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에너지 자립 마을 개발을 위한 풍력 실증 데이터 분석

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An Analysis of Wind Data for Development of Energy Independent Village

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Abstract >> In the present study, the wind characteristics were analyzed according to the time averages to evaluate the performance of small wind turbines required for the development of energy independent village. Measuring data of wind speed were recorded between January 2016 and April 2016 every second. Experimental data is averaged out using 5, 10, 15, 20 and 30 minute time steps. Throughout the experimental data analysis, 5 minutes averaged data is used to analyze the performance of the wind turbine, because it produces a minimum turbulence intensity in wind speed. The measuring power of the wind turbine is less than the designed value due to the unsteady nature wind of sudden changes in magnitude of wind speed and wind angle. Detailed wind conditions are also analysed using two variable Weibull probability density functions.

Key words : Wind data(바람 데이터), Time-averaging(시간 평균), Error analysis(오류 분석), Accuracy(정확성), Wind rose(바람 장미)

1. Introduction

Wind data time averaging has a key role to play while analysing the performance a wind turbine as it can have impact on the overall results. Several attempts have been made in the past to study the impact of time-step on the averaging of wind data. For instance, Shen et al.[1)] used six different time-steps i.e. 1, 2, 5, 10, 30 and 60 minutes to average out the measured wind data. They generally recommended all time-steps except 1-minute time step as it produced larger error. A similar study was also conducted by Stout[2)], who used shorter time-steps i.e. 2, 5, 10, 20, 30 and 60 seconds as wind data averaging time-steps.

He concluded that for averaging high wind speeds, larger time-steps are proffered whereas VICE VERSA for lower wind speeds. However, Harper et al.[3] recommended standard 10-minute time-step for wind data averaging. A study conducted by Guo et al.[4] used six different time-steps; 1, 5, 10, 15, 30 and 60 minute. The authors recommended all other time-steps except 1-minute interval as it produced significantly higher fluctuations in standard deciation. Similarly, study conducted by Gulev[5] is also significant in this scenario.

Most of the studies conducted on this topic so far, just recommended more than one time-steps. Also, neither of those studies mentioned about the impact of data averaging time-steps on turbulence intensity (TI).

In the present study, the wind characteristics of Deokjeok-do Island in South Korea are analyzed to verify the performance of small wind turbines required for the development of small-scale energy independence villages. The raw wind data mainly consists of wind conditions such as wind speed, wind direction and ambient temperature. All the data were recorded automatically for every second on a computer. Raw experimental data are averaged out using different time steps of 5, 10, 15, 20 and 30 minutes. Detailed wind conditions are also analyzed using two variable Weibull probability density function (PDF).

2. Materials and Methods

2.1 Wind data collection methodology

Wind data were collected using a vertical tower called the “wind master” at Deokjeok-do Island. The wind master has all the necessary equipments, such as anemometer, anemoscope and data logger. Height of the wind master from local ground is 10 m.

The data recording period corresponds to the winter season in South Korea (Jan-Apr). Five different time steps 5, 10, 15, 20 and 30 minutes were introduced to average out the experimental raw data. TI is used to evaluate the effect of different time averaging steps on the turbine performance in the present study. The time step producing minimum TI in measured wind speed, will be used to evaluate the performance of the wind turbine. TI is defined as the ratio of standard deviation (SD) and mean wind speed. Fig. 1 shows the wind master and all the necessary equipment installed on it.

2.2 Probability density function (PDF)

PDFs are introduced to estimate the wind potential. It is known that Weibull and Rayleigh probability density functions are the most suitable for estimation of wind potential[6-10]. Actually, Weibull and Rayleigh probability density functions are similar in nature but they vary in terms of parameters used[11].

General form of Weibull PDF is as follows:

$$f(v) = (k/c)(v/c)^{k-1}\exp[-(v/c)^k] \tag{1}$$

where k (dimensionless) and c (m/s) are called the shape and scale parameters respectively and v (m/s) is measured wind speed. $f(v)$ is the probability den-

Fig. 1. Wind master installed at Deokjeok-do Island

sity of wind speed v.

Shape factor and scale parameter are the defining parameters for the Weibull distribution[12]. The value of the Shape parameter determines the type of probability distribution which can vary from an exponential distribution to a Rayleigh distribution and Gaussian distribution when the shape parameter exceeds 3. When the shape parameter is equal to 2, it is considered a Rayleigh distribution[13]. k and c indicate the regional wind characteristics so determination of these two important parameters should be as accurate as possible. There are many mathematical approaches to calculate k and c like graphical, maximum likelihood, empirical, power density and moment methods[14]. Empirical method will be used in the present study to estimate k and c.

Weibull cumulative distribution function (CDF) is given as follows:

$$F(v) = 1 - \exp[-(v/c)^k] \tag{2}$$

where F (v) represents the probability of occurrence of all wind speeds less than v.

According to empirical method to calculate values of k and c, following set of equations are used.

$$v_m = \frac{1}{n}[\sum_{i=1}^{n} v_i] \tag{3}$$

$$\sigma^2 = \frac{1}{n-1}(v_i - v_m)^2 \tag{4}$$

$$k = (\frac{\sigma}{v_m})^{-1.086} \tag{5}$$

$$c = \frac{v_m}{\Gamma(1+\frac{1}{k})} \tag{6}$$

v_m is the mean wind speed, v_i is with value in a specific wind series and n is total number of entries in that wind series. Gamma function which can be determined by standard equation as below:

$$\Gamma(x) = \int_0^\infty t^{x-1}\exp(-t)dt \tag{7}$$

3. Results and Discussion

3.1 TI for different time steps of wind data

Fig. 2 shows variation of TI in measured wind speed using different time averaging steps. Two results that can be concluded from Fig. 2 are that relatively lower TI is observed in 5 minute intervals, the averaged wind speed data as compared to all other time steps used and also TI decreases with an increase in wind speed for all time steps.

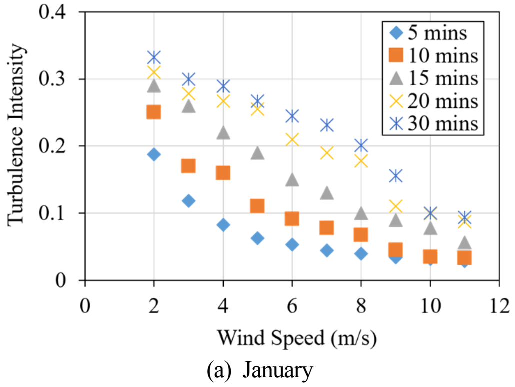
The purpose of present study is to evaluate which time step is best suitable for analyzing the performance of the small Darrieus wind turbine. In Fig. 2, it is found that 5 minutes averaged data is best suitable for analyzing the performance of a small Darrieus wind turbine installed at the real site. Therefore, from here onwards five minutes averaged data will be used in the present study.

3.2 Wind rose

As the wind turbine is installed at the site, it is very important to first analyze the wind conditions so that available wind potential can be estimated. An assumption is made in the present study that during five minute intervals, wind characteristics remains constant[15].

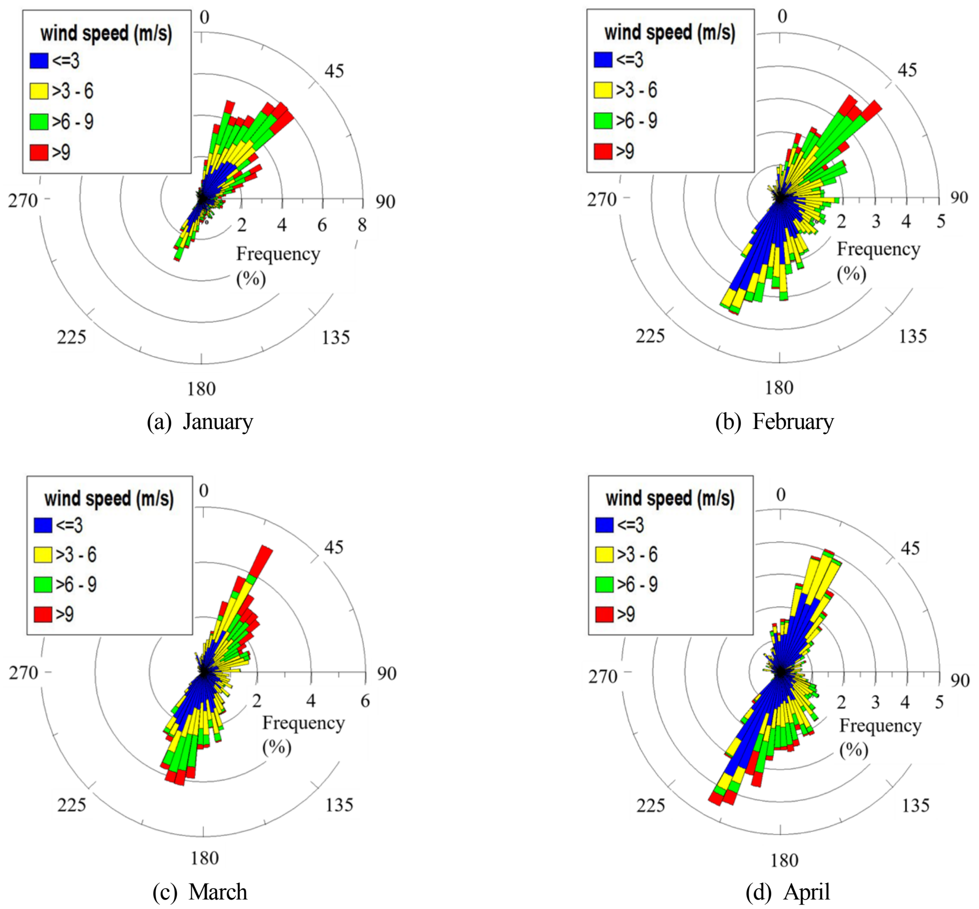
The wind rose diagrams of all four months are shown in Fig. 3. It is noted that wind data analysis is performed with exception to the period when wind velocity is zero. During January, most of the wind speed is in the range of 6 to 8 m/s and mostly coming from north-east, which is the sea side. The main wind flow from north-east direction is due to the geographical features of the island.

During March, higher magnitudes of wind speeds



(a) January (b) March

Fig. 2. TI variation with wind speed



(a) January (b) February (c) March (d) April

Fig. 3. Wind rose

are coming from north-east ranging between 7 and 8 m/s whereas lower magnitudes of wind speeds are observed from south-west with magnitude of less than 3 m/s. It is noted that most of the wind is coming from either north- north east (NNE) (0° to 45°) or from south-south west (180° to 225°) with a maximum magnitude around 10 m/s and mostly between 6 to 8 m/s.

3.3 Wind data analysis

Table 1 summarizes all the important statistical and wind potential indicating parameters for all four months. Although the mean wind speed for 4 months has a large difference but the SD is relatively constant because of the lower TI in 5 minutes averaged wind speed data as described in the previous section.

Table 2 contains the percentages of total wind speeds during each month from all directions (360°). From the Table 2, it is noted that the main wind direction is north-east side as shown in the previous wind rose diagrams.

Table 1. Weibull parameters

Parameter	Jan.	Feb.	Mar.	April
Mean wind speed (m/s)	6.21	4.89	5.01	3.90
SD	2.31	2.67	2.32	2.40
k	2.93	1.93	2.30	1.69
c (m/s)	6.96	5.52	5.64	4.37

Table 2. Variation of wind speed according to wind direction

Angle rang (°)	Percentage of total wind speed			
	January	February	March	April
0-90	69.28	54.78	51.42	28.29
90-180	12.61	25.03	18.42	32.79
180-270	13.84	15.83	27.25	30.34
270-360	4.27	4.41	2.97	8.66

3.4 Evaluation of Weibull PDF

Different statistical parameters can be used to evaluate the performance of Weibull and Rayleigh distributions in comparison with real wind data. Root mean square error analysis (RMSE), the correlation coefficient (R^2) and chi-square error (X^2) are commonly used parameters for this purpose[16] and defined as below:

$$SE = \sqrt{\sum_{i=1}^{n} \frac{(y_i - x_i)^2}{n}} \tag{8}$$

$$R^2 = \frac{\sum_{i=1}^{n}(y_i - x_i)^2 - \sum_{i=1}^{n}(x_i - z_i)^2}{\sum_{i=1}^{n}(y_i - z_i)^2} \tag{9}$$

$$X^2 = \sum_{i=1}^{n}\left[\frac{(y_i - x_i)^2}{x_i}\right] \tag{10}$$

where yi is the actual value of ith bin of wind speed, xi is the value forecasted by Weibull or Rayleigh distributions and zi is the average value of wind speed. The minimum and maximum values of each of three parameters are 0 and 1 respectively. The maximum value of correlation coefficient and minimum values of the other two parameters indicate that an accurate prediction of wind behavior and wind potential estimation has been made[16].

Table 3 contains the values of all RMSE, R^2 and X^2 for both Weibull and Rayleigh distributions for all months. All the values of the correlation coefficient

Table 3. Evaluation of probability density functions

Parameters	January		February		March		April	
	Weibull	Rayleigh	Weibull	Rayleigh	Weibull	Rayleigh	Weibull	Rayleigh
RMSE	0.04	0.07	0.02	0.04	0.01	0.03	0.02	0.04
R2	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
X2	0.03	0.07	0.01	0.02	0.00	0.01	0.00	0.01

in Table 3 are nearly equal to 1, which indicates that the predictions made by Weibull and Rayleigh probability density functions are extremely accurate and also values for RMSE and X^2 are very low which also concludes the same result. From Table 3, it is clear that Weibull predictions are more accurate than Rayleigh.

4. Conclusions

Current study was conducted to analyze the wind data of a small island in South Korea on the basis of different time-averaging steps. On the basis of detailed analysis, following conclusions can be drawn:

For optimal performance evaluation of the small Darrieus wind turbine, TI in wind speed having lower value is analyzed by introducing five time steps: 5, 10, 15, 20 and 30 minutes. It is recommended to use five minutes data averaging scheme while analyzing the performance of small Darrieus wind turbines installed at real site.

Most of the winds are coming from either the north-east side or south-west side of the test station. The main wind flow from north-east direction is due to the geographical features of the island as the test turbine is surrounded with higher mountains from the rest of the three directions. Negligible amount of wind speeds are coming from the west-north side.

Most of the wind speeds during all four months are in the range of 5 to 8 m/s. Relatively higher magnitudes of wind speeds are observed during January and Mach and VICE VERSA for other two months.

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