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Analysis and prediction of photovoltaic output power fluctuation based on plateau meteorological impact factor

In order to study the characteristics of plateau photovoltaic (PV) output power, the fluctuation analysis and prediction of photovoltaic output power in one area of Tibet are performed in this paper, where the winter and summer seasons are focused, respectively. Meanwhile, the EEMD-BP model was established. Based on the fluctuation analysis and 15-day forecast of the output power of a PV power station in the examined area, six cases are categorized and evaluated. That is, the temperature is the average of the fluctuation, the irradiance is the change, the temperature is the change, the irradiance is the average of the fluctuation, the temperature is the change, and the irradiance is the change. The results show that when the temperature variation is only considered and the irradiance is the average value of the fluctuation in the winter, the PV output power is more accurate and the fluctuation is close to the original value; when the temperature variation and the irradiance variation is considered in the summer, the output power has the best prediction accuracy and smooth fluctuations.

Keywords: Photovoltaic; plateau; volatility; meteorological impact factor; output prediction.

1. Introduction

The energy crisis and environmental pollution problems have become increasingly prominent with the rapid development of economy in China. Therefore, it is necessary to develop and utilize clean energy, such as solar energy, wind energy and so on in order to achieve sustainable economic development. Because of its abundant solar energy resources, Tibet will be built into a national clean energy base to make full use of this advantage. In the past decade, the grid connected installed capacity of photovoltaic (PV) power stations there has been increasing, and the new installed capacity will reach 1,000,000KW in 2020. PV output power is easy to be affected by meteorological factors, and strongly fluctuated and random, which has a certain impact on the safe and stable operation of the power system, which in turn also harms the consumption of photovoltaics.

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As a result, there is a necessityto carrying out fluctuation analysis and prediction of PV output power in order to overcome these problems.

At present, the research on the fluctuation of PV output power mainly focuses on the impact of meteorological factors, the negative impact on the grid, and the impact on the output power prediction of PV power stations[1, 2]. In reference [2], the correlation between the main meteorological factors and their influence on the PV output power is summarized through the zonal sensitivity, regression analysis based on SPSS software, path analysis and so on. In reference [3], Pearson correlation coefficient analysis method is used to reveal the main factors affecting PV power generation; fuzzy clustering theory is used to build similar days; and a support vector regression model is established to predict the short-term PV output when meteorological data is weakly related to PV output. In reference [4], a prediction model of PV output power is built based on the measured data, and the regression analysis shows that solar radiation has the most significant impact on the PV output power, and the impact of air quality on the PV output power in this area cannot be ignored. In reference [5-7], based on a large number of measured data, using a variety of probability models such as generalized Gaussian distribution and finite element hybrid model, the characteristics of PV output power fluctuation in different time scales are modeled, and the output power fluctuation law of PV power station is quantitatively analyzed, which is conducive to improving the penetration of PV grid connection. Tibet has unique natural environment and climate characteristics (with large temperature difference), and the PV output power there fluctuates greatly. Therefore, it is an urgent problem to accuratelyanalyze and predict the PV output power fluctuation in Tibet.

In this paper, taken a PV power station in Tibet is firstly as the research object, and then the influence factors of the output power under the seasonal characteristics of the plateau are analyzed based on the measured output power data, and finally an accurate EEMD-BP model is established to analyze the fluctuation and carry out a short-term prediction of the PV output power. The results show that the prediction accuracy of PV output power in winter is the highest, RMS error is 1.915, and the fluctuation is gentle when the temperature variation and irradiance are the average of the average of the fluctuation; and the prediction accuracy of PV output power in summer is the highest, RMS error is 1.830, and the fluctuation is close to the original value when the temperature variation and irradiance are the change.

2.Factors influencing PV output power under seasonal characteristics of plateau

There are many factors that affect the PV output power, among which the meteorological factors (temperature, irradiance, etc.) have a greater impact.According to the seasonal division in reference [8], Tibet has the plateau season of equivalent summer and winter.In this paper, the influence of meteorological factors is studied. The irradiance, temperature and PV output power of a PV power station in Tibet in winter are selected for analysis. The data used are from Tibet meteorological station.The PV output power from October 1, 2017 to September 30, 2018 was selected, with 15 minutes as the time step. Taking April 30, 2018 as the dividing point, the meteorological factors (temperature and irradiance) related to PV output power in winter and summer were analyzed to explore the impact of irradiance and temperature variation on PV output power.

2.1.Influence factors related to PV output power in winter

The average minimum temperature in winter in this area is −3℃- −6℃. The sunshine time is short and the total radiation amount of the sun is small.Figure 1 shows the curves of the PV output power and radiation intensity on a certain day in the actual measurement of a PV power station.It is observed from the figure that the change of solar irradiance in the curve in winter is roughly the same as that of PV output power. The PV output power fluctuat with the change of irradiance. During this period, the irradiance corresponding to the point where the maximum output power appears is 390W/m^2, and the output power reaches 6.06kW.At the same time, in the sampling interval of 15 minutes, the corresponding irradiance fluctuates greatly. The maximum fluctuation of output power at the DC side of PV power station is as high as 6kW, about 99% of the maximum output power.Further, Pearson correlation analysis shows that the correlation coefficient between irradiance and PV output power is 0.88, indicating that irradiance and PV output power are closely related, and the impact of environmental temperature on the output power of PV power station is mainly reflected in the change of solar cell electrical performance with the variation of temperature.As the solar irradiance has a direct impact on PV power generation, the greater the solar radiation intensity, the greater the output power, so it can be used as an important technical index to predict PV power generation.

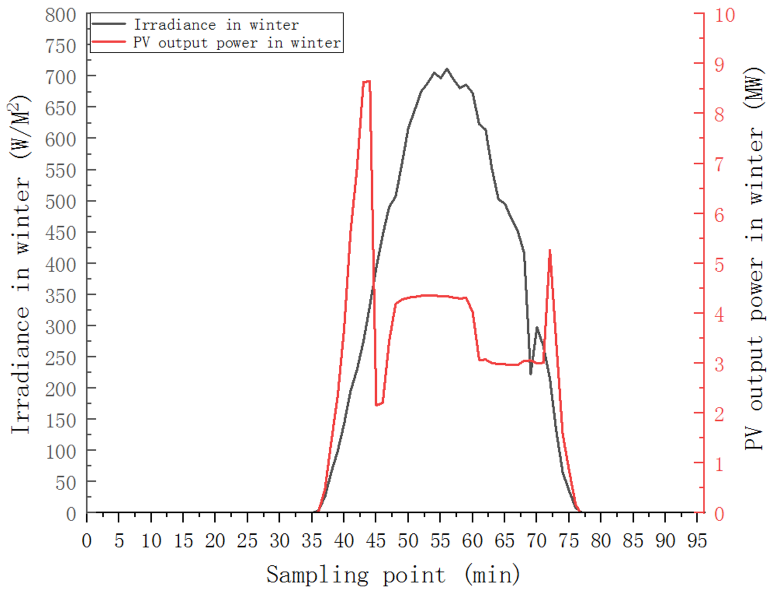

Figure 1: Irradiance and PV output power in winter

Figure 2 shows the curves of the PV output power and temperature on a certain day in the actual measurement of a PV power station. Here, the PV power station uses polysilicon solar cells. It is observed that the change of PV output power curve differs greatly from the temperature curve, the output power decreases greatly with the increase of temperature, and that the correlation coefficient between temperature and PV output power is 0.73, indicating that temperature and PV output power are closely related. That is to say, the output power of PV in winter is less affected by temperature.

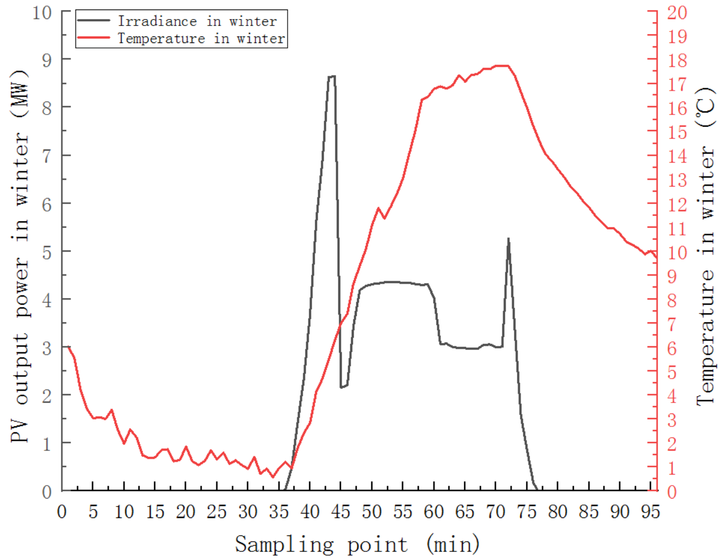

Figure 2: Temperature and PV output power in winter

2.2.Influence factors related to PV output power in summer

This area has an average temperature in summer of about 20□, a sunshine duration with a large total radiation amount of the sun.The PV output power is low in the morning and evening, high at noon, and the irradiation time is concentrated in 07:00-20:00.Figure 3 shows the curves of the PV output power and radiation intensity on a certain day in the actual measurement of a PV power station. It is observed from the figure that the change trend of irradiance is basically consistent with that of the PV output power in summer when the maximum output power point appears, with the corresponding irradiance of 1,072W/m^2 and the output power of 10.71kW. That is, when the PV output power reaches the highest value, the irradiance also reaches the maximum value.The correlation coefficient between irradiance and PV output power is 0.96, which shows that irradiance is closely related to PV output power. At the same time, in the sampling interval of 15 minutes, the corresponding irradiance also fluctuates greatly. The maximum fluctuation of the output power at the DC side of the PV power station is as high as 10kW, about 93% of the maximum output power.As the solar radiation intensity has a direct impact on PV power generation, the greater the solar radiation intensity is, the greater the output power is, so it can be used as an important technical index to predict PV power generation.

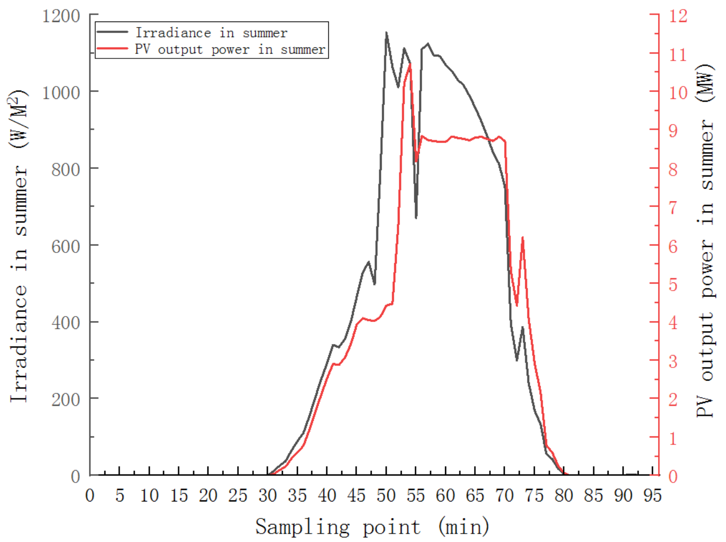

Figure 3: Irradiance and PV output power in summer

Figure 4 shows the curves of the PV output power and temperature on a certain day in the actual measurement of a PV power station. It is observed from the figure that the time when the peak value and bottom value of temperature appear is close to that of PV output power in summer, and the change trend of PV output power curve is basically the same as the temperature curve. The correlation coefficient between temperature and PV output power is 0.88, which indicates that temperature has a close relationship with PV output power, that is to say, the PV output power in summer is greatly affected by temperature.

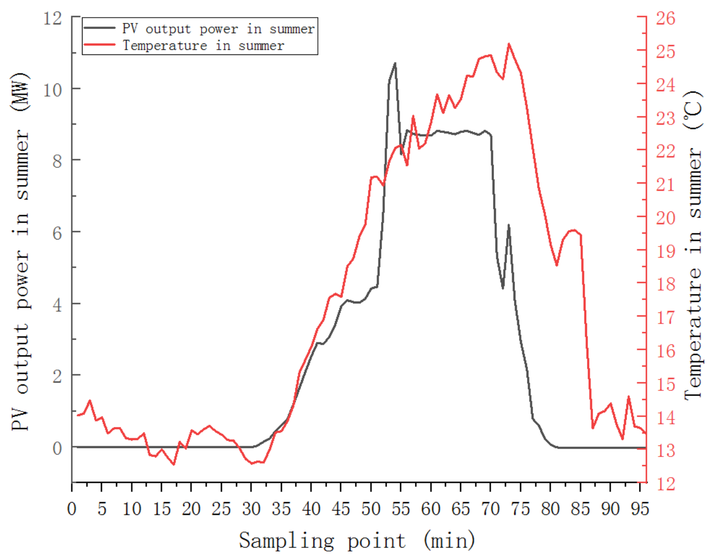

Figure4: Temperature and PV output power in summer

The above analysis shows that the curve trend of irradiance and PV output power in winter is basically the same as that in summer, but the change trend of temperature curve and PV output power curve in winter shows that the temperature in winter has less impact on PV output power. In summer, the trend of irradiance, temperature and PV output power curve is basically the same, and the temperature curve and PV output power curve have the same trend of change, and the irradiance curve is weakened to some extent by comparison.

3.Short-term prediction of PV output power

3.1. Model theory

In view of the fluctuation and randomness of PV output power, EEMD is used to decompose the original data to obtain limited and more stable components, which overcomes the problems of over envelope, under envelope, mode overlapping state, end-point effect of EMD decomposition, and BP algorithm is used to overcome the problems of slow learning speed and local minimum points.The combination of thetwo algorithms has both advantages and does not increase the calculation time of the algorithm, so the two are fused. The results show that the predicted value after EEMD decomposition has higher accuracy and smaller error, which shows the practicability of EEMD-BP model in short-term prediction.

3.1.1.EEMD Ensemble empirical mode decomposition EEMD

In order to avoid mode liasing under abnormal conditions, the method oesemble empirical mode decomposition (EEMD) [9] is introduced, which avoids that the upper and lower envelope lines obtained in EMD decomposition contain both the real local envelope lines and the local envelope lines under abnormal conditions due to the existence of abnormal data, thus resulting in the mode aliasing of IMF components.

EEMD method, based on EMD, introduces two important parameters: white noise amplitude and EMD decomposition times.EEMD makes use of the fact that Gaussian white noise is still continuous in different scales and frequencies, and introduces it on the basis of the original signal to suppress mode aliasing. Almost the same as EMD algorithm, the original signal $x(t)$ of EEMD algorithm is given and introduced to white noise. Firstly, EMD algorithm is used to decompose the original signal with white noise for many times, and the IMF vector and residual components after decomposition are lumped to get the average value.

3.1.2.BP Artificial neural network BP

The advantage of neural network lies in extracting and approaching the nonlinear relationship between input and output through learning. In its training, only input data is needed, instead of complex assumptions for input data.BP neural network has one input layer, one or more hidden layers and one output layer. Each layer has multiple neurons. The function of the neurons between layers is to realize weight connection, because the neurons in the same layer are not connected.

3.2.Data processing

Because the PV output power and meteorological data change greatly every day, the load data, temperature data and weather change index cannot directly enter the input layer of BP neural network, so the mapminmax function is used for normalization processing in order to reduce the workload of BP network and make the prediction accurate.

3.3.Model verification

The model for EEMD-BP neural network ensemble is mainly divided into four steps, and the model flow chart is shown in Figure 5.

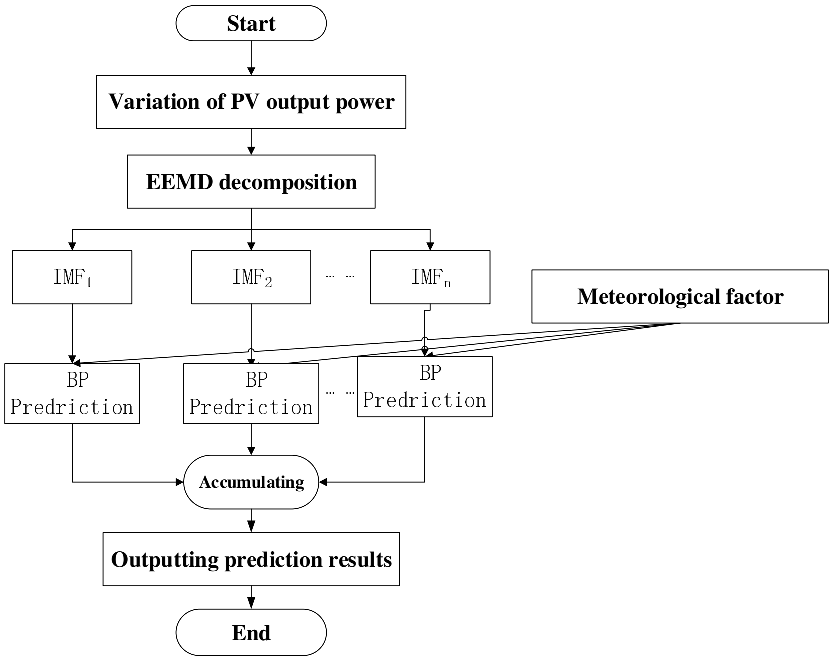

Figure5:PredictionmodelofEEMD-BP

The variation range of PV output power in 150 days (one sampling point every 15min, 96 points every day, and find out the difference between the maximum value and the minimum value, the dimension is MW) and meteorological factor (same as the processing method of output power) of a PV power station in Tibet were selected as samples, among which the output samples and meteorological factor samples in the first 135 days were used as training samples, and the load samples and meteorological factor samples in the last 15 days were used as control samples;

EEMD method was used for decomposition and combination.After EEMD decomposition of meteorological data, 7 groups of IMF components with different frequencies and 1 group of residual components were obtained.Taking a certain day as an example, eight groups of 135×3 data were obtained by the combination of IMF1, IMF2, IMF3, IMF4, IMF5, IMF6, IMF7 and residual trend components (RFE) after EEMD decomposition;

BP neural network prediction.The prediction results were integrated (accumulated) and predicted in winter and summer respectively, taking into account the influence of temperature, irradiance and other factors;

Result interpretation. The prediction results were plotted and the error was analyzed.In order to explore the prediction accuracy of the variation range of PV output power in various cases, the mean absolute error (MAE), root mean square error (RMSE), mean absolute percentage error (MAPE) were taken as the measurement indexes [10,11], and the prediction results error of the model was calculated.

3.4.Establishment of EEMD-BP to predict PV output power and fluctuation analysis

There are three scenarios (six scenarios in total) in winter and summer in the plateau seasonal climate: (1) temperature is the average value of fluctuation, and irradiance is the fluctuation; (2) temperature is the fluctuation, and irradiance is the average value of fluctuation; (3) temperature is the fluctuation, and irradiance is the fluctuation.EEMD-BP prediction model was established for prediction, and each scenario was tested 30 times independently, and the prediction results were counted. The prediction error analysis is shown in Table 1, and the prediction curves are shown in Figure 6 and Figure 7.

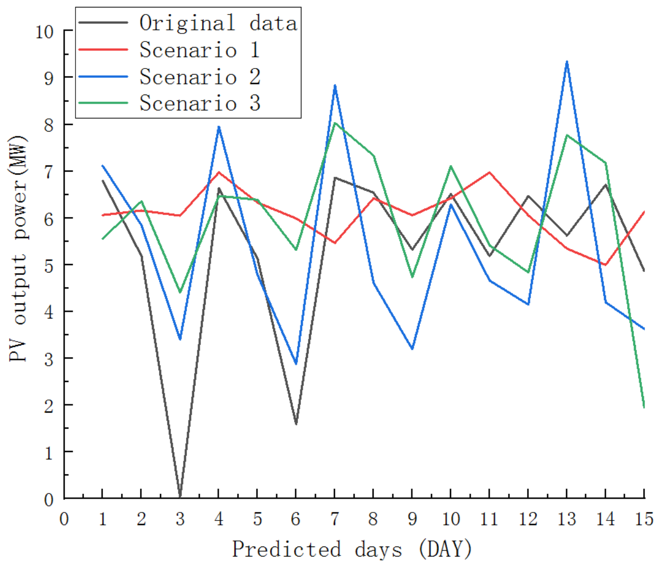

Figure 6:Threescenariopredictioncurvesinwinte

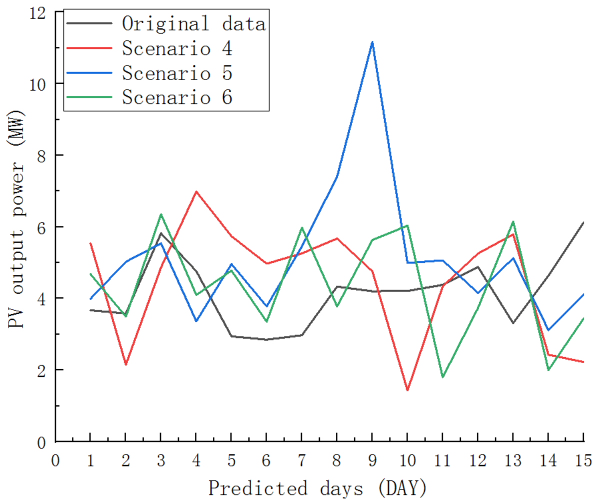

Figure 7: Three scenarios prediction curves in summer

Table 1 shows that the MAPE of the six scenarios are 13.68, 7.7, 10.0, 0.4, 0.4 and 0.3, respectively. Among them, the impact of temperature change on output power prediction was not considered in scenarios 1 and 4, and the prediction effect was poor; the impact of irradiance change on output power prediction was not considered in scenarios 2 and 5, and the prediction effect was poor. However, when the influence of irradiance change on output power was not considered in winter, the prediction accuracy was higher; when the influence of both changes was considered in summer, the prediction accuracy of output power was higher.

Table1:Predictionerror analysis

Indexes	*Winter*			*Summer*		
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
RMSE	2.146203	1.915703	1.937072	2.084526	2.374955	1.830794
MAPE	13.68275	7.760604	10.04957	0.47056	0.449982	0.395541
MAE	1.431756	1.592464	1.497736	1.824671	1.764574	1.555273

4. Conclusions

First of all, the direct impact and indirect interaction of various meteorological factors on the PV output power are analyzed through SPSS and other software based on the output power recorded by a PV power station in Tibet meteorological station and the meteorological data collected in the same period. Then, the annual data are divided into winter and summer for seasonal output analysis according to the seasonal characteristics of the plateau. Finally, an EEMD-BP model is established to predict the short-term PV output power under different scenarios. The following conclusions are drawn:

(1) Solar irradiance and temperature are still the main meteorological factors that have a great impact on PV output power under the seasonal characteristics of plateau. Among them, irradiance has a great influence on the output power in winter, and temperature is not particularly obviously related to the PV output power; the correlation between solar irradiance and temperature and PV output power in summer is significantly higher than that in winter, and the correlation between solar irradiance and PV power is the strongest in summer.

(2) The PV output power fluctuates with the change of irradiance in winter, which is less affected by temperature.The corresponding irradiance is 390W/m^2, and the output power is 6.06kW. The maximum fluctuation of the output power at the DC side of the PV power station is as high as 6kW, about 99% of the maximum output power.In summer, the change trend of PV output power curve is basically the same as that of irradiance and temperature curve. PV output power fluctuates with the change of irradiance and temperature. The corresponding irradiance is 1,072W/m^2, and the output power reaches 10.71kW. The maximum fluctuation of the output power at the DC side of the PV power station is as high as 10kW, about 93% of the maximum output power.

(3) Aiming at the fluctuation of PV output power, an EEMD-BP model is established to predict the short-term PV output power. In considering the influence of seasons and meteorological factors on the prediction of PV output power, when the temperature variation is only considered and the irradiance is the average value of the fluctuation in the winter, the PV output power is more accurate and the fluctuation is close to the original value; when the temperature variation and the irradiance variation is considered in summer, the output power has the best prediction accuracy and smooth fluctuations.

The above study provides a way to analyze the output power fluctuation and short-term prediction of PV power stations under plateau meteorological conditions in Tibet.

Acknowledgement

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