Wind Power Forecasting by using Physical and Statistical Approach

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Object

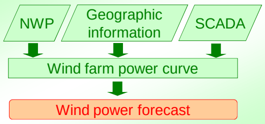
For the wind power forecasting, physical approaches [1] and statistical approaches [2] have been proposed. Statistical approach has an advantage that its prediction accuracy is improved as the data are obtained. However, at the beginning of the forecast, its prediction accuracy is limited.

In this study, a wind power forecasting model is proposed, in which physical approach is combined with the statistical approach to give the better result.

Concepts and the site

Wind farm power curve

In the wind power forecasting model, a function called "Wind farm power curve" is widely used, which relates the wind speed at a reference site in the wind farm and the total power output.



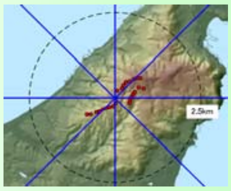
Wind farm power curve is a function of wind speed and wind direction in order to take the effect of the local terrain and wake into account.

The wind power forecasting is carried out by substituting the predicted wind speed and direction by NWP model.

The flow of the forecasting system

The map of the Wind farm

A wind farm in complex terrain was chosen as a target. Wind turbines are located on a ridge, the direction of which is NE to SW.



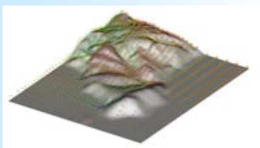
The wind farm used in this study

Physical approach

In the physical model, the effect of the local terrain is considered by CFD based local wind prediction model and the wake model.

Local wind prediction model

The local wind prediction model MASCOT [3] was used to take the effect of local terrain into account.



Wind field predicted by MASCOT

$$\frac{\partial \rho u_j}{\partial x_j} = 0$$

$$\frac{\partial u_i}{\partial t} + \frac{\partial \rho u_j u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j} - \rho \overline{u_i' u_j'}\right)$$

$$\frac{\partial k}{\partial t} + \frac{\partial \rho u_j k}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] - \rho \overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial \rho u_j \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right] - C_{\varepsilon 1}\frac{\varepsilon}{k}\rho \overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j} - C_{\varepsilon 2}\frac{\rho\varepsilon^2}{k}$$

$$\rho \overline{u_i' u_j'} = \frac{2}{3}\rho k \delta_{ij} - 2C_\mu \rho \frac{k^2}{\varepsilon} S_{ij} + 2C_2 \frac{k^3}{\varepsilon^2}\left(-S_{ik}\Omega_{kj} + \Omega_{ik} S_{kj}\right)$$

Governing Equations of MASCOT

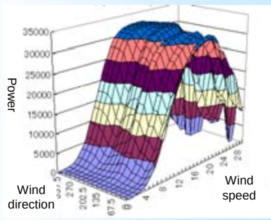
The effect of the wake model

The wake effect was calculated by using the PARK model [4].

$$\delta V = U_0\left(1 - \sqrt{1 - C_t}\right)\left(\frac{D_0}{D_0 + 2kX}\right)^2 \frac{A_{overlap}}{A}$$

Estimated power curve by a physical approach

- For northwesterly and southeasterly, the wind speed increases by the local terrain and the power increases.
- For northeasterly and southwesterly, the wake effect causes the decrease of the produced power.



Estimated wind farm power curve

Statistical approach

In the statistical approach, the effect of local terrain and the wake is estimated from the past data by using non-parametric regression method with forgetting factor, in which the power curve is estimated using the measured power P^{meas} and the predicted wind speed u^{pred} as follows.

$$f(u) = \arg\min_f \sum_{s=1}^{t}\left[\lambda^{t-s}\left(f(u_s^{pred}) - P_s^{meas}\right)\right]^2$$

The non-parametric regression can written be written as follows in a matrix form.

$$\mathbf{y}_s = \mathbf{z}_s \cdot \boldsymbol{\phi}^T(\mathbf{q}_s)$$

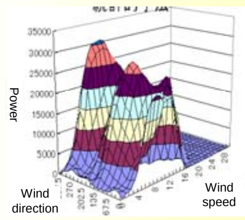
where, $\phi_{(1)}(q) = f(u_{t+k|t}, \theta_{t+k|t})$ and $\begin{cases} q_1 = u_{t+k|t} \\ q_2 = \theta_{t+k|t} \end{cases}$

This can be rewritten using recurrence formulae as follows:

$$\boldsymbol{\phi}_t = \boldsymbol{\phi}_{t-1} + w(\mathbf{q}_t, \mathbf{q}_i) R_{u,t}^{-1} \mathbf{x}_t \left[y_t - x_{t\phi_{t-1}}^T\right]$$

$$\mathbf{R}_t = \lambda \mathbf{R}_{t-1} + w(\mathbf{q}_t, \mathbf{q}_i)\mathbf{x}_t \mathbf{x}_t^T$$

The non-parametric regression reduces to solving the formulae with appropriate initial condition. In the conventional method, the initial value is set to zero and when new data is available, the shape of f approaches to the shape of the expected power curve file.



Estimated wind farm power curve by pure statistical model

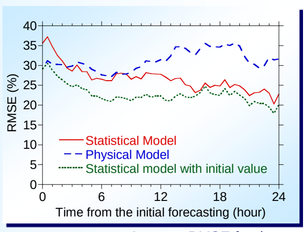
Statistical and Physical approach

In this study, two different procedure for the combination of the statistical approach and the physical approach was carried out.

Physical model as an initial value

The first approach is to use the result of physical model as an initial value of the statistical value.

- This approach can give relatively better result than the conventional approach in which the initial value is set to 0.

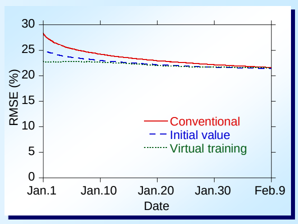


Average RMSE for three hours ahead forecast

Virtual training

The second approach is to use the measured wind speed and the physical model to generate the virtual wind power data for the training. The virtual data is generated for one year and virtual training was carried out prior to the forecast operation.

- The forecast error is small enough from the fast day of the forecast operation.



RMSE for three hours ahead forecast

Conclusions

In this study, an approach to combine the physical model and statistical model was proposed to reduce the initial error of the wind power forecasting. Following results were obtained.

- Using the result of the physical model as an initial value of the statistical model, the prediction accuracy was improved.
- Implementing the virtual training with the measured wind speed and the physical model, the prediction accuracy was further improved. This is due to the prediction error in wind speed and the non-linearity of the wind farm power curve.

Acknowledgement

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References

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