ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

Research on the Efficiency of Photovoltaic Thermal Power Generation in Gonghe County, Qinghai Province

Weijun He, Shuangyin Li*

School of Civil and Transportation Engineering, Qinghai Minzu University, Xining, 810000, Qinghai, China
**Corresponding author*

Abstract: *This article mainly studies the photovoltaic power station in Gonghe County, Qinghai Province. Through model analysis, field investigation, and data combination, the difficulties in the utilization of solar energy resources in Gonghe County are introduced. The model is fully utilized to simulate and analyze the optimal tilt angle of photovoltaic panels and the optimal cleaning cycle of electric cleaning devices. In addition, reference solutions are proposed for the heating problem of extreme weather components. At the same time, it has a reference value for improving the power generation efficiency of photovoltaic power stations in Gonghe County. The experimental results serve as a reference for improving the power generation efficiency of the photovoltaic power station in Gonghe County. In the future, the research team will further expand the monitoring samples and extend the model to surrounding parks such as Longyangxia and Talatan, verifying its universality under different landforms and wind speed zones. At the same time, they will collaborate with inverter manufacturers such as Huawei and Sungrow to integrate the "inclination-cleaning-thermal management" three-dimensional optimization algorithm into the intelligent operation and maintenance platform, enabling real-time command issuance from the cloud. It is expected to increase the annual equivalent utilization hours by another 3% to 5%.*

Keywords: *Photovoltaic Power Plants; Model Simulation; the Tilt Angle of the Photovoltaic Panel; Power Generation Efficiency*

1. Introduction

Following China's ratification of the Paris Agreement in 2016, the nation committed to peaking CO_2 emissions by 2030 and reducing carbon intensity by 60–65% relative to 2005 levels. Long-term decarbonization necessitates a strategic shift from fossil fuels to renewable energy. By 2060, non-fossil sources are projected to supply ≈80% of primary energy, compared with 16% today [1]. Concentrated solar power (CSP) and utility-scale photovoltaics (PV) are therefore pivotal to China's carbon-neutral trajectory.

China has a vast land area and is rich in solar energy resources. Especially in the high lying areas of northwest Xinjiang, Gansu, Qinghai, etc., it has an important energy strategic position in China to vigorously develop photovoltaic power stations [2]. The Chinese government is vigorously developing and promoting photovoltaic power generation through policies, subsidies, and other means[3]. Photovoltaic power generation has become an important poverty alleviation project in China. Among these key areas, the solar energy resources contained in Gonghe County, Qinghai Province have already received worldwide attention. However, there are still many potential problems with the photovoltaic power station in Gonghe County, so the solutions proposed in this article have great significance for the development of solar energy in Gonghe County:

(1) Further strengthen the utilization of solar energy resources, avoid excessive waste of resources, minimize the consumption of fossil fuels as much as possible, and protect the environment.

(2) Promote the efficient development of renewable energy and make positive contributions to China's carbon neutrality goals during the 14th Five Year Plan period.

(3) This is of great significance for promoting the construction of a clean energy demonstration province in Qinghai, optimizing the allocation of clean energy resources in Qinghai, and improving the

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

quality of electricity.

Many studies on solar energy utilization efficiency at home and abroad have provided us with many ideas. Liu Yunpeng et al. [4] prepared SWCNT transparent conductive films by rod coating method and studied their UV aging characteristics under different light intensities. The research results are beneficial for expanding the application scenarios of single-walled carbon nanotube transparent conductive films from indoor or air isolated areas to outdoor areas. Emad Abdelsalam et al. [5] integrated photovoltaic panels with cooling towers to achieve efficient utilization. Inject hot air to cool the top of the CT and dry it. Due to gravity, the cooled air falls towards the bottom of the cooling tower and interacts with the turbine placed at the bottom of the cooling tower to generate electrical energy. As the cooled air passes under the photovoltaic panels, it exchanges energy with the photovoltaic cells, reducing the temperature of the panels.

2. Resource and Problem Analysis of Gonghe County Photovoltaic Power Station

2.1 Overview of Solar Energy Resources in Gonghe County

Qinghai Province is rich in solar energy resources, especially the Qaidam Basin, which is the region with the richest sunshine resources in China and the second highest value area in the country. Under the same area and capacity, photovoltaic grid connected power generation can generate 15% -25% more electricity than neighboring Gansu and Xinjiang. Qinghai Province is located in the northeast of the Qinghai Plateau, with most areas being vast and sparsely populated. There are unused desert areas of over 200000 square kilometers, mainly distributed in the Qaidam Basin and Sanjiangyuan areas with abundant light resources. Moreover, many deserts are close to power lines and load centers, with superior grid connection conditions, making it the preferred area for building large-scale desert photovoltaic grid connected power stations and establishing solar power output bases.

The northeastern part of Qinghai Province (35.5-37.2 ° N, 99.0-101.5 ° E) is a typical plateau continental climate, characterized by warmth, large temperature difference between day and night, abundant sunshine, and scarce precipitation. The annual average temperature is 4.1 ℃, and the annual rainfall is 250-450mm. It is high altitude, dry, with few clouds, thin and clean air, and sunny with abundant sunshine. Therefore, the development prospects of solar energy that can be utilized are very broad [6]. The annual solar radiation data obtained from the Xining Meteorological Bureau in Qinghai Province is shown in Table 1 and Figure 1:

Table 1 (a) Summary Table of Annual Total Solar Radiation and Sunshine Hours at Meteorological Stations

Years	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Annual total radiation level (MJ/m2)	6438	6589	6577	6594	6594	6513	6381	6680	6644	6541
Annual sunshine hours (h)	2839	2846	2896	2942	2923	2868	2777	3006	2936	2923

Table 1 (b) Summary Table of Annual Total Solar Radiation and Sunshine Hours at Meteorological Stations

Years	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Annual total radiation level (MJ/m2)	6537	6640	6478	6563	6704	6631	6551	6692	6648	6658
Annual sunshine hours (h)	2839	2957	2873	2893	3039	2975	2938	3115	3032	3019

Table 1 (c) Summary Table of Annual Total Solar Radiation and Sunshine Hours at Meteorological Stations

Years	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Annual total radiation level (MJ/m2)	6631	6629	6461	6556	6442	6401	6289	6461	6461	6532
Annual sunshine hours (h)	3032	3051	2836	2917	2843	2791	2757	2949	2843	2813

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

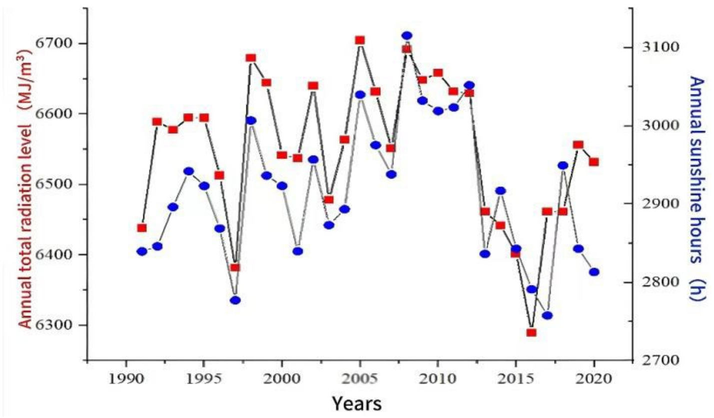

Figure 1 Annual total radiation and annual daily sunshine hours in Qinghai Province from 1991 to 2020

2.2 Factors affecting photovoltaic power generation in Gonghe County

2.2.1 Environmental temperature

When the photovoltaic system is continuously exposed to sunlight, the temperature of its internal and external components will increase. Solar panels operate continuously under high power conditions, and due to their own heat storage and continuous high temperature exposure from the sun, their internal temperature increases over time.

2.2.2 Solar Receiver Angle

When installing photovoltaic devices, the photovoltaic panels are generally installed at an angle. The sun moves with time, and the angle at which it receives sunlight constantly changes. The tilt angle of the photovoltaic panel largely determines the absorption efficiency of solar radiation.

2.2.3 Obstructive Loss

In extreme weather conditions such as strong winds and snowfall, dust easily adheres to photovoltaic power plants, causing dust accumulation on the experimental surface of the photovoltaic power plant and reducing its efficiency by 17%. In cases of heavy dust accumulation, the efficiency can decrease by 40%. When there is obstruction, the temperature in the obstructed area will be much higher than that in the illuminated area, causing thermal spot failure and affecting the heat transfer pattern inside the component, resulting in a decrease in the efficiency of the photovoltaic system and even having adverse effects on the service life of the battery.

3. Photovoltaic power plant models

3.1 Establishment of Power Station Model

This study use Revit software to replicate a simple model of the Gonghe County photovoltaic power station, select individual solar photovoltaic panels from the power station and conduct detailed analysis of the model, as is shown in Figure 2.

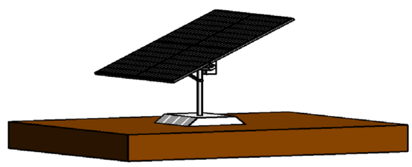

Figure 2 3D Diagram of Photovoltaic Devices in Gonghe County Photovoltaic Power Generation Park

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

3.2 Main components

As the main transparent material of the group, glass panels can use different glass materials under different environmental conditions: uncoated low iron tempered glass and coated tempered glass, but their main function is still to protect the internal structure. EVA mainly plays a bonding role. Due to the thin thickness of the solar panel, the photovoltaic glass cannot be directly bonded, so EVA film must be used for bonding. EVA film has good transparency, but if it comes into contact with air, it will turn yellow, which has a significant impact on the performance of the battery [7]. The back plate also plays the role of protecting the battery chip, and must be sealed, insulated, waterproof and anti-aging. The material is usually TPT or TPE material. The junction box is used to protect the battery, just like a relay station. If a battery short circuits, it will be connected to the junction box. Aluminum frame, as the name suggests, is made of aluminum alloy material, which has high strength and strong corrosion resistance. It can support and protect the entire battery panel, as is illustrated in Figure 3.

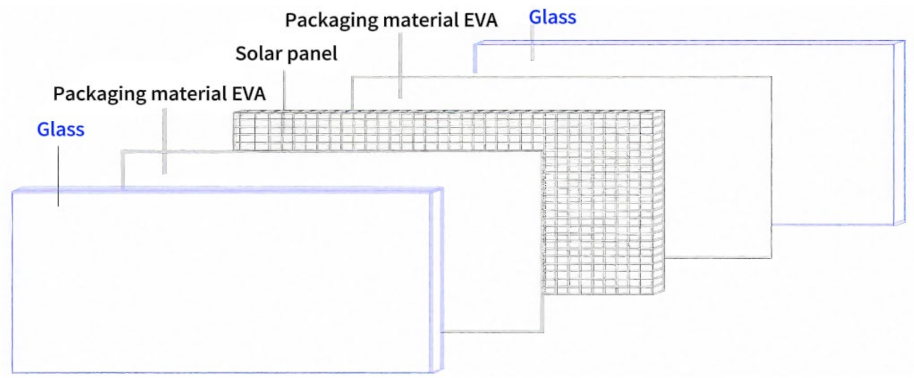

Figure 3 Photovoltaic panel structure of Gonghe County power station

3.3 Efficiency verification of photovoltaic power plants

The installation capacity and average annual utilization hours of photovoltaic modules determine the annual power generation, which is also related to factors such as photovoltaic module conversion efficiency, transformer losses, line losses, module cleanliness, and environmental temperature and humidity. According to comprehensive analysis, the calculation formula for annual photovoltaic power generation is:

$$E_p=H_A\times PAZ\times K \tag{1}$$

H_A——The annual total solar radiation on the horizontal plane (kW · h/m2);

E_p——On grid power generation(kW· h) ;

PAZ ——System installation capacity(kW) ;

K ——Comprehensive efficiency coefficient.

The rated capacity of a solar panel refers to its maximum power generation, generally expressed in watts (W). The daily average sunshine duration refers to the time it takes for the sun to radiate to the ground, usually expressed in hours (h). The average annual sunshine days refer to the number of days in a year that the sun radiates to the ground, usually expressed in days (d). The photovoltaic conversion efficiency of a photovoltaic power generation system refers to the efficiency of the photovoltaic system in converting solar energy into electrical energy.

However, this calculation did not take into account all error issues such as ambient temperature, photovoltaic panel receiving angle, and shading loss. Next, we will analyze and improve the data results.

4. Improvement of losses in photovoltaic power plants

4.1 Component heating caused by ambient temperature

The energy conversion efficiency of crystalline silicon solar cells is related to their operating temperature. When the temperature rises by 1 ℃, their photoelectric conversion efficiency will decrease by 0.4% -0.5%. More than 80% of the energy in solar cells is converted into thermal energy, and their operating temperature is generally 50 º C. With poor heat dissipation, it can reach 80 º C. Excessive temperature rise can seriously affect their photoelectric conversion efficiency. Therefore, the photovoltaic power station in Gonghe County is in great need of photovoltaic panel cooling technology.

According to the existing attached refrigeration technology, appropriate improvements can be made, and the improved cycle is shown in the following figure 4.

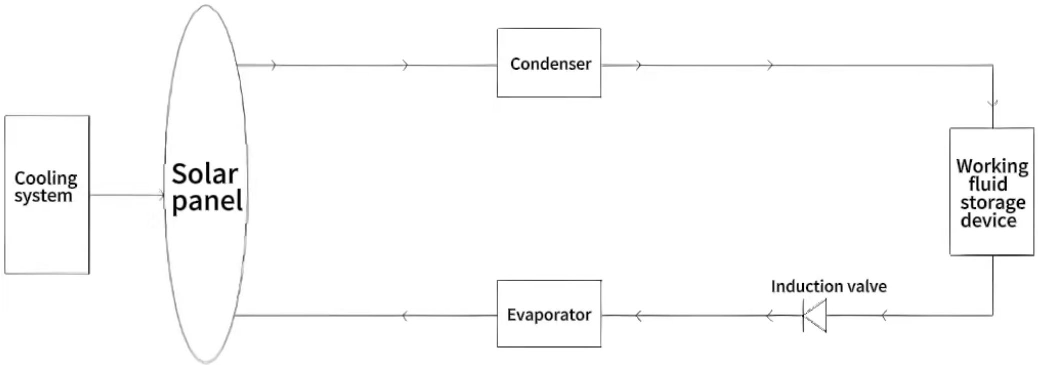

Figure 4 Schematic diagram of basic circulation system

In the working fluid storage, we use silicone water as the working fluid for heat exchange. This scheme is a single-stage adsorption refrigeration system, which achieves refrigeration effect by periodically heating or cooling the adsorption bed. When the temperature of the component is too high, the water is heated at a lower pressure, causing it to evaporate in the evaporator and adsorb onto the surface of the silicone gel, thus taking away the heat energy. With the cooling of solar panels, the adsorption performance of organic silicon materials is improved. The silica gel on the surface of the adsorption material breaks through the adsorption force and enters the pipeline, using the waste heat in the condenser to liquefy and condense the working fluid,Reuse solar energy to heat and hydrolyze the adsorption bed to absorb heat [8].

4.2 Optimal tilt angle of photovoltaic panels

Using a simple data model to simulate and calculate the angle of sunlight exposure, the model of the simulated photovoltaic panel is consistent with that of the Gonghe County power station, as shown in Figure 5.

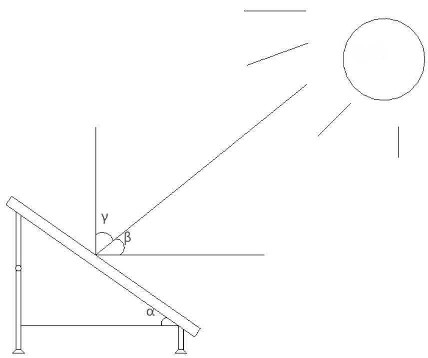

Figure 5 Simulation diagram of solar incidence angle

The solar photovoltaic intensity I on an inclined surface is composed of three parts: the direct solar photovoltaic panel intensity Ib, the scattered solar photovoltaic intensity Id, and the ground reflected solar radiation intensity Ig[9,10]:

$$I = I_b + I_d + I_g \tag{2}$$

Among them, α is the angle between the photovoltaic panel and the horizontal line, β is the angle between the sunlight shining on the photovoltaic panel and the horizontal line, and γ is the angle

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

between the sunlight and the vertical normal.

Before calculating the photovoltaic intensity, it is necessary to first verify the angle of incidence of sunlight, and the formula for verifying the angle of incidence of sunlight is:

$$\cos\theta = \cos\alpha \sin\beta + \sin\alpha \cos\beta \cos(\delta - \rho) \tag{3}$$

Among them, α is the angle between the photovoltaic panel and the horizontal line, β is the angle between the sunlight shining on the photovoltaic panel and the horizontal line,γ is the angle between the sunlight and the vertical normal,δ is the solar azimuth angle, and the oblique azimuth angle, ρ is the oblique azimuth angle. The intensity of direct sunlight on photovoltaic panels I_b

$$I_b = I_{bN} \cdot \cos\theta \tag{4}$$

I_{bN} is the intensity of solar radiation in the normal direction.

Solar scattering photovoltaic intensityI_d:

$$I_d = I_{dH} \cdot \frac{1+\cos\theta}{2} \tag{5}$$

I_{dH}The intensity of solar radiation on the horizontal plane

Ground reflection of solar radiation intensityI_g:

$$I_g = (I_{bN} + I_{dH}) \cdot \sin^2\frac{\theta}{2} \tag{6}$$

4.3 Obstruction caused by environmental impact

There are many factors that affect the power generation efficiency of solar panels, and they vary depending on the region, climate characteristics, materials, etc. Yang Yalin et al. proposed the relationship between the power generation of photovoltaic panels and the temperature during the operation of photovoltaic backboards:

$$P = \eta_{T_{ref}} A G_T \tau_{PV}[1 - 0.0045(T_C - 25)] \tag{7}$$

Among which :

P—Photovoltaic panel power generation

$\eta_{T_{ref}}$—Conversion efficiency of batteries under standard test conditions at temperature value Tref

A—Surface area of photovoltaic modules

G_T—Solar irradiance

τ_{PV}—Transmittance of photovoltaic panels

T_C—Battery operating temperature

The power generation efficiency of photovoltaic panels is positively correlated with the surface area of photovoltaic modules. However, the Gonghe County Photovoltaic Power Station is located in a basin, where wind, sand, heavy rain, and small water can easily cause sand and dust accumulation, thus blocking the efficiency of photovoltaic panels absorbing solar radiation. Therefore, an automatic cleaning device needs to be installed, as shown in the Figure 6.

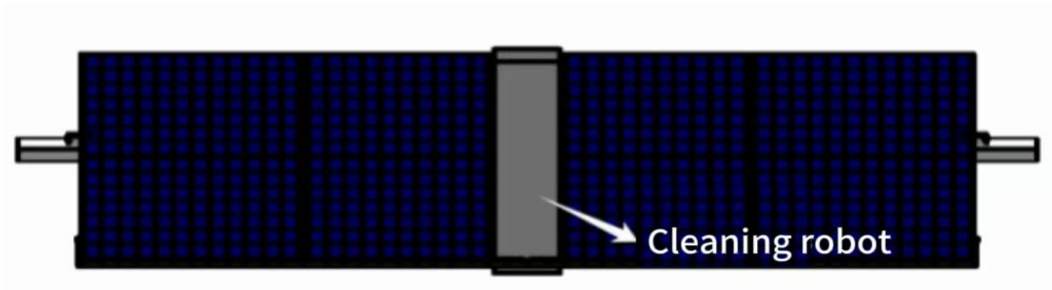

Figure 6 Photovoltaic panel model with cleaning equipment

The cleaning of solar panels is done mechanically. The mechanical cleaning equipment moves (left and right) on the guide rails of the left and right frames of the photovoltaic panel, and generates electricity through the photovoltaic power generation device to drive the motor to rotate and clean the brush head on the surface of the photovoltaic panel. From the characteristics of dry climate and low rainfall in Gonghe County, the possibility of coking ash accumulation is unlikely. Therefore, the surface ash of solar panels is regarded as easy to clean floating ash. Therefore, after each cleaning task, the dust on the solar panel can be considered as zero.

Select a certain fifteen-day period in May to measure power generation, and obtain comparative data on the impact of dust accumulation on power generation, as shown in Table 2 (for clear comparison of data, a clear method is used, as shown in Figure 7).

Table 2 Comparative data on the impact of dust accumulation on power generation

Time(d)	Measure the power generation of the array/(kW·h)	Measure the loss value of the array compared to the previous day's power generation/(kW·h)	Measure the loss value of the array compared to the first day's power generation/(kW·h)
1	2212	0	0
2	2193	19	19
3	2161	23	51
4	2140	21	72
5	2132	8	80
6	2120	12	92
7	2133	-13	79
8	2117	16	95
9	2105	17	107
10	2088	12	124
11	2063	25	149
12	2051	12	161
13	2037	14	175
14	2025	12	187
15	2015	10	197

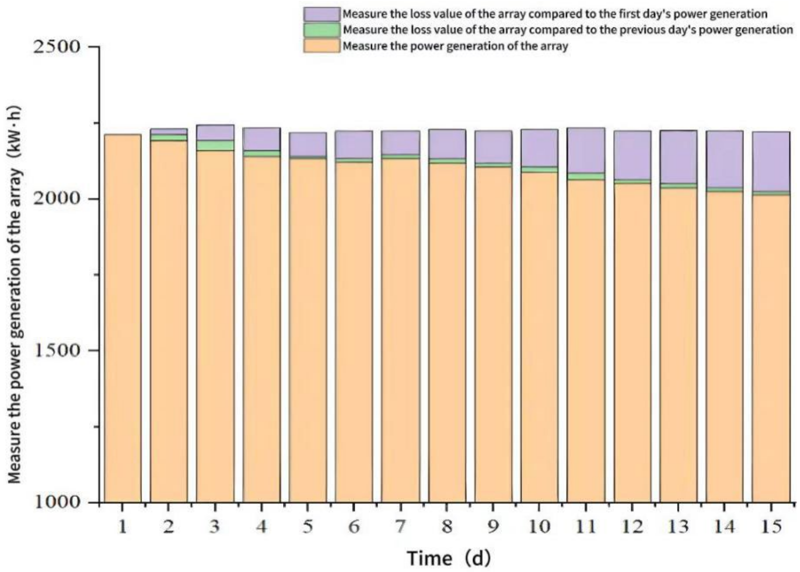

Figure 7 Comparison of data on the impact of dust accumulation on power generation

After the photovoltaic panel cleaning system is put into operation, the accumulated dust is gradually removed, and as the cleaning process progresses, the losses caused by the dust gradually decrease. According to the minimum cost cycle calculation method, the optimal cleaning cycle is the cleaning interval that minimizes the total loss per unit time[11]:

$$\frac{d}{d\theta_0}\left[\frac{f(\theta)}{\theta_0}\right] = 0 \tag{8}$$

Among them, θ_0 represents the duration of the cleaning cycle solely determined by the dust accumulation process. The optimal cleaning interval obtained is:

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

$$(\theta_0)_{opt} = \sqrt{2C/a_2} \tag{9}$$

Among them, C is the cost of equipment cleaning, and a2 is the coefficient of cost loss over time for the difference in power generation.

Under simulated conditions, there may be some errors, but with the support of data, simple adjustments can be made to achieve the best results. In the climate environment of Gonghe County, using an automatic cleaning device is the most practical cleaning method, and the economic loss caused by cleaning the accumulated dust photovoltaic panels according to the optimal cleaning cycle is minimized.

5. Conclusion and prospect

This article mainly studies how to improve the efficiency of photovoltaic power generation in Gonghe County by combining software simulation and data. The research mainly focuses on three aspects: component heating, photovoltaic panel tilt angle, and environmental impact (dust accumulation). The main conclusions are as follows:

(1) The single-stage adsorption refrigeration system can effectively reduce the loss of power generation efficiency caused by component heating, and also change the material of the working fluid to achieve better heat absorption effect.

(2) Through simple model simulation and data combination, the optimal tilt angle of the photovoltaic panel was found, simplifying the complex angle adjustment experimental process, reducing the actual measurement process, and greatly improving efficiency.

(3) By combining the electric cleaning device with the photovoltaic panel and deriving the optimal cleaning cycle from the formula, the impact of dust on the photovoltaic panel power generation is minimized as much as possible, thereby improving the efficiency of photovoltaic power generation. It has reference significance for the development of photovoltaic power generation cleaning under difficult climate conditions.

Acknowledgement

This work was sponsored in part by Postgraduate Innovation Project (66M2024012).

References

[1] Yang K P, Wang Y. Coordinating Energy Security Assurance and Green Transformation and Development: An Interview with Zhang Jianhua, Party Secretary and Director of the National Energy Administration [J]. China Electric Power Corporation,2021,(05):4-5.
[2] Yang Y. Application of Induction Filter Transformer in Photovoltaic Grid-connected System [D]. Hunan University,2018.
[3] Sun L G. Mountain large photovoltaic system grounding technology exploration and application [J]. Journal of anhui agriculture bulletin, 2015, 21 (23) : 106-108.
[4] Yunpeng L, Haoyi L ,Le L, et al.Preparation and photoaging resistance of single-walled carbon nanotubes transparent conductive thin films for Youdaoplaceholder0 dust removal of photovoltaic panels[J].Materials Today Communications,2023,37.
[5] Abdelsalam E, Alnawafah H ,Almomani F , et al.Enhancing the Efficiency of Bi-Facial Photovoltaic Panels: An Integration Approach[J].Sustainability,2023,15(20):2283.
[6] Wang W Q. Current Situation and Development and Utilization of Solar Energy Resources in Gonghe County, Hainan Prefecture [J]. Times Agricultural Machinery,2018,45(08):143-144.
[7] Chen J G, Zhang J J, Yu L T. Comparative Analysis of Power Generation Performance Evaluation Index of Photovoltaic Power Station Based on Temperature Correction [J]. Huadian Technology, 2016, 38(05): 73-76+80.
[8] Wang B Z. Lecture 5 on Solar Radiation Calculation: Calculation of Radiation on the Inclined Surface of the Earth [J]. Solar Energy,2000, (3):20-21.
[9] Yang J H, Yu Q G. Optimal orientation and inclination Angle for Solar Water Heater Installation [J]. Henan Science and Technology,1999, (11):25.
[10] Yang Y L, Zhu D L, Li D, et al. The influence of dust accumulation and light intensity on the

ISSN 2616-5767 Vol.8, Issue 5: 40-48, DOI: 10.25236/AJETS.2025.080506

output power of photovoltaic modules [J]. Transactions of the Chinese Society of Agricultural Engineering, 2019,35(05):203-211.
[11] Xu Z M, Qu H W, Wang J W, et al. The optimal cleaning cycle for dust accumulation on solar photovoltaic panels [J]. Proceedings of the CSEE,2018,38(6):1738-1742.