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ScienceDirect
Energy Procedia 61 (2014) 2262 – 2266
Energy Procedia

The 6th International Conference on Applied Energy – ICAE2014

Implication of climate change induced variation in wind extremes on wind farm in mountainous area of central China—A case study of Hengshan

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Abstract

Wind load is critical to the safety of wind turbines. Wind turbines are designed according to the referrence wind speed of 50-year recurrence interval. The climate change induced variation in extremes of wind could impact safety of wind turbines. Meteorological data from Hengshan weather station in central China is investigated. The wind data of 1973-1992 and 1992-2011 are utilized to estimate the extreme wind of 50-year recurrence interval using method of independent storm and generalized pareto distribution model.It is uncovered that although extreme wind of 50-year recurrence interval escalate a little during the two time spans, it will not affect the safety of wind turbines over there notably.

Peer-review under responsibility of the Organizing Committee of ICAE2014

*Keywords***:** Wind turbine; recurrence interval; extreme wind; climate change

1. **Introduction**

As the largest primary energy consumer, China has opted to develop wind power generation and reduce greenhouse gases emission. Its wind power sector underwent prosperous growth during the past decade. Since its wind power concentrates in the undeveloped area with abundant wind resources, wind power production over there suffered the integration dilemma. Large number of wind generation is curtailed to maintain the security of the power system. Therefore, energy sector in China has devoted to wind power development in central China with not so satisfying wind resources. Since wind abundant regions of central China locate in the mountainousareas, most wind farms are invested on the top of

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Peer-review under responsibility of the Organizing Committee of ICAE2014
doi:10.1016/j.egypro.2014.12.441

mountains and ridges of hilly area. On one hand, it is hard to install and maintain the wind turbines. On the other hand, this area tends to have adverse micro-climate with higher extreme wind.

Structural load of wind turbine consists of static and variable load. Variable load of wind turbine arises from atmospheric load, mainly wind load. Wind turbines are designed according to the given criteria of extreme wind load [1,2]. The referrence wind speed of 50-year recurrence interval can be calculated using meteorological data from ambient weather stations. Thereafter, the wind turbine classes could be determined according to particular external conditions. The wind speed for classes I, II, and III are 50m/s, 42.5m/s, and 37.5m/s, respectively [2].

The mechanism works on the premise that the climate pattern remains stationary. However, the climate system is not stationary. Therefore, the climate change induced variation in extremes of wind could impact safety of wind turbines. Meteorological data from Hengshan weather station in central China is investigated to uncovered the variation in wind extremes under the context of climate change and evaluate its impact upon wind turbines.

2. ExtremeValue Theory

Traditionally, extreme wind speed is estimated with annual-maxima method [3]. In this method, a sample of annual maximum values of wind speed is directly modelled by the generalized extreme value distribution. The Peaks-Over-Threshold (POT) method considers, instead of just annual maxima, several of the largest order statistics exceeding a sufficiently high threshold in the collected data [4,5]. In this manner, the data set is enlarged to decrease the sampling uncertainty.

In POT approach, in order to model the upper tail of the wind speed distribution, consider k exceedances of X (n samples) over a threshold u and let Y_1, Y_2, …, Y_k denote the peaks where $Y = X_i - u$. Previous research indicates that the conditional cumulative distribution of the excess $Y = X - u$ of the variate X over the threshold u given $X>u$ sufficiently large, that is, $P[Y = (X_i - u<y \mid X_i>u)]$, follows the generalized pareto distribution (GPD).

$$G(y) = 1 - (1 + c(y - h)/a)^{-1/c} \quad (1)$$

where h, a, and c denote the location, scale, and shape parameters, respectively. Generally, the location parameter h is taken as 0 and the distribution has unbounded upper tail.

Given $Y = X_i - u$, then $E(Y) = (a + c \cdot u)/(1 - c)$. Therefore, extreme events of T-year recurrence interval can be calculated according to equation (2).

$$Y_T = u - a[1 - (mT)^c]/c \quad (2)$$

Where m denotes the annual average samples larger than u. $m = k / n$; k denotes the number of sample larger than u; n denotes investigated span by years [4-6].

The scale and shape parameters of GPD can be estimated with maximum likelihood approach according to equations (3) and (4).

$$k - (\hat{c} + 1)\sum_{i=1}^{k}[t_i/(\hat{a} + \hat{c}t_i)] = 0 \quad (3)$$

$$1/\hat{c}\sum_{i=1}^{k}\left[\ln[1 + \hat{c}t_i/\hat{a}] - 1/\hat{c}\,[t_i/(ct_i + \hat{a})]\right] = 0 \quad (4)$$

With estimated scale and shape parameter, extreme wind of T-year recurrence interval can be calculated according to equation (2). The selection of threshold is critical to the POT. Among various techniques exist to aid threshold selection, conditional mean exceedance (CME) graphs is most frequently used. The threshold must be set not only high enough to select only true peaks but also relative lower to ensure that enough data are selected for satisfactory determination of the distribution parameters [6].

The Method of Independent Storms (MIS) is a similar approach as POT [4,7]. The difference between POT and MIS can be depicted as Fig.1. In MIS, a series of continuous points over the threshold are considered as an independent storm and only the largest wind speed is selected to form a sample of extreme values. Since the selected samples are independent, the MIS is not so sensitive to threshold as POT [6,7]. In order to ensure statistical independence of the selected data amount extremes required by the asymptotic theory, we use the MIS to extract the relatively independent data from the raw. This method increases the number of extremes available for analysis, while ensuring their independence by separating the parent time series of wind speeds into independent storms and then selecting the highest value from each storm.

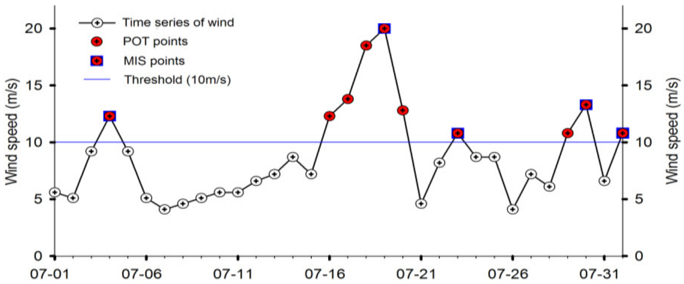

Fig. 1.Difference between MIS& POT points

3. **Variation in extreme wind with 50-year recurrence interval in Hengshan**

6 to 8 weather observation data (from China Meteorological Administration) are recorded every 3 hours in Hengshan station. 39-years weather data from 1973 to 2011 are utilized to investigate decade variation of wind extremes. The wind data is divided into two spans, 1973 to 1992, and 1992 to 2011. The mean wind speed are 5.893m/s and 5.019m/s, respectively. It can be observed that there are notable declining in the mean wind speed. The threshold of the two time spans are 19.0m/s and 17.0m/s. There are 172 and 223 wind data over the threshold and the there are 134 and 174 independent storms in the two time spans.

The quantile-quantile plot (QQ plot) is an exploratory graphical device used to check the validity of a distributional assumption for a data set. The basic idea is to compute the theoretically expected value for each data point based on the distribution in question. If the data indeed follow the assumed distribution, then the points on the plot will fall approximately on a straight line. The QQ plots of both time spans are plotted as Fig.3 to check the GPD model. It can be observed that data in both QQ plots fall approximately on a straight line, which indicates that the wind extremes over the threshold in both time spans could be fitted with GPD.

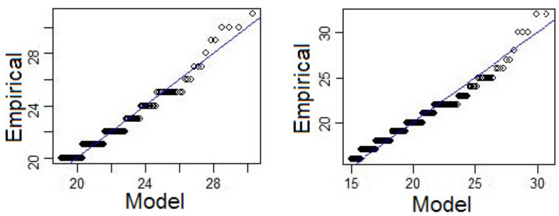

Fig. 2.diagnostic graph (a) 1973-1992; (b) 1992-2011

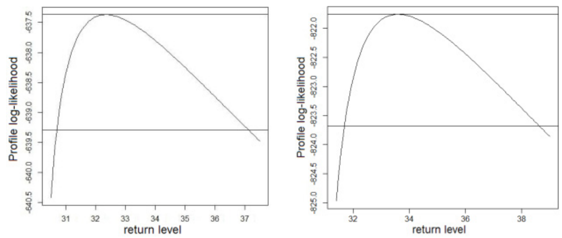

Fig. 3.Estimated extreme wind speed(a) 1973-1992; (b) 1992-2011

The statistical software R is utilized to calculate extreme wind using GPD. The calculated profile Log-likelihood is plotted as Fig.4. The log likelihood has three crossover points with the horizontal lines. The crossover point at the top horizontal line denotes estimated extreme wind speed, while the two crossover points at the bottom line denote the upper and bottom of 95% confidence interval.

Bring extracted wind extremes from 1973 to 1992 to equation (3) and (4), get a = 41.8064, c = -0.2760.

It can be observed that the estimated extreme wind is 32.357m/s and the 95% confidence interval is [30.709m/s, 37.155m/s]. Bring wind extremes from 1992 to 2011 to equation (3) and (4), get a = 57.650, c = -0.294. The calculated profile Log-likelihood is plotted as Fig.4(b). The estimated extreme wind is 33.592m/s and the 95% confidence interval are [31.697m/s, 38.608m/s] in the latter time span.

It should be noted that there is very slim escalation in the estimated extreme wind with 50-year recurrence interval. Since the wind turbines of class III are designed according to referrence wind speed of 37.5m/s, which is notably higher than the wind extremes of 50-year recurrence interval calculated with wind data of the two time spans, it is speculated that slight escalation in wind extremes will not impact safety of wind turbines over montonous area around Hengshan.

4. **Conclusion**

Wind power generation is sensitive to climate change induced variation in wind speed. Variation in extreme wind could impact safety and the variation in mean wind speed could affect wind power generation. Extreme wind of Hengshan with 50-year recurrence interval are calculated with 1973-1992 and 1992-2011 wind data. It is uncovered that there are slim escalation in extreme wind. Since the wind turbines of class III are designed according to referrence wind speed of 37.5m/s, which is notably higher than the extreme wind of 50-year recurrence interval in both time spans, the slight escalation will not impact safety of wind turbines over montainous area around Hengshan. It should be pointed out there are notable declining in the mean wind speed, whose impact might be much more significant than that of extreme wind and deserve further investigation.

Acknowledgements

The authors would like to thankfunding support of the State Key Development Program for Basic Research of China 2009CB219701, National Natural Science Foundation of China 50907005, and scientific funding of Hunan Education Department 10k004.

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Biography

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