Exploring LIDAR Remote Sensing Technology for Offshore Wind Resource Monitoring Applications

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Abstract summary

Offshore wind farm projects that require pre-construction financing cannot afford to rely on proxy data that are recorded at distant locations to characterize key design parameters present at the proposed site. Therefore, physical measurements that are specific to the project location must be obtained in order to inform the design basis, explore turbine suitability and estimate energy production. However, design and installation of offshore meteorological masts requires careful preparation and access to relatively large amounts of capital in the sensitive and uncertain initial phases of project planning. In this context the LiDAR measurement technique has emerged as a potentially attractive and economically competitive alternative to traditional offshore met masts.

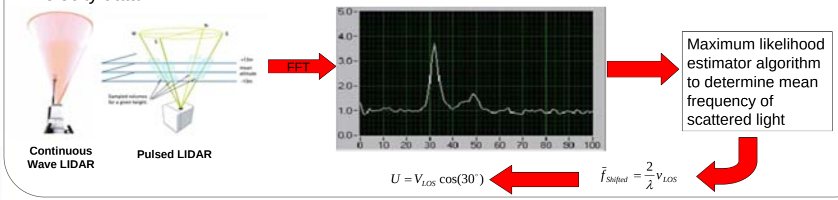
Overview

While site-specific wind data measurements from offshore meteorological masts are robust, accurate and bankable, they come at a significant cost to wind farm developers. The financial obstacles associated with traditional measurement practices have provided the motivation to consider LiDAR remote sensing (RS) as a viable alternative to in-situ measurements for wind resource assessment and site suitability purposes.

Fiber-optic based LiDAR instruments have become a commercially viable technology showing promise in on-shore validation campaigns in flat terrain[1]. As the technology develops, standards for offshore measurement applications are being developed[2]. This work presents a formal review of the benefits and limitations of using the LiDAR technique for offshore wind speed measurement and provides commentary on the best practices for offshore measurement applications.

LiDAR Measurement Fundamentals

The LiDAR probes a volume of the atmosphere by emitting electromagnetic radiation that illuminates natural aerosols and detects the scattered light that results from this interaction. Upon detection, the return signal is analyzed to determine its mean Doppler shifted frequency which is then used to obtain the line-of-sight wind velocity by $\bar{f}_{Shifted} = \frac{2}{\lambda} v_{LOS}$. The vertical and horizontal wind speeds as well as the wind bearing are then obtained by applying a curve fit to the line-of-sight velocity data.



Maximum likelihood estimator algorithm to determine mean frequency of scattered light

$$\bar{f}_{Shifted} = \frac{2}{\lambda} v_{LOS}$$

$$U = V_{LOS}\cos(30^{\circ})$$

Key Measurement Parameters for Offshore Wind Resource Assessment and Site Suitability

Parameter	Application
Mean wind speed	Energy production estimate and turbine suitability
Wind direction	Frequency distribution characterization and turbine layout design
Wind speed standard deviation*	Turbulence intensity used to inform wake loss and turbine loads calculations
Extreme wind speed	Turbine loads calculations
Barometric pressure	Air density and seasonal/diurnal power production estimates

* LiDAR devices differ significantly in this respect due to inherent temporal and spatial averaging effects. The actual attenuation will vary from one device to another and more scatter is to be expected.

LiDAR and Offshore Wind Resource Assessment

The primary goals of a wind measurement program are to enable:

1. Accurate estimation of the power production potential and
2. Definition of the design wind conditions for the project.

Measurements from hub-height anemometry are the established industry standard for offshore project finance applications. With a carefully designed wind measurement program, these instruments can directly achieve the above objectives by providing robust, accurate and redundant measurements. Therefore preference should be given to in-situ anemometry unless strong economic, permitting or logistical arguments prevent this approach. In cases where LiDAR is used as the primary measurement device for offshore applications, a comprehensive validation against conventional instruments should be implemented in order to assess the effects of the device measurement principles on the derived wind statistics.

LiDAR Validation for Offshore Measurement Applications

In order to maximize the value of LiDAR remote sensing measurements, a validation campaign should be performed before and possibly after deployment. The criteria tested as part of a well executed validation campaign may consist of:

- Mean wind speed agreement within 2% of calibrated cup anemometer measurement in the majority of meteorological conditions;
- Data recovery rate in excess of 90% across the full wind speed range 0-20 m/s;
- Minimal time series disagreement with reference cup anemometer;
- Low or consistent bias as a function of measurement height;
- Continuous operation in a variety of environmental conditions.

Proper documentation of the validation campaign is necessary to ensure full measurement traceability of the LiDAR device.

LiDAR Measurement Considerations

Horizontal Wind Speed

Good agreement between some LiDAR devices and calibrated cup anemometry has been demonstrated in offshore measurement campaigns[3]. These devices can be shown to accurately characterize wind speed up to 100m.

Vertical Wind Speed

LiDAR remote sensing instruments are designed to record the vertical wind speed component. The absence of strong thermal effects and terrain variation typically cause low vertical wind speed components. Thus, the ability of LiDAR to measure 3D wind speed vectors carries little weight for offshore applications.

Turbulence

The temporal and spatial averaging effects of LiDAR have significant implications for the characterization of turbulence. Point measurement from cup anemometers are the long-established industry 'norm' for the measurement of turbulence. A carefully designed validation campaign is pivotal to comprehend and estimate these effects and efforts should be made to carry out this campaign in the same conditions as will be encountered at the offshore site. Characterization of turbulence and turbine loading is possible, albeit with higher levels of uncertainty.

Shear

The volume scanned by LiDAR devices increases significantly with height. A validation campaign is pivotal to comprehend and estimate this effect on wind shear estimates.

Power Supply & Redundancy

LiDARs may require up to 250 watts of continuous power during certain conditions. A stable power supply must be deployed alongside any LiDAR system for offshore applications. A single sensor is used to monitor wind speed at a site at multiple heights and therefore these devices do not have the benefit of inherent redundancy provided by several independent sensors as is the case for meteorological masts.

Conclusions

It is considered to be best practice to record critical wind data parameters at or near the proposed turbine hub-height with traditional meteorological equipment such as cup anemometers. However, for economic or logistical reasons, LiDAR instruments may be substituted for, or deployed in tandem with, a met mast provided they successfully complete a validation campaign. The campaign should be designed so that the effects of the device measurement principles on the derived wind statistics can be estimated with sufficient accuracy, and that corrections may be applied as necessary. The errors associated with this process however implies that greater uncertainty in the predicted wind conditions will result than would have with conventional instruments. The intrinsic redundancy of independent sensors as used on meteorological masts is considered to be an important factor when considering different wind measurement strategies at offshore sites and some sort of redundancy should be engineered in offshore measurement campaigns.

References:

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