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1. DNV

DNV

Recommended practice for using ground-based lidar turbulence intensity

BACKGROUND

The second order quantity turbulence intensity (TI) from light detection and ranging (lidar) units is not yet widely accepted. DNV's joint-industry recommended practice (RP) for the use of TI measured by ground-based, vertical-profiling lidars (GBL) has defined acceptance criteria (AC) that provide clear limits when GBL TI can be used as an alternative to a cup or sonic anemometer TI.

OBJECTIVE

The objectives of this RP are to:

- Provide a method for using GBL TI measurements in combination with co-located met mast data.
- Serve as a supporting document when considering the use of GBL TI measurements for the application of wind resource and wind turbine (WT) certification in combination with other applicable standards, RPs, and guidelines.

APPLICATION

This RP is applicable to GBL TI in simple terrain for site suitability and validating loads for type testing the WT design and certifying WTs, and preconstruction energy production assessment wind farm modelling and reporting.

The methods proposed are technology agnostic and intended to be applicable for all GBL models and types.

RESULTS

Impact of TI on turbine loads

Analysis was completed to determine the relationship between the error metrics and wind turbine fatigue loads. A loads database was generated from a simulation employing a 10 MW WT model, a wide range of wind speeds, and TI input parameters. Damage Equivalent Loads (DEL) were processed for selected Wöhler slopes and load sensors from the blade root, machinery, and tower. The loads were put into the database where they could be accessed for chosen input parameters for wind speed and TI. Based on relevant standards and certification experience, acceptable margins for certified loads were formulated.

In a further step, measurement data sets consisting of GBL TI and co-located cup anemometer data were analyzed. TI error metrics were calculated for each valid 10-minute time series of the dataset. Linking the simulated load database with the measurement database via wind speed and TI, conclusions regarding acceptable margins on the error metrics were defined. Table 1 shows the AC bands for TI mean relative bias error (MRBE) and TI relative root mean square error (RRMSE) for both "site suitability" and "load validation type testing" use cases as a function of wind speed.

Site suitability	Load validation
• -3% ≤ TI MRBE ≤ 10% (for wind speeds above 7 m/s) • -6% ≤ TI MRBE ≤ 10% (for wind speeds below 7 m/s) • TI RRMSE ≤ 15% (for wind speeds above 7 m/s) • TI RRMSE ≤ 30% (for wind speeds below 7 m/s)	• TI MRBE ≤ ±5% • TI RRMSE ≤ 15%.

Table 1: AC for "site suitability" and "load validation type testing" use cases (left: TI MRBE and right: TI RRMSE)

Impact of TI on energy production assessment

Analysis was performed to examine the sensitivity of windfarm wake modelling to TI error that may result when using GBL TI instead of a cup anemometer as sensor a type. The analysis included datasets from 34 projects in 19 countries, onshore and offshore, featuring wind farm sizes from four (4) to 426 turbines and ambient TI at 15 m/s ranging from 4.9% to 15.9%. The energy production was modelled using the project's wind speed binned TI and then, for each wind speed bin, the TI was adjusted by ±2%, ±5%, and ±10%. A distribution of the change in energy production from the five TI scenarios and 34 projects was assembled. The distribution of error was then grouped and the change in the energy production was evaluated. The results for error metric TI MRBE are provided in Table 2. Considering the results of the sensitivity analysis, the acceptable TI metrics error for the use case "energy production assessment" is defined as TI MRBE ≤ ±10%. This AC has been chosen with the view of mitigating the risk of large changes to energy production assessment predictions, while balancing the need for sound AC with a reasonably attainable target for energy production assessment uncertainties for GBL. It is noted that a greater GBL TI error may be acceptable to certain stakeholders, and others may require more stringent criteria.

TI MRBE	Changed for approximately 95% of projects
±2%	less than ±0.10%
±5%	less than ±0.25%
±10%	less than ±0.50%

Table 2: TI MRBE for "energy production assessment" use case

USE OF GBL FOR TI MEASUREMENTS

When the GBL TI measurement dataset fulfils the TI AC (error metrics), the TI maybe used. This encompasses both direct GBL TI measurements and TI adjustment datasets. In addition to the TI AC requirement, the measurement should adhere to the following requirements:

- Cup and lidar measurements shall be conducted at the same height and shall be at the intended height above ground level used to characterize the TI.
- If the approved GBL TI and project GBL TI measurements are at different heights above ground, then the respective GBL TI measured range shall be the same. Additional uncertainty shall be taken into consideration.
- 10-minute wind speed bins' TI statistics shall be recorded with a bin width of no greater than 2 m/s. The wind speed range should be at least from 4 m/s to 20 m/s. However, for the energy production assessment use case, this can be reduced to represent the site wind speed range.
- Use case "loads" (site suitability and load validation) only: the 10-minute TI statistics can also be binned to investigate trends. From the full GBL TI dataset, the lowest quarter of TI values in each wind speed bin may be discarded when obtaining KPIs for comparison with the AC.
- The number of data points for each wind speed bin used in the comparison with the AC shall include a minimum of 400 data points per wind speed bin, or a bootstrapping method (or similar) shall be completed to show that the database yields stable TI error metrics.
- When relocating the lidar, it should be in the vicinity of the verification site. In this context, vicinity means that the new location shall have the same type or characteristic upwind terrain and vegetation and the same range of TI and wind speed as the verification site.
- The terrain and flow complexity shall be simple as defined by IEC 61400-1 or IEC 61400-12-1 as it applies to the use case.
- The envelope of environmental parameters remains identical to that of the initial approval location.
- A third party confirms that these relocation conditions are met.

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For the complete recommended practice, "DNV-RP-0661 Lidar-measured turbulence intensity for wind turbines", see: https://standards.dnv.com