1. INTRODUCTION

The forecasting system for wind power generation specialized a wind farm has been developed. This system was based on numerical and statistical models, and it enabled to forecast the wind speed and power of each wind turbine.

The main parts of the system were two kinds of numerical and statistical model. Two numerical models were used. One was the meso-scale weather forecasting model WRF. And, the other was the local-wind model NuWiCC (Numerical Wind simulation Code in CRIEPI). This model has been developed by CRIEPI. The NuWiCC based on the CFD model, which is based on the incompressible, and non-hydrostatic governing equations. The statistical model used the Model Output Statistics (MOS).

The purpose of this study was two-fold. One was to develop the combined models using of numerical and statistical models, another was to investigate into the performance of numerical and statistical models.

In this paper, the system description was summarized and the effects of each component were discussed.

2. OUTLINE OF FORECASTING SYSTEM

Fig.1 shows the flow of the forecasting system for wind power generation by combined use of numerical and statistical models.

i) The initial and boundary conditions for step ii) are made from the GPV (grid point value of numerical prediction) provided by the Japan Meteorological Agency (JMA) regional-scale model (RSM).

ii) The WRF simulated the wind speed and direction over the wind farm.

iii) The NuWiCC simulated the wind speeds at each wind turbine in the wind farm.

iv) The MOS corrected the wind speeds using SCADA (Supervisory Control and Data Acquisition) data.

v) The wind power generation of each wind turbine was calculated from the corrected wind speed and the corrected wind power curve.

vi) Total wind power generation of wind farm was calculated by the sum of each wind turbine.

As shown in the diagram, this system targets a wind farm and consists of the following models. The wind farm and wind simulation's methods of each model are shown as follows.
2.1 Wind Farm

In general, the wind power station that has two or more wind turbines is called wind farm. Fig.2 indicates the wind farm at northern part of Tohoku region in Japan. This site is located in complex terrain such as the ridge and the cape. This wind farm refers to "A-site" in this paper. A-site has 25 wind turbines, and the wind turbines are anti-clockwise arranged from A-1 to A-25(Fig.3). The output-specification is 1,300 kW, and Hub height is 68.0m. The 10-minute average values (wind speed, wind direction, wind power) of the SCADA data were obtained, and we compared simulated data with observation data.

2.2 Meso-Scale model WRF

The model used for the meso-scale simulation was the WRF model. Tab.1 shows model configurations and physics options. The period was the half-month of the latter half of January 2005, and daily-simulated 51 hours forecast (start at 21:00 JST).

Domains of the simulation and A-site are shown in Fig.2. The WRF was run on a 9km horizontal resolution parent-domain with a nested 3km horizontal resolution sub-domain. Nesting was 1-way, and nudging was not used.

2.3 Local-wind model NuWiCC

The model used for the local-wind simulation was the NuWiCC. Fig.3 shows the domain of this simulation and the location of wind turbines in A-Site. The NuWiCC was run on a 100m horizontal resolution (100x100grids), and simulated in the neutral planetary.

The increase and decrease in wind speed with a complex terrain was evaluated for each wind direction (8 wind directions). Fig.4 shows the prediction of wind speed and vectors at the hub height of wind turbine for the W wind direction, and it is found that the noticeable change in wind speed occurs in the wind farm. And, the rates of velocity correlation table were made from distribution of wind speed and vectors at the Hub height of the wind turbine (Fig.5). Next, the NuWiCC was connected with the WRF output data. The WRF output data used wind speed over A-site (about 500m height). To use the WRF output data, the grid point in the nearest WRF sub-grid domain from A-site was selected, and the wind velocities of the upper layer and the lower layer were converted into the wind velocity of 500m-height by using logarithmic linear interpolation. The NuWiCC used the WRF output data as inflow wind conditions, and simulated the wind speed of each wind turbine and each time step by using this table.

The influence of wake was also considered with the Riso model(3) to estimate the influence of the wake between wind turbines.

Tab.1 Model configurations and physics options.

<table>
<thead>
<tr>
<th>Period</th>
<th>Initial and Boundary value</th>
<th>Vertical grids</th>
<th>Horizontal grids</th>
<th>Cumulus parameterization</th>
<th>Radiation model</th>
<th>Planetary boundary layer</th>
<th>Surface model</th>
</tr>
</thead>
<tbody>
<tr>
<td>21JST January 15 2005 through 00JST February 01 2005</td>
<td>JMA RSM GPV, NOAA-OI-SST</td>
<td>50 levels (bottom layer σ=0.993)</td>
<td>parent-domain 9km (240×300grid)</td>
<td>Kain-Fritch(domain1)</td>
<td>RRTM(Long wave radiation)/Dudhia(Short wave radiation)</td>
<td>Elat Mellor-Yamada-Janjic</td>
<td>thermal diffusion</td>
</tr>
</tbody>
</table>

Fig.2 Domains of the WRF simulation and Wind Farm A-site.

Fig.3 NuWiCC 100m-grid domain and the location of each wind turbine in A-Site.
2.4 Statistical Model MOS

The wind speed was corrected with Model Output Statistics based on regression, where the predictant Ws (SCADA wind speed) was formulated by the following linear combination of predictors, i.e. output from NuWiCC.

\[ W'(t) = A_s W_{sn}(t) + A_e W_{em}(t) + A_v W_{vm}(t) + B \]

In the formulated, WSm, WUm, and WVm indicated wind speed, wind east-west component and north-south component, respectively.

The coefficients As, Au, Av and B were determined so that the error, \( E_w = \langle (W_s' - Ws)^2 \rangle \), averaged during 1-15 January 2005 was minimized.

The wind power P was converted from Ws' with the following formula.

\[ P' = \min (P_{max}, CW_s^3) \]

where C was determined so that the error, \( E_p = \langle (P' - P)^2 \rangle \), averaged during 1-15 January 2005 was minimized.

3. Result

The effects of numerical and statistical models (each stage of GPV, WRF, NuWiCC and MOS) were discussed.

3.1 Wind Speed

To see the effects of each model (each stage of GPV, WRF, NuWiCC), Fig.6 shows the time series of the simulated wind speeds and observed wind speed (during the period of January 17th 12:00 - 18th 12:00). The wind turbines of A-site (A-2, A-10, A-12, and A-19) that had differences from the table (Fig.5) were selected, and this period was the wind direction from the north.

The GPV and the WRF predicted the average wind speed of the wind farm. On the other hand, the NuWiCC predicted the wind speeds of each wind turbine in the wind farm.

3.2 Wind Power

Fig.7 indicates the time series of the wind power estimated with wind speed by each stage of the system and observed wind power of A-site. To aim to compare the effects of numerical and statistical models, the total power of 17 wind turbines operating with stability for the period were selected and used.

The forecasting system simulated 51 hours forecasts every day. To avoid the influence of operational situation (ex. spin-up and prediction error), this study used only the forecast time (4 hours < lead time < 27hours).

In Fig.7 (a), it's found that RSM is underestimated and large fluctuations in comparison with the observation data. The WRF and NuWiCC almost solved underestimate and good agreement with observed data (Fig.7 (b) and (c)), and the MOS improved the statistical errors (Fig.7 (d)).
4. CONCLUSIONS
   In this study, the forecasting system for wind power generation by combined use of numerical and statistical models have been developed. And, the performances of numerical and statistical models are discussed.
   The follows are to be remarked.
   1. The performance is increasingly improved by piling up the models.
   2. The meso-scale model enables to generate several fast changes.
   3. The local-wind model enables to express the differences between wind speeds at each wind turbine.
   4. The MOS improves the average accuracy.

Fig.7 Comparison of wind power (The total power of ten wind turbines operating with stability for the period.).
   The red dot in Figure indicates each case data, and the green dot in indicates observation data.

ACKNOWLEDGMENT
This study is executed as part of the research and development of "Wind Power Stabilization Technology Development Project -- Development of Wind Power Prediction Models Based on Numerical Weather Prediction--" that is the consignment business of New Energy and Industrial Technology Development Organization (NEDO).

REFERENCE