PREDICTION OF STRUCTURAL MECHANICAL PROPERTIES OF ENERGY-SAVING MATERIALS FOR SOLAR PHOTOVOLTAIC PHOTO-THERMAL SYSTEM BASED ON DEEP LEARNING

by

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In order to study the annual operating efficiency of solar photovoltaic/photo-thermal collectors, this paper proposes a prediction of structural mechanical properties of energy-saving materials for solar photovoltaic photo-thermal systems based on deep learning. Based on the test data of a solar photovoltaic module, the performance of photovoltaic photo-thermal module is evaluated from the perspectives of the First law of thermodynamics, the Second law of thermodynamics, power generation efficiency and heat collection efficiency. The experimental results show that the working temperature difference increases from 6.8 K to 45.3 K, the normalized temperature difference increases from to, and the power generation efficiency decreases from 0.105 to 0.095 by 0.010, the percentage of change is 9.4%, the heat collection efficiency is reduced from 0.4534 to 0.2120 by 0.2414, and the reduction rate is 53%, compared with the generation efficiency and heat collection efficiency, the efficiency changes during the test period are relatively small. In conclusion for photovoltaic/photo-thermal components, environmental parameters have a greater impact on the heat collection efficiency.

Key words*: solar photovoltaic photo-thermal module, deep learning, heat collection efficiency, power generation efficiency*

Introduction

With the growth of the population and the continuous development of people's lifestyle, people's demand for fossil energy is increasing, which leads to the aggravation of pollution and hinders the sustainable and healthy development of the economy. Researchers have been working to develop RES to change the energy mix and relieve the pressure of rapid energy consumption, due to its abundant resources and friendly environment, it has attracted much attention in the past decades [1]. At present, solar energy mainly includes photo-thermal technology for electricity production, photovoltaic energy production for electricity production, photo-thermal energy production and photochemical conversion. The calculation results show that photovoltaic photo-thermal (PV/T) system can be generated and independent on the basis of reducing the collector area by 40% [2].

In recent years, scholars at home and abroad have studied different application modes and application scenarios of solar PV/T system, some domestic enterprises have also started to produce PV/T, but it involves power generation and heat utilization, so how to evaluate PV/T performance evaluation has become an urgent problem, as shown in fig. 1.

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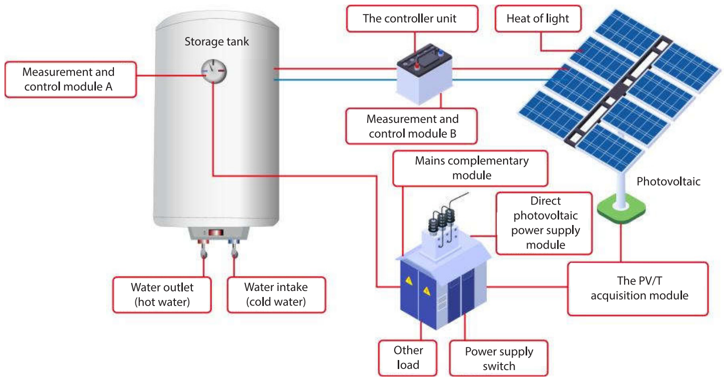

Figure 1. Solar PV/T system and its control method and process

Studies show that ordinary PV/T modules can only convert 4-17 of the incident solar radiation into electrical energy, and more than 50 of the solar radiation more will be converted into heat energy on the surface of the collector. Too much of the temperature of the PV system will not only reduce the energy production of the system, but also cause irreversible damage to PV modules. In recent years, PV/T system has been applied more and more widely, this system can utilize the heat energy on the surface of the system while generating PV power, which effectively solves the problem of excessive panel temperature in PV system, it also improves the utilization efficiency of solar energy [3].

Literature review

The solar PV/T collector was put forward by Mike *et al*. in 1976. It is a device that integrates solar cells and solar collectors. While generating electric energy, the cooling fluid (such as air or water) in the collector module moves and uses the PV residual heat. The device cannot only improve the comprehensive utilization efficiency of solar energy, but also meet the users' demand for both photo-thermal and photoelectric energy.

Li *et al.* [4] proposed a new artificial photosynthesis model, by integrating a PV water splitting unit with a solar-heated CO_2 hydrogenation unit, achieve scalable production at the square meter level, at a lower cost (equivalent to 1/7 of the reported artificial photosynthetic system), a solar powered 19.4% solar-chemical energy efficiency (STC) synergy was successfully achieved, for CO production (2.7 times higher than the state of the art of large artificial photosynthesis systems). In addition, 1.268 m^2 outdoor artificial photosynthesis demonstration showed that CO production was 258.4 Lpd, and STC produced by CO in winter was about 15.5%, operating costs can be recovered within 833 suuny days by selling CO. Zhong, *et al.* [5] studied the effect of CeO_2-water nanofluid on the performance of flat plate solar collector. Two flat panel solar water heating systems were manufactured, one for the conventional mode and the other for the heat exchanger mode, with a daily capacity of 100 L and a collector area of 2 m^2. In heat exchanger mode, a stepped heat exchanger is used to transfer heat from the collector to the water. The average particle size of 25 nm and the lower volume fraction of 0.05% were considered in the experimental study. Polyvinylpyrrolidine (PVP) was used in the experiment, but it was not used as a surfactant [5].

Based on the test data of the National Solar Water Heater Quality Supervision and Inspection Center, and on the basis of domestic and foreign literature research, this paper proposes an evaluation method of solar PV/T modules, which can be used to guide the performance evaluation of PV/T and promote the application of this technology.

Methods

Working principle of solar PV/T module

Theoretical research shows that the maximum theoretical photoelectric conversion of monocrystalline silicon solar cell is about 30. According to some light sources, the voltage of the solar cell decreases with the increase at its own temperature, which reduces the output of the battery. The energy output is less than 0.3 for each increase of 1 °C. In the process of practical application, the use of module surface light and soil will also affect the energy conversion of solar crystal silicon cells [8, 9].

Evaluation method

Evaluation index

The performance evaluation of PV/T components at home and abroad is mainly based on the First law and the Second law of thermodynamics. The PV/T components are evaluated by the First law of thermodynamics, which is generally evaluated by the total photo-thermal efficiency. It can basically reflect the energy gain of PV/T quantitatively:

$$\eta_0 = \eta_t + \eta_e \tag{1}$$

where η_0 [%] is the total photo-thermal efficiency of PV/T and η_1 [%] – the thermal efficiency of PV/T.

Compared to thermal energy, the level of electrical energy is higher. Therefore, the photoelectric photo-thermal comprehensive efficiency, E_f, is proposed as a measure of PV/T. The E_f takes into account the quantity and level of electrical energy and thermal energy, and can affect the ability of PV/T to convert the sun's influence into electrical energy and thermal energy:

$$E_f = \eta_t + \frac{\eta_e}{\eta_{power}} \tag{2}$$

where η_{power} is the power generation efficiency of conventional thermal power plants, the energy efficiency of gas-fired boilers in China is usually 35-42% and E_f – the PV/T photoelectric photo-thermal comprehensive efficiency.

The Second law of thermodynamics is used to evaluate the performance of PV/T components, mainly for efficiency evaluation:

$$\varepsilon_{put} = \varepsilon_{pv} + \varepsilon_t = \eta_{pv} + \left(1 - \frac{T_a}{T_2}\right)\eta_t \tag{3}$$

where ε_{put} is the dimensionless exergic efficiency of PV/T, ε_{pv} – the exergy efficiency of PV cells, dimensionless, ε_t – the was the overall thermal efficiency of the system (non-dimensional), T_a [K] – the ambient temperature, and T_2 [K] – the outlet temperature of heat collector:

$$\varepsilon_{pvt} = \frac{\int_{t_1}^{t_2}\left(A_C Ex_t + A_{pv} Ex_{pv}\right)dt}{\max\left(A_{pv}, A_C\right)\int_{t_1}^{t_2} Ex_{sun}\,dt} = \varepsilon_t + \varepsilon_{pv} \tag{4}$$

where Ex_{Sun} [Wm^{-2}] is the exergy input from solar irradiation, A_C [m^2] – the heat collection area, and A_{pv} [m^2] – the component area:

$$Ex_{\mathrm{pv}} = E_{\mathrm{pv}} \tag{5}$$

where E_{p} [Wm^{-2}] is the power generation per unit component area:

$$Ex_{\mathrm{t}} = E_{\mathrm{t}}\left(1-\frac{T_{\mathrm{a}}}{T_2}\right) \tag{6}$$

where E_1 [Wm^{-2}] is the heat obtained per unit heat collection area:

$$Ex_{\mathrm{sun}} = G\left(1-\frac{T_{\mathrm{a}}}{T_{\mathrm{sun}}}\right) \tag{7}$$

where T_{sun} is the solar irradiation temperature, generally considered to be 6000 K and G [Wm^{-2}] – the solar irradiance.

The design of PV power generation system requires the power generation performance parameters of PV modules under standard test conditions. The design of solar photo-thermal system needs to know the thermal efficiency of the solar collector under different working temperatures.

Deep learning model

Deep learning is a new research in machine learning. Compared with traditional machine learning and signal processing, deep learning simulates the hierarchical system of human visual nervous system, and has more hidden unit layers. Through layer-by-layer non-linear transformation of raw data, higher level and more abstract feature expression can be obtained. High-level expression can enhance the discrimination ability of input data, and weaken the adverse effects of unrelated factors [10].

The BP neural network is popular and mature because of its ability to deal with non-linear problems, strong learning ability and data fusion. Based on a large number of experimental data and data characteristics obtained from PV/T system experimental bench, the author established a prediction model of PV/T system photo-thermal efficiency based on BP neural network, by comparing the influence of different quantity factors and data sample size on the neural network prediction model, the model with better accuracy is obtained, and then applied to the prediction of photoelectric and photo-thermal efficiency of PV/T system [11].

Test samples

A polycrystalline silicon component is used to conduct PV /T performance evaluation, the component size is 1560 mm × 790 mm, the collector size is 1650 mm × 890 mm, and the cover material is single-layer glass. Polycrystalline silicon components are made of glass, EVA, battery sheet, backplane, aluminum frame, junction box, silica gel and other main materials, packaging according to a certain production process, a PV device that achieves certain output power and voltage under certain illumination conditions. The attenuation of component power means that as the time of illumination increases, a gradual decrease in the output power of a component.

Test methods

The PV/T photoelectric total efficiency

Test conditions: Solar irradiance is not less than 800 W/m^2, ambient wind speed is less than 4 m/s, ambient temperature is less than 40 °C.

Test method: Control the inlet and outlet temperature of PV/T modules to be close to the surface temperature, and measure the power generation and thermal performance of PV modules after the system inlet and outlet temperatures are stable.

Power generation characteristics of PV modules

The test method of PV module performance is given, the main test indexes include performance under standard test conditions, rated operating temperature and performance test*, etc.*, performance under standard test conditions mainly refers to standard test conditions (AM1.5, component temperature 25 °C, solar irradiance 1000 W/m^2), the ratio of the maximum output power of a PV module to the power of sunlight shining on the module, that is the PV module photoelectric conversion efficiency. The power generation performance of thin-film cells used as PV/T power generation modules can be tested according to the design, identification and finalize of thin-film PV modules used on the ground [12-14].

Results and discussion

The PV/T photoelectric total efficiency and photo-thermal photoelectric comprehensive efficiency

Figure 2 shows the measurement results of the output voltage and the current of the PV/T module change with the operating temperature. Analyzing the measurement results in fig. 1, it can be seen that with the increase of the working temperature of the module, the output voltage and the current of the module decrease, and the output voltage electricity is greatly affected by temperature.

The measurement results of the power generation change with working temperature are shown in fig. 3 With the increase of working temperature of the collector, the power generation is less from 11.7-9.6, and the power generation is less than 0.06 for every 1 °C increase in the working temperature.

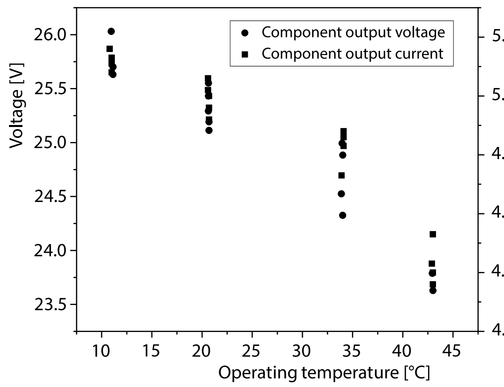

Figure 2. Test results of influence of operating temperature difference on output voltage and current of components

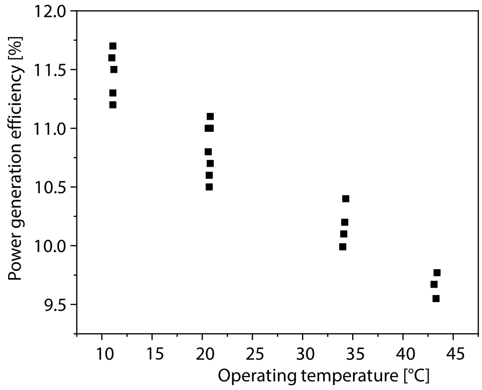

Figure 3. Test results of power generation efficiency variation with operating temperature

The test results of collecting heat exchangers with working temperature are shown in fig. 3 and the curve of PV/T photoelectric overall performance and photo-thermal photoelectric performance changes with operating temperature are shown in fig. 4. It can be seen from figs. 3 and 4 that heat collection, PV/T photoelectric overall efficiency and photoelectric comprehensive efficiency decrease with the increase of operating temperature. Compared with figs. 2, 4, and 5, the heat collection equipment, PV/T photoelectric overall efficiency and photo-thermal photoelectric comprehensive efficiency, performance heat has little effect on power generation [15].

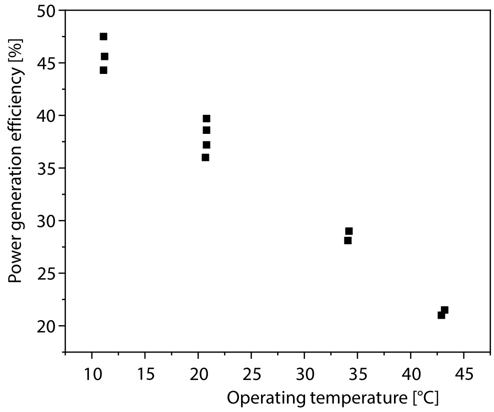

Figure 4. Test results of thermal efficiency variation with operating temperature

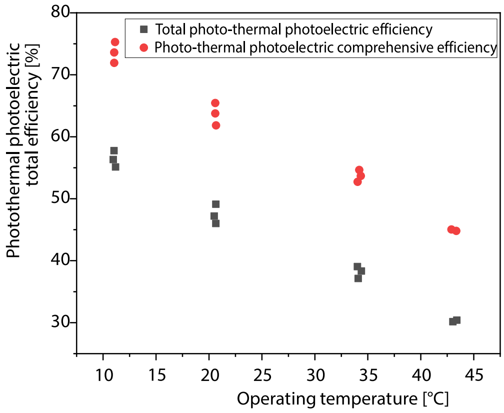

Figure 5. Test results of total photo-thermal-photoelectric efficiency and comprehensive photo-thermal-photoelectric efficiency varying with working temperature

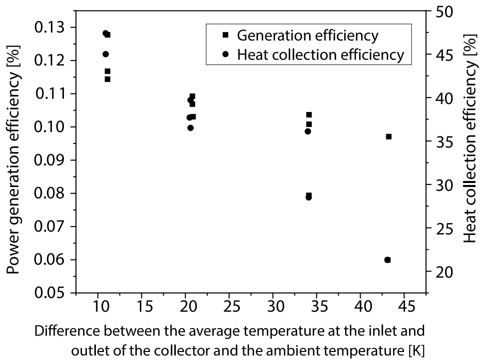

Figure 6. Test results of influence of operating temperature difference on power generation efficiency and heat collection efficiency

The PV/T heat collection efficiency curve and power generation efficiency curve

During the test period, solar irradiance did not change very much, therefore, only the influence of average working temperature of heat collection (average temperature of inlet and outlet of heat collection) and temperature difference of ambient temperature (defined as working temperature difference) on power generation efficiency and heat collection efficiency was considered, the test results were sorted out to obtain fig. 6.

By analyzing the test results in fig. 6, it can be seen that the power generation and heat generation of the sample decrease to different levels with the increase of the operation temperature difference.

The measured data were fitted to obtain the first curve of the power generation and the heating efficiency with different working temperatures, as shown in tab. 1.

Table 1. Variation curves of power generation efficiency and heat collection efficiency with working temperature difference

	A grain number [%K^{-1}]	Intercept [%]	R^2
Generation efficiency curve	–0.0464	11.749	0.9590
Heat collection efficiency curve	–0.6275	49.323	0.9944

According to the comparison results in tab 1. and fig. 5, it can be found that with the increase of the working temperature difference, the power generation efficiency and the heat collection efficiency both decrease, but the trend of the heat collection efficiency decreases faster, which indicates that the heat collection efficiency is more sensitive to the change of the working temperature difference, and the sensitivity of the power generation efficiency is smaller. For every 1 K increase in the temperature difference, the power generation efficiency decreases by 0.05%, and the heat collection efficiency decreases by 0.63%.

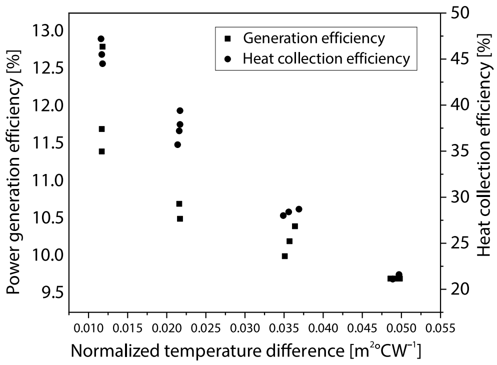

Figure 7. Test results of the influence of normalized temperature difference on power generation efficiency and heat collection efficiency generation efficiency and heat collection efficiency

In order to better apply the test data, the concept of normalized temperature difference is introduced. The normalized temperature difference is the ratio of the working temperature difference to the total irradiance. The test results of the power generation efficiency and the heat collection efficiency are processed to obtain fig. 7 and tab. 2.

Table 2. Variation curves of power generation efficiency and heat collection efficiency with normalized temperature difference

	Coefficient of first order [m^2°CW^{-1}]	Intercept	R^2
Generation efficiency curve	–0.4052	0.1168	0.9463
Heat collection efficiency curve	–5.4902	0.4850	0.9860

Combining the curve in tab. 2 and the test data in figs. 2 and 3, it can be found that, the working temperature difference increased from 6.8-45.3 K, and the normalized temperature difference increased from m^2 to, the generation efficiency is reduced from 0.105-0.095, the generation efficiency is reduced from 0.105-0.095, the percentage change is 9.4%, the heat collection efficiency is reduced from 0.4534-0.2120 by 0.2414, and the reduction rate is 53%, compared with the generation efficiency and heat collection efficiency, the efficiency changes during the test period are relatively small. Therefore, for PV/T components, environmental parameters have a greater impact on heat collection efficiency [16].

Conclusion

In this paper, the prediction of structural mechanical properties of energy-saving materials for solar PV/T system based on deep learning is proposed. Through the analysis of the performance test results of PV/T modules, for the performance evaluation of PV/T modules, the curve of PV/T module power generation efficiency and heat collection efficiency with the normalized temperature difference should be given. The test data can be used to facilitate the PV/T system design. Referring to the thermal performance evaluation method of solar collectors, it is recommended to take the intercept of the curve and the coefficient of primary term as the evaluation indicators, and the specific values should be determined on the basis of a large number of tests and investigations.

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