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1.5 kW 다리우스 풍력터빈 현장 실증 및 성능분석

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Field Testing and Performance Evaluation of 1.5 kW Darrieus Wind Turbine

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Abstract >> The purpose of the present study is to analyze and evaluate the performance of a small Darrieus wind turbine installed at the Urumsil region of Deokjeok-do Island in the west of South Korea 50 km away from Incheon. This place has no government electricity so alternate resources of energy needed to be installed there. For this purpose a small Darrieus wind turbine with the capacity of 1.5 kW was developed and installed at the site. The experimental power output of the wind turbine is less than the designed power at the same values of wind speed. This power loss is mainly due to the highly unsteady nature wind of sudden changes in magnitude of wind speed and wind angle. The results of current study can be used to make a future power generation plan for Deokjeok-do and other nearby small islands.

Key words : Capacity factor(용량 계수), Darrieus wind turbine(다리우스 풍력 터빈), Standard deviation(표준 편차), Weibull distribution(웨이블 분포), Wind speed data(풍속 데이터)

1. Introduction

In general, a turbine performance is determined by wind energy, wind speed and wind direction, which have an unsteady nature due to the geographical features of the installation site.

Wind energy has been introduced to the research and government community over the last few decades[1-4]. There are two general categories of wind turbines named as horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). HAWT is usually preferred over VAWT in terms of aerodynamic performance but it has some structural issues in high wind conditions. The rotor of VAWT is mounted near the ground so making it more stable as compared to HAWT. Bianchini et al.[5] showed that the cost of 500 kW power generation at an average wind speed of 5.4 m/s with a VAWT turbine is 18-39% lower than using a HAWT. Continuously changing the angle of attack of wind on VAWT rotor drops its aerodynamic efficiency[6]. Brulle[7] experimentally studied VAWT on wind tunnel scale with unsteady wind conditions. In their study, wind speed was 7 m/s with fluctuations of 7% and 12% at frequency of 0.5 Hz. They also performed a numerical analysis, using Reynolds averaged Navier Stokes equations, to investigate the effects of both steady and unsteady wind conditions on the performance of VAWT[8].

Until now, most of the studies focus on the performance enhancement of wind turbines or lab scale testing but performance analysis using experimental data which comes from real site, is not considered clearly.

In the present study, the performance of the 1.5 kW vertical axis wind turbine has been analyzed by the experimental data obtained through field test performed at the Urumsil region of Deokjeok-do Island in South Korea. The raw data mainly consists of wind conditions, turbine power and rotational speed of the turbine rotor; its statistics are saved per second on a computer. Raw experimental data is averaged out using different time steps and compared to analyze the performance of the wind turbine. Detailed wind conditions are also analyzed using two variable Weibull probability density functions.

Fig. 1. Picture of test station[9]

2. Wind turbine

The Darrieus wind turbine having the capacity of 1.5 kW and a vertical tower, called the wind master, are installed at the Urumsil region of Deokjeok-do Island as shown in Fig. 1.

An anemometer, anemoscope, ambient temperature sensor and data logger are installed on the wind master. The heights of both are 10 meters from local ground and both are located at a distance of eight meters apart from each other. Geometrical dimensions and performance curve of Darrieus wind turbine are shown in Fig. 2 whereas Table 1 contains important design parameters of the wind turbine like rated power, rated wind speeed tc.

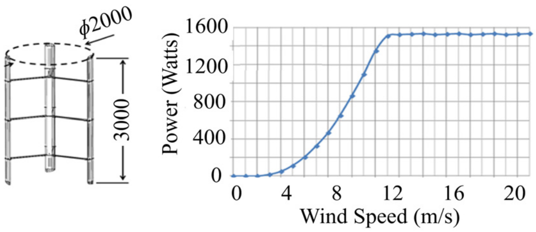


Fig. 2. Dimensions of tested wind turbine rotor and power curve[9]

Table 1. Specifications of test Darrieus wind turbine

Parameter	Value
Rated power (kW)	1.5
Rated wind speed (m/s)	13.5
Rated rotational speed (RPM)	300
Cut-in wind speed (m/s)	3
Chord length (m)	0.2
Blade length (height) (m)	3
Rotational diameter (m)	2
Blade profile	NACA0015

The wind turbine is surrounded by mountains from three sides and sea from the other side. The north side is considered as zero degree of wind angle and the remaining three directions are also assigned a corresponding wind angle.

Fig. 3 shows the data acquisition system to record experimental data from the wind turbine and the wind master. Rotor rotational speed, voltage, electric current and power of the wind turbine are measured between turbine rotor and power transducer. The power output of the wind turbine is first stored in battery bank. Using a power inverter, it is converted to AC voltage for users.

3. Experimental data analysis methodology

To evaluate the performance of the wind turbine, local real time wind conditions, local wind velocity, wind direction, ambient air temperature and atmospheric pressure are stored in a computer by a data acquisition system. The data recording period corresponds to the winter season in South Korea (Jan-Apr) because of huge measuring data over 10 million values for each variable, it needs to average out the raw data for analyzing the meaningful results. Five different time steps 5, 10, 15, 20 and 30 minutes were introduced to average out the experimental raw data.

Turbulence intensity (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. SD is defined as follows:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_{avg})^2}{n}} \quad (1)$$

where x_i and x_{ave} denote the specific and average values of a particular variable x, respectively and n is the total number of values of variable x.

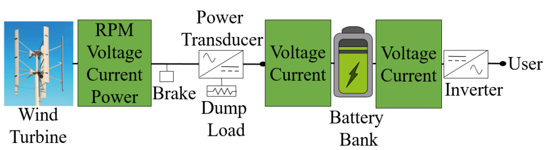


Fig. 3. Diagram for data acquisition methodology

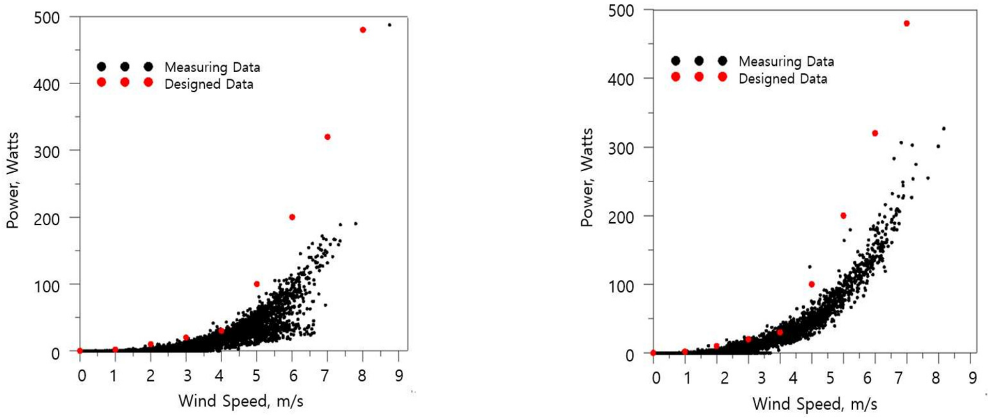
4. Result and Discussion

4.1 Wind turbine performance analysis

Wind turbine power output measured at different wind speeds has been analysed and compared to the designed power output. Fig. 4 shows turbine power production with respect to measuring wind speed for January and March, respectively.

In the Fig. 4, the power output obtained by measurement at every value of wind speed is lower than the designed power curve. There are several reasons behind this drawback. The designed power curve is obtained by wind tunnel testing where usually steady state wind conditions are employed. Even if transient conditions are generated in the wind tunnel then those conditions are not as severe as in the real field. At the real site it is very hard to predict the behavior of wind as it can change its magnitude and angle of attack at any time. This surely effects the performance of the wind turbine and the difference is clear in Fig. 4. On the other hand, weather conditions like snow, rain, sunshine and fluctuation in ambient temperature also affect the performance of wind turbine at the real site.

Table 2 contains the information about electrical energy produced by wind turbines, its capacity factor



(a) January (b) March

Fig. 4. Wind turbine power output

Table 2. Performance analysis of wind turbine on daily basis

	January					February					March					April				
Time (days)	Mean Wind Speed (m/s)	Turbulence Intensity (-)	Wind Turbine Energy Production (kWh)	C.F (%)	C_p(%)	Mean Wind Speed (m/s)	Turbulence Intensity (-)	Wind Turbine Energy Production (kWh)	C.F (%)	C_p(%)	Mean Wind Speed (m/s)	Turbulence Intensity (-)	Wind Turbine Energy Production (kWh)	C.F (%)	C_p(%)	Mean Wind Speed (m/s)	Turbulence Intensity (-)	Wind Turbine Energy Production (kWh)	C.F (%)	C_p(%)
1	3.2	0.3	2.9	8.1	17.3	4.4	0.2	20.9	58.0	23.6	3.0	0.2	1.7	4.8	14.1	4.0	0.3	0.0	0.0	0.0
2	3.6	0.2	7.7	21.4	22.0	3.6	0.3	9.8	27.1	22.6	2.6	0.3	21.0	58.3	19.0	1.8	0.7	0.0	0.0	0.0
3	3.6	0.2	0.0	0.0	0.0	3.4	0.3	0.1	0.3	1.3	2.4	0.3	2.4	6.6	25.4	0.8	1.6	2.9	8.0	19.4
4	3.2	0.3	18.4	51.0	24.9	3.2	0.3	3.3	9.2	16.0	2.8	0.2	1.0	2.8	9.2	1.0	1.3	1.2	3.3	12.8
5	2.8	0.3	14.5	40.4	10.6	2.8	0.3	5.3	14.6	16.6	3.2	0.2	7.0	19.4	23.5	1.0	1.3	3.7	10.4	29.6
6	4.0	0.2	3.5	9.6	16.3	2.0	0.5	16.8	46.6	20.8	3.0	0.2	0.2	0.5	5.6	4.0	0.3	1.9	5.3	10.7
7	3.8	0.2	8.1	22.6	21.7	3.4	0.3	6.0	16.7	15.7	3.4	0.2	1.4	3.9	21.1	5.6	0.2	3.0	8.3	14.0
8	2.2	0.4	4.8	13.2	19.0	2.6	0.4	2.6	7.3	13.7	3.2	0.2	14.0	38.9	4.8	5.8	0.2	20.1	55.7	31.9
9	3.2	0.3	0.1	0.3	2.3	3.6	0.3	6.1	17.1	17.1	3.0	0.2	23.0	63.9	4.8	4.8	0.3	2.8	7.8	20.5
10	1.4	0.6	17.7	49.3	21.8	3.2	0.3	1.3	3.7	10.9	3.6	0.2	21.0	58.3	17.8	3.4	0.4	1.5	4.0	12.5
11	2.4	0.4	19.2	53.4	17.5	2.4	0.4	1.7	4.7	11.2	3.6	0.2	18.2	50.5	33.8	4.2	0.3	14.0	38.8	32.6
12	0.8	1.1	3.4	9.5	19.0	2.2	0.4	7.4	20.5	19.3	3.8	0.2	22.0	61.1	34.0	2.8	0.4	5.3	14.8	31.6
13	1.0	0.9	9.5	26.4	21.6	3.2	0.3	0.0	0.1	2.8	4.0	0.2	1.3	3.6	22.6	2.2	0.6	0.0	0.0	0.0
14	1.2	0.7	1.6	4.3	11.5	4.4	0.2	20.7	57.4	32.5	3.0	0.2	12.9	35.9	33.0	4.6	0.3	0.6	1.7	17.6
15	1.0	0.9	6.8	19.0	21.5	6.0	0.2	21.0	58.3	18.0	2.2	0.3	0.0	0.0	0.0	4.4	0.3	1.5	4.2	33.1
16	1.8	0.5	0.4	1.0	8.5	5.6	0.2	5.5	15.3	34.2	2.6	0.3	0.0	0.0	0.0	2.4	0.5	6.0	16.6	27.5
17	1.8	0.5	4.1	11.4	18.3	3.8	0.2	2.5	6.8	24.9	2.0	0.3	0.0	0.0	0.0	2.4	0.5	0.0	0.1	0.8
18	1.6	0.5	20.2	56.2	7.2	3.6	0.3	3.5	9.8	19.5	1.4	0.5	1.0	2.8	8.8	3.4	0.4	2.9	8.1	20.1
19	2.2	0.4	19.2	53.4	12.1	3.0	0.3	20.2	56.2	35.4	3.2	0.2	0.7	1.8	6.3	4.0	0.3	0.0	0.0	0.0
20	2.0	0.4	13.3	37.0	20.5	2.8	0.3	0.0	0.0	0.0	2.4	0.3	0.0	0.0	0.4	3.6	0.3	0.6	1.8	13.1
21	2.6	0.3	25.6	71.0	23.4	3.8	0.2	15.8	43.8	23.4	3.2	0.2	1.8	5.1	11.0	3.2	0.4	0.0	0.0	0.0
22	3.0	0.3	12.3	34.3	4.7	3.4	0.3	2.3	6.3	18.6	2.2	0.3	16.1	44.8	26.7	3.4	0.4	0.0	0.0	0.0
23	2.4	0.4	18.3	50.9	7.4	1.8	0.5	6.7	18.7	28.8	2.0	0.3	23.0	63.9	9.8	3.2	0.4	5.6	15.4	23.8
24	2.0	0.4	23.0	64.0	22.0	3.0	0.3	21.0	58.3	14.3	2.8	0.2	0.9	2.5	9.0	2.0	0.6	1.0	2.7	13.2
25	2.6	0.3	0.4	1.1	6.4	2.6	0.4	6.1	17.0	25.4	2.8	0.2	0.9	2.6	3.7	3.6	0.3	21.0	58.3	11.1
26	3.2	0.3	0.0	0.0	0.0	3.4	0.3	1.9	5.4	19.2	2.4	0.3	3.8	10.7	14.8	4.0	0.3	20.1	55.9	35.0
27	2.6	0.3	5.3	14.6	11.9	2.8	0.3	1.1	3.1	10.5	2.2	0.3	22.4	62.3	29.1	3.2	0.4	17.5	48.6	31.1
28	2.0	0.4	19.3	53.6	8.0	4.6	0.2	0.0	0.0	0.0	2.0	0.3	19.0	52.8	7.5	1.4	0.9	8.4	23.4	32.6
29	2.4	0.4	2.2	6.0	13.7	3.2	0.3	22.0	61.1	10.3	1.0	0.7	3.1	8.5	25.1	2.6	0.5	0.1	0.4	2.5
30	3.2	0.3	10.9	30.2	18.7	3.6	0.3	14.0	38.9	11.0	2.0	0.3	0.0	0.0	0.0	3.2	0.4	9.8	27.2	32.7

(*CF*) and power coefficient (C_p), on a daily basis. *CF* and C_p are defined as below.

$$CF(\%)=\frac{E}{P_R\times 86{,}400}\times 100 \quad (2)$$

$$C_P(\%)=\frac{2P_t}{\rho A v^3}\times 100 \quad (3)$$

where P_R (watts) is rated power of the wind turbine, P_t (watts) is power produced by the wind turbine, ρ (kg/m^3) is air density (assumed as 1.25 kg/m^3) A (m^2) is wind turbine swept area and v (m/s) is wind speed, respectively. *CF* value indicates that how much energy has been extracted by the wind turbine as compared to its rated capacity.

This parameter purely depends upon the aerodynamic design of the wind turbine but not on wind conditions. So from Table 2 it is clear that average value of *CF* is higher whenever energy extracted by the wind turbine is higher. However, this is not the case for the power coefficient because C_p does not only depend upon the aerodynamic performance of the wind turbine but wind potential also effects it. Therefore, the more the energy extracted by the wind turbine does not necessarily mean that the higher are the values of C_p (as this is true for *CF*) as shown in Table 2. Overall, during January and February relatively higher values of both the parameters are observed and VICE VERSA for the other two months.

Fig. 5 shows the distribution of wind speed data and variation in power coefficient with wind speed. Higher magnitudes of wind speed are observed during January and February as compared to the other two months. As it was discussed briefly in last para-

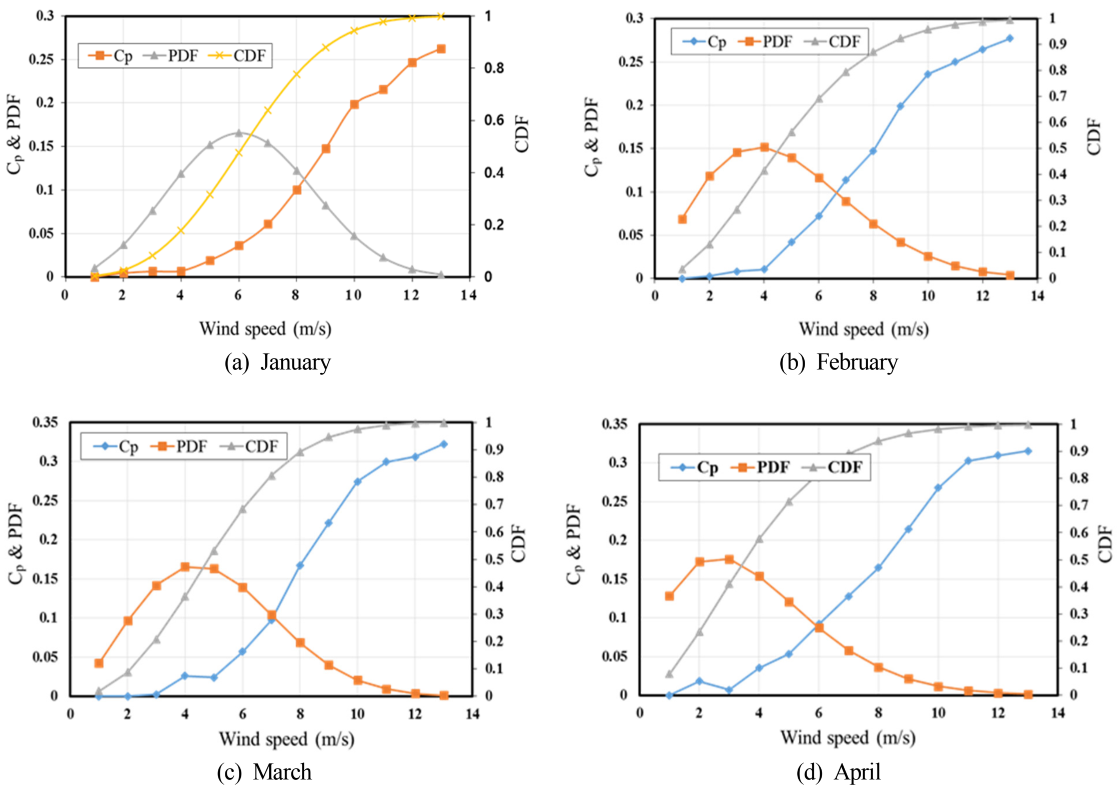


Fig. 5. Wind speed data distribution and power coefficient

graph that C_p is function of both, aerodynamic design of wind turbine as well as the wind conditions. Fig. 5 has been prepared in order to study the effect of wind speed on C_p. From Fig. 5 it is clear that generally during all the months C_p increases lineally with wind speed.

5. Conclusions

Performance analysis of a small Darrieus wind turbine, installed at the Urumsil region of Deokjeok-do Island in South Korea, is being carried out in the present study. On the basis of experimental investigations and wind conditions, the following conclusions are drawn:

(1) 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.

(2) The experimental power output of the wind turbine is less than the designed power at the same values of wind speed. This power loss is mainly due to the highly unsteady nature wind of sudden changes in magnitude of wind speed and wind angle.

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