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EFFECTIVE TURBULENCE: APPLICATION OF IEC STANDARDS

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Abstract

In order to assess a potential wind farm site there is not only the need to compute the energy yield. Also other parameters are needed to be taken into account for a complete design. In the present work there is a particular focus on the calculation of the effective turbulence at each turbine location of a wind farm, accounting also for wake induced turbulence.

There is a direct relationship between wind turbulence and fatigue loads acting on wind turbines. Wind farms have to be constructed with turbines capable of withstanding turbulence which is a combination of ambient and wake-turbulence.

The international standard IEC 61400-1, Edition 3 (2005), Amendment 1 (2010), recommends a version of the Frandsen model to compute the wake induced turbulence as well as methods to evaluate the effective turbulence, which must be smaller than the design turbulence in a range of wind speeds. WindSim has implemented an interpretation of the standard into its CFD software which allows calculating effective Turbulence.

New methods for turbulence analysis have been developed based on the interpretation of the aforementioned IEC standards and information on the wind flow given by CFD/RANS simulations. Final fatigue calculations account for different loadings by weighting them with a Wöhler coefficient of ten, specific for glass-fiber materials, considered the component of the wind turbines to be verified.

The procedure suggested in the standards has been generalized to any wind farm layout and any wind rose. Moreover, there has been a need to interpret the standards, especially for turbulence in overlapping wakes.

Assessment of a wind turbine for site-specific conditions

Among the environmental conditions that might affect the structural integrity of a wind farm the turbulence has to be considered. Fatigue loads are induced on wind turbines by the turbulence itself.

Considering the "Assessment of a wind turbine for a site-specific condition", § 11 of the IEC 61400-1 standards [1], for the assessment of the structural integrity of a turbine all the environmental and electrical conditions have to be below the design values (§ 11.9) or demonstrated that the wind turbines will withstand the loads due to the site-specific conditions (§ 11.10).

In particular, when considering a wind park also the neighboring turbines have to be accounted for the determination of the actual site conditions. When considering the turbulence intensity the 3rd edition of the IEC 61400-1 [1] and its 1st Amendment [3] suggest to consider the model proposed by S. Frandsen [2] to account for the turbulence contribution of the neighboring turbines.

While in [1] the *Ieff* is computed on an average of the expected I, in [3] it is recommended to calculate an average of the 90th percentile of I, changing therefore the definition of *Ieff*. Consequently also the inequality (35) to be verified is changed from [1] to [3].

$\sigma_1 \ge I_{eff} \cdot V_{hub} + 1,28\hat{\sigma}_\sigma$ equation (35) from [1]

$\sigma_1 \ge I_{eff} \cdot V_{hub}$ equation (35) from [3]

The definition of *Ieff*, given in the Annex D of [3], for practical calculations needs to be discretized from the original integral form to a sum of directional values, a weighted average of turbulence intensities I at the power of m, Wohler coefficient.

$$I_{eff}(V_{hub}) = \left\{ \int_0^{2\pi} p(\theta | V_{hub}) I^m(\theta | V_{hub}) d\theta \right\}^{\frac{1}{m}}$$

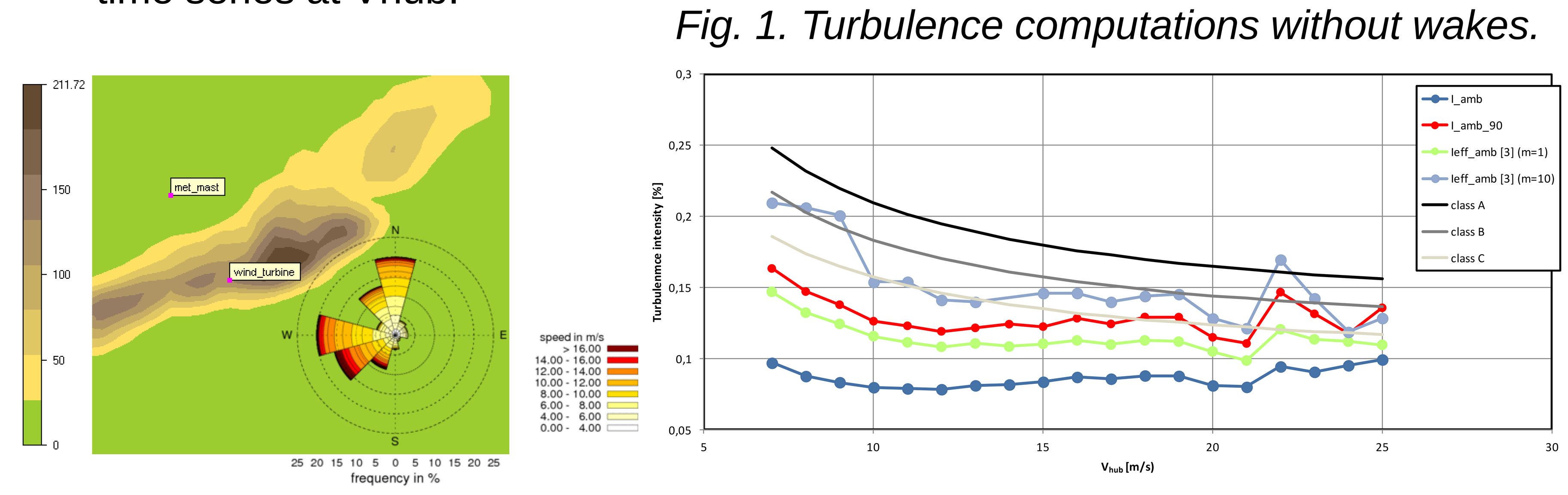
$$I_{eff}(V_{hub}) \approx \left\{ \sum_i p_i(V_{hub}) I_i^m(V_{hub}) \right\}^{\frac{1}{m}}$$

A simple application of this procedure is given in the following paragraphs.

Case of isolated turbine

In case of an isolated wind turbine the *Ieff* will be affected by the ambient turbulence and by the Wöhler coefficient m of the part of the wind turbine to be verified. Practically it is common to verify the most fragile material, that normally it's the glass-fiber, considering a Wöhler coefficient m=10. It is interesting to notice that, while the *Ieff* according to [1] for m=1 is equivalent to the expected turbulence intensity I, when Ieff is defined as average of 90th percentiles of I, as in [3], always considering m=1 *Ieff* is not equal to the 90th percentile of the entire time series at Vhub.

Fig. 1. Turbulence computations without wakes.



Case with wake effects

The wake turbulence superimposes over the ambient turbulence modifying it. In presence of neighboring turbines there is a change in calculation when passing from the edition 3 of the IEC 61400-1 [1] to its latest amendment [3]. Both approaches are based on the study from S. Frandsen [2], in the amendment [3] it has been preferred to compute the wake induced turbulence as function of the thrust coefficient and wind speed at hub V_{hub} rather than only the V_{hub}. The latest update of the standards are used to compute the *Ieff* , an example is given in fig.1.

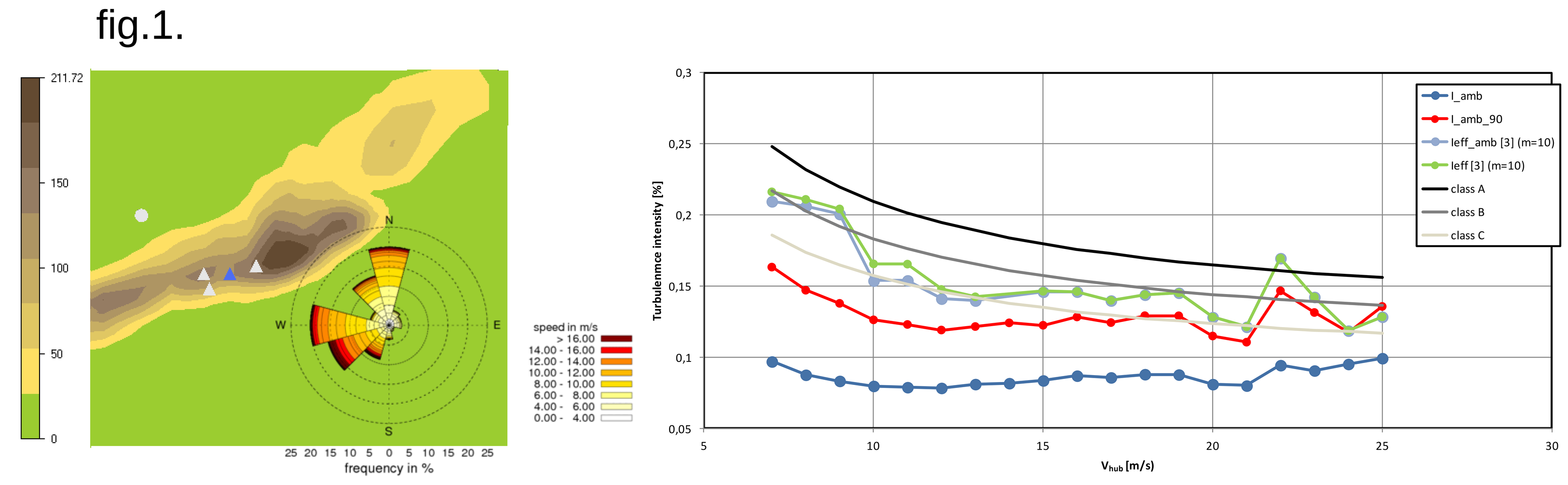


Fig. 1. (LEFT) Layout of wind farm on a ridge. (RIGHT) Turbulence parameter for verification of structural integrity according to IEC standards [3].

In the example in Fig. 1 the met-mast, sketched with a gray round is located at the north-west of the ridge, at the sea level. A group of four turbines are deployed over the ridge. The turbines are sketched with triangles, the blue one has a distance of 5 rotor diameters from the other three turbines. In the right part of Fig. 1 the effective turbulence *Ieff* is shown for the turbine pointed with a blue triangle, with and without wake effects (Frandsen model [3]), the ambient *Ieff* (without wake effects) is shown with a Wohler coefficient of 1 and 10.

It is interesting to note that the wake effects, at least in this example, are minor, while it is significant the consequence of the averaging with high Wohler coefficients.

Conclusions

- The effective turbulence is computed according to the last IEC standards 61400-1, amendment 1 [3];
- A substantial difference is noticed between the approach from [1] to [3]. While the weighted average of the expected sector turbulence intensities with m=1 returns the expected turbulence intensity of the entire time series, for each Vhub, when applying the same weighting (m=1) to the 90th percentiles it is not obtained the 90th percentile of the turbulence intensity of the entire time-series;
- The application of the Frandsen model [3] for the wake turbulence in some cases, as the one shown in example, do not provide a significant increase of turbulence compared to the ambient contribution;
- Much more relevant than the wake effects is the weighting of the 90th percentiles of the sector turbulence at the power m=10.

References

1. IEC 61400-1 Edition 3 (2005). *Wind turbines – Part 1: Design requirements*
2. S. Frandsen (2003). *Turbulence and turbulence generated fatigue in wind turbine clusters*, Risø report R-1188
3. IEC 61400-1 Edition 3 Amendment 1 (2010).