

Presentation of Windfarm Assessment Tool

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Introduction

Wind energy siting engineers are sometimes asked to estimate environmental conditions such as extreme wind, turbulence, flow inclination and vertical wind shear. These parameters are needed in order to select the optimal turbine for a wind energy project. The main objective of Windfarm Assessment Tool (WAT) is to post-process WAsP Engineering results for this purpose. This is done according to the site assessment rules specified in the IEC 61400-1 standard for turbine safety.

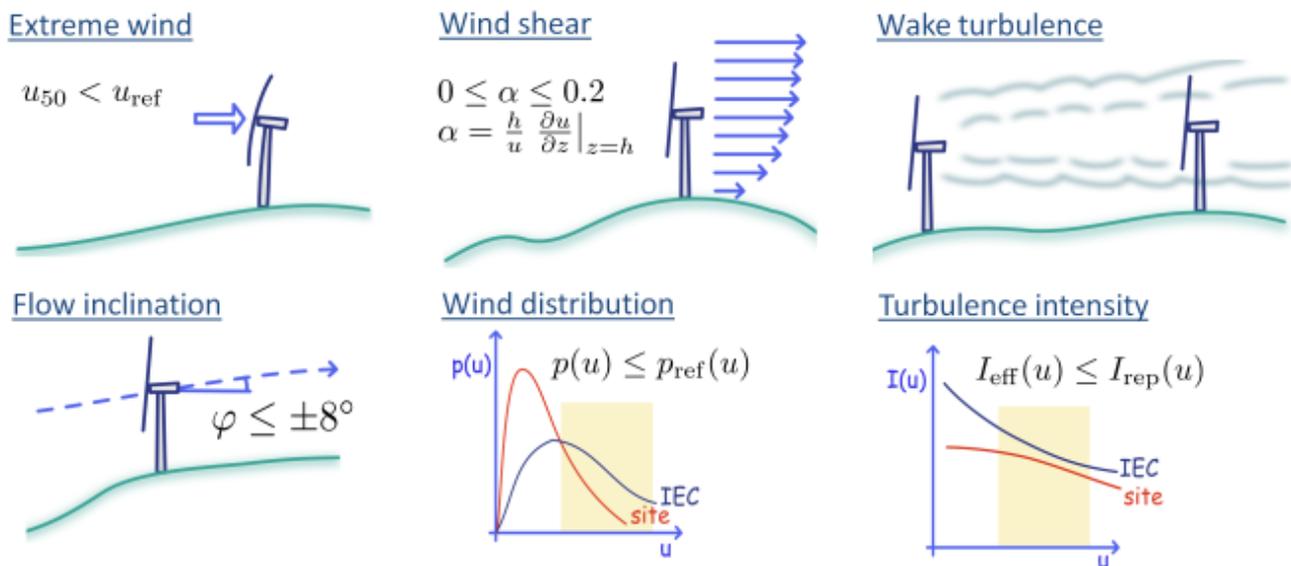


Figure 1: IEC site assessment criteria.

The IEC 61400-1 turbine safety standard

This article will focus on WAT, but first we review some wind-related aspects of the IEC 61400-1 standard.

You may have heard that IEC defines wind turbine classes with labels like III_B, where the roman number refers to a reference wind speed and the index letter refers to a turbulence category. To verify that a wind turbine belongs to a give wind turbine class, it must be proven safe under a set of predefined load cases. Each load case is specified by combinations of mode of turbine operation, wind conditions, and load type. Examples of modes of operation are normal operation, idling, and operation with yaw error. Wind conditions are specified by extreme wind speed, vertical wind shear, flow inclination, turbulence and rare gust-like events. The load type is either an ultimate load, which might instantly damage the turbine, or a fatigue load.

Turbine designers will typically model turbine vibrations and dynamic forces on critical components by aeroelastic simulation programs such as HAWC2. Depending on the load case, the wind interacting with the turbine is either deterministic or a pseudo-random wind field with realistic turbulence characteristics. Aeroelastic simulations are processed for all IEC load cases, and turbine safety is verified for each of the deterministic load cases. In addition, the accumulated fatigue damage caused by stochastic forcing is evaluated for a design life time of twenty years and compared to the material strength. Wind load models are scaled differently for each wind turbine class, thus a class I_A turbine is tested for higher extreme wind speed and more severe turbulence than a class II_B turbine.

The siting engineer must verify the safety of the deployed turbines. In principle, the aeroelastic simulation could be repeated with local wind conditions at specific turbine positions. It is, however, simpler to apply some site-assessment rules specified in another chapter of IEC 61400-1. Here, the main principle is that local wind conditions must not exceed those of the models used for turbine classification. This imposes simple limits on fifty-year extreme wind, flow inclination and wind shear, see Figure 1, whereas turbulence assessment is more complicated.

Variable atmospheric stability, unsteady wind, and directional variation of upwind terrain will introduce variations in observed turbulence intensity. Material damage has a highly non-linearly relation to load amplitudes and thus to turbulence intensity, so a few situations with extreme turbulence may cause most of the fatigue damage. Therefore, the IEC standard applies a representative turbulence intensity for turbine classification, which is defined as a high percentile of the expected natural variation. This variation will generally decrease with wind speed, and the IEC normal turbulence model (NTM) accounts for this effect.

Unlike the NTM turbulence model, site-specific turbulence usually depends on wind direction. To facilitate comparison with the NTM model, the IEC standard suggests the so-called effective turbulence intensity, which is an ideal turbulence independent on wind direction and expected to cause the same fatigue damage as variable turbulence in winds from all directions. The effective turbulence intensity includes added turbulence from wakes of neighbour turbines, and a simple wake turbulence model is provided. Effective turbulence intensity will generally decrease with wind speed due to decreasing stability effects and turbine thrust coefficient.

Site assessment with WAT

To prepare a site assessment with WAT, you model the wind farm with WAsP Engineering (WEng) and call a special module calculating wind, turbulence, and mean wind climate for individual turbine sites. The mean wind climate is actually calculated with a call to a WAsP DLL, so you need a twin WAsP/WEng license for this. The combined WAsP/WEng results are collected and loaded into WAT. At this stage WAT will prompt for a WAsP turbine generator file and an IEC wind turbine class. You can merge WEng results for several turbines groups, in case the hub heights differ, see Figure 2.

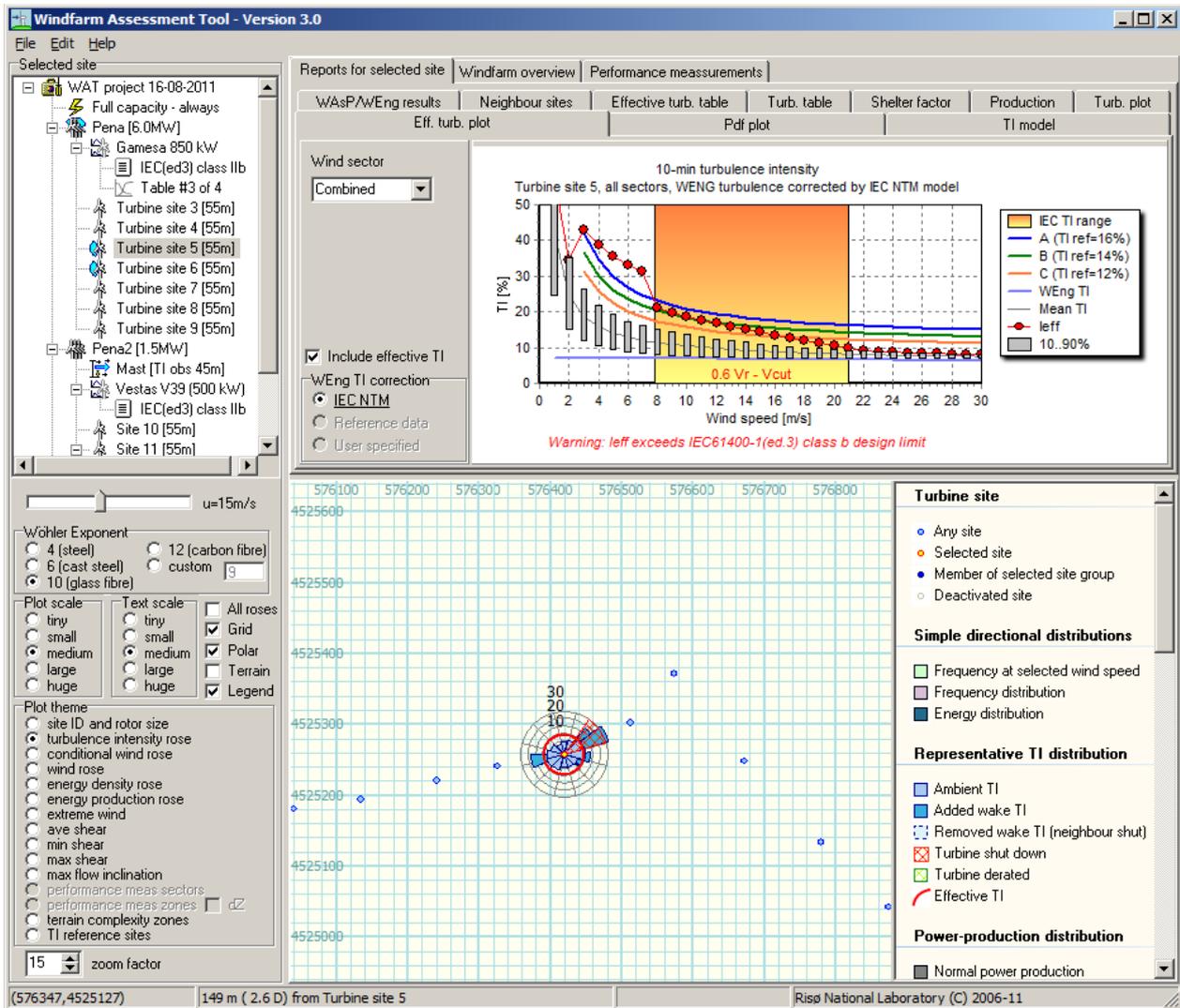


Figure 2: The WAT user interface

The main objective of WAT is to calculate effective turbulence in wind farms with irregular turbine layout. This is done for individual turbine sites using wind direction distributions conditioned by local wind speed. Wakes from neighbour turbines are estimated by the wind speeds at these neighbour sites corrected for terrain-induced speed up and wake effects of turbines further upstream. Figure 3a shows a WAT prediction of turbulence intensity as a function of wind direction. Everything in this plot, including the effective turbulence intensity marked by the horizontal red line, will depend on wind speed. Figure 4 compares the effective turbulence intensity as a function of wind speed to the NTM model. The IEC site assessment rule is that effective turbulence intensity must not exceed the NTM model corresponding to the selected wind turbine class in the wind-speed range marked by the orange box. To identify potential problems you can inspect such figures for individual turbine sites or read a summary of conclusions. This summary includes site assessment criteria like extreme wind, shear, and flow inclination.

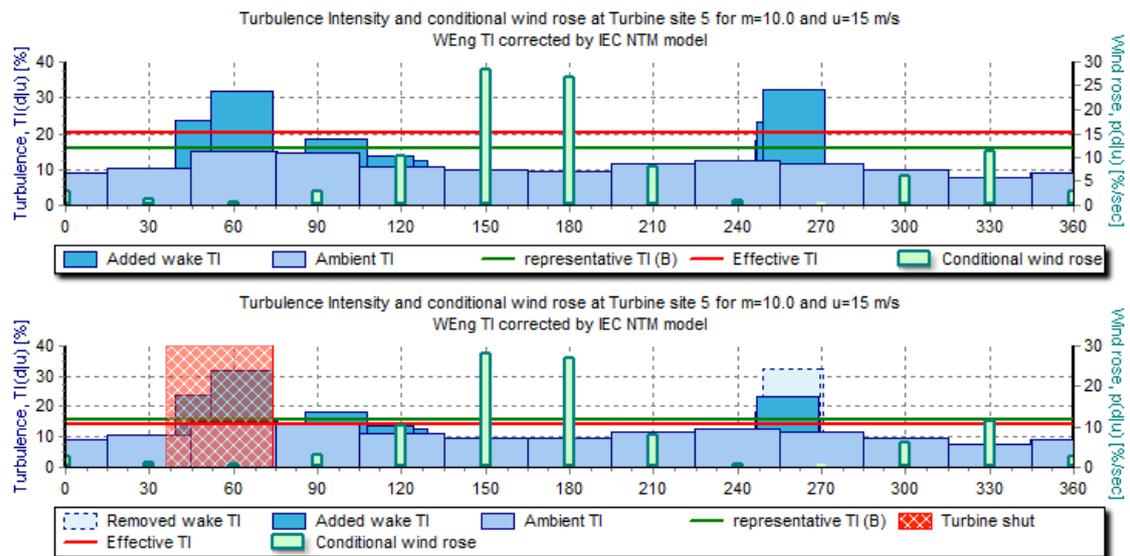


Figure 3: Turbulence intensity as function of wind direction a) under normal operation and b) with sector management. The red line indicates the effective turbulence intensity at the selected wind speed.

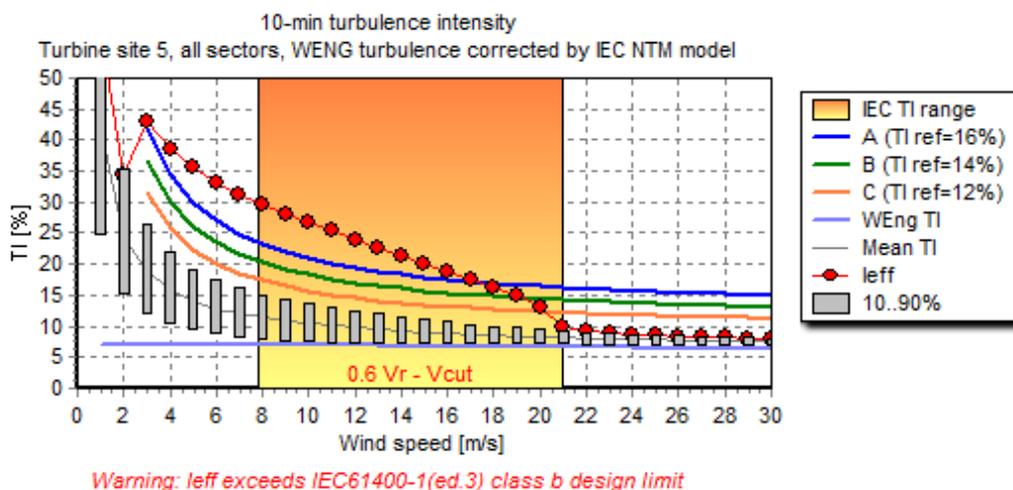


Figure 4: Effective turbulence intensity as function of wind speed under normal operation.

WEng turbulence intensity estimates does not account for non-steady mean wind or atmospheric stability, which is indeed difficult to model for sites in real terrain. To account for such effects the previous WAT versions simply used the NTM model with an offset matching the neutral-stability WEng turbulence estimate at high wind speed. This was, however, felt to be a too conservative method, so the new WAT 3 includes an option for turbulence statistics based on field measurements. With this approach you first model turbulence at the measurement position with WEng. These results are ported to WAT where differences between WEng turbulence estimates at turbine sites and reference mast are used to extrapolate measured turbulence statistics to turbine sites.

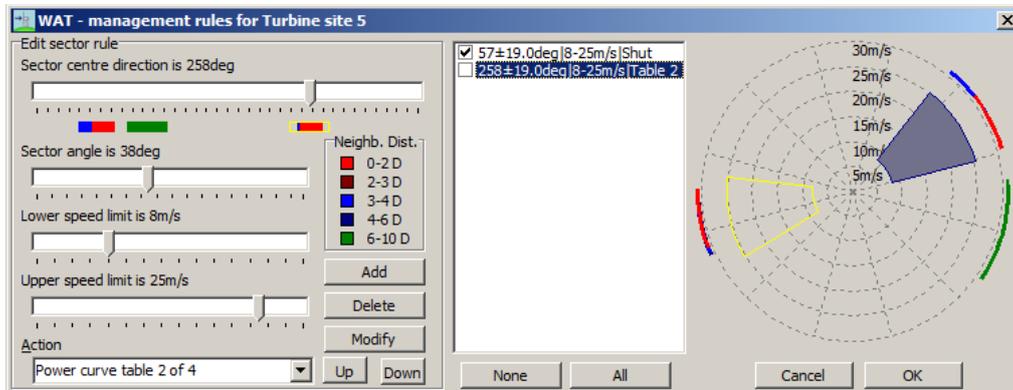


Figure 5: User-defined sector-management rules.

Investigating wind sector management and grid limitation

For some wind-farm layouts, e.g. a single row of turbines on a ridge, operation in the wake of neighbour turbines may be infrequent. In this case, it is tempting to reduce turbine separations, as the loss of power production will be modest. The problem with such a design is, however, that fatigue-damage of materials like glass fibre is sensitive even to rare occasions of severe turbulence. Although not yet sanctioned by the IEC, developers sometimes mitigate effects of wake turbulence by shutting down selected turbines during special wind conditions or operate them in load-reducing modes.

WAT models sector management by a list of wind conditions, where individual turbines are either shut down or working with alternative power- and thrust-coefficient curves, see Figure 5. Turbulence in sectors where the local turbine is shut is excluded from the effective turbulence intensity estimate, and turbulence from sectors with regulated neighbour turbines is modified. These differences will reduce the effective turbulence intensity, see Figure 2 and 3b.

The cost of sector management is of course lost energy production. For this purpose WAT calculates the annual energy production (AEP) by a modified version of the WAsP method, using a probability-weighted integral of power production at all wind speeds and directions. During the integration over wind direction the turbine sites are sorted after upwind distance, and AEP contributions are always calculated for upwind turbines before downwind ones. Wind speeds are corrected for terrain effects and wakes from upwind turbines before evaluating site-specific power production and thrust coefficients. AEP contributions from turbines with active sector management are either rejected or evaluated by alternative power curves. If the upwind turbine has active sector management, its wake is ignored or evaluated by an alternative thrust-coefficient curve.

Sometimes it is an economic advantage to install turbines with a slightly higher total capacity than the capacity of the transmission line. The wind farm will have to be de-rated during high-wind situations, but the AEP per turbine may still be acceptable, as turbines produce less than rated power for most of the time. There will be unused grid capacity at low wind speeds and, in case of wake loss and sector management, even above rated wind. These effects are included in the WAT AEP model.

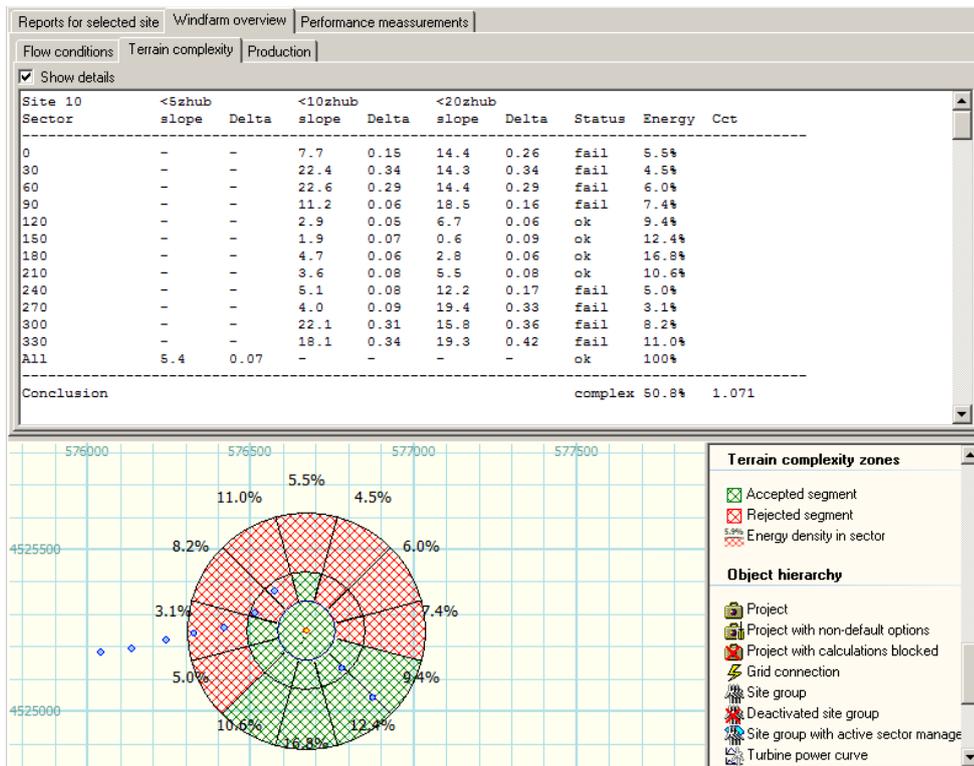


Figure 6: Assessment of terrain complexity according to the IEC 61400-1 safety standard.

Terrain assessments

IEC 61400-1 prescribes turbulence corrections factors for site assessment in complex terrain and rules for evaluation of terrain complexity. The basic idea is first to fit planes to the terrain in various areas around each turbine sites and then to check their slope and maximum deviation from the terrain. This is implemented in WAT, both for the old rules based on circular areas and for the new sector-based ones, see Figure 6.

Another standard, the IEC 61400-12-1 for in-situ power-curve measurements, includes similar though different terrain assessment. The main issue is whether the terrain significantly alters the flow at the tested turbine compared to the reference mast, which would call for site calibration and extra field measurements. With WAT it is easy to try different reference mast positions, accept or adjust the measurement sector, and evaluate the need for site calibration, see Figure 7.

New features in WAT 3

WAT has been available since 2006. The latest version 3.0 has been in preparation for longer time than a usual upgrade. This is due to a major code reorganization, which hopefully will ease future maintenance. The new features are:

- Wind-sector management by alternative turbine modes of operation as a supplement to full shut-down
- Import and export of sector-management rules
- Turbulence corrections by reference mast data
- Support for new IEC 61400-1/A1 sector-based complex terrain assessment
- AEP estimates under grid limitations
- More flexible models for turbine class S turbines
- Temporary blocking of AEP calculations (useful for big projects)
- Wind-speed dependent WEng turbulence intensity (useful for offshore projects)
- Improved object hierarchy editing
- Model options stored with project
- Legend for main plot
- Faster calculation
- Better error messages

Conclusions

WAT is as a tool for WAsP Engineering users and its main purpose is to facilitate IEC site assessment including estimates of effective turbulence intensity for wind farms with irregular turbine layout. Additional feature were inspired by users and course participants.

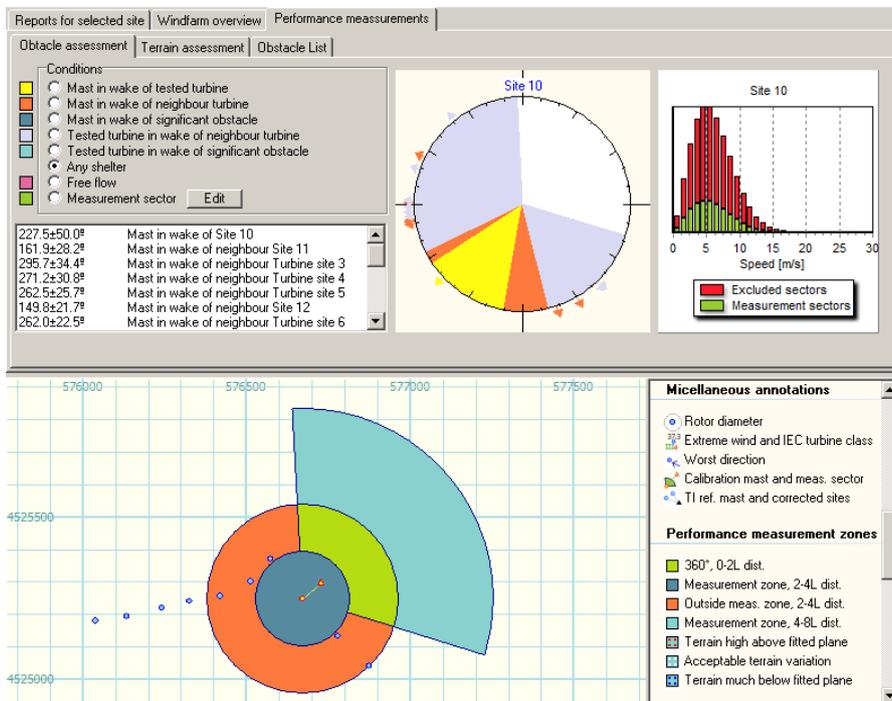


Figure 7: Assessment of measurement sector according to the IEC 61400-12-1 standard on in-situ power performance measurements.