The Impact analysis on non-Stationary Extreme Wind Speed Evolution to Wind Turbine

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Abstract—It is highly preferred to evaluate evolution of wind extremes over long time-scale with nonstationarity extreme distribution model. The annual extreme value methods, which single out the maximum wind of each year as sample data, are utilized. Thereafter, the annual wind extremes are test for nonstationarity. Finally, the maximum possible wind extreme is calculated with generalized extreme value distribution model to evaluate the influence of nonstationarity of wind extreme on safety of wind turbines. It is uncovered that the wind extreme in Hailisu, Guaizihu and Chengshantou are non-stationary. However, there is no maximum possible wind extreme and it is a positive impact on the safety of wind turbines. The wind extreme of Hengshan is stationary. The wind extremes of Huangshan is non-stationary and the maximum possible wind extreme over there is 41.416 m/s, which is not larger than the design wind speed of 37.5 m/s of wind turbines. It is of negative impact on the safety of wind turbines.

1. INTRODUCTION
Since the beginning of the new century, wind energy as a renewable and clean energy has been greatly developed due to the increasing attention paid to environmental issues in various countries. Traditionally, wind turbines are designed to meet the extreme wind speed in many years on the premise of a fixed climate model. When the climate model changes over a long time scale, the extreme wind speed in many years during the life of wind turbines may change significantly, which has a great impact on the reliability and safety of wind turbines. Influence. Reference [1-7]

In recent years, the increasingly serious problem of climate change has significantly changed the statistical distribution of surface temperature, and also affected the surface wind speed. Compared with the change of average wind speed, the change of extreme wind speed will affect the life of wind turbine [1,2,3]. Reference [8-14] The change of climate model leads to the stationary and non-stationary characteristics of extreme wind speed in many years. Different methods are needed to analyze and calculate the two different characteristics of extreme wind speed. However, only the stability of extreme wind speed is considered in the design of wind turbines for multi-year extreme wind speed, which leads to the pairing of wind turbines. Reference [15-19] The non-stationary extreme wind speed analysis is inaccurate, which affects the risk estimation of non-stationary extreme wind speed for wind turbines.

Extremum theory is particularly important in calculating extreme wind speed once in many years. Liu Cong et al. used GEV distribution model to analyze the extreme wind speed in many years, and
used maximum likelihood estimation method to estimate the parameters of GEV distribution model. By calculating the recurrence level and confidence interval of extreme wind speed in many years, their risk assessment in practical engineering application was given by analyzing the lower reaches of the Yangtze River in different periods. The 95% confidence interval of annual extreme wind speed is given. It is found that the upper limit of annual extreme wind speed increases and the lower limit decreases in the middle and lower reaches of the Yangtze River. Reference [16-21]

Extreme value theory has special value and practical significance in the analysis and calculation of extreme events in meteorological field. Reference [22-23] Through the analysis and calculation of extreme events in meteorological field, the occurrence of extreme events can be predicted and prevented to reduce the impact of extreme events. As a typical climatic extreme, the once-in-a-year extreme wind speed has a prominent impact on the safety of wind turbines. Reference [24] The design wind speed of wind turbines is designed according to a fixed climate model, which leads to the possibility that wind turbines may suffer from multi-year extreme wind speed far greater than the design wind speed under climate change, thus affecting the safety of wind turbines. Therefore, the analysis of multi-year extreme wind speed needs to be carried out urgently.

2. EXTREMUM THEORY
There are two main models for calculating extreme wind speed in many years: GEV distribution model and GPD distribution model. The extreme wind speed samples based on annual extreme value method obey GEV distribution model, while the extreme wind speed samples based on cross-threshold method and independent storm method obey GPD distribution model. Different sampling methods correspond to different distribution models. GEV distribution model requires a large number of sample data, but GPD distribution model does not. Reference [25]

When the non-stationarity of the extreme wind speed is not considered, the cross-threshold method can be used to select the extreme samples and calculate the extreme wind speed of each station once in many years according to the GPD distribution model. The extreme wind speed may show a non-stationary trend over a long time scale, and then the stationary GPD distribution model will no longer be applicable. Reference [26-27] The GEV distribution model considering non-stationarity can better give the variation characteristics of extreme wind speed in long time scale.

In the initial study of extremum theory, distribution families with three distributions are usually used to analyze extremum samples, but this method has higher requirements for the selection of distribution families, and the estimation of extremum may lead to larger errors [2]. To solve this problem, statisticians will combine the distribution families formed by the three distributions. For a uniform distribution [3]. Let’s set X1, X2, ..., Xn is a set of independent and identically distributed variables, and the GEV distribution model is as follows [4]:

\[
G_{\mu, \sigma, \xi}(x) = \begin{cases} 
  \exp\left\{-\left[1+\xi \left(\frac{x-\mu}{\sigma}\right)\right]^{-\frac{1}{\xi}}\right\}, & \xi \neq 0 \\
  \exp\left\{-\exp\left(-\frac{x-\mu}{\sigma}\right)\right\}, & \xi = 0 
\end{cases}
\] (1)

Among them, \(\mu\), \(\sigma\) and \(\xi\) respectively represent the position parameters, scale parameters and shape parameters of GEV distribution model, and the position parameters \(\mu\) and the shape parameters \(\xi\) satisfy the following requirements: \(-\infty < \mu < +\infty\), \(-\infty < \xi < +\infty\). GEV distribution model is divided into extremum type according to the value of shape parameter \(\xi\), and the applicable conditions of the I, II, III three extremum distribution models are different.

The annual extreme value method based on GEV distribution model is often used to calculate the recurrence level of wind speed of wind turbines in many years. The annual extreme value method takes only one maximum of each year as the extreme value sample, which inevitably wastes some effective extreme wind speed data, and the selected extreme value sample may not be able to fit the GEV distribution model well, which leads to the limitation of the annual extreme value method based on the GEV distribution model. In order to solve the problems of GEV distribution model, the POT method
and MIS method based on GPD distribution model are proposed to calculate the recurrence level of the extreme wind speed once in many years for over-threshold extreme samples.

3. DATA SOURCES AND PREPROCESSING

Wind power development in China is mainly concentrated in the three North and coastal areas, which are rich in wind resources. In recent years, in order to speed up the development of wind power, we began to guide the development of wind power in the central and eastern regions close to the load center through the way of wind resource classification price subsidy. In this paper, several meteorological stations with better wind resource conditions are selected from key areas of wind energy development such as Gansu, Zhongshan and Shandong coastal areas for research and analysis. In this paper, Gansu Jiuquan, Ma Zongshan, Shandong Longkou, Central China Nanyue and Anqing are selected as the research objects.

The basic information of each site is as follows:

Gansu is rich in wind energy resources and has built a large number of wind power projects. Jiuquan and Mazongshan stations are located in desert area, far from the city center. They are the basic meteorological stations in the difficult areas of the country. There are no obvious changes in the surrounding environment and complete data records.

The wind resource in central China is poor, but it is easy to absorb wind energy because it is in the load center. In recent years, some wind power projects have been built in areas with rich wind energy resources in central China. Anqing and Nanyue stations are national-level cultural relics protection zones, belonging to alpine meteorological stations. New buildings are prohibited. There is no obvious change in the surrounding environment, and the data records are complete.

Longkou is located in the Chengshan Mountains at the easternmost end of the Jiaodong Peninsula. It is surrounded by the sea without new buildings. Its surrounding environment has not changed significantly and its data records are complete.

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4. EXTREME WIND SPEED CALCULATION BASED ON NON-STATIONARY GEV DISTRIBUTION AND ITS INFLUENCE ON FAN SAFETY

In the calculation of the stability of extreme wind speed, the annual extreme value method based on GEV distribution model will waste a lot of useful sample information when selecting extreme samples,
and the GEV distribution model has three parameters, while the GPD distribution model has only two parameters. The parameter calculation of GEV distribution model is also more complicated than that of GPD distribution. However, the model used in IEC regulation is GEV distribution model when calculating the extreme wind speed of wind turbines in many years. Therefore, this section gives the stationarity calculation of the annual extreme value method based on GEV distribution model, in order to compare the difference between the calculation of GEV distribution model and GPD distribution model, the annual extreme value method based on GEV distribution model and GPD distribution model are synthesized. A more convincing conclusion can be obtained from the calculation results of MIS method of distribution model. In order to compare the results of GEV and GPD distribution models, this section assumes that the extreme wind speed is stationary.

Using the annual extreme value method based on the GEV distribution model, the maximum value of each year in the 40-year wind speed data of each station from 1973 to 2012 is selected as the extreme value sample of the GEV distribution model. The obtained extreme value samples are fitted to the GEV distribution model, and then the parameters of the GEV distribution model are calculated according to the maximum likelihood estimation method. After getting the GEV distribution model, the contour likelihood functions of the extreme wind speed at five stations in 50 years are plotted respectively as shown in Fig. 1 to Fig. 5. In the figure, the abscissa is the reproducing level and the ordinate is the corresponding contour likelihood function value. In the contour likelihood function graph, the higher intersection point is the recurrence level of the extreme wind speed once in 50 years, and the lower and upper bounds of 95% confidence intervals correspond to the two intersections on the lower and lower sides respectively.
The annual extreme value method based on GEV distribution model is used to calculate the 50-year once-in-a-lifetime extreme wind speed with two different forms of stationary and non-stationary. When the non-stationarity of extreme wind speed is not considered, the annual extreme value method using GEV distribution model is similar to the MIS method using GPD distribution model. The non-
stationarity of extreme wind speed is often not taken into account in IEC regulations when specifying the design wind speed of wind turbines. Under the condition of climate change, the extreme wind speed of some stations will be non-stationary in a long time scale, and the maximum possible wind speed $x_{\text{max}}$ may be much higher than the designed wind speed, which will pose a great challenge to the safety of wind turbines. This chapter chooses extreme wind speed samples from Jiuquan and Mazongshan stations in Gansu Province, Longkou stations in coastal areas and Nanyue and Anqing stations in inland areas for non-stationary analysis, and draws the following conclusions:

The extreme wind speed at Jiuquan, Mazongshan and Longkou of Gansu station is non-stationary. Because the shape parameter $\varepsilon(t)<0$ there is a minimum possible wind speed $x_{\text{min}}$, which has a positive impact on the safety of wind turbines.

The extreme wind speed of Nanyue inland station is stationary, and there is no maximum possible wind speed.

The extreme wind speed of Anqing is non-stationary. The maximum possible wind speed $x_{\text{max}}=41.416$ m/s in a long time scale is much higher than the designed wind speed 37.5 m/s, which has a great negative impact on the safety of wind turbines.

5. CONCLUSION

Traditionally, wind turbines are designed to meet extreme wind speeds once in many years on the premise of a fixed climate model. The life of wind turbines is generally about 20 years. Under the climate change, the extreme wind speed may change during the life of wind turbines, which has a prominent impact on the safety of wind turbines. In this paper, the 40-year wind speed data of Jiuquan and Mazongshan stations in Gansu, Nanyue and Anqing stations in Central China and Longkou stations in Shandong coastal areas from 1973 to 2012 are selected as extreme samples. The GPD distribution model and GEV distribution model are used to calculate the extreme wind speed of the five stations once in many years. The main work and conclusions are as follows:

The extreme wind speed of 50-year and 1-year encounters has obvious regional change trend. The design wind speed of once-in-a-year extreme wind speed is converted to 80% of that of 50-year extreme wind speed. The conversion coefficient is converted from global data, which results in large errors at some stations with strong regional characteristics.

When the non-stationarity of extreme wind speed is not considered, the GPD distribution model and GEV distribution model have similar conclusions. In Jiuquan, Mazongshan and Longkou stations, the probability of extreme wind speed and over-design wind speed decreased significantly in the past 20 years, 50 years and 1 year. Under the climate change conditions, extreme wind speed changes have a positive impact on the safety of wind turbines. The extreme wind speed at Nanyue Station increased slightly in the past 20 years, 50 years and 1 year, and the probability of over-design wind speed changed little. The extreme wind speed and the probability of over-design wind speed increase significantly in Anqing Station in the past 20 years, 50 years and 1 year. Under the climate change, the change of extreme wind speed has a negative impact on the safety of wind turbines.

The extreme wind speed of Jiuquan, Mazongshan and Longkou of Gansu station is non-stationary, and there is a minimum possible wind speed $x_{\text{min}}$, which has a positive impact on the safety of wind turbines; the extreme wind speed of Nanyue of inland station is stationary, and there is no maximum possible wind speed; and the extreme wind speed of Anqing of inland station is non-stationary. The maximum possible wind speed $x_{\text{max}}=41.416$ m/s in Anqing is much larger than the designed wind speed 37.5 m/s in a long time scale, which poses a great challenge to the safety of wind turbines.

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