An upscaling approach for the regional wind power forecasting

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Object

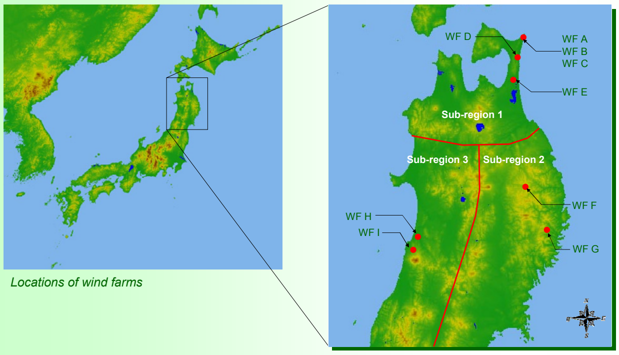
The prediction of the regional wind power from number of wind farms needs an upscaling approach. The accuracy of the expected power output of a region depends on number and location of reference wind farms.

In this study, an upscaling approach was investigated systematically to clarify the effects of the number and location of reference wind farms on the expected power output and error of a region. Measurements and predictions for nine sites distributed over the northern part of Japan, were used, which are a part of the "Development of Wind Power Prediction Models Based on Numerical Weather Prediction" funded by NEDO.

A bi-exponential function was proposed to estimate the cross-correlation for each pair of sites. It approaches to 1 when the distance between two sites is zero and shows a good fitting .

Overview of This Study

An upscaling approach was investigated systematically by using measurements and predictions for nine sites distributed over the northern part of Japan for the year 2006. The wind power production from each wind farm is predicted by a model with the physical downscaling procedure and multi-timescale model. Selected wind farms for each case are shown in the table. Five wind farms are located in northern region of Tohoku area and two wind farms in eastern and western regions, respectively.



Locations of wind farms

Description of wind farms

Case	Number of reference wind farms	Reference wind farms	Total installed capacity (kW)	Ratio※1 (%)
1WF	1	A	32,500	13.4
2WF	2	A,H	62,500	25.7
3WF	3	A,G,H	105,400	43.3
4WF	4	A,E G,H	138,400	56.9
5WF	5	A,B E,G,H	165,400	68
6WF	6	A,E,F G,H,I	184,150	75.7
7WF	7	A,B,E F,G,H,I	211,150	86.8
8WF	8	A,B,D,E F,G,H,I	224,150	92.1
9WF	9	A,B,C,D E,F,G,H,I	243,400	100

※1 :Ratio between total capacity of reference wind farms and regional one .

Effect of Number and Location of Reference Wind Farms (RWFs)

Upscaling Approach

A typical upscaling function using the utilization time for groups of free wind farms and reference wind farms is given as

$$P_{area}(t) = \left(1 + \frac{P_{rate}^{free} \cdot UT^{free}}{P_{rate}^{ref} \cdot UT^{ref}}\right) \cdot P_{pred}(t)$$

where $P_{area}(t)$ is total power production, P_{rate}^{ref} is installed power of reference wind farms, UT^{ref} is the utilization time of reference wind farms, P_{rate}^{free} is installed power of free wind farms, UT^{free} is the utilization time of free wind farms and $P_{pred}(t)$ is the wind power prediction of reference wind farms.

In this study, it is assumed that the utilization time of free wind farms is equal to that of reference wind farms and the upscaling function is simplified as

$$P_{area}(t) = \left(1 + \frac{P_{rate}^{free}}{P_{rate}^{ref}}\right) \cdot P_{pred}(t)$$

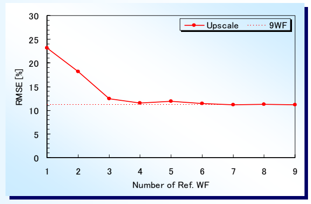
An alternative upscaling function based on the sub-region concept is expressed as

$$P_{area}(t) = \sum_{i=1}^{n} \left\{ \left(1 + \frac{P_{rate\ i}^{free}}{P_{rate\ i}^{ref}}\right) \cdot P_{pred\ i}(t) \right\}$$

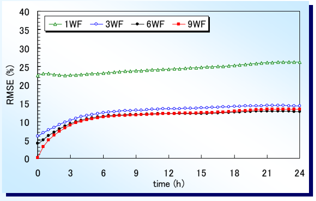
where $P_{area}(t)$ is the sum of the power production of reference wind farms. i and N are the index and number of sub-region, respectively.

Dependency on Number of RWFs

Dependency of the prediction error is investigated systematically.

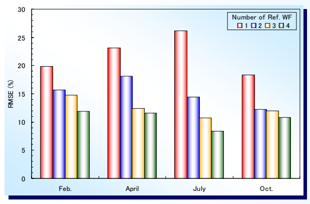


Variation of prediction errors with the number of reference wind farms in April, 2006



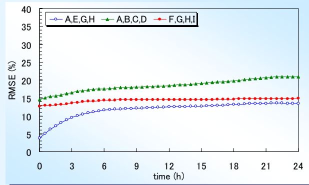
Variation of prediction errors with forecasting horizon for several cases in April, 2006

- The prediction error for the power output of the whole region decreases with the increase of the number of RWFs.
- The prediction error approaches to the reference value obtained from data of all sites when the normalized capacity of the reference wind farms is close to 50%.
- Improvement of prediction is found for all forecasting horizon with the increase of the number of reference wind farms.
- Decrease of prediction errors with the number of reference wind farms is observed in any season.



Seasonal variation of prediction errors with numbers of reference wind farms in 2006

Dependency on Location of RWFs



Variation of prediction errors with the locations of reference wind farms in April, 2006

- Prediction errors also depend on the location of reference wind farms, even though the numbers of reference wind farms are same for each case.
- The upscaling based on sub-region concept shows good performance when the normalized capacities of reference wind farms in each sub-region are almost same.

Description of Sub-region

Sub-region	1	2	3
Wind farms in the sub-region※2	A, B,C, D, E	F, G	H, I
Total installed capacity in the sub-region (kW)	124,750	63,900	54,750
Total installed capacity of ref. wind farms (kW)	65,500	42,900	30,000
Ratio of total installed capacity of reference wind farms and that of sub-region(%)	52.5	67.1	54.8

※2 :Reference wind farms used for the upscaling are shown by underline.

A Cross-correlation Model

Standard Deviation

The standard deviation of prediction error for a whole region should be smaller than that of a single wind farm due to spatial smoothing effects. The standard deviation is normalized by the installed capacity allowing to compare relative errors of wind farms with different sizes.

The standard deviation is defined by

$$\sigma_{area} \approx \sqrt{\frac{1}{N_{area}^2} \sum_{i=1}^{N_{area}} \sum_{j=1}^{N_{area}} \sigma_i \sigma_j r_{ij}}$$

where σ_i and σ_j denote the standard deviation of prediction error of single wind farm i and j, respectively. r_{ij} represents cross-correlation function between them and N is the number of wind farm. For the reference wind farms, the standard deviation and cross-correlation can be calculated directly. On the other hand, those for the free wind farms are unknown. The standard deviations for the free wind farms are estimated by assuming

$$\sigma_i = \overline{\sigma_{ref}}$$

where $\overline{\sigma_{ref}}$ denotes the averaged standard deviation of the reference wind farms.

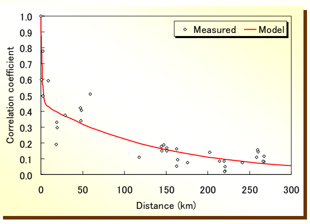
Cross-correlation Model

A cross-correlation model is proposed as

$$r_{ij} = (1-a) e^{-\frac{d_{ij}}{b}} + a \cdot e^{-\frac{d_{ij}}{c}}$$

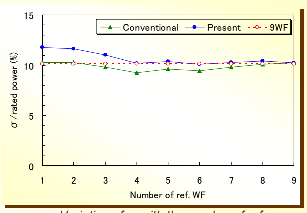
where a, b and c are fit parameters and d_{ij} is the distance between the two sites. The cross-correlations of the prediction errors are calculated by using measurements and predictions in Feb., Apr., July and Oct. in 2006.

- The proposed cross-correlation approaches 1 automatically as the distance between two sites is zero.

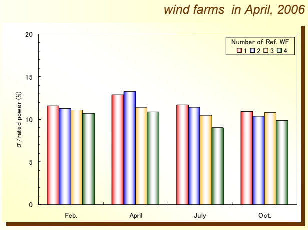


Cross-correlations obtained from data in Feb., Apr., July and Oct., 2006

- The standard deviation by proposed model shows good agreement with the reference value in comparison with the conventional one.



Variation of σ with the number of reference wind farms in April, 2006



Seasonal variation of σ with the number of reference wind farms in 2006

Conclusions

In this study, a typical upscaling approach was investigated systematically to clarify the effects of the number and location of reference wind farms on the expected power output of a whole region and its error. Following results were obtained.

- Prediction error for the power output of a whole region depends on the number of reference wind farms. The prediction error decreases with the increase of number and approaches to the reference value when the normalized capacity of RWFS is close to 50%.
- Prediction error also depends on the location of reference wind farms and the upscaling based on sub-region shows good performance when the normalized capacities of reference wind farms in each sub-region are almost same.
- A bi-exponential function was proposed to estimate the cross-correlation between the two sites. The proposed model shows good performance in comparison with the conventional one.