The Wind Observation on the Pacific Ocean for Offshore Wind Farm

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Summary

For the investigation on the possibility of wind farm in the Pacific Ocean near Japan, wind speed and direction were observed using a platform for natural gas mining, 37 km far from a coastline. The platform is located on the east sea of the Tohoku district, northeast part of Japan. There is no island around the platform.

The platform has a trussed tower, and a windmill-type anemometer was installed at the top of the tower. The sensor height is 94 m above the sea level. The anemometer was non-spark type for the gas-mining site. The observation was started in September 2004, and it will be continued for three years. We recorded wind speed and wind direction averaged over ten minutes, maximum and turbulence of wind speed.

The characteristics of observed wind are good for wind turbines. The annual wind speed average is 7.5 m/s, the turbulence intensity is 8%.

1. Introduction

Offshore wind farms, which are currently being developed in Europe, are expected to be introduced in Japan. Consequently, many attempts have been made to estimate the offshore wind energy available around Japan. Ishihara estimated that the offshore wind energy available along the coastline of the Kanto area near Tokyo is 280 billion kWh/year. [1]

However, all the estimates made thus far are based on numerical simulations that have not been validated by field measurements. The full-scale development of offshore wind farms requires an investigation of the offshore wind conditions through measurement and validation of numerical simulations. For this reason, the authors conducted offshore wind observations at a sufficient height at an offshore natural gas platform located 37 km off the coast, in the Pacific Ocean.
2. Outline of the wind observations

Fig. 1 shows the locations where the wind observations were carried out. The observations were carried out at two locations — one offshore and the other onshore.

The offshore observations were made at a platform for natural gas mining, 37 km off the coast. Photo 1 shows the platform. A windmill-type anemometer was installed on the top of the drilling tower at a height of 94 m above sea level. (Fig. 2) In general, drilling facilities for natural gas specify that only explosion-proof electrical equipment be used; therefore, the anemometer used was of the type that detects the number of revolutions of the propeller and the wind direction with optical signals through an optic fiber, instead of with electrical signals. The observations began in September 2004 and are currently in progress.

For comparison purposes, a three-cup anemometer and a wind vane were installed on the top of a 24-m-high pole for the onshore wind observations. (Photo 2)
3. Results of the wind observations

The characteristics of the annual wind, which observed from October 2004 to September 2005, are presented below.

3.1 Average wind speed

Fig. 9 shows the changes in the time-averaged wind speed on monthly basis, respectively. Fig. 3 shows the changes in the average monthly wind speed. The average annual offshore wind speed is 7.5 m/s, and the average annual onshore wind speed is 3.5 m/s.

The changes in the average monthly wind speed tends to be higher in winter and lower in summer. In particular, during the period of January to May, the average monthly offshore wind speed is high, exceeding 8 m/s. The highest average monthly onshore wind speed — 9.1 m/s — is observed in January. In June and July, the average monthly offshore wind speed falls below 6 m/s, the lowest being 5.7 m/s in July.

![Anemometer and wind vane](image)

Photo 2 On shore observation site in Hirono thermal power plant.

![Bar chart showing average annual and monthly wind speeds](image)

Fig. 3 Average annual and monthly wind speeds.

The average annual and monthly wind speeds shown in Fig. 4 were calibrated for a height of 80 m above sea level (and above the ground) to allow an easy comparison between the offshore and onshore measurements. The following formula was used for the height calibration.
\[ V_{\text{Offshore}80m} = V_{\text{offshore}94m} \left( \frac{80m}{94m} \right)^{0.1}, \quad V_{\text{Onshore}80m} = V_{\text{onshore}24m} \left( \frac{80m}{24m} \right)^{0.2} \]

Equation 1

The average annual offshore wind speed at a height of 80 m is 7.4 m/s, and the average annual onshore wind speed is 4.4 m/s. The average annual offshore wind speed is 70% higher than the onshore wind speed.

3.2 Turbulence intensity

The average annual offshore turbulence intensity is 8%, indicating that the offshore wind has a low turbulence. The average annual onshore turbulence intensity is 24%. However, this value was obtained at a ground height of 24 m and is therefore considered to be significantly affected by the surrounding buildings, trees, and topography.

Fig. 5 shows the turbulence intensity for each wind direction. Fig. 11 shows the changes in the time-averaged turbulence intensity on a monthly basis, respectively.

3.3 Wind speed occurrence frequency

Fig. 6 compares the wind speed occurrence frequency between the offshore and onshore observations. The two observations reveal clear differences. The offshore observations show a smoother occurrence distribution and a
higher frequency of the occurrence of high wind speed as compared to the onshore observations. For the offshore observations, the Weibull distribution shape factor for the wind speed occurrence frequency is 1.67 and the scale factor is 8.5.

Assuming a rated wind speed of 12 m/s for wind power generators, the occurrence frequency of wind speeds higher than the rated wind speed is high at 17%.

3.4 Wind direction occurrence frequency and wind energy density

Fig. 7 shows the wind direction occurrence frequency. The most frequently occurring offshore wind direction is northwesterly (9.4%). The occurrence frequency of northwesterly to north-northeasterly winds is 7.8% to 9.2% and that of southerly winds is 9.3%, which indicates a relatively high occurrence frequency of north-southerly winds. The onshore and offshore wind direction occurrence frequencies show a similar trend. Fig. 12 shows the changes in the time-averaged wind direction on monthly basis, respectively.

The annual offshore wind energy density is 613 W/m². Fig. 8 shows the offshore and onshore wind energy density for each wind direction. As with the wind direction occurrence frequency, the offshore wind energy distribution relative to the wind direction shows larger energy densities in the northwest and south directions.
Fig. 9  Example of one hour mean wind speed time history.

Fig. 10  Example of maximum wind speed time history.

Fig. 11  Example of turbulence intensity time history.

Fig. 12  Example of one hour mean wind direction time history.
4. Discussion

Table 1 shows the results of the offshore and onshore wind observations. The average annual offshore wind speed is 7.5 m/s. If wind power generators are installed at this location, an annual capacity factor of more than 35% can be expected.

The observations show that the average monthly wind speed is higher than 8 m/s in winter and about 6 m/s in summer — a difference of more than 2 m/s.

The offshore turbulence intensity is 8% and is thus small. The durability of wind power generators increases with decreasing turbulence intensity. This is one of the advantages of siting wind turbines offshore, as demonstrated by the observation.

<table>
<thead>
<tr>
<th>Observation Site</th>
<th>Offshore</th>
<th>Onshore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation Height</td>
<td>94 m</td>
<td>24 m</td>
</tr>
<tr>
<td>Annual mean wind speed</td>
<td>7.5 m/s</td>
<td>3.5 m/s</td>
</tr>
<tr>
<td>Maximum wind speed</td>
<td>39.0 m/s</td>
<td>37.5 m/s</td>
</tr>
<tr>
<td>Weibull shape factor</td>
<td>1.67</td>
<td>1.70</td>
</tr>
<tr>
<td>Weibull scale factor</td>
<td>8.5 m/s</td>
<td>3.9 m/s</td>
</tr>
<tr>
<td>Wind energy density</td>
<td>613 W/m²</td>
<td>63 W/m²</td>
</tr>
</tbody>
</table>

5. Conclusions

Wind observations were made at a height of 94 m above sea level for one year at a natural gas platform in the Pacific Ocean, located 37 km off the coast.

1) The average annual offshore wind speed (calibrated for a height of 80 m) is 7.4 m/s ~ 70% higher than the onshore wind speed (calibrated for a height of 80 m), which was measured at the same time.

2) The average monthly wind speed is higher in winter and lower in summer. The average monthly wind speed drops by more than 20% over the average annual wind speed, particularly in June and July.

3) The average annual offshore turbulence intensity is 8% and is thus small.

Further observations are in progress. The measurement of time-history data with a sampling time of 1 second began in December 2005. We will continue the analysis of these data with the aim of introducing offshore wind farms in Japan.

Reference

For this reason, the authors conducted offshore wind through measurement and validation of numerical simulations. The full-scale development of offshore wind farms requires an investigation of the offshore wind conditions through measurement and validation of numerical simulations. For this reason, the authors conducted offshore wind observations at a sufficient height at an offshore natural gas platform located 37 km off the coast, in the Pacific Ocean.

### Offshore Wind Observations

A windmill-type anemometer was installed on the top of the drilling tower at a height of 94 m above sea level. In general, drilling facilities cannot supply the type of electrical equipment that would be used to protect the anemometer from severe weather. Therefore, the anemometer used was of a type that detects the wind direction and its optical signals through an optic fiber, instead of with electrical signals. The observations began in September 2004 and are currently in progress.

### Onshore Wind Observations

For comparison purposes, a three-cup anemometer and a wind vane were installed on the top of a 24-m-high pole for the onshore wind observations.

### Wind Observation Results

The average annual offshore wind speed is 7.5 m/s, and mean power density is 600 W/m². If wind power generators are installed at this location, an annual capacity factor of more than 35% can be expected.

The observations show that the average monthly wind speed is higher than 8 m/s in winter and about 6 m/s in summer — a difference of more than 2 m/s.

The offshore turbulence intensity is 8% and is thus small. The durability of wind power generators increases with decreasing turbulence intensity. This is one of the advantages of siting wind turbines offshore, as demonstrated by the observation.

### Example of Time History

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**Conclusion**

Wind observations were made at a height of 94 m above sea level for one year at a natural gas platform in the Pacific Ocean, located 37 km off the coast.

- The average annual offshore wind speed (calibrated for a height of 80 m) is 7.4 m/s—70% higher than the onshore wind speed (calibrated for a height of 80 m), which was measured at the same time.
- The average monthly wind speed is higher in winter and lower in summer. The average monthly wind speed drops by more than 20% over the average annual wind speed, particularly in June and July.
- The average annual offshore turbulence intensity is 8% and is thus small.

Further observations are in progress. The measurement of time-history data with a sampling time of 1 s began in December 2005. We will continue the analysis of these data with the aim of introducing offshore wind farms in Japan.