Field test comparison using different LiDAR systems for Complex terrain

Nobutoshi Nishio *1, 2, Hiroaki Fujio*1, Satoshi Nakashima*1, Makoto Iida*1
*1 The University of Tokyo, Japan
*2 Electric Power Development Co., Ltd., Japan

1. Introduction

As the energy source of a wind turbine is the naturally occurring wind, a detailed understanding of wind conditions is essential. The inflowing wind to the turbine has been measured by conventional devices such as nacelle anemometers and wind vanes, but these devices create unwanted effects from the nacelle and blade and from their points of installation [1]. In IEC 61400-1 [2], uncertainty about these effects is addressed by measuring each separate condition and applying statistical processing and averaging. This allows estimation and validation only under a limited range of conditions. The environmental conditions under which wind turbines are operated in Japan are more severe than those in other countries, and the unregulated wind conditions in the IEC present significant challenges in turbine design and operation. Remote sensing devices including LiDAR offer a state-of-the-art approach to the measurement of wind conditions [3]. LiDAR technology offers the additional advantage of being deployable at hub height.

Most studies of LiDAR have used a single LiDAR system [4][5]. In this study, we set out to investigate the basic characteristics of a range of LiDAR systems. These were installed in both flat and complex terrain and wind speed, turbulence intensity, and wind shear were measured.

This study reports the results from flat terrain, the first stage of the project to be completed.

2. Approach

LiDAR field testing was conducted in the south of Japan. Figure 1 gives an overview of the field test site, which is located near the shoreline, with sea wind flowing from the north and land wind flowing from the south. A single wind turbine was installed at this site. Most of the LiDARs were mounted at ground level, 90 m from the metrological wind mast. The Galion LiDAR was installed beneath the turbine, 180 m from the metrological mast. During this period, the turbine was completely stopped to prevent wake from being generated.

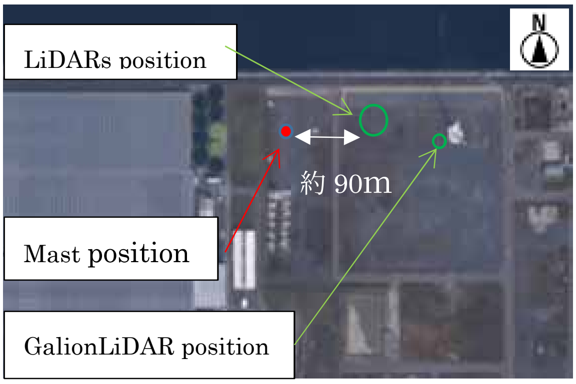


Fig. 1 Overview of field test site

The features of each of the LiDARs tested are as follows.

ZephIR: Manufactured by ZephIR Lidar. The wind speed is calculated from 50 radial wind measurements using Doppler shifts obtained from each rotation.

SpiDAR: Manufactured by Pentalum Technologies. This system generates conical scanning beams with a full cone angle of some degrees. The wind speed and direction at any height up to and including 200 m can be derived as a generalization of the cross correlation among air densities.

DIABREZZA: Manufactured by Mitsubishi Electric. Four beams are sent successively in four cardinal directions along some scanning cone angle, followed by a fifth vertical beam. Laser pulses are backscattered by aerosol particles in the air (e.g., dust, water droplets, aerosol), moving at the same speed as the wind.

Galion: Manufactured by SgurrEnergy.G4000. In this study, 2D vertical scans of the wind field were performed by varying the elevation angle of the laser while keeping the azimuthal angle fixed (the vertical cross section scan type).

WINDCUBE : Manufactured by LEOSPHERE. This LiDAR uses infrared laser pulses. Four beams are sent successively in four cardinal directions along some scanning cone angle, followed by a fifth vertical beam. Again, the laser pulses are backscattered by aerosol particles in the air, which are moving at the same speed as the wind. The collected backscattered light allows the wind speed and direction to be calculated using the Doppler induced laser wavelength shift.

Measurements were taken at heights of 50 m and 40 m on the metrological mast. A cup anemometer, wind vane, and ultrasonic anemometer were available at both heights. In this study the cup anemometer and ultrasonic anemometer were used, with a sampling rate of 20 Hz. The analysis used 10-min averaged data because the sampling rates of data from each LiDAR and from the metrological mast were different.

The key parameters used were those that are significant in a complex site. We estimated the coefficient of correlation of wind speed between each LiDAR and the metrological mast, and the wind shear of each LiDAR in the main wind direction. The wind direction was measured at a standard height of 50 m at the metrological mast. The different LiDAR systems were randomly coded A, B, C, D, and E.

3. Main body of abstract

3.1 Overview of wind conditions at the site

Figure 2 shows the wind rose measured by the metrological mast during this period, in which the average wind speed was 5.66 m/s. It can be seen that major wind directions were NNE, NE, ESE, and SSW.

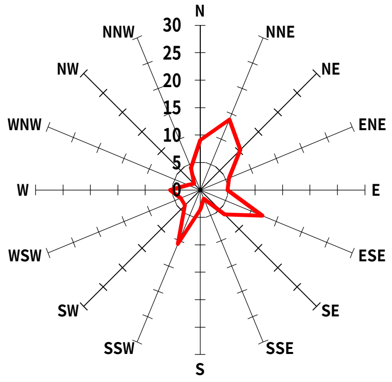


Fig. 2 Wind rose of field test site

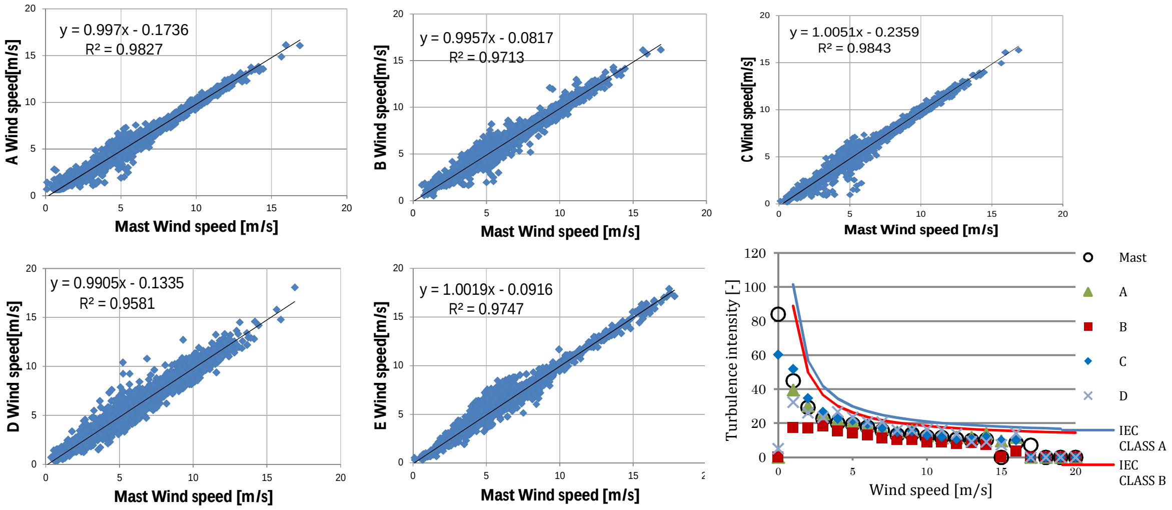


Fig. 3 Coefficient of correlation and Turbulence Intensity

3.2 Experimental Results

3.2.1 Coefficient of correlation

Figure 3 shows the coefficient of correlation for the 10-min averaged wind speed between each LiDAR system and the metrological mast at a height of 50 m.

The coefficient of correlation (R) of all the LiDARs was greater than 0.9, with slopes close to 1.0. At the flat site, all LiDARs were demonstrated to offer the same level of accuracy in wind measurement.

3.2.2 Comparison of turbulence intensity

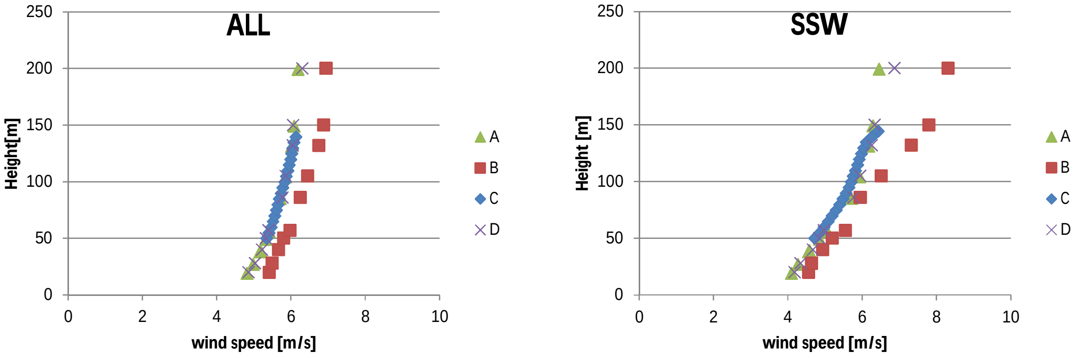
Figure 3 compares the turbulence intensity measured by each LiDAR at a height of 50 m. As it was tested in a different period, LiDAR E is excluded.

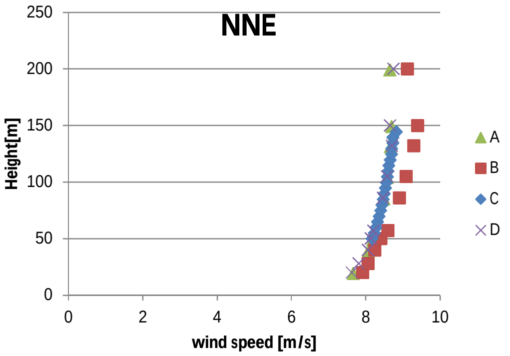
The turbulence intensity was lower than IEC category A because this site is located near the shoreline. Data from all the LiDARs corresponded well with the metrological mast data. All systems showed the same trends as well as the same average wind speeds.

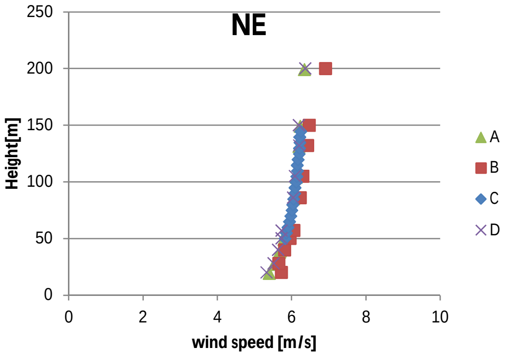
3.2.3 Comparisons of wind shear

Based on the wind rose shown in Figure 2, we analyzed the wind shear of each LiDAR in the major wind directions: NNE, NE, ESE, and SSW. We evaluated them using wind shear exponent (=α). This formula is specified in IEC 61400-1.The results are shown in Figures 4.

Under sea winds from the NNE and NE, the wind shear was small (α=0.09~0.14). In contrast, under land wind from the SSW, the wind shear was large, with LiDAR B recording the highest value (α=0.28). We attributed this to the different measurement method used by LiDAR B and its lower data acquisition rate. Additional data should be collected to improve the reliability of this assumption.







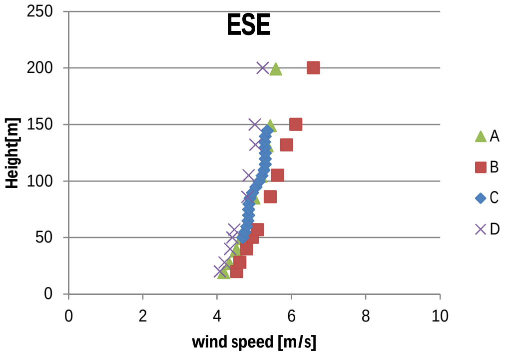


Fig. 4 Wind shear in each direction

4. Conclusion

In this study, we present the benchmark data acquired for flat terrain. All the parameters of average wind speed, turbulence intensity, and wind shear showed the same trends.

5. Learning Objectives

We are currently conducting measurements of different LiDAR systems at a complex site (Figures 5 and 6) to derive the wind features. Our goal is to clarify the measurement uncertainly and develop filtering methods for estimating wind conditions in complex terrain.

Fig. 5 Arial view of complex site

Fig. 6 LiDAR measurements at complex site

Acknowledgments

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