Prediction of Wind Energy with Limited Observed Data

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Abstract *Wind environment is the most important factor for wind energy siting. The power production is much dependent on the wind environment of each site. To estimate the power production in a particular location, it is desirable that wind data has been measured at the site for long term enough to be already averaged over years. However, in many cases, shorter data is only available and modification is necessary to exclude some bias in that period. Especially in Asia, where seasonal change of wind climate is generally significant, this prediction technique is more important to get more accuracy.*

In this research, prediction technique is discussed. Wind data from several meteorological stations was analysed. Several estimation techniques were compared with different length of available data. The error in the estimated results was investigated.

Prediction of long-term wind climate may contain large error in the calculation process. To get better results, the calculation method should be carefully selected. Further investigation is necessary to improve the way of estimation.

Wind energy, Prediction technique, Mean wind speed, MCP method

1. Introduction

Wind environment is the most important factor for wind energy siting. The power production is much dependent on the wind environment of each site and it often decides the economic efficiency of the project.

To estimate the power production in a particular location, the most desirable situation is that long-term measurement of wind has been done exactly at the site. However, this is not common in most cases and shorter record is available at most. Because of the variation of wind environment in space and time, it is often the problem how to estimate the averaged wind environment from such limited observation. period. Especially in Asia, where seasonal change of wind climate is generally significant, this prediction technique becomes important to get more accuracy.

In this research, it is supposed that the period of wind measurement is less than one year, which means a worse case. Since seasonal change is common in wind environment, estimation of annual averaged characteristics becomes more difficult in this case.

2. Prediction Technique

The techinique to estimate long-term wind climate is often referred as measure-correlate-predict (MCP) method.The basic idea is taking short-term wind measurement at the target point and corellating them with measurement at a nearby reference point where the measurement has been taken for longer-period[1]. Generally, meteorological staition is used as a reference point.

In a simlple application is to suppose linear relationship between the wind speed at the target U^{T} and that at the reference U^{R}:

$$U^T = aU^R + b$$

Once the relashiship is established, the long-term wind speed at the target can be estimated with the wind speed record at the reference. The relation is assumed to be dependent on the surrouding condition of both location, i.e. terrain, surface roughness, obstacles and so on, and it is constant over years.

There are some difficulties in applying the above idea in calculation:

- how the relation ship, or the constants a and b, should be decided;
- the relation ship be decided depending on wind direction;

- how the reference point should be chosen from several candidates.

In the follwing, several calculation way is compared with sample wind data.

3. Wind Measurement Record

Wind measurement records at three meteorogical stations (AMeDAS System) in northern Japan were examined.In these stations, wind speed and direction is automatically recorded at every hour. The data was derived from CD-ROM ditribution[2].

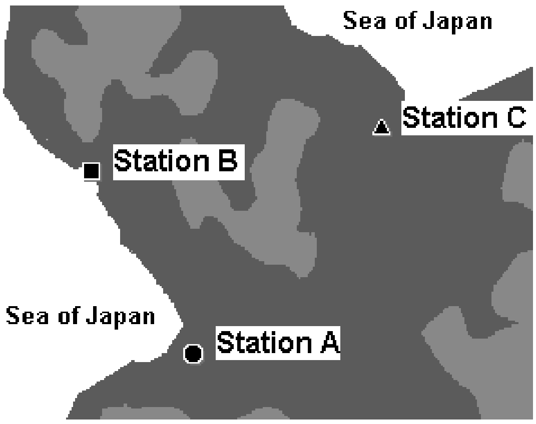

Fig. 1 Meteorogical Stations A, B and C

The arrangement of the stations is shown in Fig. 1. The distance between stations is about twenty or thirty kilometers. All the stations are located near the shore, but Station C is separated from the other two stations, A & B, by mountains. All the stations are located near the shoreline, but station C is faced to the sea in different derection.

In the following calculation, Station A was assumed to be the target, where available wind data is limited for from three to nine months. Station B & C was the reference, where the record was assumed to be available for the whole year and more.

As it can be easily expected from the map, the wind environment at Station C was rather different from the that of other two stations. For example, the wind rose at Station A and that of B was quite similar to each other, but the dominant wind direction at Station C was different, as in Fig. 2. In Fig. 3, the monthly mean wind speed was compared. The seasonal change of wind speed was prominent at Station A & B, but not so much in Station C.

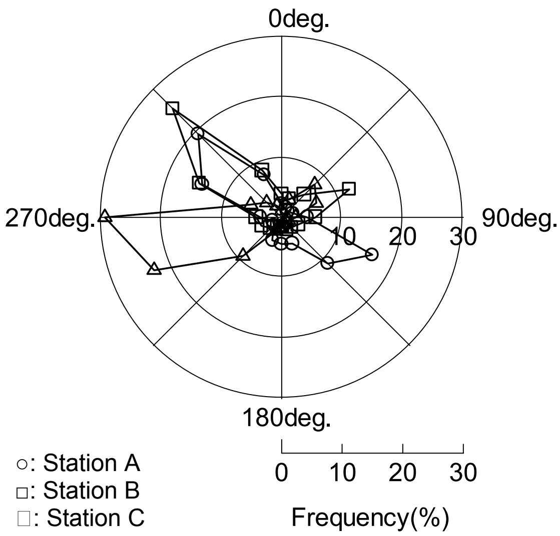

Fig. 2 Wind Rose (For the whole year)

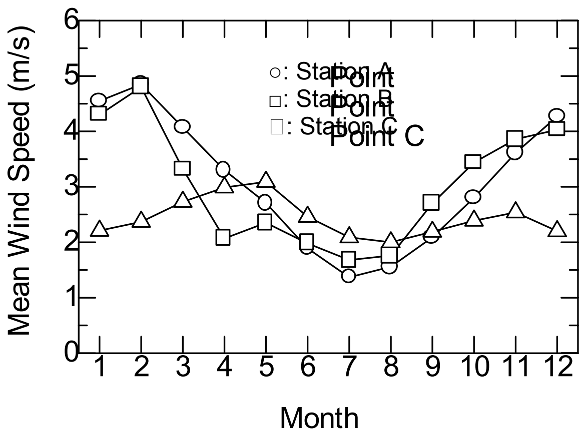

Fig. 3 Monthly Mean Wind Speed

4. Estimation of Annual Mean Wind Speed

4.1. Estimation without Directional Consideration

In the filed of wind energy, the most common and simplest indicator which reflects the amount of wind energy is the annual mean wind speed at the site. To estimate the mean wind speed, two different estimation models were tried.

The first way was to estimate from the monthly mean wind speed shown in Fig. 3. The difference of wind speed between two stations was expressed by 'wind speed ratio', which was assumed to be universally applied to all wind directions. The estimation can be expressed as:

$$\overline{U}_{year}^{A} = \frac{\overline{U}_{s}^{A}}{\overline{U}_{s}^{B}} \overline{U}_{year}^{B}$$

where $\overline{U}_{year}$ is the annual mean wind speed and $\overline{U}_s$ is the mean wind speed during simultaneous observation. The suffix *A* is the target station and *B* is the reference station.

Example of estimation is shown in Fig. 4. The estimation target was Station A and the reference was Station B. The period of simultaneous observation was set from three months to nine months. The estimated wind speed is plotted against the period of used simultaneous data. Because of seasonal difference, the estimated value, which is shown as the rectangular sign '☐', shows wide scattering depending on which part of the year was taken as the simultaneous observation. Hereafter, the estimation result s are shown as the standard deviation of error, which is shown as dash line in Fig. 4.

Fig. 5 compares the results depending on the reference point. The plotted wind speed is the standard deviation error around the true mean value. As easily expected, the estimation error became larger when the reference point was set to Station C, where the data correlation with the target was much worse.

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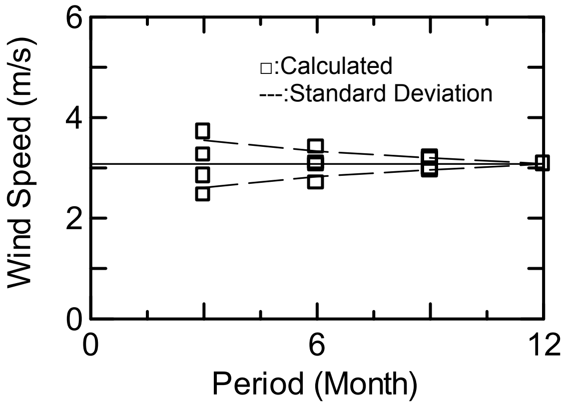

Fig. 4 Estimation Results
(From Station B, No Directional Consideration)

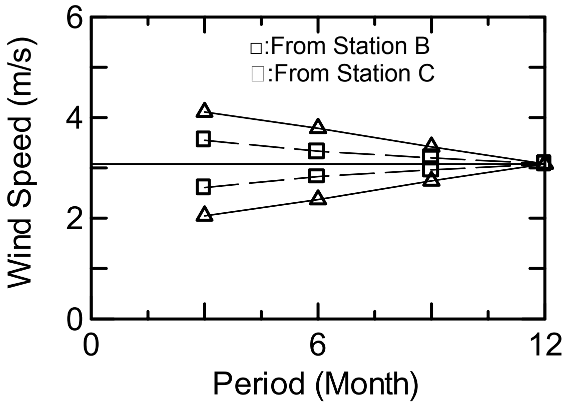

Fig. 5 Estimation from Two Reference Stations
(No Directional Consideration)

4.2. Estimation with Directional Consideration

To improve the estimation, the wind characteristics dependent on wind direction was newly introduced. As for the directional correlation between two wind observations, some models have been suggested[3) 4)], but it is not clear which way should be applied to get better estimation for a particular target of estimation.

In this section, 'wind speed ratio' in the previous section was assumed to change with the wind direction. The simultaneous wind observation data was divided into sectors of wind direction at the reference station, then 'wind speed ratio' was calculated at each sector. The estimation process was repeated at each observation as:

$$U_i^A = \frac{\overline{U}_{s,j}^A}{\overline{U}_{s,j}^B} U_i^B$$

where U_i is the wind speed at time i and $\overline{U}_{s,j}$ is the mean wind speed during simultaneous observation, for the wind direction j at the reference station B. The annual mean wind speed at the target station A can be calculated from the series of U_i estimated for the whole year.

The results are compared with the previous result in Fig. 6 for the reference Station B and in Fig. 7 for the reference Station C. Despite the introduction of the dependency on wind direction, the difference of results were not large. In detail, small improvement can be seen in Fig. 7, where the correlation between stations was not good, but the opposite in Fig. 6. These results should be examined further.

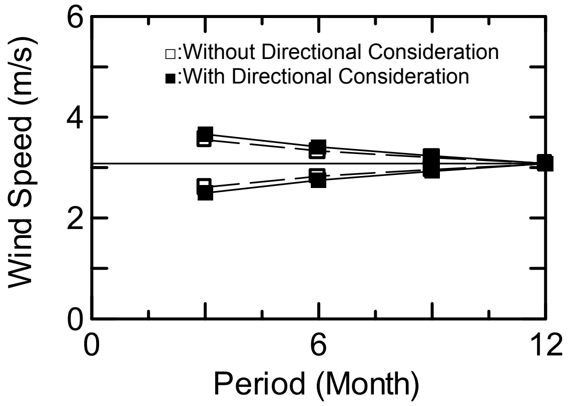

Fig. 6 Estimation from Station B (With/Without Directional Consideration)

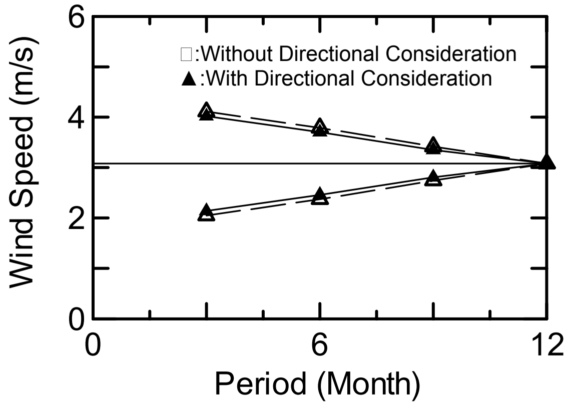

Fig. 7 Estimation from Station C (With/Without Directional Consideration)

5. Application to the Power Production

Though mean wind speed is the convenient indicator, the common final interest in the filed of wind energy is the power production. Since wind power production is different in each type of wind turbine, a typical power curve for a horizontal-axis pitch-regulated machine was assumed as in Fig. 8. The power output was normalized by the rated power and the line was expressed by polynomial equations.

Due to the non-linearity between wind speed and power output, the estimation error in power production may differ from that in mean wind speed. The relation between the errors was calculated when the distribution of wind speed was expressed by Weibull distribution with k = 2.0, which is common approximation in wind energy calculation.

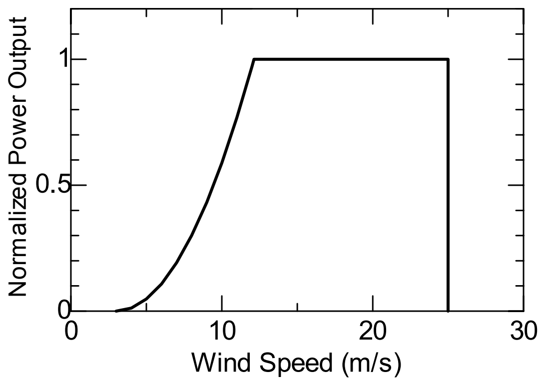

Fig. 8 A Typical Power Curve of Wind Turbine (Normalized by Rated Power)

Fig. 9 shows the relation of estimation error between mean wind speed and power output. The error in power production was generally greater than that of mean wind speed, especially when the mean wind speed was relatively low, and the error was greater when wind speed was low and estimation error was plus (over estimation). The shape of the power curve, whose slope increases with the wind speed, can explain this difference. Thus estimation of power production is easily affected by estimation error.

In the mean wind estimation in Section 3, wind speed at the target station can be calculated for each time and distribution of wind speed can be formed. It may be necessary to discuss the theoretical background of the effect of data scattering, some results were obtained for the same data in Section 3.

First, wind speed record at the reference station B or C was converted to that at the target station A, using the 'wind speed ratio' for all/each wind direction. Then power output production was calculated at each time and annual power production was obtained. The result was normalized by the 'true' power production calculated directly from the true wind speed at Station A.

The results are shown in Fig. 10 for the reference station B and in Fig. 11 for the reference station C. The estimation error was greater than that of mean wind speed. In Fig. 11, where the correlation of wind observation was relatively poor, the estimation of power production was improved by introducing the wind direction dependency. This suggests estimated mean wind speed can not explain all of the estimated wind environment including the power production.

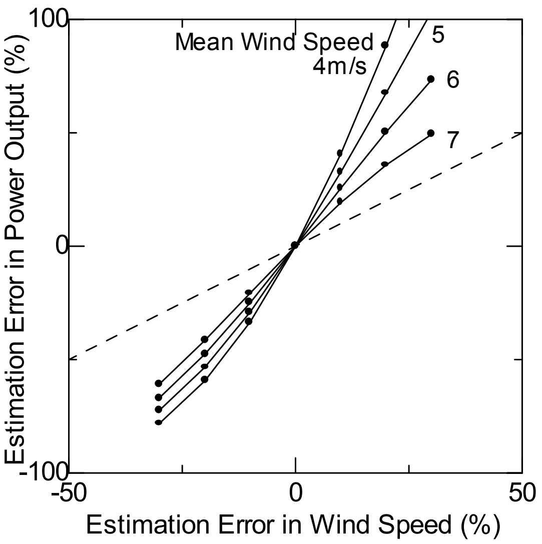

Fig. 9 Estimation Error in Wind Speed and Power Output (k=2.0)

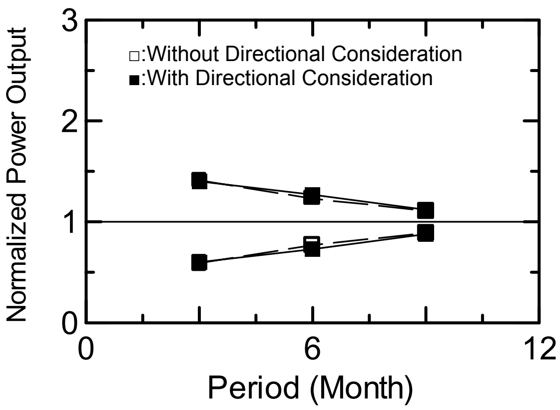

Fig. 10 Power Estimation from Station B (With/Without Directional Consideration)

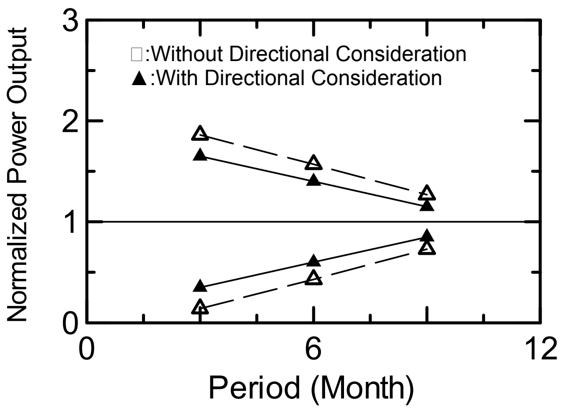

Fig. 11 Power Estimation from Station C (With/Without Directional Consideration)

6. Conclusion

Estimation of wind environment was examined in the view of power production for wind energy.

The introduction of wind direction was considered in sample calculation. The improving effect was not clear for the estimated mean wind speed, but greater for the estimated power output, especially the correlation of wind environment was relatively poor.

However, predicted long-term wind climate may contain error, which may be large enough to affect the feasibility of the project. Other approach is using numerical weather prediction models, which calculates wind flow at the site from the daily numerical predection for weather forecasts. Further investigation combining these approaches would be necessary to improve the estimation at the site.

7. References

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