Research on Wind Field Characteristics along Power Transmission Lines Based on Full-scale Measured Data in High-altitude and Strong Wind Regions

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Abstract. High-altitude regions are featured by complicated geographical environment, in which strong wind events occurs frequently. At present, the engineering meteorological data of relevant projects are limited. Moreover, the rationality of determination methods of design wind loads for power transmission lines in the high-altitude regions is still unclear, which severely threatens the safety of power transmission lines. Therefore, this paper focuses on actual full-scale measurements of wind fields along power transmission lines in the high-altitude strong wind regions. The average wind speed and turbulence intensity characteristics under the typical high-altitude terrains terrain are analysed. Through the profile fitting of power law profile and the analysis on probability of actually measured data, the value scopes of parameters, such as profile index, are obtained. Through comparing with existing Chinese codes, some theoretical reference and basis for the wind-resisting design and maintenance of power transmission lines in relevant regions are suggested.

1 Introduction

The southwest region is an important energy base in China, in which accelerating hydropower development is an important measure to implement the national energy development strategies in China. With the rapid development of ultra-high voltage power grid in China, the hub status of the southwest power grid is outstanding gradually. The geographical environments in Sichuan, Tibet and Chongqing in the southwest of China are complicated, which include multiple kinds of topographic conditions such as Qinghai-Tibet Plateau, Sichuan Basin and Qinba Mountainous Regions, with relatively high altitudes, large differences in geographical environments, and frequent occurrence of strong wind weather. These severely threaten to power facilities[1]. The observation and research on engineering parameters under extreme environmental conditions such as strong wind and high altitude in China are relatively late. At present, the accumulated meteorological and geographical data of the projects are relatively lack. In case of relying on meteorological data provided by the existing observation stations in the southwest purely, it is difficult to meet the engineering technical demands of design and running of ultra-high voltage power transmission line in this region in the future. According to the research on high wind distribution characteristics and wind disaster region division in Tibet presented by Zhang Hezhen[2], it is found that the distribution of meteorological stations is not uniform, mainly distributed in the southeast, and most of meteorological stations are distributed around Lhasa, while only a small part among them are distributed in the regions where the strong wind occurs frequently, such as Naqu and Shigatse. For the spatial scope represented by single meteorological station is too large, and the power transmission line is far away from the meteorological station, so the wind speed observed from the meteorological station cannot represent the authentic wind speed along power transmission line. Meanwhile, there are relatively large differences between wind field parameters such as wind profile and turbulence intensity in the high altitude southwest regions compared with those in the low-altitude regions. The influence of these differences in design wind load values are still not mentioned in the current design codes of power transmission lines. The above mentioned problems severely influence the exactness of design of power transmission line and the safety of power grids in the high-altitude southwest regions.

Therefore, numerous Chinese and international scholars have implemented relevant researches. Yuan Hongliang[3] have had a systematic analysis on advantages and disadvantages of application of frequently used power law and logarithmic law wind profile models into the high-altitude regions. Momomura et al.[4] have conducted actual field measurement to the power transmission tower located in some mountainous region for two years. The wind speed characteristics of the typhoon wind field and the wind-induced effect of the power transmission tower were studied. Turnipseed et al.[5] have conducted actual measurement of wind field for the Niwot Ridge located in the rocky mountains in the USA for 4 months, and have obtained the wind field laws of mountainous terrains such as single mountain, multiple mountains and gorge. Zhang Hongjie et al.[6] have researched and analyzed the distribution laws of wind profiles on the ridge in the gorge terrain and on the central axis of gorge, and given the calculation formula of typical positions. Li Zhengliang et al.[7] have performed research on wind field characteristics for the double mountains under different working conditions, and have exerted the measured wind field parameters to the system of ultra-high voltage power transmission tower line, so as to calculate the reliability of structural power; and they also have investigated the power reliability of the system of the ultra-high voltage power transmission tower line. Yao Dan et al.[8-9] have conducted wind tunnel tests on wind field parameters under the typical 3D steep mountains, and have analyzed the influence of topographic factors on the wind load of power transmission line tower. Based on the summary, it is found that at present, the relevant data of wind field characteristics in the high-altitude regions and determination values of their parameters are in limited. Most of theory and test researches about power transmission lines in complicated terrains focused on mountainous and gorge terrains with low altitude. Therefore, this study implements the research on actual full-scale measurement of wind field along with power transmission line in the high-altitude strong wind region. The average wind speed and turbulence intensity characteristics under the typical high-altitude terrain as well as the basis of value taking are analyzed. A certain theoretical references for the construction and maintenance of power transmission line in relevant regions in the future are suggested.

2 Actual Measurement of Wind Field Characteristics in High-altitude Regions

Since the numbers of strong wind (the instantaneous wind speed is greater than 17m/s) days each year are more than 100 in Shenzha, Naqu City, Tibet, China, these places are one of famous regions[2] with frequent strong wind occurrences in Tibet all over the country. Therefore, the actual full-scale measurement of wind field implemented in this paper is conducted in Shenzha of Naqu City. Based on the observation data, it can be known that on the path where the trace of the circular with radius of 10km sweeps around the actual measurement region of Naqu City, the average altitude is 4,882 m with the minimum altitude is 4,703m, and the maximum altitude is 5,276m, with relatively small difference in ground surface elevation. The terrain is similar to the plain terrain, as shown in Figure 1. Through setting an anemometer tower (80m), a set of gradient wind observation system (measuring point A) is established; the altitude where the testing system is located is 4,886m, and 5 layers of anemographs are set along with the tower body at the height of 10m, 30m, 40m, 50m and 70m above the ground, as shown in Figure 2; wherein, the ultrasound anemograph is adopted at the height of 70m. To verify the consistency among meteorological factors in the medium scale in the high-altitude regions of Tibet, a short-term wind speed monitoring point (measuring point B) as shown in Figure 3 is set in the place 13.94 km away from the Naqu anemometer tower (measuring point A). In Figure 4, the average wind speed and time interval at the height of 10 m of both measuring points A and B are compared. Through the result, it is found that the correlation of the wind speed data in the medium scale scope is very strong, which proves that the wind speed is featured by good consistency of Tibet Region in the medium scale weather system.

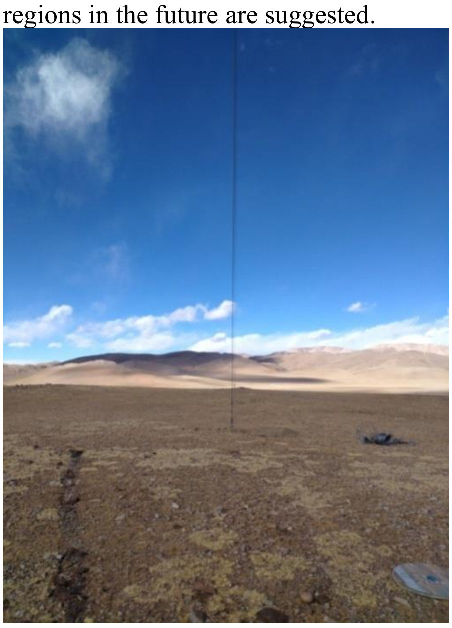

Figure 1. Terrain Conditions around Actual Measurement Region (Measuring Point A) in Shenzha County, Naqu City

Figure 2. Anemometer Tower (Measuring Point A) and Actual Measurement Equipment of Tower Body in Shenzha County, Naqu City

Figure 3. Short-term Actual Measurement Equipment Installed on Power Transmission Iron Tower at Measuring Point B in Naqu City

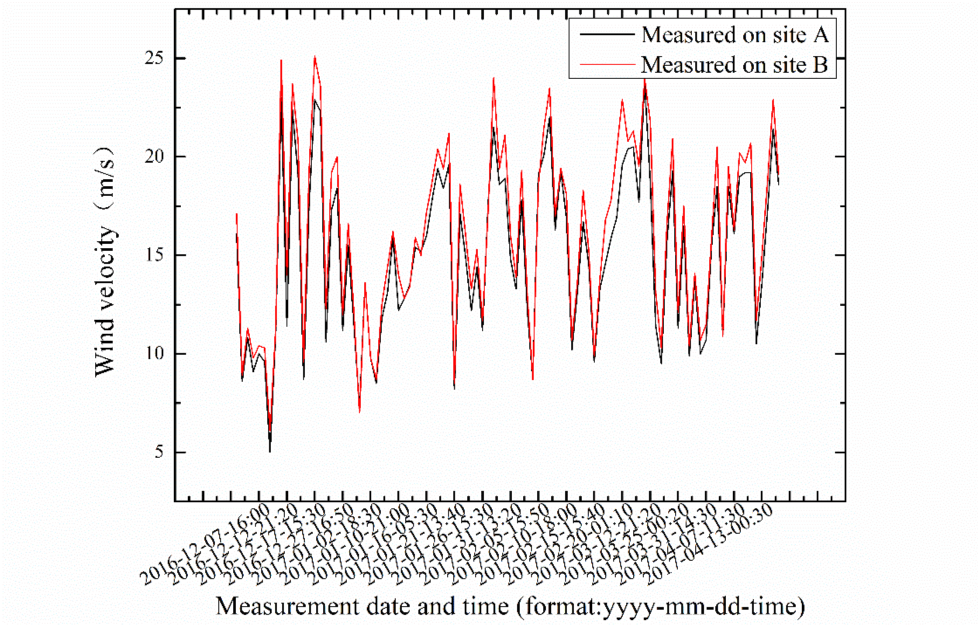

Figure 4. Average Wind Speed Curve Measured at Two Measuring Points (A and B) with Distance of 13.94km in Naqu City

3 Analysis on Wind Field Characteristics of High-altitude Regions Based on Actually Measured Data

In this Section, based on the data obtained from above mentioned actual measurement system, the research on average wind speed and turbulence intensity characteristics for the high-altitude regions (open terrain) in Tibet is conducted. The distribution characteristics of average wind speed and turbulence intensity profile and corresponding parameter value taking characteristics are analyzed, and they have been compared with relevant rules in the existing Chinese code in a quantitative method.

3.1 Characteristics of Average Wind Speed

According to the principle of takes the value of strong wind speed as 8m/s, this paper conducts fitting to the average wind speed data distributed along with heights actually measured in Shenzha County, Naqu City (measuring point A), and researches the change laws of average wind speed and its wind profile index along with time during the actual measurement period.

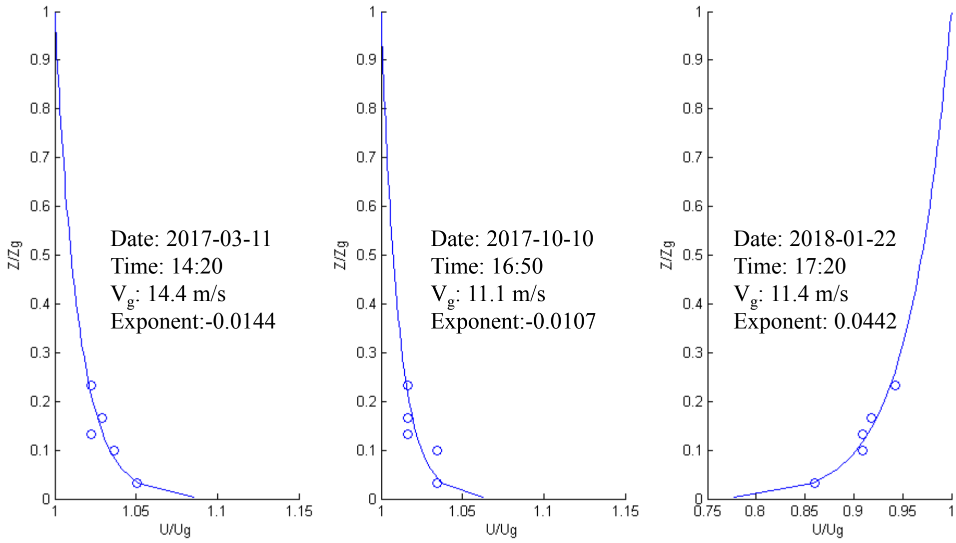

Figure 5. Average Wind Speed Profile Actually Measured at the Measuring Point (A) in Shenzha County

Figure 5 refers to the average wind speed profiles actually measured within three different time periods at the measuring point (A) in Shenzha County; wherein, the reference height (Z_g) is 10 m above the ground, and the corresponding reference wind speed is V_g. The result shows that the actually measured wind speeds at the 5 heights in the Figure are very compatible with the wind profile curve, and the adopted exponential law model of wind profile also has excellent fitting effect. It should be pointed out that between two actual measurement zones, i.e. March 11, 2017 and October 10, 2017, the wind profile index is negative, which are -0.0144 and -0.0107 respectively. At this time, the wind speed is reduced along with the increasing of height, and this means that different from the low-altitude site, the shear wind speed in the actual measurement region with high altitude in Shenzha County is more violent, with inverse shear. Considering that the inverse shear is not very frequent compared with the routine situation, and to avoid mutual disturbance, the later research in this paper removes the situation of inverse shear, mainly focusing on the situation when the wind profile factor is positive.

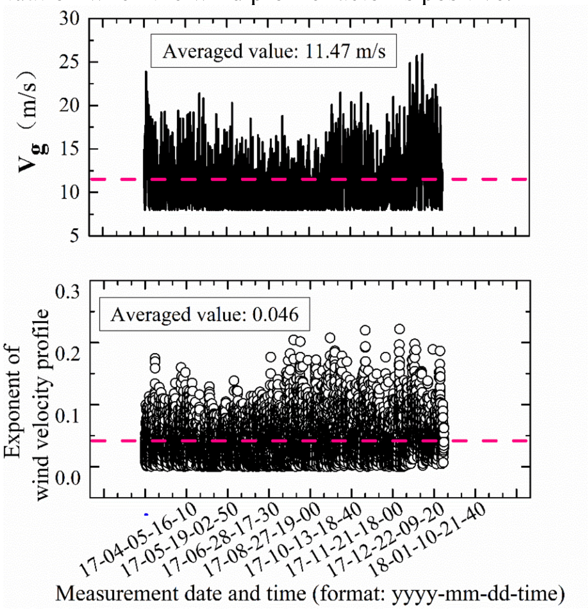

Figure 6. Change Curve of Average Wind Speed (Vg) and Wind Speed Profile Factor at the 10m Reference Height Actually Measured at Measuring Point (A) in Shenzha County along with Time

Figure 6 gives the change laws of average wind speed (V_g) and wind profile index at the reference height of 10 m, i.e. measuring point (A) in Shenzha County and wind profile index along with the time. The result shows that the average value of V_g is 11.47 m/s, and the maximum wind speed is 25.90 m/s. The average value of wind profile index is 0.036, and most of samples are distributed nearby such average value randomly. Based on the above mentioned wind profile index data, and through the analysis on probability density, the histogram of probability density of wind profile index at this measuring point in Shenzha County is as shown in Figure 7, and it can be found that its statistical characteristics are of extreme value distribution approximately, with obvious left-skewed tendency. After comparing with the wind profile index value 0.12 ruled under the open ground terrain specified in Chinese code, most of actually measured values are smaller than this specified value, and the corresponding accumulation probability exceeds 98%, as shown in Figure 8.

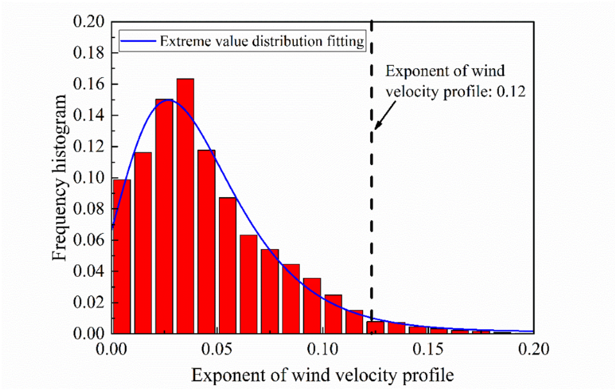

Figure 7. Histogram of Probability Density of Wind Profile Factor at Measuring Point (A) in Shenzha County

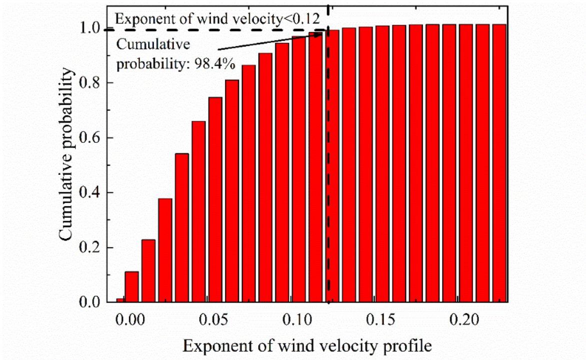

Figure 8. Histogram of Accumulative Probability Distribution of Wind Profile Factor at Measuring Point (A) in Shenzha County

3.2 Characteristics of Turbulence Intensity

Based on the wind speed data (the average wind speed is greater than the sample, which is 8m/s) actually measured in Shenzha County, this paper examines the turbulence intensity characteristics within the actual measurement time period. Figure 9 gives the profiles of actually measured turbulence intensities within three different time periods of the measuring point (A) in Shenzha County of Naqu City. The turbulence intensities at 5 m heights in the Figure are very compatible with the exponential law profile curve. Excellent fitting effect is found. Figure 10 gives the turbulence intensity (I_{10}) and the scope of index distribution of turbulence intensity profile at the height of 10 m measured within each time period in Shenzha County of Naqu City, and from the Figure, it can be known that the average value at the measuring point I_{10} is 0.128, with the scope from 0 to 0.35. The average value of turbulence intensity profile index is -0.085, and most of turbulence intensity profile indexes are distributed nearby their own average values.

The actually measured value of turbulence intensity at the height of 10m at the measuring point in Shenzha County of Naqu City for analysis on probability intensity is selected, as shown in Figure 11. The result shows that the distribution of actually measured turbulence intensities is similar to extreme value distribution, with the left-skewed tendency. The terrain category of the measuring point in Shenzha County of Naqu City refers

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to plateau open ground terrain, and from the histogram of accumulative probability of turbulence intensity at the height of 10m as given in Figure 12, it can be known that most of actually measured turbulence intensities (60%) are smaller than the ruled value 0.12 for the open ground terrain [10] in Chinese code. According to the probability statistic, the actually measured value of turbulence intensity with accumulative probability reaching 98% in this actual measurement region is 0.24.

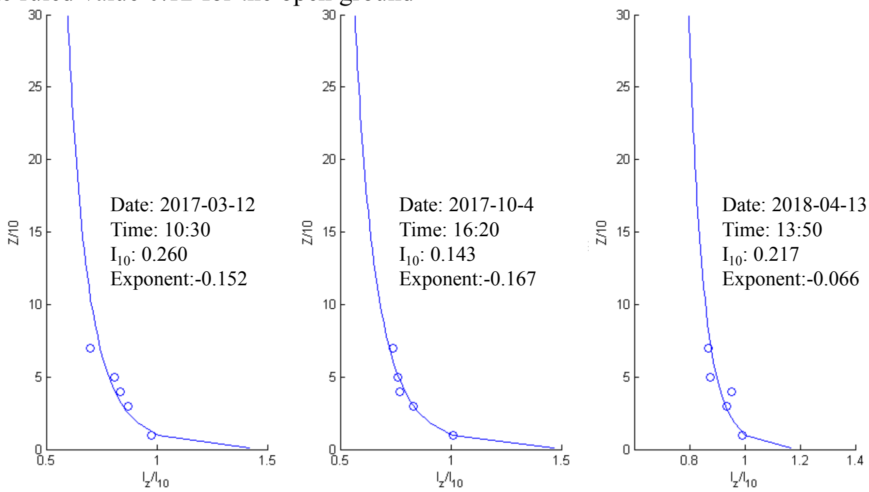

Figure 9. Profiles of Actually Measured Turbulence Intensities at Measuring Point (A) in Shenzha County

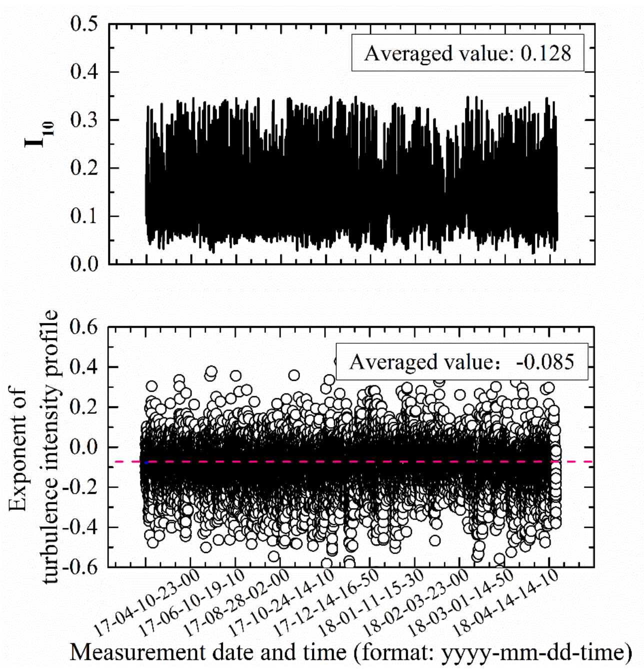

Figure 10. Turbulence Intensity (I10) and Turbulence Intensity Profile Index at Actual Measurement Height of 10m at Measuring Point (A) in Shenzha County

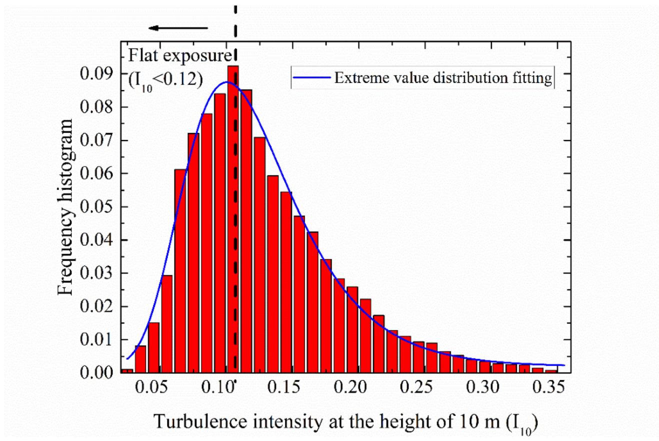

Figure 11. Histogram of Probability Density of Turbulence Intensity at Height of 10m at Measuring Point (A) in Shenzha County, Naqu City

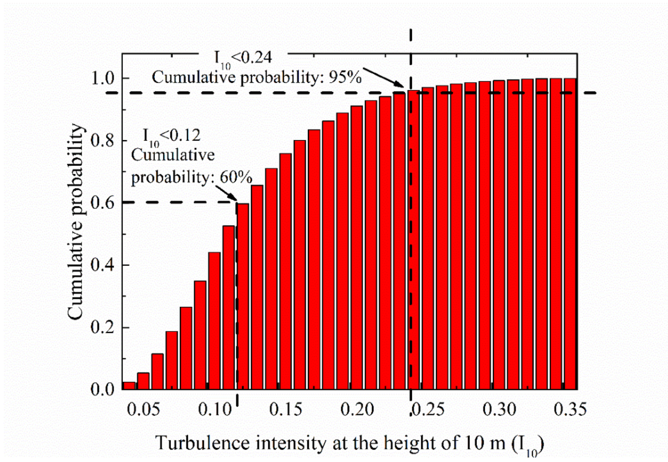

Figure 12. Histogram of Probability Density of Turbulence Intensity (I10) at Height of 10m at Measuring Point (A) in Shenzha County, Naqu City

4 Conclusions

Based on the actually full-scale measured data, this paper researches and analyzes the wind field characteristics along the power transmission line under the open ground terrain in the high-altitude region, discussed the wind field parameter characteristics and value taking laws at different spatial points in the actual measuring region in Shenzha County, Naqu City, Tibet, China. Through comparing with the existing Chinese code, the adaptability of clauses in the code is investigated, and the main research findings and conclusions are shown as follows:

(1) The effect of adopting the exponential law way to fit the average wind speed and turbulence intensity profile in the high-altitude open area researched in this paper is good, and the actually measured value is relatively compatible with the fitting curve.

(2) The average wind speed value at the actual measurement height of 10m in Shenzha County (in the high-altitude open area) is 11.47m/s, and the profile index of the average wind speed shows left-skewed extreme value distribution, and the corresponding average value is 0.036. The actually measure value of such profile index with accumulative probability exceeding 98% is smaller than the ruled value 0.12 about the open ground terrain specified in the Chinese code. Different form the low-altitude regions, the profile index of average wind speed in the actually measured region in Shenzha County shows negative value, and the shear of wind speed is violent, and there is even inverse shear phenomenon.

(3) The distribution of turbulence intensity probability at the height of 10 m in the actual measurement region in Shenzha County is similar to left-skewed extreme value distribution, with statistical average value of 0.128. The actually measured turbulence intensity with accumulative probability of 60% is smaller than the ruled value 0.12 for the turbulence intensity of open ground terrain specified in Chinese code.

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