantly decreased. Although it is still higher than the traditional power generation mode, with the continuous development of technology, the new energy with solar energy as the main body will become the main body of energy supply in the future, which cannot be compared with and replaced by other renewable energy sources [12]. Most research activities at home and abroad focus on the research and development of parabolic cylindrical mirrors and Fresnel lens condenser systems. But the parabolic cylindrical surface and Fresnel lens surface are difficult to process, the precision is low, the cost is high, and the product life is short. It is not easy to popularize and apply. The constant voltage electronic load is used to simulate the function of battery charging; that is, the voltage at both ends of the load is stable and unchanged, and the generated current that changes with the light intensity at different times is released through the electronic load circuit to obtain the process of receiving light. In the application research of solar cells, it is very important to study the light intensity for the power generation performance of solar cells. In the previous research methods, due to the influence of various parameters of photovoltaic cells, it consumes too much useless electric energy and thermal energy and costs too much, and the overall cost performance of the research method is low. In view of this situation, a new research method of the influence of light intensity on the performance of solar cells is proposed.

2. Study on the Influence of Light Intensity on the Performance of Solar Cell

2.1. Determine the Influencing Factors of Photovoltaic Cell Power Generation Performance. The manufacturing methods of photovoltaic cells vary, but there are mainly the following types: monocrystalline silicon cell, polycrystalline silicon cell, amorphous silicon cell, chromium telluride cell, Gu selenium copper cell, etc. [13]. Table 1 shows the types and characteristics of common photovoltaic cells.

Based on the characteristics of different types of photovoltaic cells mentioned above, it is determined that monocrystalline silicon photovoltaic cells are mostly used in trough solar energy. Under the condition of constant light intensity, the photocurrent produced by the solar cell does not change with time. Therefore, it can be equivalent to an ideal constant current source [14]. Part of the photogenerated current flows into the load R_0 of the external circuit, which is defined as the current I_0, forming the terminal voltage U_0 at both ends of the external circuit; I_d is the dark current, which is opposite to the photogenerated current. When the voltage is positively biased to the equivalent diode of the PN junction, the current will be generated; due to the contact between the front electrode and the back electrode, and the material itself having a certain resistivity, it is not allowed to flow into the external circuit in the middle to avoid the introduction of additional resistance; it can be regarded as a series resistance R_1 in the equivalent circuit; in the equivalent circuit, a parallel resistance R_1 is often used, because in the process of making the battery, leakage will occur on the edge of the battery, and the metal leakage will be caused by tiny cracks and scratches when making the metalized electrode, which will lead to a part of the electric abortion that should have passed through the load. The phenomenon of short-circuit can be improved by using resistance to equivalent this phenomenon. To sum up, the solar cell can be equivalent to a single diode five-parameter circuit model. The five parameters are the photovoltaic cell current I_{ph}, the equivalent diode reverse saturation current I_c, the junction capacitance C_0, the series resistance R_1, and the parallel resistance R_2.

According to the circuit principle and Shockley's diffusion theory, the $I-V$ equation of photovoltaic cells can be obtained. As shown below,

$$I_0 = I_{\mathrm{ph}} - I_c\left\{\exp\left[\frac{q(V+R_1I_0)}{n\kappa T}\right]-1\right\} - \frac{V+R_1I_0}{R_2}. \quad (1)$$

In the formula, q represents the electronic charge (1.6×10^{-19} C), n represents the diode factor (value range is 1-5), κ represents the Boltzmann constant (1.38×10^{-23} J/K), and T represents the absolute temperature.

According to the current-voltage relationship of the working state of photovoltaic cells in Formula (1), the factors describing the power generation performance of slot solar photovoltaic cells, namely, the main parameters of photovoltaic cells, are determined as follows.

Open circuit voltage: the voltage at the output when the photovoltaic cell circuit disconnects the load.

Table 1: Types and characteristics of common photovoltaic cells.

Type	Monocrystalline silicon	Polysilicon	Amorphous silicon
Photoelectric conversion efficiency	12%~17%	10%~15%	6%~8%
Service life	15-20 years	15-20 years	5-20 years
Average price	Expensive	More expensive	Cheaper
Stability	Good	Good	Poor (attenuated)
Colour	Black	Navy blue	Brown
Main features	The photoelectric conversion efficiency is higher than other types of batteries, with high reliability and relatively high cost	Stable and reliable operation, low cost, can be widely used, but compared with monocrystalline silicon, the conversion efficiency is lower	Low price, mostly used in calculators, electronic watches, etc., with the lowest conversion efficiency

Short-circuit current: the current flowing through the short contact when the output terminal of photovoltaic cells is short-circuited.

Curve factor (also called filling factor): in order to correct the difference between the ideal photovoltaic cell volt-ampere characteristic curve and the actual photovoltaic cell, curve factor [15] is introduced. Define the curve factor as

$$\chi = \frac{I_{p\ \max} \times U_{p\ \max}}{I_{sc} \times U_{oc}} = \frac{P_{\max}}{I_{sc} \times U_{oc}}. \quad (2)$$

In the formula, I_{sc} represents short-circuit current, U_{oc} represents open circuit voltage, $P_{\max}$ represents maximum power, $I_{p\ \max}$ represents optimal working current, $U_{p\ \max}$ represents optimal working voltage, and $I_{p\ \max}$ represents optimal working current. The ideal curve factor of battery characteristics is 1. Generally, the curve factor is between 0.5 and 0.8.

Conversion efficiency: under standard test conditions, the ratio of the maximum output power when the external circuit of the photovoltaic cell is connected to the optimal load to the solar incident operation. The standard test conditions for determining the influence factors and determining the influence of light intensity on the power generation performance of slot solar photovoltaic cells are as follows: the solar spectrum distribution and the ambient temperature are 25 ± 1°C when the atmospheric quality is AM1.5 [16].

2.2. Research Scheme Design of the Influence of Light Intensity on the Power Generation Performance of Photovoltaic Cells. Based on the solar energy storage and heating system of the 12th Five-Year Plan National Science and Technology project, this paper studies the influence of light intensity on the power generation performance of solar cells under constant resistance load. The schematic diagram of slot solar energy heat storage and heating system is as shown in Figure 1 [17].

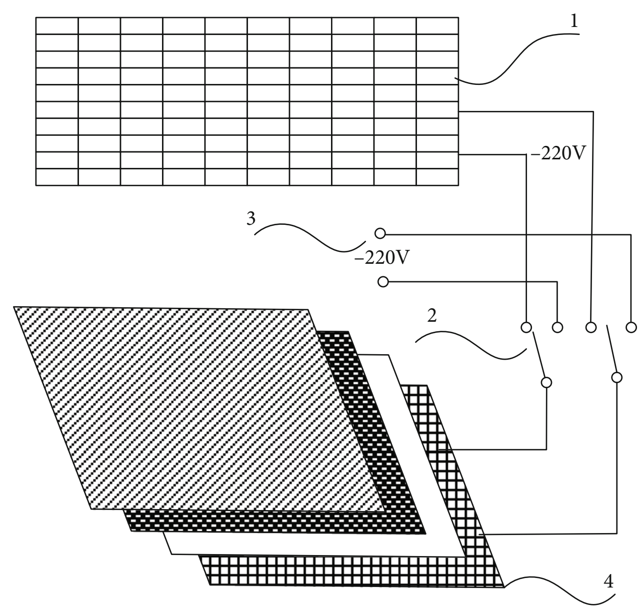


Figure 1: Schematic diagram of heat storage and heating system for photovoltaic power generation.

In Figure 1, the mark 1 indicates solar photovoltaic panel, 2 indicates automatic power switching device, 3 indicates 220 V AC household power supply, and 4 indicates far-infrared heating soft plate and pebble thermal reservoir. The trough type solar photovoltaic power generation heat storage and heating system refers to the photovoltaic cell as the power source, as the energy conversion carrier to convert direct current into heat energy, which is the far-infrared thermal fiber soft board with constant resistance value, which stores the heat energy in the indoor floor tiles or the heat storage medium pebble layer under the floor [18]. The heating form is to store the heat energy in the daytime and release the heat energy at night. In order to reduce the self-loss of the inverter device, the photovoltaic cell is directly connected with the heating load in the working process of the photovoltaic cell, which is energy delay utilization, electrothermal integration, and effective energy conversion technology [19].

In order to simulate the working state of the residential trough solar photovoltaic power supply system, the same type of polysilicon photovoltaic cell module and its matching far-infrared thermal fiber soft board with constant resistance value are used [20]. The technical parameters of polysilicon PV modules used in the impact study are shown in Table 2.

In order to obtain the power generation performance data of photovoltaic cells under different light intensity, the research data were tested in a certain area for six consecutive months and measured in half an hour from 8.00 a.m. every

Table 2: Technical parameters of polysilicon photovoltaic cell module.

Type	Project	Parameter
Working parameters	Peak power P/W	245 W
	Maximum working voltage U/V	30.2 V
	Maximum working current I/A	8.13A
	Open circuit voltage U/V	37.5 V
	Short-circuit current I/A	8.68A
Temperature coefficient	Standard operating temperature (°C)	46 ± 2
	Peak power temperature coefficient (%/°C)	-0.45
	Open circuit voltage temperature coefficient (%/°C)	-0.37
	Temperature coefficient of short-circuit current (%/°C)	0.06
Operating conditions	Reverse current	Do not load an external voltage greater than the open circuit voltage
	Front maximum static load	2400 Pa
	Maximum static load on opposite side	2400 Pa

day. Research data were obtained such as photovoltaic cell temperature, photovoltaic cell surface light intensity, photovoltaic cell output voltage, and current.

For the measurement of the temperature of photovoltaic cells, the actual power generation of photovoltaic cells depends not only on the solar radiation absorbed and transmitted but also on the actual operating temperature of photovoltaic cells. When the rated temperature is increased by 1°C, the output of photovoltaic cells will be reduced by about 0.5% of the rated capacity. Therefore, it is necessary to determine the actual operating temperature of photovoltaic cells in a day. A RC-4 temperature recorder is used to measure the temperature of photovoltaic cells. In order to measure the temperature of photovoltaic cells more accurately, temperature sensors are pasted on the surface and back of photovoltaic cells.

For the measurement of light intensity on the surface of the photovoltaic cell module, a Tm-207 solar power meter was used to measure the light intensity on the surface of photovoltaic cells. Five light intensity values are quickly measured each time, which are the light intensity values of four corners and their centers of the photovoltaic panel, and then, the average value is the light intensity of the photovoltaic panel surface.

For the measurement of output voltage and current of the photovoltaic cell module, in this test, a DC voltmeter and a DC ammeter are used to measure the output voltage and current of photovoltaic cells at the same time [9].

Based on the above research scheme, the influence of different light intensities on the performance of solar cell power generation is studied.

2.3. Calculation of Incident Angle and Surface Radiation. During the outdoor operation of photovoltaic cells, with the rotation of the earth and the rotation around the sun, the solar direction on the surface of photovoltaic cells changes at all times, so it is necessary to calibrate the different positions of the sun. The angle of intersection between the sun's light and the equatorial plane is the declination angle of the sun, which is represented by ω. In the northern hemisphere of the earth, the change range of solar declination angle ω is ±23°27'. According to Cooper's equation,

$$\omega = 23.45 \sin \left[\frac{360}{365}(284 + n)\right]. \tag{3}$$

In the formula, n represents the number of days from January 1 of any year [10]. The angle between the sun's rays and the sun's rays projected on the ground is the sun's height angle, which is expressed by γ. The angle between the projection of the sun's horizontal plane and the true north direction is the sun's azimuth, which is represented by β. When the earth rotates, the sun's altitude angle and azimuth angle will change accordingly; that is, the sun's time angle λ will be considered:

$$\lambda = \nu T. \tag{4}$$

In the formula, ν represents the earth's rotation velocity $(15°/h)$ and T represents the time from noon (defined as positive in the morning and negative in the afternoon) [11]. Define ϕ as the local latitude, and calculate the solar altitude angle γ and solar azimuth angle β:

$$\gamma = \arcsin\left(\sin\phi \sin\omega + \cos\phi \cos\lambda\right), \tag{5}$$

$$\beta = \arccos \frac{\sin\gamma \sin\phi + \cos\phi \cos\phi \cos\lambda}{\cos\gamma \cos\phi}. \tag{6}$$

The solar radiation angle on the surface of photovoltaic cells is different with different tilt angles. According to the research of scholars, the radiation quantity of an inclined plane can be divided into three parts: direct solar radiation quantity, ground reflected solar radiation quantity, and scattering radiation quantity. It is assumed that the sky scattering radiation quantity is evenly distributed. According to this characteristic, many scholars also put forward different models and different calculation methods for sky scattering. Based on the research models of various researchers, the hay model is used to calculate the radiation intensity and radiation amount on various inclines. The hay model is shown in the following formula:

$$H_S = H_z + H_f + H_t. \tag{7}$$

In the formula, H_S represents the total radiation of the inclined plane, H_z represents the direct radiation of the inclined plane, H_f represents the reflected radiation of the ground, and H_t represents the scattered radiation of the sky. The calculation formulas of the direct radiation quantity of the inclined plane, the reflection radiation quantity of the ground, and the sky scattering radiation quantity are as follows:

$$H_z = H_1 + K_1, \tag{8}$$

$$K_1 = \frac{\cos(\sigma - \psi) - \cos\omega \sin\lambda + \pi/180\omega \cdot \sin(\sigma - \psi) \cdot \sin\omega}{\cos\sigma \cos\omega \sin\lambda + \pi/180\omega \cdot \sin\sigma \sin\omega}, \tag{9}$$

$$H_f = \frac{\mu}{2} H(1 - \cos\psi), \tag{10}$$

$$H_t = H_2 \left[\frac{H_1}{H_0} K_1 + \frac{1}{2}(1 + \cos\psi)\left(1 - \frac{H_1}{H_0}\right) \right]. \tag{11}$$

In the above formula, H_1 represents the horizontal direct radiation amount, K_1 represents the ratio of the inclined plane direct radiation amount to the horizontal plane direct radiation amount, σ represents the local latitude, ψ represents the tilt angle of the battery board, μ represents the ground reflection coefficient, H represents the total horizontal radiation amount, H_2 represents the horizontal plane scattering radiation amount, and H_0 represents the total horizontal plane solar radiation amount outside the atmosphere. Different angles and different light intensities have different effects on the performance of solar cells. When the light is radiated to the photovoltaic cell material, some of the incident light is reflected or scattered on the surface, and some of it is absorbed by the photovoltaic cell. Assuming the incident light energy is G, the light energy at the distance L from the surface

$$G_0 = G \cdot \exp(-\rho L). \tag{12}$$

ρ in the formula represents the absorption coefficient of crystalline silicon in photovoltaic cells. The absorption coefficient of crystalline silicon material is larger than $10^5\,\text{cm}^{-1}$. Therefore, it can absorb most of the solar energy. The light absorbed by the crystal silicon cell makes the electrons with lower energy in silicon jump to a higher energy level. When the transition takes place in the conduction band or valence band, there are no excess nonequilibrium carrier electrons or holes, only the energy is exchanged with the lattice, and finally, the light energy is converted into heat energy. Only the photon whose energy is larger than the forbidden bandwidth is absorbed; it is possible to make the electron transition from the valence band to the conduction band and produce the electron-hole pair. Therefore, the absorption of light leads to the generation of unbalanced carriers, the increase of total carrier concentration, and conductivity. The photovoltaic effect occurs in crystalline silicon solar cells. When the external circuit is turned on, the current is generated. The condition for the above reaction is that the incident light energy is larger than the bandgap width M of the crystalline silicon battery, according to the formula

$$\frac{Bv}{\xi} = Bf > M. \tag{13}$$

In the formula, B represents Planck constant, v represents light speed, ξ represents light wavelength, and f represents light frequency. Only the incident light whose wavelength is less than ξ can be absorbed by the photovoltaic cell. In conclusion, in the study of the influence of light intensity on the power generation performance of solar cells, the incident angle of light and the absorption of light by solar cells need to be considered [12].

Table 3: Output voltage and current data of maximum power point under different light intensities.

Light power (W/m^2)	Voltage (V)	Electric current (A)	Light power (W/m^2)	Voltage (V)	Electric current (A)
50	170	0.6	450	350	5.5
100	270	1.8	500	329	6.5
150	340	1.4	550	352	6.4
200	348	1.7	650	346	5.8
250	346	2.3	700	348	6.4
300	324	3.3	750	363	6.7
400	349	4.5	800	375	7.2

2.4. Qualitative Study on Power Generation Performance of Trough Solar Photovoltaic Cells

2.4.1. Light Affects the Output Characteristics of Photovoltaic Cells. Under the same temperature of different light intensities, the test output characteristics of crystalline silicon solar cells are shown in Table 3. It can be seen from the table that with the change of light intensity, the output voltage V_m and current I_A at the maximum power point of the trough solar photovoltaic cell change.

Know from Table 3 that with the increase of light intensity from 50 W/m^2 to 800 W/m^2, the maximum power point output current of the photovoltaic cell increases linearly from less than 1 A to more than 7 A. When the light intensity reaches 150 W/m^2, the output voltage of the maximum power point of the photovoltaic cell quickly climbs from 200 V to about 300 V. when the light intensity is greater than 200 W/m^2, with the increase of the light intensity, the voltage is approximately the same, and it fluctuates at about 340 V.

Based on the above data, the influence of light on the performance of solar cells is analyzed by using the determined influence factors. Under different light intensities, the total energy of light on the battery board is different. The short-

Table 4: Temperature, output voltage, and current of the photovoltaic cell.

Temperature range of photovoltaic cell	Average output voltage	Average output current
24~28	31.36	5.71
32~36	30.21	5.55
40~44	29.35	5.41
48~52	28.90	5.33
56~60	27.67	5.13

circuit current of crystalline silicon solar cells is closely related to the incident photon energy. Therefore, the quantum efficiency/collection efficiency (QE) is defined to characterize the relationship between the photocurrent and the incident light on the surface of crystalline silicon solar cells. QE is an energy function, which is usually expressed by internal quantum efficiency, that is, the ratio of the number of photogenerated carriers that contribute to the short-circuit current to the number of photons absorbed by the battery. Therefore, with the increase of light intensity, the number of effective carriers increases. When the crystalline silicon solar cell is short-circuited, the measured current is the short-circuit current.

For the short-circuit current, it can be seen from the above data that the short-circuit current of the battery increases linearly with the increase of the light intensity; for the open circuit voltage, when the temperature of the photovoltaic panel is constant, the short-circuit current of the panel increases linearly with the increase of the light intensity, and the open circuit voltage of the panel increases logarithmically. After calculation, the curve factor is between 0.71 and 0.82.

2.4.2. Temperature Affects the Output Characteristics of Photovoltaic Cells. The light intensity loading on the panel will cause its own temperature change. Therefore, the light intensity on the surface of the PV module and the corresponding output voltage and current data are analyzed under different temperatures of the PV cell. Due to the packaging of photovoltaic modules, the temperature data of the back surface of the surface muscle area of photovoltaic modules are measured, respectively, and the average value is the photovoltaic panel temperature. Then, the influence of the temperature change of the photovoltaic cell on the output voltage and current is shown in Table 4.

Through the data in Table 3, we can know the relationship between the temperature of the photovoltaic cell itself and the output voltage and current and analyze the photoelectric conversion rate of the photovoltaic cell [13]. The photoelectric conversion rate of the photovoltaic cell is the ratio of the output power of the photovoltaic cell to the total solar radiation power radiated on the surface of the photovoltaic cell:

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}}. \tag{14}$$

Table 5: Data under different light intensities.

Light intensity	Voltage	Power supply	Input light power	Output power	Conversion rate
183.2	9.60	4.64	304.24	11.99	4.09
232.8	10.5	1.98	381.05	21.29	5.63
313.7	14.6	2.70	513.34	40.25	8.06
359.8	16.40	3098	588.94	48.54	9.4
439.2	20.65	3.78	718.74	78.44	10.91
518.1	22.50	4.15	848.03	92.70	13.45
553.0	25.80	4.76	905.15	122.81	13.57
575.9	27.00	4.98	842.03	95.31	13.46
637.4	28.10	5.12	1043.31	158.45	14.56
718.6	29.25	5.46	1198.45	169.12	14.11

In the formula, P_{out} represents the output power of the cell, P_{in} represents the total solar radiation power projected on the surface of the photovoltaic cell, and η represents the photoelectric conversion rate. Because the influence of the temperature of the photovoltaic cell on its output power and conversion occurs at the same time, the two factors are analyzed together in the subsequent analysis and research.

The output voltage, output current and corresponding input light power, output power, and conversion efficiency of the PV module under the light intensity from small to large are shown in Table 5.

According to the data in Table 5, the output power of photovoltaic cells increases gradually with the increase of light intensity. When the light intensity increases to about 700, the output power tends to be saturated; when the light intensity is greater than 650, the growth rate of P_{out} is less than that of P_{in}. According to the conversion rate formula of photovoltaic cells, the photovoltaic conversion rate of photovoltaic cells will gradually decrease with the increase of light intensity [14].

Through the above research and analysis, it is concluded that the output voltage, current, and photoelectric conversion rate of solar photovoltaic cells are closely related to the light intensity and the cell temperature. For the photovoltaic cells with constant resistance load, the output voltage, current, and output power of the photovoltaic cells decrease obviously with the increase of the temperature of the photovoltaic cells, and the photoelectric conversion rate of the photovoltaic cells shows a linear downward trend.

The temperature of photovoltaic cells has a great negative impact on their power generation performance. Therefore, it is necessary to take cooling measures for photovoltaic cells [15]. For example, the installation mode of solar photovoltaic cells should try to ensure the air circulation on the upper and lower sides of the photovoltaic cells to maintain rapid heat dissipation; when the photovoltaic power station battery panels are arranged in groups, they should be arranged in staggered rows as much as possible.

3. Experimental Study

3.1. Experimental Data Simulation. In the experimental study of the influence of light intensity on the performance of solar

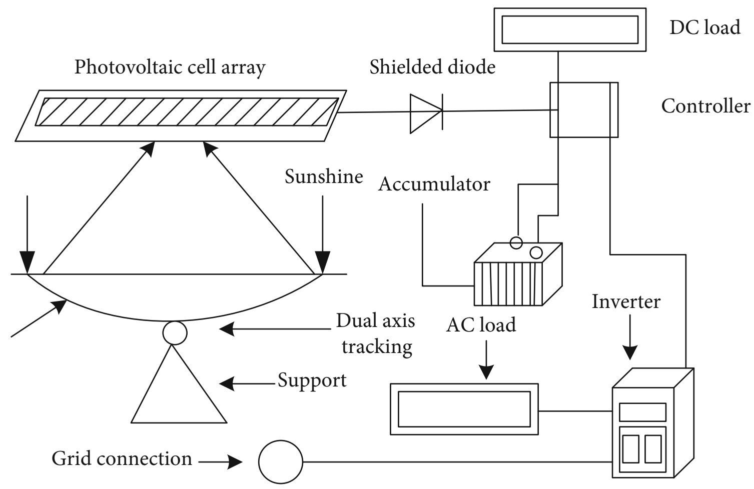


Figure 2: Trough type concentrating photovoltaic power generation system.

Figure 3: Slot collector.

energy generation of trough photovoltaic cells, the trough concentrated photovoltaic power generation system with high cost performance is used, as shown in Figure 2.

The annual total power generation and heat gain are analyzed as experimental research data, and the investment cost of research methods for the influence of different light intensities on the power generation performance of photovoltaic cells is carried out. The trough collector and concentrating photovoltaic cell used in the experiment are shown in Figure 3.

The daylighting area of the trough concentrator is 1.82 m^2, and the volume of the heat storage tank is 80 L. The calculation formula of electric efficiency and thermal efficiency of the trough photovoltaic power generation system is as follows:

$$J_{el} = \frac{P_{max}}{W_d \cdot S_m}, \tag{15}$$

$$J_{th} = \frac{l_m \cdot C_0 \cdot (T_{out} - T_{in})}{W_d \cdot S_m}. \tag{16}$$

In the formula, J_{el} represents the electrical efficiency, J_{th} represents the thermal efficiency, P_{max} represents the maximum output power of the battery array, S_m represents the daylighting area of the trough concentrating mirror, W_d represents the direct solar radiation, l_m represents the mass flow of cooling working fluid water, C_0 represents the specific heat capacity of cooling working fluid at constant pressure under the average temperature, T_{out} represents the outlet temperature of cooling working fluid, and T_{in} represents the inlet of cooling working fluid temperature. In the unit area, according to the light intensity, the energy generation model of the trough solar photovoltaic cell, the electrical energy, and thermal energy coefficient of the trough concentrated photovoltaic power generation system are

$$D_e = J_{el} \cdot W_d. \tag{17}$$

The calculated monthly power and heat output of the trough type concentrated photovoltaic power generation system are shown in Table 6.

The difference in direct solar radiation per month has an effect on the monthly power output and heat output of solar cells. The higher the direct radiation is, the higher the light intensity is. Because of the different seasons, the light intensity of each month is different. It can be seen from the data in the table that the greater the average direct radiation in

Table 6: Monthly power and heat output of trough type concentrated photovoltaic power generation system.

Month	Monthly average direct radiation (MJ/m^2)	Electric efficiency (%)	Thermal efficiency (%)	Monthly power generation (kW·h)	Monthly heat production (MJ)
January	289.30	4.21	52.7	7.26	148.50
February	301.44	4.25	53.2	7.74	167.92
March	381.53	4.29	51.7	7.64	178.85
April	382.54	4.19	50.9	8.12	195.28
May	364.21	4.23	51.5	6.74	164.52
June	265.36	4.20	51.3	4.25	94.52
July	192.39	4.21	52.4	4.16	88.03
August	211.52	4.16	52.6	3.95	95.26
September	187.36	4.12	53.1	3.84	94.21
October	198.64	4.12	53.9	3.69	117.62
November	238.51	4.16	53.4	4.14	113.25
December	264.84	4.23	53.7	5.38	126.41

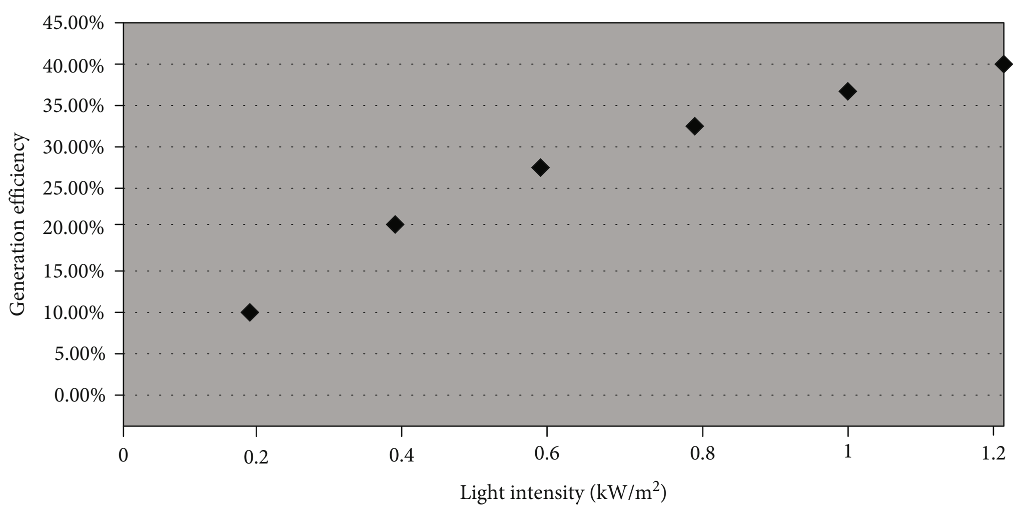


Figure 4: Power generation efficiency of photovoltaic cells.

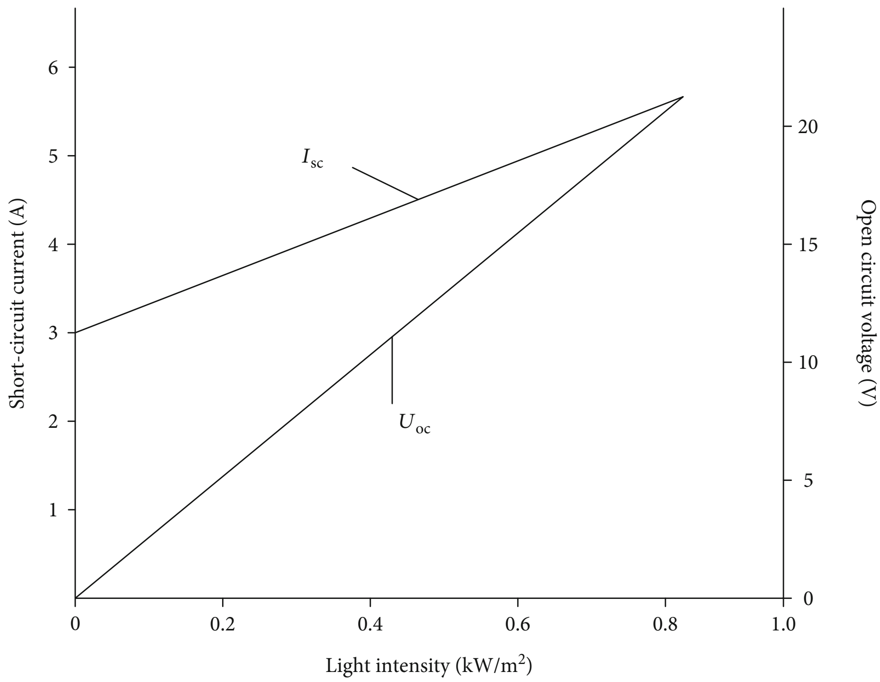
the current month, the greater the monthly power and heat output of the trough type concentrated photovoltaic power generation system.

Set the light intensity of the six points as 0.2 kW/m^2, 0.4 kW/m^2, 0.6 kW/m^2, 0.8 kW/m^2, 1.0 kW/m^2, and 1.2 kW/m^2, the maximum output power is 20.7 W; the surface light power of the trough solar photovoltaic cell is 297.4 W, and the efficiency of the trough solar photovoltaic cell is 6.96%. Draw the experimental results into the scatter diagram as Figure 4.

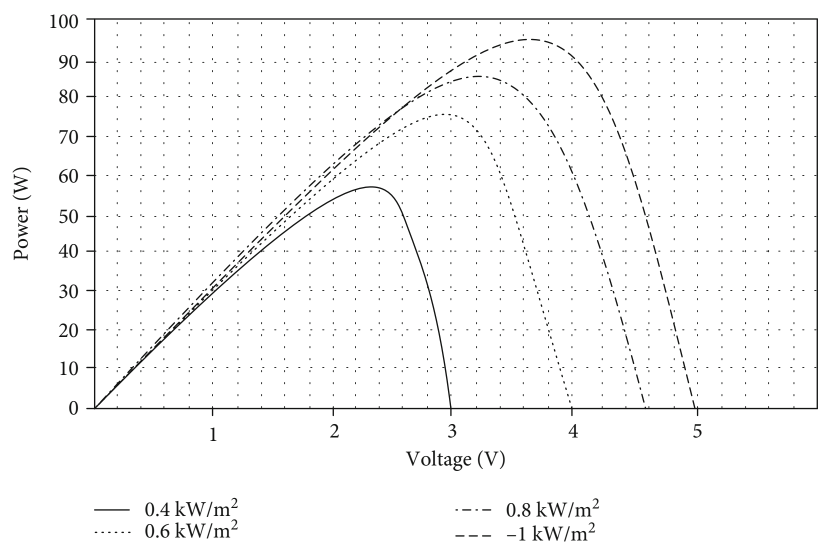
Figure 4 shows the power generation efficiency of the trough solar photovoltaic cell. The maximum power generation efficiency of the trough solar photovoltaic cell is 40% when the light intensity is 1.2 kW/m^2. It can be seen that, with the gradual increase of the light intensity, the power generation efficiency of the photovoltaic cell under the research method of the influence of the light intensity designed in this paper on the power generation performance of the trough solar photovoltaic cell is also increased.

3.2. Experimental Results and Analysis of Maximum Output Power. Firstly, the random illumination model is used as the input condition to observe the change of basic parameters I_{SC} and U_{OC}. Then, set the light intensity to 1 kW/m^2, 0.8 kW/m^2, 0.6 kW/m^2, and 0.4 kW/m^2, respectively, and observe the change of the output power curve of the trough solar photovoltaic cells.

It can be seen from Figure 5(a) that the increase of light intensity has an impact on both the short-circuit current and the open circuit voltage, but it has a greater impact on the former, which is consistent with the actual situation, proving the effectiveness of the model established in this paper. As can be seen in Figure 5(b), the change of light intensity has a very obvious effect on the maximum power output of solar cells, and it shows a linear downward trend with the gradual decrease of light intensity. When the light intensity is 1 kW/m^2, the maximum output power is as high as 95 W. When the light intensity is reduced to 0.4 kW/m^2, the maximum output power is also reduced to 57 W. It can



(a) Influence of different illumination on short-circuit current and open circuit voltage



(b) The effect of specific illumination on output power

Figure 5: Effect of light intensity change on output characteristics of maximum utilization of electric energy of photovoltaic cells.

be seen that the light intensity has a certain impact on the power generation performance of trough solar photovoltaic cells, and the lower the light intensity is, the less the power generation capacity is.

4. Conclusion

This paper studies the influence of light intensity on power generation performance of trough solar photovoltaic cells. Through reasonable analysis of the electrical performance parameters of photovoltaic cells, the influencing factors are determined and targeted research and analysis are conducted. It is concluded that when the light intensity gradually increases, the open circuit voltage and short-circuit current of the trough solar photovoltaic cell gradually increase; the open circuit voltage and short-circuit current of the trough solar photovoltaic cell gradually increase. The maximum output power increases with the light intensity, large and enlarged to solve the problems of traditional research methods. With the gradual increase of light intensity, the power generation efficiency of photovoltaic cells under the research method of light intensity on the power generation performance of trough solar photovoltaic cells designed in this paper also increases. Certain help and data support are provided for follow-up research to promote the application and development of solar photovoltaic cells in the future.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding authors on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. Z. Sahin, K. G. Ismaila, B. S. Yilbas, and A. Al-Sharafi, "A review on the performance of photovoltaic/thermoelectric hybrid generators," *International Journal of Energy Research*, vol. 44, no. 5, pp. 3365–3394, 2020.

[2] M. H. Ahmadi, A. Baghban, M. Sadeghzadeh et al., "Evaluation of electrical efficiency of photovoltaic thermal solar collector," *Engineering Applications of Computational Fluid Mechanics*, vol. 14, pp. 545–565, 2020.

[3] Y. Wu, Z. Wang, M. Liang et al., "Influence of nonfused cores on the photovoltaic performance of linear triphenylamine-based hole-transporting materials for perovskite solar cells," *ACS Applied Materials & Interfaces*, vol. 10, no. 21, pp. 17883–17895, 2018.

[4] Y. Lu, G. Li, Y. G. Akhlaghi et al., "Effect of grid and optimization on improving the electrical performance of compound parabolic concentrator photovoltaic cells," *Solar Energy*, vol. 196, pp. 607–615, 2020.

[5] M. Zamen, A. Baghban, S. M. Pourkiaei, and M. H. Ahmadi, "Optimization methods using artificial intelligence algorithms to estimate thermal efficiency ofPV/T system," *Energy Sci. Eng.*, vol. 7, no. 3, pp. 821–834, 2019.

[6] P. Zhang, Z. Ling, G. Chen, and B. Wei, "Influence of thermal annealing-induced molecular aggregation on film properties and photovoltaic performance of bulk heterojunction solar cells based on a squaraine dye," *Frontiers of Materials Science*, vol. 12, no. 2, pp. 139–146, 2018.

[7] C.-C. Chang, W. J. M. Kort-Kamp, J. Nogan et al., "High-temperature refractory metasurfaces for solar thermophotovoltaic energy harvesting," *Nano Letters*, vol. 18, no. 12, pp. 7665–7673, 2018.

[8] M. A. M. Ramli and H. R. E. H. Bouchekara, "Estimation of solar radiation on PV panel surface with optimum tilt angle using vortex search algorithm," *IET Renewable Power Generation*, vol. 12, no. 10, pp. 1138–1145, 2018.

[9] Y. Wang, Y. Zhang, G. Lu et al., "Reconstructing space- and energy-dependent exciton generation in solution-processed inverted organic solar cells," *ACS Applied Materials & Interfaces*, vol. 10, no. 16, pp. 13741–13747, 2018.

[10] H. R. F. Kohan, F. Lotfipour, and M. Eslami, "Numerical simulation of a photovoltaic thermoelectric hybrid power generation system," *Solar Energy*, vol. 174, pp. 537–548, 2018.

[11] S. Zandi and M. Razaghi, "Finite element simulation of perovskite solar cell: a study on efficiency improvement based on structural and material modification," *Solar Energy*, vol. 179, pp. 298–306, 2019.

[12] S. Yoon, S. H. Lee, J. C. Shin et al., "Photoreflectance study on the photovoltaic effect in InAs/GaAs quantum dot solar cell," *Current Applied Physics*, vol. 18, no. 6, pp. 667–672, 2018.

[13] O. Kaspi, A. Yosipof, and H. Senderowitz, "Pv analyzer: a decision support system for photovoltaic solar cells libraries," *Mol. Inform.*, vol. 37, no. 9-10, p. 1800067, 2018.

[14] Y. Liu, P. Cheng, T. Li et al., "Unraveling sunlight by transparent organic semiconductors toward photovoltaic and photosynthesis," *ACS Nano*, vol. 13, no. 2, pp. 1071–1077, 2019.

[15] L. R. Diaz, B. Cocilovo, A. Miles, W. Pan, P.-A. Blanche, and R. A. Norwood, "Optical and mechanical tolerances in hybrid concentrated thermal-PV solar trough," *Optics Express*, vol. 26, no. 10, pp. A602–A608, 2018.

[16] F. Yang, F. Yang, G. Wang, T. Kong, H. Wang, and C. Zhang, "Effects of water temperature on tissue depletion of florfenicol and its metabolite florfenicol amine in crucian carp (_Carassius auratus gibelio_) following multiple oral doses," *Aquaculture*, vol. 515, p. 734542, 2020.

[17] Z. Wu, Y. Liu, and X. Jia, "A novel hierarchical secret image sharing scheme with multi-group joint management," *Mathematics*, vol. 8, no. 3, p. 448, 2020.

[18] H. Cheng and Y. Liu, "An improved RSU-based authentication scheme for VANET," *Journal Internet Technology*, vol. 21, pp. 1137–1150, 2020.

[19] N. Gao, B. Cheng, H. Hou, and R. Zhang, "Mesophase pitch based carbon foams as sound absorbers," *Materials Letters*, vol. 212, pp. 243–246, 2018.

[20] N.-S. Gao, X.-Y. Guo, B.-Z. Cheng, Y.-N. Zhang, Z.-Y. Wei, and H. Hou, "Elastic wave modulation in hollow metamaterial beam with acoustic black hole," *IEEE Access.*, vol. 7, pp. 124141–124146, 2019.