Analytical Assessment of the Relationship between 100MWp Large-scale Grid-connected Photovoltaic Plant Performance and Meteorological Parameters

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Abstract. This paper helps in study of the relationship between the photovoltaic power generation of large scale “fishing and PV complementary” grid-tied photovoltaic system and meteorological parameters, with multi-time scale power data from the photovoltaic power station and meteorological data over the same period of a whole year. The result indicates that, the PV power generation has the most significant correlation with global solar irradiation, followed by diurnal temperature range, sunshine hours, daily maximum temperature and daily average temperature. In different months, the maximum monthly average power generation appears in August, which related to the more global solar irradiation and longer sunshine hours in this month. However, the maximum daily average power generation appears in October, this is due to the drop in temperature brings about the improvement of the efficiency of PV panels. Through the contrast of monthly average performance ratio (PR) and monthly average temperature, it is shown that, the larger values of monthly average PR appears in April and October, while it is smaller in summer with higher temperature. The results concluded that temperature has a great influence on the performance ratio of large scale grid-tied PV power system, and it is important to adopt effective measures to decrease the temperature of PV plant properly.

1. Introduction
Solar photovoltaic (PV) technology is a promising means of generating clean, sustainable energy, and the use of this technology is rapidly developing around the world [1-4]. By the end of 2015, the capacity of photovoltaic (PV) plants in China has already passed 43.18 GW, and the new additions in photovoltaic capacity is 31 GW in 2016. China has become the country with the largest photovoltaic power capacity of the world [5]. However, photovoltaic power generation output is sensitive to change of climate. With the rapid expansion of the PV plant, the intermittent and uncontrollability of the output power has brought great pressure to the safe, reliable and economic operation of the power system.

Photovoltaic power generation is a multivariable coupling nonlinear stochastic process. The main impact factor is the solar radiation, which is related to the easily determined astronomical factor and geography factor as well as many uncertain meteorological factors, including cloud cover, aerosol, sunshine hours, temperature, and humidity [6]. In recent years, many domestic and international
scholars carried on a great deal of empirical research to the impact of meteorological environment factors on photovoltaic power generation, and some useful conclusions were obtained [7-10]. Most of these studies were based on pilot environmental data, the conclusions were idealistic or do not tally with the operation of the actual and commercialized photovoltaic power station.

In this paper, it is intended to research on the impact of typical meteorological factors on the photovoltaic power generation of a 100MWp grid tied photovoltaic plant. Firstly, the correlation analysis of meteorological factors to photovoltaic power generation was carried out by using the whole year’s data; Moreover, the influence of meteorological parameters on energy generation capacity was analysed with monthly mean data; Last but not least, the monthly mean performance ratio was analysed to quantifies the overall effect of equipment failure and efficiency on the rated plant potential output.

2. System details

![Figure 1. The 100MWp grid connected solar power plant.](image)

The 100MWp grid connected polycrystalline PV system under performance assessment has been installed at the Yangzhou city of Jiangsu Province of China. With the theme of "ecological equilibrium, energy conservation and environmental protection" and by the pattern of "fishing and PV complementary", the solar PV plant has been installed above a fishpond with ornamental plants in it. The project makes full use of water resources in the region, organically combined solar photovoltaic power generation and aquaculture, as well as ecological agriculture and tourism, and formed a three-dimensional developed comprehensive new energy power base with special features. The schematic diagram of the system is shown in Fig. 1. The total investment of the project was one billion yuan, more than four hundred thousand pieces of polycrystalline silicon solar panels were laid in the area of 2500 mu. The grid connected PV system has been put into operation in December 2014, and realized the connection to the utility grid of the whole district in December 2015. The total energy output generated from solar PV plant was 97.588 million kWh in 2015, which amount to saving about 29000 tons of standard coal, reducing the pollutants such as SO₂, NOₓ and CO₂ about 73 tons for the country.

The photovoltaic power generation data adopted in this paper was from December 2015 to November 2016 by hours throughout the whole year. The Radiation data and conventional meteorological data of the same period were taken from the real-time monitored data by hours throughout the year by environmental monitoring equipment that installed at the photovoltaic power plant.

3. Methodology

3.1. Correlation analysis

There are many meteorological factors that make great influence on the yield of photovoltaic power generation. In order to identify the importance of the impact factors, it is appropriate to measure the linear correlation degree of relationship between the electricity energy generation and various
meteorological factors by using correlation analyse. The most commonly used Pearson correlation coefficient of two-dimensional variables is defined as shown in formula (1).

\[ \eta_{cor} = \frac{\sum_{i=1}^{N}(x_i-x)(y_i-y)}{\sqrt{\sum_{i=1}^{N}(x_i-x)^2}\sqrt{\sum_{i=1}^{N}(y_i-y)^2}} \]  

(1)

Where, \( N \) is length of sample series, \((x_i,y_i)\) is the observed value of sample \( i \) of the two-dimensional variable \((X,Y)\), and \((\bar{x}, \bar{y})\) is the average value of the \( N \) samples of the two-dimensional variable \((X,Y)\).

3.2. Performance ratio (PR)

The Performance Ratio (PR) is one of key parameter to determine efficiency of the PV systems regardless of module efficiency. The PR is useful to compare great amount of datasets graphically in order to analyse the influence of different factors. The PR indicates that how much the PV power plant is energy efficient and reliable. It provides the option for checking performance, output, seasonal oscillations and long-term degradation [9]. It is given in formula (2).

\[ \text{PR} = \frac{Y_f}{Y_r} = \frac{E_{AC}/P_{PV}}{G_f/G_{STC}} \]  

(2)

Where, \( Y_f \) is the yield factor, which is defined as the ratio of the AC Energy generated by PV power plant \( (E_{AC}) \) to the rated DC power of the PV power plant \( (P_{PV}) \) at ideal condition \((1000 \text{ W/m}^2, 25^\circ \text{C}, 1.5 \text{ AM})\); \( Y_r \) is the reference yield that can be defined as the ratio of the total in plane radiation \( (G_i) \) to module's reference in-plane irradiance \( (G_{STC}) \) which is generally taken as 1000W/m².

4. Results and discussion

4.1. Correlation analysis of meteorological factors to photovoltaic power generation

Table 1. Correlation analysis of daily photovoltaic power generation to daily meteorological factors

| variables | photovoltaic power generation | average radiation | average temperature | mean wind speed | temperature range | maximum temperature | minimum temperature | hours of sunshine |
|-----------|-------------------------------|-------------------|---------------------|----------------|------------------|---------------------|---------------------|-----------------|
| photovoltaic power | 1 | 0.937 | 0.248 | 0.058 | 0.659 | 0.282 | 0.106 | 0.522 |
| average radiation | 0.937 | 1 | 0.063 | 0.090 | 0.638 | 0.092 | -0.077 | 0.300 |
| average temperature | 0.248 | 0.063 | 1 | -0.150 | 0.058 | 0.988 | 0.966 | 0.782 |
| mean wind speed | 0.058 | 0.090 | -0.150 | 1 | -0.111 | -0.143 | -0.113 | -0/114 |
| temperature range | 0.659 | 0.638 | 0.058 | -0.111 | 1 | 0.106 | -0.158 | 0.255 |
| maximum temperature | 0.282 | 0.092 | 0.988 | -0.143 | 0.106 | 1 | 0.965 | 0.751 |
| minimum temperature | 0.106 | -0.077 | 0.966 | -0.113 | -0.158 | 0.965 | 1 | 0.678 |
| hours of sunshine | 0.522 | 0.300 | 0.782 | -0.114 | 0.255 | 0.751 | 0.678 | 1 |

The correlation analysis of photovoltaic power station daily output data to the daily meteorological data for the whole year (December2015-November2016) was made by using SPSS statistical software, and the results are shown in Table 1. Firstly, it is obvious that daily photovoltaic power generation is significantly positively related to daily average radiation, the Pearson correlation coefficient is 0.937; Secondly, the positive correlation coefficient of daily photovoltaic power generation to daily temperature range is 0.659; Then, the positive correlation coefficients of daily photovoltaic power generation to daily hours of sunshine, daily maximum temperature, daily average temperature, daily minimum temperature and daily mean wind speed are 0.522, 0.282, 0.248, 0.106 and 0.058 respectively.

Because of the adoption of yearly data, there may be the phenomenon of the offsetting between positive and negative ones in variable correlation analysis. Therefore, it is need to have further
detailed analysis in order to determine the influence of the key meteorological factors on photovoltaic power generation.

According to the physical process of photovoltaic power generation, solar radiation is the most direct and key impact factors that is influenced by astronomical factors, such as the revolution and rotation of the earth, and has a larger difference between each month. As shown in Table 1, the positive correlation coefficients of daily temperature range to daily average radiation is 0.638, which means a strong correlation between them. It makes little sense to analyse the impact of the temperature diurnal range on the power generation, while temperature has great influence on the efficiency of PV panels. As a result, the three key meteorological factors were confirmed as daily average radiation, daily average temperature and daily hours of sunshine.

4.2. Data analysis of meteorological parameters

By processing meteorological parameters data measured by real-time climate environment sensors in PV substation, the monthly average values of daily solar radiation, daily average temperature and daily average sunshine hours from December 2015 to November 2016 were obtained, as shown in Fig.2.

As can be seen from the Fig.2, the maximum value of the monthly average daily solar radiation appeared in August, which as high as 443.72 W/m², while the minimum value appeared in October as 199.30 W/m²; the maximum value of the monthly average daily average temperature was also appeared in August as 30.7 °C, while the minimum value appeared in January as 4.4 °C; The tendency of sunshine hours was consistent with daily average temperature, the maximum and minimum values respectively appeared in August and January.

4.3. Analysis of the energy generation capacity

Based on the obtained values of meteorological parameters from the above methods, it is now possible to study the influence of meteorological parameters on the output power from PV modules during the daylight hours. Fig. 3 exhibits the daily electricity generated scatter plot of the whole year, and Fig.4 illustrates the histogram of monthly mean value of daily energy generation capacity.

As shown in the two figures, the maximum daily energy yield throughout the year was 670,705.20 kWh, which appeared on 3 May 2016. The daily average solar radiation was 579 W/m², the daily average temperature was 21.1 °C, and the daily sunshine hours were 12.83h on that day. The maximum monthly value of daily energy yield was 449,674.61kWh, which appeared on August 2016. The monthly average value of daily solar radiation, daily average temperature and daily average sunshine hours were 43.72 W/m², 30.68 °C and 12.82h respectively of August 2016.

It was mainly due to the higher sunshine intensity and the longer sunshine hours of the month, making the monthly day output is larger in August. There were two reasons that make the maximum
day output appeared on 3 May. For one thing, the daily solar radiation was relatively large; and for the other more important thing, the daily average temperature was much lower on that day. The influence of the temperature on the photovoltaic power generation is complicated. On the one hand, the environment temperature affects the module operating temperature, and the performance of PV battery changes over the module operating temperature. The increase in temperature leads to the increase in conductivity of the semiconductor of solar cell, and outermost electrons acquire energy and leave the shell of the atom, as well as the reduction of the band-gap thereby increases the photocurrent slightly and decreases open circuit voltage of cell heavily. As a result, the total energy created by the solar cell decreases with increment of temperature [6,9,11]. On the other hand, there is an obvious positive correlation between temperature and solar total radiation. The solar total radiation increases, the temperatures and the corresponding photovoltaic power generation also increases. It means the temperature brings about positive effects on the photovoltaic power generation through the solar total radiation.

Figure 3. Daily energy generation capacity

Figure 4. Monthly mean value of daily energy yield

Therefore, it is necessary to take appropriate measures to control the temperature of the photovoltaic panels. Making the PV panels work at a proper temperature ensures the efficient utilization of solar radiation, as well as the efficient control of the adverse effect on the performance of the solar PV module of temperature.

4.4. Analysis of the monthly mean PR

Figure 5. Monthly mean value of daily performance ratio

The monthly mean daily performance ratio is shown in Fig.5. The PR was found above 90% in April, May, and October. Among these three months, the PR were 94.4%, 92.3% and 92.1% in April, May and October respectively. The minimum value of PR is 79.2% that appeared in September. It was noteworthy that the PR of August with maximum energy output was only 81.6%, while it was as high
as 92.1% in October with minimum energy generation capacity. The main reason was that although the soiling in August is higher, but the temperature was also higher which brought about the lower operating efficiency of solar cell. In October, the monthly average daily temperature was 19.2 °C that made the solar cell works with efficient utilization of solar radiation.

5. Conclusions
The impact of typical meteorological factors on the photovoltaic power generation under different months of a 100MWp grid tied photovoltaic plant has been carried out in this study. The solar PV plant has been installed above a fishpond at the Yangzhou city of Jiangsu Province of China since December 2014.

From the correlation analysis, it can be concluded that the daily PV power generation has the most significant correlation with daily global solar irradiation, followed by diurnal temperature range, daily sunshine hours, daily maximum temperature and daily average temperature. The maximum monthly average power generation appears in August, and the maximum daily average power generation appears in October. Through the contrast of monthly average PR and monthly average temperature, the larger values of monthly average PR appears in April and October with lower temperature while it is smaller in summer with higher temperature.

The results concluded that temperature has a great influence on the performance ratio of large scale grid-tied PV power system, and it is important to adopt effective measures to decrease the temperature of PV plant properly.

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7. References
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