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, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656 Japan
*2 Electric Power Development Co., Ltd., 6-15-1, Ginza, Chuo-ku, Tokyo, 104-8165 Japan
Keywords; LiDAR, Field measurement, Flat terrain, Complex terrain

Abstract

Light Detection and Ranging (LiDAR) technique is known as a state-of-the-art approach to the measurement of wind conditions. There are some different types LiDARs that have another principle. Recently, LiDAR installations in both flat and complex sites are of interest to researchers. However, there are only a few comparative studies concerning different LiDARs, which are installed near reference cup anemometers. In the present study, different five LiDARs were installed on the flat place, and three LiDARs have been installed on the complex site. This paper shows the measurement and analysis results about the key parameters such as wind speed, turbulence intensity, and wind shear. On the flat site, all the parameters concerning average wind speed, turbulence intensity, and wind shear showed similar trends. While, on the complex site, the wind shear is showed the same trend, but with different values.

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 normally create unwanted effects from the nacelle and blade or from their installation points [1]. In IEC 61400-1 [2], some uncertainty about these effects is addressed by measuring each separate condition and applying statistical processing and averaging. This allows some 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 of the studies related to LiDAR techniques have used only a single LiDAR system [4, 5]. In this work, we investigate the basic characteristics of several LiDAR systems installed in both flat and complex terrains.

2. Testing site and LiDAR

2.1 Flat site

Figure1 gives an overview of the testing field site and sector, 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, at the east 90m from the metrological wind mast. The Galion LiDAR was installed beneath the turbine, at the east 180m from the metrological mast. During this period, the turbine was completely stopped to prevent wake from being generated. The sector selection was considered from IEC 61400-12-1.

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

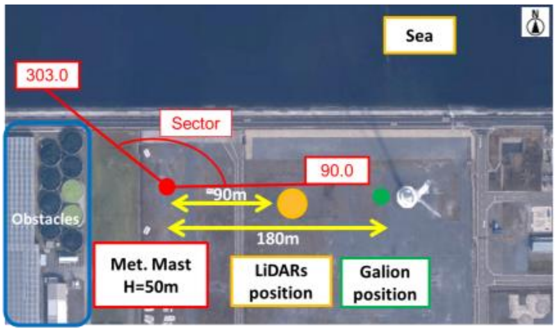


Fig. 1 Overview of the flat testing site.

2.2 Complex site

Figure2 shows outline of the complex terrain. Figure gives terrain profile for the line NW-SE, which is located in a mountainous terrain. As several wind turbines of the same kind were installed at the same position of this site, sector sections were decided to 89.8~171.5° and 302~335.8° to avoid turbine wakes.

As a reference mast was not installed, we compared 3 LiDAR systems with the nacelle anemometer of WTG which is installed close to LiDARs. One of the LiDARs had limited data recording because of a short measurement period of time. The analysis used 10-min averaged data as in the case of the flat site.

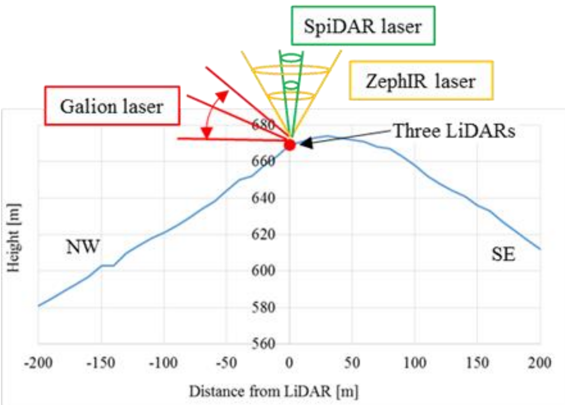


Fig. 2 Terrain profile for the line NW-SE in complex test site

2.3 LiDAR systems

The main features for each tested LiDAR are as follows.

ZephIR: Manufactured by ZephIR Lidar [6]. The wind speed is calculated from 50 radial wind measurements using Doppler shifts obtained from each rotation.

SpiDAR: Manufactured by Pentalum Technologies [7]. 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 [8]. Four beams are sent successively in four cardinal directions along some scanning cone angles, followed by a fifth vertical beam. Laser pulses are backscattered by aerosol particles in the air (e.g., dust, water droplets or aerosol), moving at the same speed as the wind.

Galion: Manufactured by SgurrEnergy [9].

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

WINDCUBE：Manufactured by LEOSPHERE [10]. This LiDAR uses infrared laser-pulses. Four beams are sent successively in four cardinal directions along some scanning cone angles, 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 of the wind. The collected backscattered light allows the wind speed and direction to be calculated by using the Doppler induced laser wavelength shift.

In this study, five different LiDARs are measured on the flat site and three are measured on the complex site. The conditions of the different LiDAR settings are shown in Table1. The different LiDAR systems were randomly coded as A, B, C, D, and E.

LiDARs	LiDAR manufactured	Flat	Complex
ZephIR	ZephIR Lidar	O	O
SpiDAR	Pentalum Technologies	O	O
Galion	SgurrEnergy	O	O
DIABREZZA	Mitsubishi Electric	O	-
WINDCUBE	LEOSPHER	O	-

Table. 1 Conditions of LiDAR setting

2.4 Estimation parameters

It is important to consider key parameters for the complex site. We estimated the coefficient of correlation (R) of wind speed between each LiDAR and the reference data, and the wind shear of each LiDAR in the main wind direction. On the flat site, the wind direction was measured at a standard height of 50 m at the metrological mast. Major wind directions were NNE, NE, ESE, and SSW.

On the complex site, the wind direction was measured at the nacelle anemometer of WTG. Major wind directions were NW and SE.

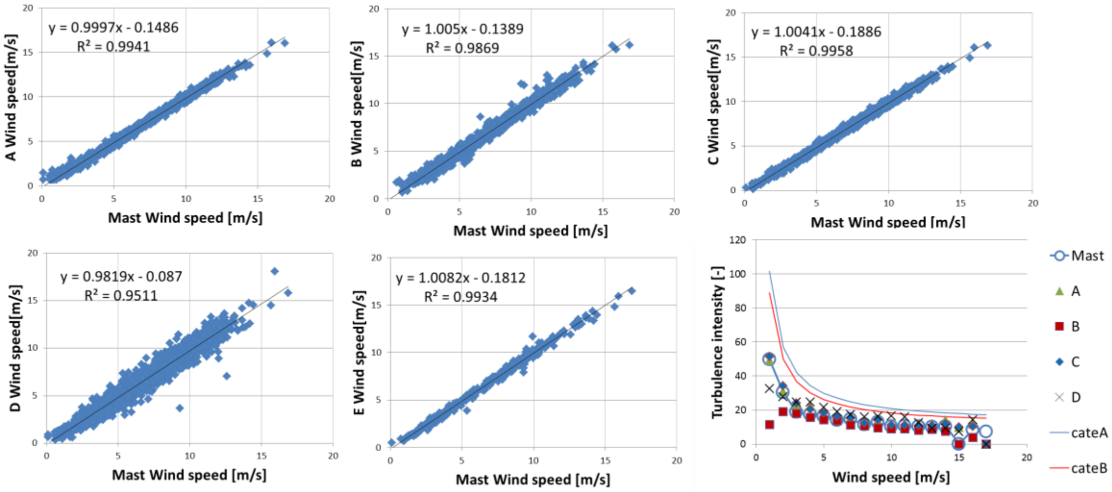


Fig. 3 Coefficient of correlation and Turbulence Intensity at 50-m height.

3. Results (Flat site)

3.1 Flat site

3.1.1 Coefficient of correlation

Figure 3 shows the coefficient of correlation (R) 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 of all the LiDARs was higher than 0.9, with slopes close to 1.0. At the flat site, all LiDARs offered the same level of accuracy concerning wind measurements.

3.1.2 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.

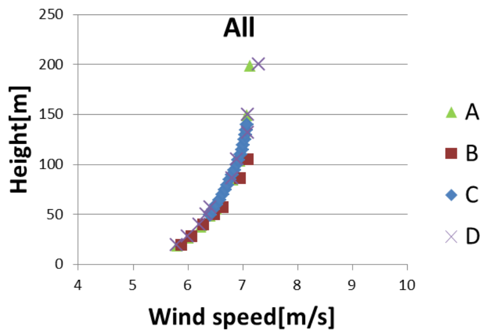
The turbulence intensity was lower than IEC category A because this site is located near the shoreline. The data from all the LiDARs were in accordance with the metrological mast data. All systems showed the same trends as well as the same average wind speeds.

3.1.3 Comparison of wind shear

We analyzed the wind shear of each LiDAR in the major wind directions: NNE, NE, ESE, and SSW. As ESE and SSW do not satisfy IEC, these are only reference values.

We evaluated them by using the wind shear exponent (α). This formula is specified in IEC 61400-1. The results are shown in Figure 4.

In all cases, the wind shear presented the same shape (α = 0.06–0.09). Under sea winds from the NNE and NE, the wind shear was small (α = 0.07–0.09). In contrast, under land wind from the SSW, the wind shear was large (α=0.23).



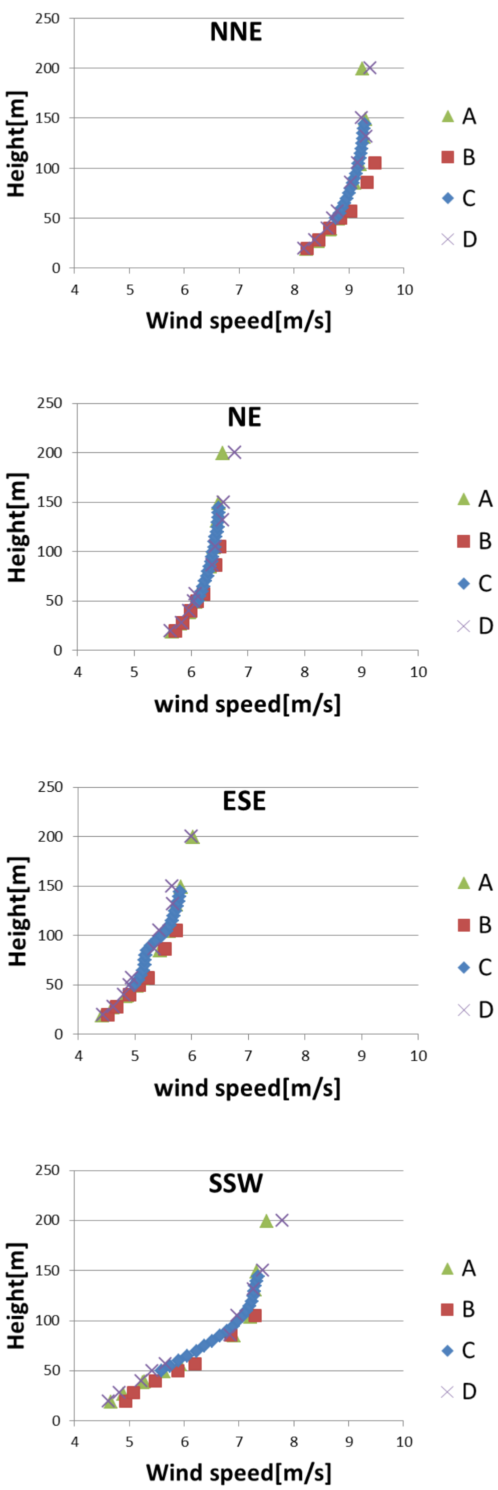


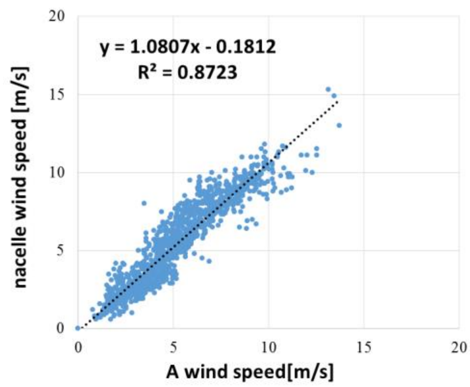
Fig. 4 Wind shear in each direction.

3.2 Complex site

The tests comparison of the complex site is still an ongoing project to retrieve LiDAR wind data. We have started using LiDAR-C for measurements. In this paper, we estimated different two LiDARs excluding LiDAR-C. The intermediate results are summarized as follows.

3.2.1 Coefficient of correlation

Figure 5 shows the coefficient of correlation (R) for the 10-min averaged wind speed between each LiDAR system and the nacelle anemometer of WTG. Compared with the flat site, the coefficient of correlation of all the LiDARs was low but still greater than 0.8. Concerning the R value of the wind speed between LiDAR-A and LiDAR-B, the coefficient of correlation was good, but the wind speed of LiDAR-A was lower than that of LiDAR-B.



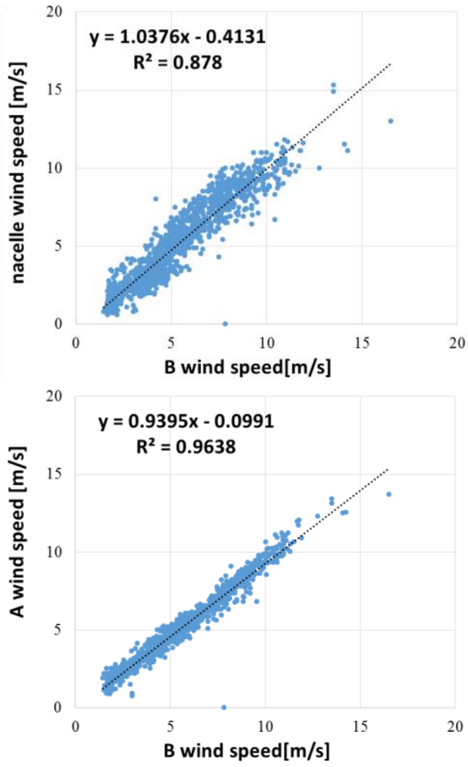


Fig. 5 Coefficient of correlation.

3.2.2 Comparison of wind shear

We analyzed the wind shear of each LiDAR in the major wind directions: NW and SSE. Results are shown in Figures 6.

According to data, the wind shear showed the same trend (α = 0.06–0.13). Under winds from the NE, the wind shears were negative. In contrast, by land wind from the SSE, the wind shears presented the same shapes (α = 0.17–0.18). Both LiDARs are using a different measurement method with low data acquisition rate. Hence, additional data should be collected to improve the reliability of this assumption.

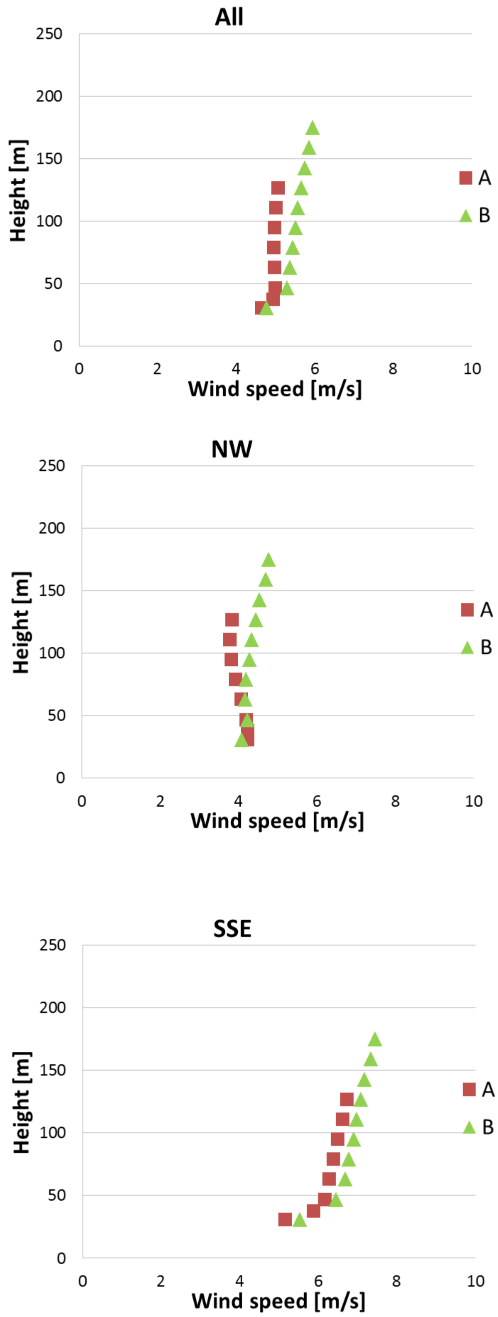


Fig. 6 Wind shear in each direction.

4. Conclusion

In this study, we present an evaluation of data acquired for flat and complex terrains. On the flat site, all the parameters of averaged wind speed, turbulence intensity, and wind shear showed similar trends. On the complex site, the wind shear showed the same trend, but with different values. Additional data are required for a more reliable assumption.

.

Acknowledgments

I acknowledge NT SYSTEMS Corporation, Mitsubishi Electric Corporation, Japan Meteorological Corporation and EKO Instruments for their support in obtaining LiDAR data measurements.

References

[1] Arezki Smaili, EST Canada "On the Roter Effects upon Nacelle Anemometry for Wind turbines, 2004

[2] IEC 61400-1 Wind turbines-Part 1: Design requirements, 2005

[3] MEASNET "EVALUATION OF SITE-SPECIFIC WIND CONDITIONS" Versrion2, 2016

[4] Ameya Sathe DTU Wind Energy, Denmark "Measuring Accurate Turbulence using Commercial Lidars," EWEA2015

[5] Fabrice Guillemin IFP Energies nouvelles, France "Performance study of Lidar measurements filtering for turbulence estimation," EWEA2015

[6]ZephIR Lidar homepage, http://www.zephirlidar.com/ ,(accessed 2016-9-28)

[7]Pentalum Technologies homepage, http://www.pentalum.com/ ,(accessed 2016-9-28)

[8]Mitsubishi Electric homepage, http://www.mitsubishielectric.com/bu/lidar/ ,(accessed 2016-9-28)

[9]SgurrEnergy homepage, http://www.sgurrenergy.com/ ,(accessed 2016-9-28)

[10]LEOSPHERE homepage, http://www.leosphere.com/en/ ,(accessed 2016-9-28)