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WIND ENERGY POTENTIAL ASSESMENT and SITING a WIND FARM in CHEJU ISLAND

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제주도에서의 풍력에너지 포텐샬 평가와 풍력단지 선정에 관한 연구

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ABSTRACT

The possibility in the practical use and supply of the wind turbine in Cheju island was investigated. The wind data measured in three regions which have a plenty wind energy potential were utilized to quantify the wind power resources by statistical analysis. Power output was calculated for 600 kW wind turbine. The coastal area of Guja was superior to Daejung and Hoichun in wind power energy densities. The calculated capacity factor of 600 kW wind turbine in this site was high as much as 30%. Hoichun site, the intermediate region between the Halla mountain and the sea, was rich in wind power energy resources in winter. Hourly ideal energy density at three regions increased at sunrise, reached the maximum at 13-16 O′clock, decreased steadily, and finally remained constant at sunset.

Key words : Wind energy, Weibull distribution, Ideal wind energy density, Capacity factor

I. INTRODUCTION

Recently, the energy production cost of wind turbine has become decreased considerably due to an impressive technical improvement and can compete with the fossil fuel in the region which

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has a high wind potential.

Based on the plan Time for Action from European Wind Energy Association (EWEA), 10% of European electricity will be replaced by wind by the year 2030[1)-3)].

Wind is only an intermittent source of energy which varys with time and region. It is now clear that the major application of wind energy will involve electricity generation, with the wind turbines operating with utility grid systems or in parallel with diesel engines. A clear understanding of power output with wind speed is essential to the site with most available power and wind direction vary in the area. Therefore, wind direction and speed for the possible site of a windfarm should be measured. Local measurement of wind resources has been conducted from May 1996 to April at 15m and 30m height for three locations. Those data are average over 60 minutes intervals during the meaning periods. Wind speed distribution required to estimate the real wind energy should be developed by a statistical model.

Justus[4)] proved that Weibull probability density function is more reliable as a statistical model. Bowden[5)] recommended Weibull three parameter model for analysis of wind speed profiles. Dixon[6)] determined the local wind speed of the system using Weibull distribution function as an economical design method of the wind turbine. Stevens[7)] tested five methods for calculating Weibull parameters(shape, scale), and concluded that the least square method produced less error compared to the wind histogram. Justus model[8)] has also been used to extrapolate to the hub height from the wind speed data measured at different measuring points.

The objectives of this paper are to investigate the performance of wind turbine in different areas by extrapolating to 45m height from the wind speed and direction measured in three regions in Cheju Island using Weibull distribution function and to choose the optimal site of a wind-farm on the basis of the estimated data of the regional power outputs by applying 600kW wind turbines which were verified from the international authorized institute on wind turbine.

II. MEASURMENTS

1. Measurement sites

Since the investigation on the survey of wind speed measurement and analysis in Cheju island has been carried out for a long time, approximate prediction of high wind energy potential region is possible. But the variation in surface roughness and level height in Cheju island is very irregulars and hence the wind resource variations in according with region is also high. Three measuring site have been chosen according to following reasons.

- high wind energy potential region
- public region which can be purchased
- region located more than 1km away from a village to reduce the wind turbine noise

Fig. 1 Location map for the wind measurement sites

Table 1. Spec. of sensors and data acquisition system

Cup anemometer	Output signal: Sine wave voltage that varies frequency with speed. Output frequency: Varies linearly with wind speed 60Hz=45m/s Average slope : 0.764m/s per Hz
Wind direction vane	Output signal: A ratio-metric DC voltage Potentiometer excitation: 1 to 15VDC Range: 360 ° mechanical, continuous rotation
Data logger	Data sampling rate: 1 Hz(all inputs) Averaging interval: Sampled data may be averaged over 60 minutes intervals Acquired data: Average, standard deviation, daily min., daily max. Data storage: FLASH data card

- region where the utility grid connection is possible

Daejung and Guja measuring site are located 1.2km for from #12 state road and about 1km for from near village. This regions, owned by Cheju province, are possible for the grid connection. Hoichundong measuring site is located 7.5km for from Cheju city. In this region, grid connection is also possible. This place is garbage dump region and hence wind-solar hybrid power generation is suitable. Fig. 1 shows the measuring sites.

2. Measuring equipment

Measuring equipments for the wind data are sensors and data logger. Table 1 shows the main functions of the measuring equipment.

3. Tall tower(measuring pole)

The height of tall tower is 30m and the tower is made by high strength steel pipe. The data loggers are installed at 1.5-3m for from the bottom of the tower, two anemometers at 15m and 30m, and a wind direction vane at 30m height. All the towers are equipped with light rod to protect the sensors at data logger from the electrical hazard.

III. BASIC EQUATIONS

1. Weibull distribution and ideal wind power density

Power, P(watt) from wind resources is expressed as kinetic energy and flowrates passed through a cross sectional area of wind turbine, i.e.,

$$P=\frac{1}{2}\rho A V^3 \qquad (1)$$

where V is an instant wind velocity, ρ is air density, and A is a cross sectional area of wind turbine.

Actually, the wind speed utilized in wind turbine is ranged from cut-in speed to furling speed. Therefore, distribution probability of those wind speed ranges are important. Most of wind speed data actually measured is expressed as probability of distribution in different levels. It has been identified that those are in agreement with Weibull distribution. Probability function $P(V)$ is the specific wind speed(V) is expressed as (2).

$$P(V) = (K/C)(V/C)^{K-1} \exp(-(V/C)^K) \qquad (2)$$

where C is scale parameter related to the average distributed wind speed, K is shape parameter related to the deviation size of distributed wind speed.

Wind potential of the specific region can be expressed with C and K values because P(V) for the proposed speed is calculated from two parameters(C and K). To calculate C and K from the measured data of wind speed, equation (2) was accumulated as (3).

$$F(V)=\int_0^V P(V)dV=1-\mathrm{EXP}\left(-\left(\frac{V}{C}\right)^K\right) \qquad (3)$$

From this equation, C and K can be obtained using the least square method. For application of moment method, average wind speed $\overline{V}$ is

$$\overline{V}=\int_0^\infty P(V)VdV=C\Gamma\left(1+\frac{1}{K}\right)$$

Therefore, $\overline{V}^3$ is expressed as

$$\overline{V}^3=C^3\Gamma\left(1+\frac{3}{K}\right)$$

Finally, C and K are determined because, standard deviation and $\overline{V}^3$ can be calculated from the measured data. The above two methods has been utilized in this research.

Fig. 2 shows the accumulated distribution as a function of wind speed measured at 30 m height and the solid line in Fig. 2 is Weibull probability density function calculated from above methods.

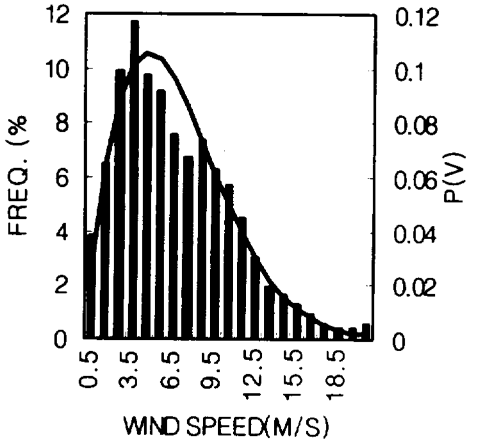

Fig. 2 Wind velocity frequency and Weibull probability function at Guja site

By using Weibull distribution of equation (1), quantity of average energy generated from wind is calculated as equation (4)

$$\overline{P}=\frac{1}{2}\rho A\int_0^\infty V^3P(V)dV = \frac{1}{2}\rho AC^3\Gamma(1+\frac{3}{K}) \qquad (4)$$

Ideal wind power density(IWPD) is as the follow.

$$\overline{P}/A=\frac{1}{2}\rho C^3\Gamma(1+\frac{3}{K})=\frac{1}{2}\rho\overline{V^3}[W/m^2] \qquad (5)$$

IWPD is calculated by Weibull coefficients(C, K) for the specific region into equation (5), where Γ is Gamma function.

However, IWPD gives only the available wind power for the specific region, can not be applied to the real wind turbine, and is only used as a basic data for choosing the possible site of a windfarm for utilization of wind energy.

2. Height extrapolation

It is important to estimate wind speed characteristics at different heights wind turbine from the measured wind data for accurately estimating power performance of wind turbine. Generally, variation of wind speed is greater in a windbreak area which is large in the ground roughness than in the seashore and sandy shore because behavior of wind is affected greatly by the ground roughness. In this research, (1) wind speed data measured at different heights were corrected by try and error at the hub height of the wind turbine, (2) the following equation proposed by A.S. Milhail and C.G. Justus[8] in 1981 was utilized to build the unmeasured wind speed data.

Wind speed at different heights was estimated from the power law model proposed by Panpfsky as follows.

$$u(z) = u_{10} \times (Z / 10)^{\alpha_p}$$

where, u is wind speed, Z is height, and 10 is the measuring height in meter. α_p is the index of wind speed variation at different heights based on ground roughness and calculated from the following equation. If the wind speed is measured at 10 m of the height as a standard, the coefficient is calculated from the following equation.

$$a_p = 1/\ \ln(Z_g/Z_0)\ -\ 0.0881\ \ln(u/6)$$

If the height is not 10 m, the following equation is used,

$$a_p = 1/\ln(Z_g/Z_0)$$
$$-\ (0.0881/(1-0.081\ln(Z_{a/10})))\ \ln(u/6)$$

where Z_g is calculated from the following equation.

$$Z_g\ =\ \exp\ (\ln(10)\ +\ln(z))\ /\ 2$$

3. Wind potential analysis program

The measured data was recorded as NGR 930 format based on NGR data acquisition system in this research. Using those measured data, data input and handling in wind potential analysis program was performed.

Wind potential analysis program includes the following detailed solutions of wind potential.

- MEAN WIND SPEED (M/SEC)
- STANDARD DEVIAT. OF WIND SPEEDS
- MEAN WIND POWER DENSITY (W/M2)
- MAX. WIND SPEED(M/S) AND OCCURRED TIME (Y/M/D/H)
- DOMINANT WIND ENERGY DIRECTION
- DOMINANT WIND SPEED DIRECTION
- WEIBULL SHAPE FACTOR, K
- WEIBULL SCALE FACTOR, C(M/S)
- WIND SPEED DATA RECOVERY(%)
- CAPACITY FACTOR(%)
- OVERALL EFFICIENCY(%)
- ANNUAL ENERGY INPUT (KWH)
- ANNUAL OUTPUT BY WECS (KWH)

4. Power performance curve and capacity factor

Each wind turbine has its own power performance. And the theoretical power output of wind turbine can be calculated from the accumulated wind speed distribution at the desired site based on power performance curve of the commercial system. Fig. 3 is power performance curves of 600 kW · wind turbines manufactured in three European companies. Those three systems are the major products of each company. We assumed that those systems can be put to practical use in Cheju, and calculated the expected power output. In the performance curves in Fig. 3, MCM and NTK are the stall control types which varied the power output with the rated wind speed, and VESTAS is the pitch control type which has the constant power at the higher speed than the rated one. Therefore, the regional wind potential can be calculated based on the capacity factor of each system. From those data, the optimal system of the wind performance for the specific area can be chosen. The capacity factor is defined as

$$\begin{array}{c}\text{Capacity}\\ \text{factor}\end{array} = \frac{\begin{array}{c}\text{Actual energy delivered}\\ \text{over year}\end{array}}{\begin{array}{c}\text{Energy delivered at}\\ \text{continuous rated power}\end{array}}$$

IV. RESULTS AND DISCUSSION

1. Analysis of ideal wind energy density at different regions

From statistical analysis, ideal wind energy densities at 45 m height during

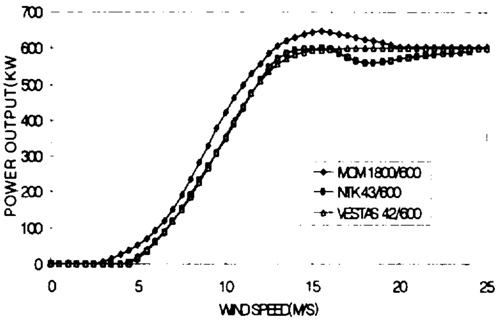

Fig. 3 600kW wind turbine characteristic curves

the measured periods were 217.7 at Daejung, 478.8 at Guja and 274.1 W/m^2 at Hoichun, respectively. This means that the energy density at Guja was the highest of the measured regions. Fig. 4 shows the wind roses at Daejung, Hoichun and Guja site during the measured periods. The occurrence frequency of wind at those regions showed the same tendency such as the north wind from seashore to inland, and the southeast wind from inland to seashore. Based on Fig. 4 major wind direction was in agreement with the major wind speed at those three regions. Therefore, the energy produced by wind was originated from the combined wind of seashore and inland. The wind of seashore can generate the energy while the wind of inland can't without the influence of the ground roughness because Cheju area consists of many roughness areas. Therefore, topographical and meteorological conditions are the most important factors for choosing the optimum site for the windfarms.

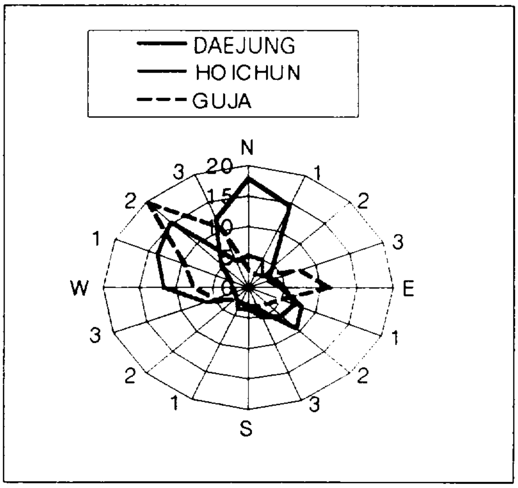

Fig. 4 Total wind rose(45m height)

Fig. 5 shows the average scale and shape factors in Weibull probability density function at different directions calculated statistically from the extrapolated average wind speed. The average measured wind speeds at 15 and 30 m were optimized and extrapolated to the wind speed at 45 m which is the height of commercial wind turbine. The

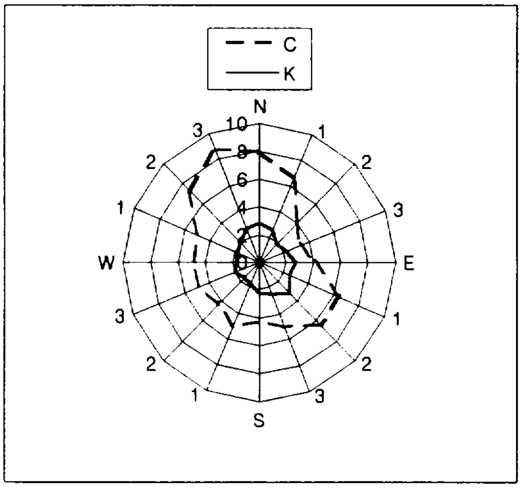

Fig. 5 Directional variation of Weinbull parameters at Daejung site

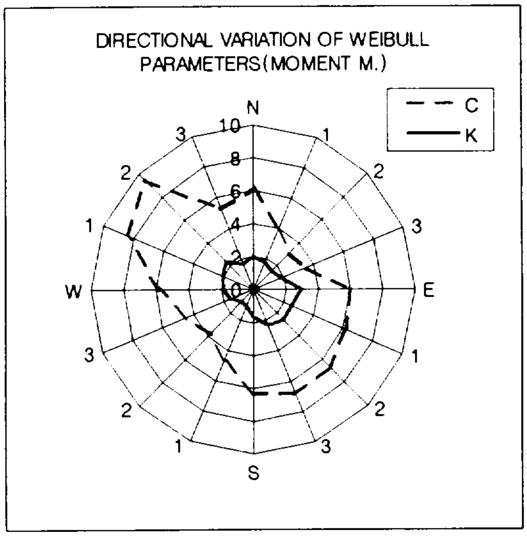

Fig. 6 Directional variation of Weinbull parameters at Hoichun site

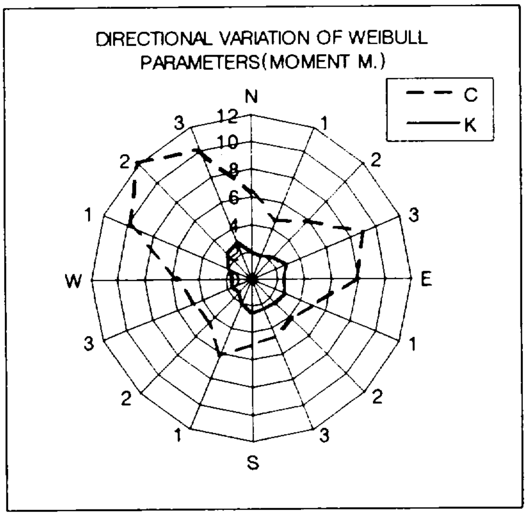

Fig. 7 Directional variation of Weinbull parameters at Guja site

scale factor related to average wind speed was high in the wind at the north and southeast, and were greater specially in the southeast wind. The major wind direction at Daejung was the one from the seashore and the scale factor was about 8 m/s. The scale factor for the wind of the southeast was 6 m/s and this can be utilized as the energy resource.

Hoichun site is located about 420 m above the sea level and there are several ranches which are an open field towards Halla mountain. As mention in the above section, the frequency of the southeast wind was very low. However, as shown in Fig. 6, the scale factor was greater than 6 m/s compared to Daejung. As shown in Fig. 7, Guja site showed 8 m/s of the scale factor originated from the southeast wind. From those results, It turns out that Cheju has different wind speeds at different regions due to Halla mountain, and the intermediate region between Halla mountain and the sea was rich in wind potential and has capability as a complex unit of wind energy.

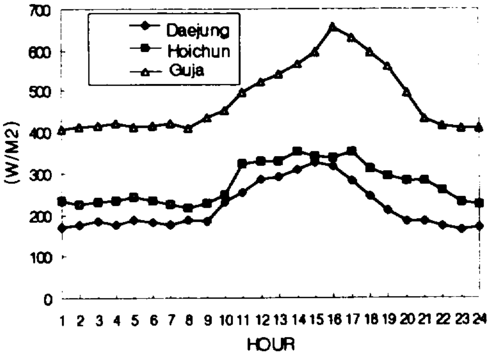

Fig. 8 Hourly ideal wind energy density

Fig. 8 shows the ideal energy density as a function of time at 45 m height of Daejung, Hoichun and Guja. The density begins to increase at sunrise, reached the maximum at 13-14 O'clock, decreased steadily, and finally remained constant at sunset. Specially, the energy density at night at Guja which has relatively high wind speed increased from 400 to 600 W/m^2.

Table 2. Comparison of calculated monthly C. F and power output of 600kW wind turbines

(a) Daejung

	MCM 1800		NTK 43		VES TAS 42	
ONT	CF(%)	UT(KWH	CF(%	UT(KWH	CF(%)	UT(KW
96. 5	31.0	138281	24.3	108433	24.3	108632
6	12.9	55906	9.3	39996	9.4	40417
7	12.1	54104	7.9	35268	8.1	35994
8	12.1	53848	8.3	36912	8.4	37442
9	10.9	46919	7.2	30902	7.3	31461
10	17.2	76892	12.6	56465	12.8	56967
11	34.5	148848	28.3	122061	28.3	122182
12	25.2	112649	20.1	89804	20.2	90113
97. 1	41.7	186098	35.0	156305	35.0	156264
2	36.8	148247	30.1	121204	30.1	121304
3	22.6	100800	17.5	78004	17.6	78381
4	11.1	47824	7.5	32309	7.6	32808
NNUA	22.2	1164343	17.3	907840	17.3	911860

(b) Guja

	MCM 1800		NTK 43		VES TAS 42	
ONT	CF(%)	UT(KWH	CF(%	OUT(KWH	CF(%	UT(KW
96. 5	67.4	300725	57.7	257427	57.9	258285
6	18.7	80608	15.0	64883	15.1	65386
7	20.2	90333	15.9	70815	15.9	71170
8	20.8	92770	16.1	71747	16.2	72106
9	14.0	60540	10.2	44156	10.3	44559
10	35.8	159733	29.5	131534	29.5	131626
11	51.4	221987	44.5	192129	44.6	192627
12	42.8	191144	36.6	163420	36.8	164246
97. 1	63.4	283160	56.0	250021	56.5	252081
2	52.4	211303	45.3	182564	45.3	182592
3	43.5	194171	36.6	163232	36.5	163098
4	31.6	136353	25.4	109934	25.5	110128
NNUA	36.0	1890548	30.2	1587320	30.3	1592801

(c) Hoichun

	MCM 1800		NTK 43		VES TAS 42	
MONT	CF(%)	OUT(KWH	CF(%	UT(KWH	CF(%)	UT(KWH
96. 5	0.0	0	0.0	0	0.0	0
6	23.0	99148	18.8	81103	18.9	81709
7	18.0	80475	13.8	61551	13.9	61912
8	14.9	66296	10.4	46467	10.5	47068
9	7.4	32167	4.4	18814	4.5	19358
10	16.1	71750	11.3	50541	11.5	51181
11	31.6	136322	25.9	111853	25.9	112078
12	29.2	130306	23.9	106883	24.0	107229
97. 1	41.7	186257	35.4	158156	35.5	158533
2	33.9	136870	27.9	112314	27.9	112441
3	21.8	97376	16.8	75124	16.9	75505
4	11.1	47779	7.5	32247	7.6	32748
NNUA	24.2	1271487	19.4	1022215	19.5	1026338

2. Estimation of calculation power output of 600 kW wind turbines

Table 2 shows the calculated power output and capacity factor from the integration of the performance curve (Fig. 3) as a function of the accumulated time by extrapolating to 45 m height from the measured wind speed data . The capacity factors at Daejung, Hoichun and Guja were 17.3 and 22.4%, 19.5 and 24.2%, and 30.2 and 36.0% in NTK and VESTAS, and MCM, respectively. Of three regions, Guja was remarkable in terms of the calculated power output. Therefore, Guja should be considered as the first site for a windfarm.

V. CONCLUSION

The objective of this research was to investigate the possibility in the practical use and supply of the wind turbine in Cheju. Three regions were chosen because those were expected to have a plenty wind energy potential and were available as a site for a windfarm. The wind speed data measured in those regions were utilized to quantify the wind power resources by statistical analysis. Power output was calculated for 600 kW wind turbine verified internationally as the most economical one based on examination. The results were summarized as the followings:

1. The coastal area of Guja was superior to the other regions tested in the wind power energy density and calculated power outputs. The calculated capacity factor of 600 kW wind turbine was high as much as 30%.
2. Hoichun was rich in wind power energy resources in winter. The reclaimed land located in this region can be reused for installing the wind turbine in connection with the solar energy system. It was also find out that the intermediate region between Halla mountain and the sea was rich in wind potential.
3. Hourly ideal energy density at three regions tested increased at sunrise, reached the maximum at 13-16 O'clock, decreased steadily, and finally remained constant at sunset.

요 약

본 연구는 제주도내 풍력발전기 보급 및 적지선정을 검토하는데 그 목적을 두었다. 이를 위하여 제주도내 다풍지역으로 예상되는 3개 지역을 선정하여 1년간 풍력자원조사를 행하였고, 계측된 자료는 통계분석으로 풍력자원을 정량화하였으며 또한 세계적으로 경제성이 인증된 600kW 풍력발전기를 모델로하여 가상 출력을 산출함으로서 최적 풍력단지를 제시하였다.

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