

Photovoltaic Power Prediction Considering the Influence of Smog on Solar Radiation

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Abstract. As smog significantly weakens the intensity of solar radiation, the impact of smog on photovoltaic power generation cannot be ignored. This article aims to improve the prediction accuracy of photovoltaic power generation under smog weather. The impact of main atmospheric meteorological factors on atmospheric aerosols under smog weather is studied, and radial basis function neural network is adopted to predict the optical thickness of atmospheric aerosols; then, the inclined plane radiation model is established to predict the radiation intensity received by the photovoltaic panel; finally, considering fully the factors affecting the photovoltaic power generation under the smog weather, the RBF neural network is used to predict the photovoltaic power. Experimental verification proved that the presented photovoltaic power prediction model has high accuracy.

Index Terms—Smog, Inclined surface solar radiation intensity, Radial basis function neural network, PV power forecast

1 Introduction

The goal of carbon neutrality and carbon peaking is a test for improving the safe and stable operation of the power grid. For photovoltaic power generation, it is urgent to improve the accuracy of photovoltaic power prediction to provide a reliable basis for grid dispatching[1]. The smog has an obvious weakening effect on solar radiation, and the smog weather has become a factor that cannot be ignored in the research of photovoltaic power generation[2-3].

At present, there are few studies on the influence of smog factors on photovoltaic power [4]. Zhu Honglu et al. [5] studied the impact of environmental factors on the output of photovoltaic systems and concluded that solar irradiance has the greatest impact on the output of photovoltaic systems; The temperature of the panel has the second effect on the output of the photovoltaic system. Literature [6] studied the impact of ash accumulation on photovoltaic prediction under smog and showed the importance of in-depth study of photovoltaic power prediction under the influence of smog. In terms of solar radiation intensity prediction, consider the reduction of solar radiation intensity by atmospheric aerosol optical depth (AOD), Calculate the radiation intensity of the earth's surface through atmospheric radiation transmission theory, and then rely on the photoelectric conversion

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model to predict the photovoltaic power generation [7]. As AOD is difficult to obtain accurately and in real time, Literature [8] calculated the PM2.5 concentration and PM10 concentration of MODIS aerosol optical thickness products, and got a more accurate PM2.5 concentration. Wang Jun et al. [8] proved that there is a good correlation between AOD and PM2.5 concentration.

The main work of this paper is as follows, Firstly, a radial basis function neural network prediction model is established fully considering the correlation analysis of PM concentration and meteorological factors on the weakening of solar radiation intensity under smog weather conditions, which could predict the AOD ; Secondly, on the basis of the predicted AOD, the solar radiation intensity reaching the photovoltaic panel is calculated based on the atmospheric radiation transmission theory and the calculation model of the solar radiation intensity of the inclined plane; Thirdly, a photovoltaic power prediction model is established in consideration of meteorological factors to realize the forecast of photovoltaic power generation under smog weather.

2 Analysis on the impact of smog weather on AOD

2.1 Data collection

Atmospheric aerosols are various granular substances uniformly dispersed in the air to form a relatively stable and huge suspension system. According to the aerodynamic diameter, it can be divided into TSP, PM10 and PM2.5, Because atmospheric particulate matter is affected by factors such as temperature, humidity, wind speed, air pressure, and aerosol elevation, this paper analyzes the correlation between AOD in the 440nm band and 1020nm band and the main meteorological factors in smog weather.

The meteorological data used in the AOD prediction model in this paper comes from the China Meteorological Data Network (<http://data.cma.cn/>) Beijing Chaotaichang Station; PM2.5 and PM10 data are taken from Chaoyang monitoring point of Beijing Environmental Protection Testing Center (<http://www.bjmemc.com.cn/>); The AOD data uses a more accurate ground-based observation method and is taken from the global ground-based aerosol remote sensing automatic observation network (<https://aeronet.gsfc.nasa.gov/>), The monitoring station selected the Beijing monitoring station closest to the meteorological observation point in Chaoyang District (coordinates: 116.583°E/39.783°N); The aerosol elevation data is selected from literature [10], 1.563km in spring, 1.77km in summer, 0.851km in autumn and 0.909km in winter. In order to adapt to the atmospheric transmission model, the acquired data was screened, and finally 2274 sets of data from May 14, 2014 to March 6, 2018 were screened out.

2.2 Correlation analysis

Analyze the correlation between 440nm band AOD and 1020nm band AOD with PM concentration, aerosol elevation, temperature, wind speed and other meteorological factors, and the correlation is shown in the calculation formula (1)

$$r(X, Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad (1)$$

Among them, $r(X, Y)$ represents the closeness of the correlation between X and Y, and \bar{x} and \bar{y} are the average values of data sets X and Y, respectively.

Through calculation and analysis, the correlation results of relevant data are obtained, as shown in Table 1.

Table 1. Correlation coefficients of dual band aod and related factors

Related Factors	440nmAOD	1020nmAOD
PM2.5	0.740	0.673
PM10	0.671	0.725
Temperature	0.207	0.243
Humidity	0.551	0.432
Wind speed	-0.282	-0.340
Pressure	-0.304	-0.184
Aerosol elevation	0.118	0.182

It can be seen from Table 1 that the AOD of the two bands has a relatively strong correlation with PM2.5 concentration, PM10 concentration and relative humidity, and a certain correlation with temperature. 440nmAOD has a weak correlation with aerosol elevation, while 1020nmAOD has a strong correlation with the aerosol elevation. The aerosol elevation shows a certain correlation. Considering that the aerosol elevation is the seasonal average, the calculated correlation is weak and within a reasonable range. The AOD of the two bands has a certain negative correlation with wind speed and air pressure.

3 AOD prediction model

RBF neural network has simple structure, simple training, fast learning convergence speed, can approximate any nonlinear function, and overcome the local minimum problem. Therefore, this paper establishes an AOD prediction model based on RBF neural network.

In this paper, the AOD value of two bands is used as the training target to establish a radial basis function neural network, gradually increase neurons, and continuously redesign the linear layer of the network to gradually reduce the error. This paper conducts data training by setting the maximum number of neurons. By randomly selecting 2100 sets of data as training samples, and the remaining 174 sets of data as test samples, the number of neurons added each time in this article is set to 50, and the maximum number of neurons is set to 300. The mean square error(MSE) of the training results at this time is 0.01208. This shows that the training model can get a better fitting effect. The fitting result of the training sample is shown in Fig.1.

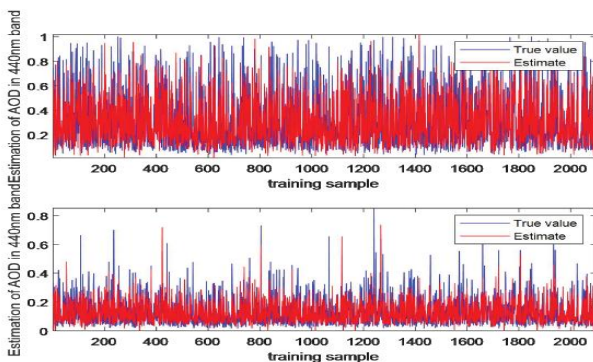


Fig. 1. Estimation results of training samples based on RBF neural network.

In order to test the generalization applicability of the training model, the absolute error between the predicted value of the test sample and the true value is calculated, and the occupancy rate of the absolute error less than 0.2 is calculated. The result of the absolute error of the test sample is as follows, 440nm waveband AOD inspection samples accounted for 83.93%; 1020nm waveband AOD inspection samples accounted for 98.85%. The absolute error results are shown in Fig.2. From the results, it can be seen that the training model in this paper has good generalization and prediction accuracy.

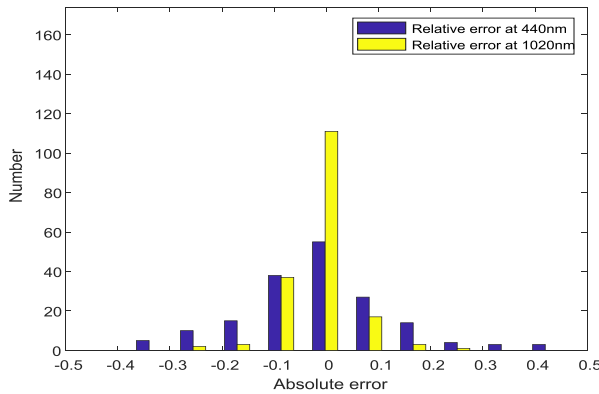


Fig. 2. Absolute error distribution of test samples.

The comparison between the predicted AOD value and the actual value of the two bands is shown in Fig.3.

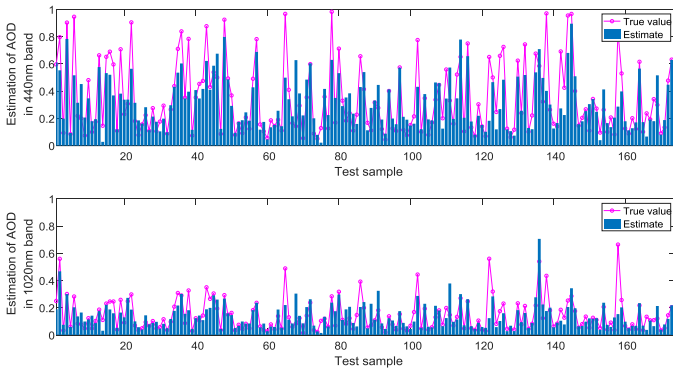


Fig. 3. Comparison of predicted and actual values of dual band AOD.

4 Prediction of the radiant intensity of the slope of photovoltaic panels

At present, there are many studies on solar radiation models, most of which are irradiance models under clear sky conditions. Among them, the REST2 model has higher prediction accuracy than other models [11-12]. The REST2 model is an atmospheric radiation transmission model that calculates the direct and scattered intensity values of solar radiation in the 0.29~0.70 μ m band and 0.70~4 μ m band.

This paper uses the REST2 model to calculate the intensity of direct and scattered radiation reaching the surface, then through the direct radiation calculation formula of the inclined surface, the Koronakis model of the inclined surface radiation intensity calculation model and the classical formula of the ground reflected radiation[13].Get the final total radiation intensity of the inclined surface of the photovoltaic panel.

4.1 Calculation of the total radiation intensity of the inclined surface

The total radiation intensity I_t of the inclined surface is composed of three parts: direct radiation I_{bt} of the inclined surface, scattered radiation I_{dt} of the inclined surface, and ground reflection radiation I_r . The relevant formula is

$$\begin{cases} I_t = I_{bt} + I_{dt} + I_r \\ I_{bt} = I_{bn} \cdot \cos \theta_i \\ I_{bh} = I_{bn} \cdot \cos Z \\ I_{dt} = I_d \frac{2 + \cos \beta}{3} \\ I_r = \rho_{gi} I_b \frac{1 - \cos \beta}{2} \\ I_b = I_{bh} + I_d \end{cases} \quad (2)$$

The photovoltaic panels involved in this article are placed in the true south direction, that is, the azimuth angle $\gamma=0$, so the sun incident angle on the inclined plane can be defined as:

$$\cos \theta_i = \sin \phi \sin(\phi - \beta) + \cos \delta \cos \theta \cos(\phi - \beta) \quad (3)$$

In formulas (2) and (3), θ_i is the incident angle of the sun on the inclined surface, and β is the inclination angle of the photovoltaic panel.

4.2 Model accuracy check

This article uses TES-1333R photometer to collect data on the light radiation intensity of inclined surfaces under the smog weather conditions in a certain place in Baoding City from April to May 2021, and a total of 106 sets of data. Then through the PM2.5 concentration, PM10 concentration, temperature, wind speed, relative humidity data measured by the local air quality monitoring station, and the China Meteorological Data Network, the air pressure data is obtained, and the dual-band AOD prediction is carried out. Substitute the predicted AOD data, temperature, relative humidity, and air pressure into the REST2 model used in this article to calculate the atmospheric solar radiation intensity. Finally, the slope radiation intensity calculation model is used to obtain the slope radiation intensity data, and the calculated slope solar radiation intensity data is verified with the measured data. The measured slope solar radiation intensity is selected from 11:00 to 16:00, The result is shown in Fig.4.

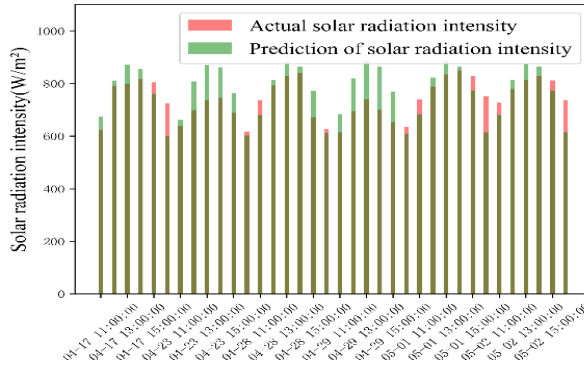


Fig.4. Comparison of measured and estimated solar radiation intensity.

In order to test the credibility of the model, this paper calculates the relative error, and the relative error analysis is shown in Fig.5.

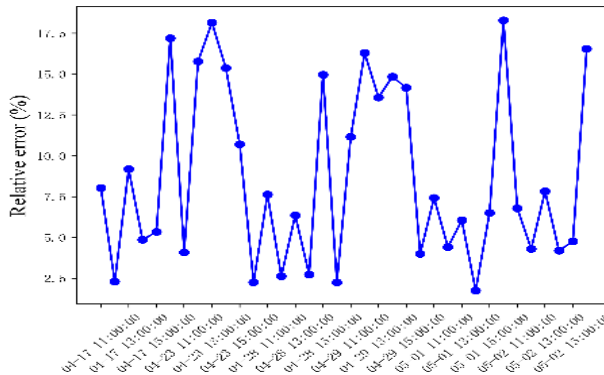


Fig.5. Error analysis of radiation intensity estimation on inclined plane.

It can be seen from the analysis that data with a relative error of less than 15% accounted for 81.6%, of which the prediction error at 16 points per day was too large. The overall average relative error is 9.23%, indicating that the accuracy of the model in this paper has high prediction accuracy.

5 Photovoltaic power prediction and verification

5.1 Photovoltaic power prediction model

Taking into account that traditional photovoltaic power generation forecasting mainly uses photoelectric conversion models, and the empirical factors are used to modify the forecast results, the stability and accuracy of the forecast results are not good. This paper mainly considers the influence of solar radiation intensity, temperature, wind speed and time series in the photovoltaic power generation forecast. The data used in the experiment was collected from July to October 2019 and April to May 2021. A total of 387 sets of data were screened for smog weather, and the actual solar radiation intensity value of the inclined plane was collected through a light intensity meter perpendicular to the photovoltaic panel. Baoding The weather data monitoring point of a certain place in the city publishes the temperature and wind speed data published on the website in real time, and the time series

are used as the input of the RBF neural network training model. Through the 50W photovoltaic power generation system experimental platform, the actual photovoltaic power generation power is collected as the output of the RBF neural network training model for training, and the photovoltaic power generation power prediction model is established. The structure diagram of the RBF neural network used in this article is shown in Fig.6.

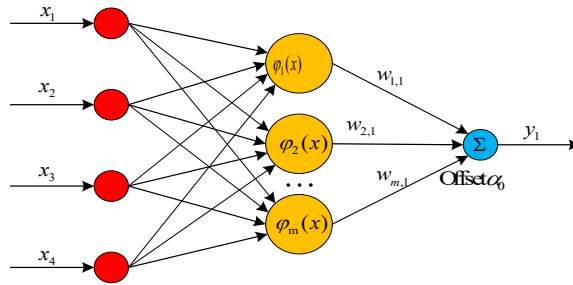


Fig.6. Structure of RBF neural network.

x_1, x_2, x_3, x_4 , respectively represent the actual collected solar radiation intensity, temperature, wind speed, and time of the inclined plane; The output is the actual collected photovoltaic power, and the maximum number of neurons in the RBF neural network is set to 41. Each time one neuron is added to redesign the linear layer of the network, the mean square error of the final training result is 0.03484. It shows that the established photovoltaic power prediction model has a good fitting result.

5.2 Experimental verification

In order to test the accuracy of the established model, this paper selected three measurement days under the smog weather: April 18, 2021 (light pollution), April 19 (moderate pollution), and April 27 (moderate pollution). Validate the prediction model, First, predict the solar radiation intensity of the inclined surface through the meteorological data collected by the monitoring station, and then predict the photovoltaic power generation power through the predicted solar radiation intensity, temperature, wind speed data and time series of the inclined surface.

First, verify the prediction of the solar radiation intensity on the inclined plane. This paper collects relevant meteorological data from the monitoring stations on three measurement days under the smog weather. The prediction model of this paper is used to predict the solar radiation intensity of the inclined surface, and the comparison with the actual measured radiation intensity of the inclined surface is shown in Fig.7.

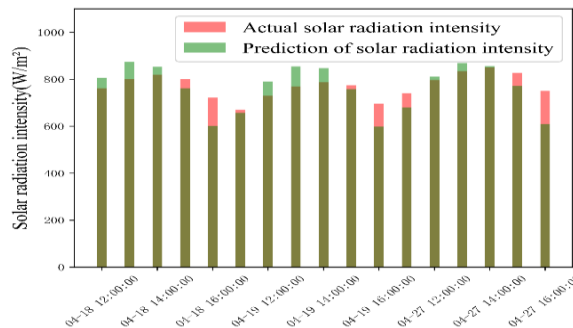


Fig. 7. Estimation of solar radiation intensity on inclined plane for three measurement days

Through calculation, the average relative error of the forecast of the solar radiation intensity of the inclined plane on the three measurement days is 11.76%, and the relative error is larger at 16:00 each day. Comprehensive analysis shows that the overall prediction accuracy of the inclined plane radiation intensity prediction model in this paper is relatively high, and the relative errors of the three measurement days are shown in Fig.8.

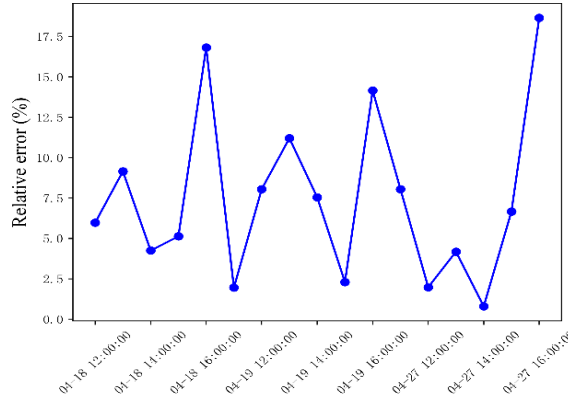


Fig. 8. Relative error calculation results of three measurement days.

Based on the predicted value of the solar radiation intensity on the inclined surface, as well as the temperature and wind speed data released in real time at the monitoring points, the trained photovoltaic power generation power prediction model is used to predict the power generation power of the three measurement days. The comparison between the predicted result and the actual measured value and the corresponding PM concentration change value are shown in Fig.9.

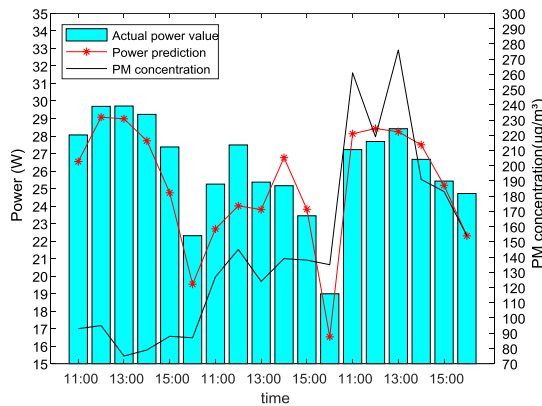


Fig. 9. Photovoltaic power prediction

The experimental results show that the average relative error of the predicted power generation for the three measurement days under the smog weather is 5.96%, but the relative error of the forecast at 16:00 each day is relatively large. Considering that the error is mainly affected by the prediction accuracy of the solar radiation intensity prediction model on the inclined plane at 16:00. The relative errors of the three measured daily power generation forecasts are shown in Fig.10. The results show that the photovoltaic power

generation power prediction model that considers the influence of smog on solar radiation intensity in this paper has high prediction accuracy.

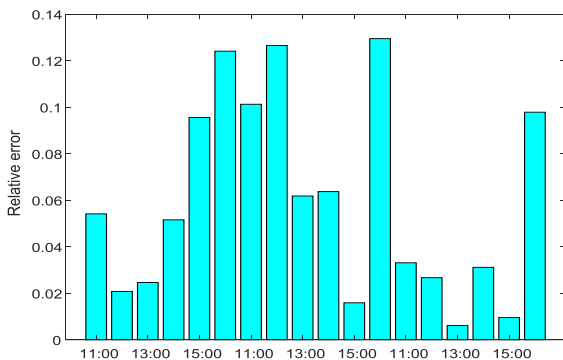


Fig. 10. Relative error of photovoltaic power prediction.

6 Summary

Considers the influence of smog on solar radiation intensity, this paper firstly establishes an RBF neural network model based on PM concentration, temperature, air pressure, wind speed, etc. to predict AOD, which has high generalization and accuracy. Then, the calculation model of the slope radiation intensity is established to predict the solar radiation intensity of the slope with the solar radiation transmission theory under clear sky, and finally the RBF neural network is used to predict the photovoltaic power. The average relative error of the power prediction under the smog pollution weather is 5.5%. The next research work will consider the changes in the attenuation rate of solar radiation intensity over time each day, and revise and optimize the prediction model to further improve the prediction accuracy.

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