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Determination of extreme wind values using the Gumbel distribution

Dongbum Kang [a], Kyungnam Ko [a,*], Jongchul Huh [b]

[a] Faculty of Wind Energy Engineering, Graduate School, Jeju National University, 102 Jejudaehakro, Jeju, Republic of Korea
[b] Department of Mechanical Engineering, Jeju National University, 102 Jejudaehakro, Jeju, Republic of Korea

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ABSTRACT

An investigation of what types of extreme wind values are the most suitable for the Gumbel distribution was conducted on Jeju Island, South Korea. Three measurements and reference sites that have different topographical conditions were selected to clarify the influence of the topographical conditions on extreme wind values. Because long-term wind data are required to estimate extreme wind speeds with a higher degree of confidence, the MCP (Measure-Correlate-Predict) technique was applied to generate ten-year wind data from one-year measurements. Extreme wind values were sampled from the ten-year wind data based on periodic maximum wind speeds and the wind speeds above a threshold, which were divided into three types each. The six types of extremes were examined to determine which type was more suitable for the Gumbel distribution under the assumption that the Gringorten formula is the best plotting position method for the Gumbel distribution. In addition, we predicted the appropriate wind turbine class for the measurement sites in compliance with IEC international standards. As a result, daily maximum wind speeds were the best extreme wind values for the Gumbel distribution in the six types irrespective of the topographical conditions. The site that has a higher average wind speed was estimated to have a higher extreme wind speed, indicating that a higher wind turbine class was needed at the site.

1. Introduction

The importance of the estimation of EWS (extreme wind speed) has been growing due to the safety issues of wind turbines. EWS causes a mechanical load on a wind turbine and might result in wind turbine failure in severe cases. The international standard of IEC 61400-1 ed.3 defines the wind turbine class according to EWS for wind turbine safety [1].

The Gumbel distribution is widely used as an extreme value distribution in many research studies, such as on air pollution, hydrology, and structures [2,3]. This distribution has also been used to estimate EWS for the determination of the wind turbine class in the wind power industry. Oh et al. [4] have performed a study on the economic feasibility of future offshore wind farms. Based on IEC standards, the annual energy production and capacity factor were calculated, and a reliable wind turbine class was determined in the study. Lee et al. [5] have studied the estimation of the EWS from the Korean wind map. The EWS was estimated using the Gumbel and Weibull distribution for the probability distribution of extreme values. They found that the Gumbel distribution was more reliable than the Weibull distribution for modelling the EWS.

On the other hand, the probability plotting positions have been used for the estimation of the exceedance probability of extreme values. Various plotting position methods using the criteria of unbiasedness and maximum variance were proposed by Cunnane [6], and the Gringorten formula was found to be the best for the Gumbel distribution. Ahmad et al. [7] proposed the best probability position for the estimation of two Gumbel parameters in accordance with the size of the random variables from twenty different Gumbel distributions.

However, most of the research studies have mainly investigated what type of probability plotting position is more suitable for the Gumbel distribution. There have been few investigations on how to extract extreme values from the data set for a Gumbel distribution, to obtain reliable results. Because the Gumbel distribution was known to vary with the extraction method of extreme values, the extraction of extreme values is very important for forming a more appropriate probability distribution. The purpose of this study is to propose a method to obtain more appropriate extreme wind values for the Gumbel distribution. Six ways of extracting extreme wind values from time series wind data were tested for their accuracy. In

* Corresponding author.
E-mail addresses: dongbum@jejunu.ac.kr (D. Kang), gnkor2@jejunu.ac.kr (K. Ko), jchuh@jejunu.ac.kr (J. Huh).

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addition, proper wind turbine classes were estimated for various topographical conditions in accordance with IEC international standards.

2. Sites and wind data

Fig. 1 shows the location of Jeju Island, including measurements and reference sites. Jeju Island is located off the southern coast of the Korean peninsula. It has an area of 1849.2 km^2, and approximately 600,000 people inhabit the Island. It is a volcanic island, and the 1950 m-high Halla Mountain is located at the center of the Island. There, 60 m-high met masts were positioned at Jeonhul, Handong and Cheongsoo for measuring the wind conditions, and 10 m–14 m-high AWSs (Automatic Weather Systems) are situated at Udo, Gujwa and Seogwang, at which reference data were recorded. This approach was used for the application of the MCP (Measure-Correlate-Predict) technique. The reference site of Jeonhul is Udo, with Gujwa for Handong and Seogwang for Cheongsoo.

The 3D images shown in Fig. 2 were created from terrain maps. Each image represents an actual area of about 6 km × 6 km. The center of each map coincides with the midway point between each pair of measurement and reference sites. The distances separating each site pair are as follows: 1.36 km for Jeonhul-Udo; 2.29 km for Handong-Gujwa; 3.94 km for Cheongsoo-Seogwang. For the topographical conditions, Jeonhul and Udo are considered to be islet areas, and Handong and Gujwa are coastal areas. Cheongsoo and Seogwang are mountainous areas. By analysing the wind data under these three conditions of topography, the influence of the topographical conditions on the extreme wind values could be clarified.

Table 1 shows the sites and measurement conditions and the average wind speed. The wind data were measured for one year by wind sensors of 60 m-high met masts and 10 m–14 m-high AWSs recorded the wind data for ten years. All of the wind data were recorded at 10-min intervals on average. The average wind speed for the measurement period was the highest in the islet areas, followed by the coastal and mountainous areas, for both the measurement and reference sites.

Fig. 3 shows a comparison of wind speed distribution at each met mast. Each Weibull probability density function was estimated using the maximum likelihood method. The Weibull parameters for shape, k and scale, c, were presented in the Figure. Each wind speed distribution had a different shape possibly due to differences in topographical conditions. Jeonhul had the widest range in high wind speed, followed by Handong and Cheongsoo.

The specification of wind sensors on met mast and AWS are listed in Table 2. Here, WS stands for the wind speed and WD for the wind direction.

3. Data validation

Before the analysis of the wind data, data validation was performed to obtain more reliable results. This step was performed through three measurement data tests: the range test, relation test and trend test [8,9]. The wind data that showed significant errors on these tests (less than one percent of the whole data) was removed. The international standard of IEC 61400-1 ed.3 states that wind conditions that are experienced in tropical storms such as hurricanes, cyclones, and typhoons are not considered to determine wind turbine classes I, II and III [1]. Thus, the wind data for the two days that were affected by the two typhoons named MAEMI (in 2003) and NARI (in 2007) were excluded in this work.

4. Results and discussion

4.1. MCP application

To extract the various types of extreme wind values for ten years that are recommended for obtaining more reliable estimates of EWS, the MCP technique was applied using one year of measurements and ten years of reference data. A number of MCP techniques have been developed for prediction, which include Regression, Weibull parameter scaling, and Matrix methods [10–12]. The linear regression method was applied in this study; this method is commonly used in a variety of research areas. It characterises the relationship between the measurement and the reference data linearly [13,14].

Table 3 shows statistics from the application of linear regression to Handong and Gujwa. The statistics at the two sites are presented as representative of three sets of measurements and reference sites. The wind direction was divided into 12 sectors with an angle of thirty degrees each because the division of the wind direction raises the accuracy of prediction [11,12]. The mean of the coefficient of correlation, R, is 0.89, which is generally considered to be good for the MCP application [15]. For the other sites, the results showed 0.90 at Jeonhul and Udo and 0.86 at Cheongsoo and Seogwang. If

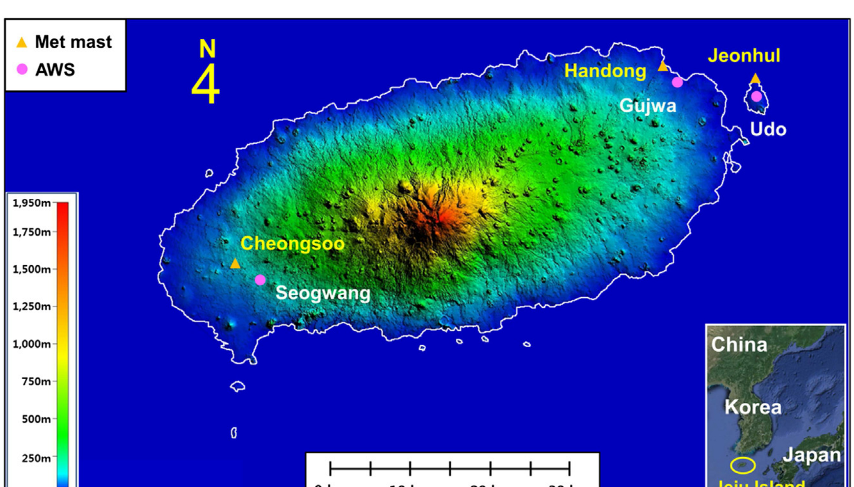

Fig. 1. Location of Jeju Island, including measurements and reference sites.