Wind Energy Working Group: Turbine Performance in 'Non-Standard' Wind Conditions

Kick Off Meeting Minutes: Wellcome Collection London, 4th December 2012

Attended by: Peter Stuart (RES), Mike Anderson (RES), Alan Derrick (RES), Andrew Tindal (GLGH), Staffan Lindahl (GLGH), Mark Young (DNV), Oisin Brady (Natural Power), Michael Brower (AWS True Power), Ralph Torr (Sgurr), Rasmus Svendsen (Vestas), Ioannis Antoniou (Siemens), Peder Bay Enevoldsen (Siemens), Thomas Blodau (REPower), Henk-Jan Kooijman (GE), Wiebke Langreder (Suzlon), Gareth Craft (Crown Estate), Rebeca Rivera Lamata (Dong), Luis Prieto Godino (Iberdrola), Daniel Paredes Beato (Iberdrola), Daniel Stevens (SSE), Temi Gocheva (RWE), Patrick Moriarty (NREL), Rozenn Wagner (DTU), Axel Albers (Wind Guard)& Jan-ake Dahlberg (Vattenfall).

Key Outcomes

- The power function of a wind turbine is dependent on wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity, directional variation and inflow angle.
- There is a need for greater clarity on the range of conditions for which power curves are representative. This will give a clear starting point for considering corrections for 'non-standard' conditions.
- Corrections should be applied for 'non-standard' conditions which are different to those for which a power curve is representative. These corrections fall into two categories:
    - **Type A**: Adjustments made to reflect changes in the energy available for conversion across the rotor in a ten minute period due to 'non-standard conditions'.
    - **Type B**: Adjustments made to reflect changes in the conversion efficiency due to 'non-standard conditions'.
- The corrections for wind shear, wind veer and turbulence intensity in the current working draft of the IEC Power Performance standard should be considered as candidate methods for incorporation into resource assessment methodologies (Type A corrections).
- Further collaboration between manufacturers, developers and consultants is required to improve communication of power function information and explore corrections for non-standard conditions.

Presentations

- "Why are we here?" Mike Anderson (RES)
- "What are the issues?" Daniel Stevens (SSE Renewables)
- "Physical Mechanisms Behind Some Wind Turbine Performance Issues" Michael Brower (AWS TruePower)
- "How to improve energy predictions?" Andrew Tindal (GLGH)
- "Influence of Turbine Design Choices" Tomas Blodau (RE Power)
- "Modelling the Impact of Non-Standard Conditions", Axel Albers (Wind Guard)
- "Power Curves for Different Ambient Conditions" Henk-Jan Kooijman (GE)
- "Impact of non-standard inflow" Ioannis Antoniou (Siemens)

Minutes of Discussion

The working group members acknowledge that turbine performance is sensitive to the following parameters:

- wind speed (traditional power curve variable)
- air density (traditional power curve variable)
- vertical wind shear[1]
- vertical wind veer[2]
- turbulence intensity[3]
- directional variation[4]
- inflow angle[5]

Given the acknowledged sensitivity of turbine performance to multiple variables the working group considers the term 'power function' to be more appropriate than the traditional term 'power curve'.

The working group acknowledges the need for short term action on incorporating the full range of relevant variables into resource assessment methodologies. This should come from a greater understanding of what conditions a given power function is representative of and the provision of methods to correct for different conditions if required.

Given the acknowledged sensitivity of turbine performance to multiple variables the working group considers that greater clarity is required with respect to what conditions a given power function is valid for or representative of e.g. 'this power curve assumes a fixed shear exponent of 0.2 and turbulence intensity of 10%' or 'this power curve has been derived using a range of shear exponents between 0.1 to 0.3 and turbulence intensities between 9-11%'.

Some members of the working group proposed that consideration of vertical wind shear and turbulence intensity were more important than vertical wind veer, directional variation and inflow angle. There was a general consensus that this would be true for many sites but that the relative importance of different factors is a site specific question.

Some parts of the working group considered that four dimensional (wind speed, air density, vertical wind shear and turbulence) look up tables of turbine performance are potentially awkward and

[1] Wind Shear: Change in horizontal wind speed with height.

[2] Wind Veer: Change in wind direction with height.

[3] Turbulence Intensity: Standard deviation of horizontal wind speed over an averaging period normalised to the mean horizontal wind speed over the same period.

[4] Directional Variation: Standard deviation of direction over an averaging period.

[5] Inflow Angle: The inverse tangent of the ratio of the vertical wind speed and horizontal wind speed.

three dimensional look up tables are perhaps a practical upper limit. Other parts of the working group expressed a preference for four dimensional look-up tables. Three dimensional look up tables describing power as a function of wind speed, density and turbulence intensity are already available in some instances. An alternative to a four dimensional look up table is a three dimensional look up table (based on wind speed, density and turbulence) and a recommendation to use rotor average wind speeds (instead of hub height wind speeds).

The working group acknowledges that measurements of the vertical profile of wind speed and wind direction is an important part of dealing with 'non-standard' conditions. Greater clarity on the need to make adjustments to a given power function for 'non-standard' conditions would be of significant assistance in making the investment case for these measurements.

Assuming a good understanding of the conditions for which a given power function is valid the working group considers it appropriate to make adjustments/corrections to the power function for different wind conditions (if these deviate from those for which the power curve is representative).

The group considers that a clear statement describing how a power function should be adjusted between certain thresholds would be useful e.g. 'this power curve should be adjusted as follows if the turbulence intensity falls outside of the range 9-11%'.

The working group considers that 10 minute averages are the most practical variables for defining the power function in the immediate future because of their availability to developers.

Longer term the working group foresees the need for additional research to further refine the treatment of non-standard inflow conditions e.g. the averaging period of measurements, the impact of turbulence lengthscale, distinction between turbulence intensity and turbulence kinetic energy etc.

A proposal was put forward that methods for determining turbine performance in 'non-standard' conditions fall into two broad categories:

- **Type A**: Adjustments made to reflect changes in the **energy available** for conversion across the rotor in a ten minute period due to 'non-standard conditions'.
- **Type B**: Adjustments made to reflect changes in the **conversion efficiency** due to 'non-standard conditions'.

Type A corrections are inherently machine agnostic while in contrast Type B corrections are inherently machine dependent.

The group considers the corrections for wind shear, wind veer and turbulence intensity in the current working draft of the IEC Power Performance standard should be considered as candidate methods for incorporation into resource assessment methodologies. The group noted that these are all Type A corrections. Some members of the group did not have direct experience of applying the draft IEC Power Performance standard methods for resource assessment applications and so could not provide comment until they had investigated this further.

The group acknowledged that incorporating the IEC corrections into resource assessment procedures and software is not a trivial task. In particular the use of rotor averaged wind speed is a challenging departure from the current status quo. The group agreed on the value of a round robin exercise whereby members would trial the use of these corrections and share their experiences.

The group acknowledged that currently in the absence of consensus on this issue pragmatic corrections are being applied to resource assessments based on experiences from field measurements. As the sensitivity of power curves to a broader range of parameters becomes better understood there needs to be an onus on the industry to make full use of the available data from sites. In particular new ways of extracting valuable information from remote sensing devices will need to be a focus area.

The group acknowledged that there may be limitations to the proposed IEC corrections. An IEC committee member stated that applying these corrections was almost always better than doing nothing.

The group acknowledged that the transfer of a body of evidence on the performance of a turbine is very useful e.g. details of a number of power performance tests for a given machine. Greater clarity on how a power function has been measured is also advantageous e.g. details of specific anemometer type and the wind tunnel in which it was calibrated. It may also be advantageous for manufacturers to supply power functions measured by both a cup anemometer and a Lidar. Such evidence could become a key way in which developers and consultants distinguish between the likely real performance of different turbine models.

The group acknowledged that turbine performance in non-standard conditions is an issue whose resolution relies upon good communication between all stakeholders. Greater clarity on the assumed conditions for a sales power curve will be a very helpful step in this process. Additionally, requests for, and supply of, bodies of evidence to support the performance of a turbine will help improve energy predictions.

The group discussed the possibility of a ‘gold standard’ based on the publication of a threshold number of power performance tests e.g. 5 published tests. While elements of the group saw merit in the idea others disagreed stating that 5 tests would be insufficient.

It was acknowledged that it is currently difficult to compare how different technologies respond to ‘non-standard’ conditions. The proposed IEC corrections treat all technologies equally which may not be the case. A body of evidence on historic turbine performance would be useful in making this distinction. Certain technical details may also be very helpful e.g. the stall margin of a turbine.

The group acknowledges the importance of the distinction between information supplied to assist in resource assessment and information forming part of the turbine warranty. The focus of the working group is to determine what information is required to perform resource assessments. Some parts of the working group felt that information would not be used unless warranted, however other parts disagreed citing the example of turbine availability for which it is common to assume a different value in the resource assessment from that which is warranted.

The issues addressed by this meeting have become increasingly important as the deployment of Megawatt scale turbines in locations with “non-standard” conditions has increased. It has taken some time for statistically significant volumes of high quality power curve measurement data to have become available to allow our understanding of the performance of turbines in these conditions to improve. With this information now available it is timely to refine our approaches and methods to address the issues identified. However, it is important to stress that for regions in which the wind conditions may be considered to be "standard" only small adjustments are expected and even for those sites with rather extreme "non-standard" conditions power curve adjustments of no more than a few percent are anticipated.

The group acknowledges that other issues may induce 'non-optimal' turbine performance such as; yaw misalignment[6], blade fouling, blade degradation, blade icing, turbine sensor malfunctions and incorrect software configuration. These effects are relevant for all wind conditions and hence are distinct from the issue of turbine performance in 'non-standard wind conditions'.

The group acknowledges that assessing performance in non-standard conditions becomes more difficult if control settings vary e.g. software upgrades, active load management etc. For the purpose of discussion the group assumed static control software/settings. Concern was expressed by one member that with current information exchange levels if manufacturers were to routinely implement load management strategies this would prevent a formal energy assessment being conducted with a suitable degree of rigour. Improved exchange of information on load management strategies, curtailment strategies and hysteresis strategies have the potential to improve energy predictions in such cases.

The group acknowledges that it is possible that in some cases a statistical treatment of 'non-standard' conditions may be limited and a time series approach may be required.

The potential merits of forward facing Lidars in power performance tests was acknowledged by the working group.

The potential merits of a 'black box' model for power functions was discussed i.e. manufacturers could supply a model of turbine performance to developers who could use the model without knowing what's in the box. One group member made the point that we should not be constrained by history and that a 'black-box' approach may be a truer reflection of the likely differences in behaviour of different turbine models.

The group acknowledged that they were happy for the presentations to be shared within the working group. The group agreed that it would be preferable for the presentations and minutes to be available publically. Permission would be sought from the individual presentations prior to releasing the presentations publically.

The group agreed that as a next step trailing and validating power function adjustment models was necessary to improve energy predictions and that the candidate IEC models described above should form a part of this process.

The group agreed that the EWEA Technology workshop in Dublin in 2013 would be a good forum for the working group to share the outcomes of this discussion with the wider industry and furthermore to exchange information on the efficacy of various power function adjustment models.

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[6] Yaw misalignment: turbines perceiving the wind direction incorrectly and incorrectly aligning themselves with the wind direction.