Study on The Relationship Between Meteorological Factors and Photovoltaic Power Generation Efficiency and Influence Mechanism

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Abstract. The paper uses the minute-by-minute photovoltaic power data of a photovoltaic power station in Lanzhou of Huadian from June 1, 2018 to May 31, 2019 and the meteorological observation data of the Lanzhou National Climate Observatory in the same period to analyze the impact of meteorological elements on the power of photovoltaic power plants. The results show that the daily and hourly output power of photovoltaic power plants are highly positively correlated with sunshine time and light intensity. The longer the sunshine time and the greater the light intensity, the more the output power of the module; the cloud cover and relative humidity weaken the photovoltaic power, and The influence of low cloud cover is greater than the influence of total cloud cover, and cloud shape also has a significant influence; the influence of temperature on the power of photovoltaic power plants is more complicated, and the increase of temperature reduces the power of photovoltaic power, and the mechanism needs to be further studied.

Keywords: Meteorological factors, light intensity, photovoltaic power generation efficiency, influence mechanism.

1. Introduction
Photovoltaic power generation is a multi-variable coupling nonlinear random process. The most important factor is solar radiation. The influence of meteorological and environmental factors such as high temperature in summer, snow and ash in winter cannot be ignored, and solar radiation is not only easy to determine in addition to astronomical factors (periodical changes) and geographic factors, it is also related to cloud cover, aerosols, sunshine hours, temperature, humidity, water vapor and many other uncertain meteorological factors. At present, domestic and foreign researchers have begun to study the impact of photovoltaic the meteorological factor of power generation, the most important meteorological factor affecting photovoltaic power generation is solar irradiance, but factors such as high temperature in summer and snow in winter cannot be ignored [1]. The correlation analysis method is used to analyze the correlation degree between photovoltaic power generation and various
meteorological factors, and a power generation prediction model is established. There are many methods for generating power prediction. Some scholars have summarized the ultra-short-term and short-term prediction techniques of photovoltaic power, which mainly include linear regression algorithms, Markov chain algorithms, support vector machine algorithms, and neural network algorithms. The amount of radiation is used as input. The method is simple and easy to implement, but only one impact factor is considered. Some scholars have studied the characteristics of photovoltaic arrays and used the Markov chain method to directly predict the photovoltaic power generation, but this method is only suitable for conditions where the weather changes little. Some scholars use the method of grey neural network combination model, which only predicts for sunny days, and the accuracy of other weather forecasts is unknown. In view of this, this paper uses the data of Lanzhou photovoltaic power station to diagnose and analyze the relationship between photovoltaic power generation and meteorological conditions, which is of great significance for further forecasting the output of photovoltaic power stations.

2. Materials and methods

2.1. Source of information
Photovoltaic power generation data comes from the minute-by-minute photovoltaic power data of a photovoltaic power station in Lanzhou, China from June 1, 2018 to May 31, 2019, and the meteorological observation data from the Lanzhou National Climate Observatory in the same period. The meteorological data mainly include hourly and daily average temperature (t/°C), maximum temperature (tmax/°C), minimum temperature (tmin/°C), relative humidity (R/%), daily average air pressure (P/hPa), and the daily temperature difference calculated from this (td/°C).

2.2. Analysis method
Since there are many meteorological factors affecting photovoltaic power generation, correlation analysis can be used to measure the close degree of linear correlation between power generation and various meteorological factors to identify the importance of influencing factors [2]. The Pearson correlation coefficient of the most commonly used two-dimensional variable CORR is defined as follows:

$$C_{CORR} = \frac{\sum_{i=1}^{N}(x_i - \bar{X})(y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{X})^2 \sum_{i=1}^{N}(y_i - \bar{Y})^2}}$$

Where: N represents the length of the sample sequence; i represents the i sample; (xi, yi) represents the observation value of the i sample of the two-dimensional variable (X, Y); (X, Y) represents the two-dimensional variable (X, Y) N The average of the observed sample.

2.3. Rate definition and calculation method

2.3.1. Conversion efficiency η of photovoltaic array. That is, the ratio of the maximum possible DC power output of the photovoltaic array to the total solar radiation received by the slope of the photovoltaic array in a period of time:

$$\eta = \frac{E_{dc}}{QS}$$

(2)
In the formula, \( E_{dc}, Q \) represents the maximum DC power generation (kWh) of the photovoltaic array and the amount of solar radiation received by the slope of the array per unit area within a period of time (kWh/m²); \( S \) represents the area of the photovoltaic array, m².

2.3.2. Inverter efficiency \( \eta_e \). It is the ratio of the AC power output from the grid-connected inverter to the input DC power (i.e., photovoltaic array output) over a period of time:

\[
\eta_e = \frac{P_{ac}}{E_{dc}} = \frac{\int P_{ac}(t) dt}{\int P_{dc}(t) dt}
\]  

(3)

In the formula, \( P_{ac}(t), P_{dc}(t) \) represents the real-time input DC power and output real-time AC power obtained by the grid-connected inverter from the photovoltaic array; \( E_{ac} \) represents the AC power output of the grid-connected inverter in a period of time, in kWh.

2.3.3. Overall power plant efficiency (PR). It is the ratio of the AC power generation of the grid-connected photovoltaic power station to the total solar radiation on the horizontal plane where the photovoltaic array is located in a period of time:

\[
PR = \frac{Y_f}{Y_s}
\]  

(4)

In the formula, \( Y_f \) represents the grid-connected photovoltaic power plant's full power generation hours, that is, the ratio of the power plant's AC power generation to the rated installed capacity within a period of time; \( Y_s \) represents the peak sunshine hours at the location of the grid-connected photovoltaic power plant, that is, the total horizontal level within a period of time. The ratio of irradiance (exposure) to standard irradiance (its value is 1 kW/m²).

3. Result analysis

3.1. Correlation analysis of power generation and meteorological factors

The thesis uses the monitoring data of photovoltaic power plants from June 1, 2018 to May 31, 2019 to analyze \( P/kW \) and \( H/kWh, S/h, T/°C, T_{\text{max}}/°C, T_{\text{min}}/°C, Td/°C, V/m\ s^{-1} \) was used for correlation analysis (Table 1 and Figure 1).

Table 1. Correlation analysis of two-year daily photovoltaic power generation and meteorological factors over the same period

| Variable | \( P \) | \( H \) | \( S \) | \( T \) | \( T_{\text{max}} \) | \( T_{\text{min}} \) | \( Td \) | \( V \) |
|----------|--------|--------|--------|--------|----------------|----------------|--------|--------|
| \( P \)  | 1      | 0.902  | 0.782  | 0.319  | 0.364          | 0.292          | 0.244  | 0.124  |
| \( H \)  | 0.902  | 1      | 0.728  | 0.051  | 0.098          | 0.025          | 0.233  | 0.076  |
| \( S \)  | 0.782  | 0.728  | 1      | 0.367  | 0.400          | 0.343          | 0.198  | 0.127  |
| \( T \)  | 0.319  | 0.051  | 0.367  | 1      | 0.985          | 0.981          | 0.079  | 0.201  |
| \( T_{\text{max}} \) | 0.364 | 0.098  | 0.400  | 0.985  | 1              | 0.965          | 0.185  | 0.170  |
| \( T_{\text{min}} \) | 0.292 | 0.025  | 0.343  | 0.981  | 0.965          | 1              | 0.055  | 0.198  |
| \( Td \) | 0.244  | 0.233  | 0.198  | 0.079  | 0.185          | 0.055          | 1      | 0.069  |
| \( V \)  | 0.124  | 0.076  | 0.127  | 0.038  | 0.170          | 0.198          | 0.069  | 1      |
Figure 1. Correlation analysis of daily photovoltaic power generation and meteorological factors in the same period

As can be seen from Table 1, there is a significant positive correlation between the annual daily photovoltaic power generation and the total daily horizontal radiation, with a Pearson correlation coefficient of 0.893; a positive correlation coefficient with sunshine hours of 0.892; a positive correlation coefficient with daily temperature difference of 0.650; It is negatively correlated with the daily relative humidity, and the correlation coefficient is -0.404; the positive correlation coefficient with the daily maximum temperature is 0.375, and the positive correlation coefficient with the daily average temperature is 0.227; the positive correlation coefficient with the daily minimum temperature is 0.170, and the daily average The negative correlation coefficient of air pressure is -0.095 and it has not passed the significance check.

3.2. The relationship between photovoltaic power and solar radiation
Taking 1, April, July, and October to represent the four seasons of winter, spring, summer, and autumn respectively, the relationship between time-to-hour photovoltaic power and solar radiation in each season is analysed, as shown in Figure 2. It can be seen from the figure that the two have a linear relationship in each season, that is, the stronger the solar radiation, the more photovoltaic power generation. From the fitting equation of photovoltaic power and solar radiation, it can be seen that the photovoltaic power in winter has the strongest response to solar radiation [3]. For every increase in solar radiation by 1 MJ/m², the photovoltaic power will increase by 3423.3 kW; the spring and autumn seasons are second, with 2412.8 and 2412.8, respectively. 2504.8kW; the lowest in summer, 2032.9kW.

Figure 2. Hourly total radiation and photovoltaic power changes in the four seasons
3.3. The relationship between photovoltaic power and cloud cover

Cloud cover is a meteorological factor that characterizes the degree of sky occlusion, and its influence on radiation reflects the weakening of water vapor and aerosols in a certain place. Generally speaking, an increase (decrease) in cloud cover will cause a decrease (increase) in solar radiation on the ground. From the variation curve of photovoltaic power and total cloud cover (Figure 3), it can be seen that the total cloud cover is negatively correlated with photovoltaic power, that is, as the cloud cover increases, the photovoltaic power decreases [4]. From the simulation straight-line trend, it passed the extremely significant test of $P<0.001$, the total cloud amount increased by 10%, and the photovoltaic power decreased by 282.48kW.

![Figure 3. The relationship between daily photovoltaic power and total cloud cover](image)

3.4. The relationship between photovoltaic system's daily power generation and sunshine hours and daily maximum temperature

The paper will calculate the daily power generation, sunshine hours and daily maximum temperature of photovoltaic power station monitoring data from June 1, 2018 to May 31, 2019 according to different seasons, and the daily generation power, sunshine hours and daily maximum temperature of photovoltaic systems in different seasons the relevant situation is shown in Table 2. It can be seen that the correlation between the number of sunshine hours in summer and the daily power generation is relatively significant, with a correlation coefficient of 0.641, followed by autumn and spring. The correlation coefficients of the two are 0.562 and 0.502, respectively. The correlation between the two in winter is the weakest, and the correlation is the coefficient is 0.419. At the same time, it can be seen that the correlation between power generation in spring and winter is not consistent with the number of sunshine hours and solar radiation. It may be due to the snow accumulation of photovoltaic panels in winter [5]. Under the same sunshine hours, the amount of solar radiation is small, and the power is generated. The power is also less.

| variable | $S$  | $T_{\text{max}}$ |
|-----------|------|----------------|
| spring    | 0.502| 0.146          |
| summer    | 0.641| 0.336          |
| autumn    | 0.565| 0.382          |
| winter    | 0.419| 0.006          |

Table 2. Correlation analysis of daily photovoltaic power generation, sunshine hours and daily maximum temperature
Compared with the daily average ambient temperature, the daily maximum temperature has a higher correlation with the power generation. Perhaps because the daily maximum temperature usually occurs during the day, the daytime temperature is mainly affected by solar radiation, so in terms of daily average ambient temperature, the daily maximum temperature has a stronger positive correlation with the intensity of solar radiation [6]. It can be seen from Table 2 that the correlation between the daily maximum temperature and daily photovoltaic power generation is the most obvious in autumn, with a correlation coefficient of 0.382, followed by the correlation between the two in summer, with a correlation coefficient of 0.336. The correlation between daily power generation and daily maximum temperature in northern winter is the lowest. The coefficient is only 0.006.

3.5. Research on Comprehensive Efficiency of Power Plant

Figure 4 shows the daily variation of the grid-connected comprehensive efficiency of photovoltaic power plants from June 1, 2018 to May 31, 2019. The daily comprehensive efficiency is mostly concentrated between 0.5 and 0.7, and the relative fluctuations in winter are relatively large. The annual peak sunshine hours are 1120.6h, the annual full-generation hours are 622.0h, and the annual comprehensive efficiency of the power station is 0.56. Equivalent to the average installed photovoltaic capacity per watt, installed at a 40° inclination angle, it can generate approximately 0.64 kWh of electricity per year in Lanzhou. Due to the installation method with an inclination angle of 40°, the calculation found that in the summer half of the year when the solar radiation is better from May to August, the total monthly irradiation of the photovoltaic array is smaller than the total monthly irradiation of the horizontal plane [7]. Therefore, the inclination method is installed It is not appropriate. Under a suitable installation angle, the annual comprehensive efficiency of the Lanzhou photovoltaic power station should be greater than 0.56, and the annual power generation per watt of photovoltaic installed capacity should be greater than 0.64 kWh. The specific data needs to be further collected for research on photovoltaic power plants [8].

Figure 4. Daily changes in the overall efficiency of the power station

4. Conclusions

The output power of photovoltaic power plants is highly positively correlated with sunshine time and light intensity. The longer the sunshine time and the greater the light intensity, the greater the output power of the module. Cloud cover and relative humidity have a weakening effect on photovoltaic power, and the impact of low cloud cover is greater than that of total cloud cover, and cloud shape also has a significant impact. The effect of temperature on the power of photovoltaic power plants is more complicated. The increase of temperature will reduce the photovoltaic power, but the temperature has
a positive effect on the photovoltaic power through radiation. The response of photovoltaic power to radiation intensity and sunshine hours in winter is more sensitive than other seasons.

Acknowledgements
Fund Projects: Gansu Province Higher Education Industry Support Program Project (2020C-34); 2020 Arid Meteorological Research Fund Project (IAM202009)

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