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

## 2nd Meeting Minutes: Remisen Brande, 12th March 2013

**Theme**: The 1st meeting gave a clear statement of the problem. The 2nd meeting will focus on possible solutions e.g. power curve correction methods, integrating corrections into the resource assessment process, measurement campaigns, improving communication between stakeholders etc.

**Attending**: Andrew Tindal (GLGH), Erik Tuxen (GLGH), Rozenn Wagner (DTU), Anna Marsh (DNV KEMA), Daniel Marmander (Natural Power), Dan Bernadett (AWS True Power), Ralph Torr (Sgurr), Jesper Graugaard (Vestas), Ioannis Antoniou (Siemens), Peder Bay Enevoldsen (Siemens), Jochen cleve (Siemens), Apostolos Piperas (Siemens), Jeppe Johansen (Siemens), Lei Simonsen (Siemens), Thomas Blodau (Repower), Wiebke Langreder (Suzlon), Rebeca Rivera Lamata (Dong), Mikkel Haugaard Windolf (Dong), Daniel Stevens (SSE), Peter Stuart (RES), Alan Derrick (RES), Anabel Gammidge (RWE), Andy Clifton (NREL), Axel Albers (WindGuard), Jens Madsen (Vatenfall), Jan-ake Dahlberg (Vatenfall), Wayne Miller (Lawrence Livermore National Laboratory), Petter Lindelöw-Marsden (EON), Jørgen Højstrup (Romo Wind), Erik Hale (EDF), Lasse Svenningsen (EMD).

**Key Outcomes:**

- The dependency of power output to five parameters (wind speed, density, wind shear, wind veer and turbulence intensity) should be made more explicit in power curve documentation.
- A proposal was made to improve stakeholder communication by supplying power curves with two ranges of conditions:
    - The '**inner range**': the conditions for which a manufacturer believes a turbine will achieve its power curve (without correction).
    - The '**outer range**': the conditions for which a manufacturer expects a turbine's performance will degrade below its power curve (and will require correction).

  These ranges of conditions could be tied to the level of warranty e.g. X% warranty for the 'inner range' and Y% warranty for the 'outer range' where Y < X
- The use of rotor equivalent wind speed in wind resource assessment offers the opportunity to correct the wind speed input to the power curve so that it representative of the whole rotor. This approach is an effective way of dealing with the sensitivity of power output to wind shear.
- Tip-height measurements (using remote sensing devices e.g. LiDAR/SoDAR) have a big role to play in improving wind resource assessment. If such information is available it should not just be used in just the 'traditional' way (to verify mast measurement wind shear), instead it should form a core part of the resource assessment strategy.
- A round robin exercise will be conducted within the working group using a dataset including tip height measurements from a RES site in Sweden.

**Presentations:**

- "Introduction". Peter Stuart (RES)
- "Rotor Average wind speed for power curve performance". Ioannis Antoniou, Jochen Cleve & Apostolos Piperas (SWP)
- "Equivalent wind speed for AEP". Rozenn Wagner (DTU)
- "Observed Performance in High Shear and Turbulence". Daniel Stevens (SSE)
- "5 distinct power curves as a function of shear and turbulence in time-series energy capture calculations". Daniel W. Bernadett (AWS)
- "Integrating corrections into the resource assessment process." Andrew Tindal (GLGH)
- "Experience of Rotor Averaged Power Curve Measurements in Cold Climates". Alan Derrick (RES)
- "Using Machine Learning to Create Turbine Performance Models". Andy Clifton (NREL)
- "Dynamic Power Curves and the LLNL Wind Power Program". Wayne Miller (LLNL)
- "Measurements as a Basis for Extended use of Standard Power Curves". Thomas Blodau (REPower)
- "Resource Assessment Methods Incorporating Rotor Equivalent Wind Speed, Density and Turbulence on a Time Step Basis". Anna Marsh (DNV KEMA)
- "Roadmap for Industry to More Accurately Predict the Performance of Wind". Ralph Torr (Sgurr)

**Minutes of Discussion**

It was noted that the current range of participants (8 Manufacturers, 10 Developers, 9 Consultants and 4 Academics/Researches) provides a good cross section of the relevant industry stakeholders. Efforts will be continued to engage manufacturers who are not currently involved in the working group.

**Discussion Point #1: How best to provide greater clarity on the range of conditions a given power curve is representative of?**

A proposal was made to improve stakeholder communication by supplying power curves with two ranges of conditions:

- The '**inner range**': the conditions for which a manufacturer believes a turbine will achieve its power curve (without correction).
- The '**outer range**': the conditions for which a manufacturer expects a turbine's performance will degrade below its power curve (and require correction).

These ranges of conditions could be tied to the level of warranty e.g. X% warranty for the 'inner range' and Y% warranty for the 'outer range' where Y < X. Revisiting historic power curve tests with looser filters could be used to justify an 'inner range'; it is considered this will be wider than that currently stated as applicable for a given turbine.

The group discussed the merits of the 'two range proposal'. The clear separation between "what's in and what's out" was seen as advantageous while the reduced warranty in the 'outer range' was considered a pragmatic approach. The group stated that this approach would be applicable during both early developer-manufacturer engagement and later contractual discussions. Early engagement would most likely be based on relatively generic information which could be refined using site specific information as a project progresses. If during a tender process multiple manufacturers responded using the proposed structure a more meaningful appraisal of the bids would be made possible. Two manufacturers stated that one advantage of the proposed approach is that it could help avoid needing to supply multiple power curves which they are not keen on. Another advantage perceived by manufacturers was that it put some onus on the developer to help make the power curve better i.e. by supplying better measurements to the site specific power curve definition.

A comment was made that guarantees are not the 'whole story' and it's important to understand what power output that can be expected in both the 'inner' and 'outer' ranges. For example a 4% deficit in AEP could pass the performance warranty, but still have a big impact on the energy yield and its associated project economics.

One manufacturer stated that he believed that the spread of historic power performance results are primarily associated with measurement uncertainty rather than power curve uncertainty and people should keep this in mind.

One developer said that he would rather have a power curve based on equivalent wind speed than a power curve based on the 'two-range proposal'. A manufacturer stated that the equivalent wind speed seems to have a negligible impact on some sites. Another manufacturer stated that, dependent on site specific conditions, hub height measurements may or may not be representative of the whole rotor i.e. using hub height wind speed means you can be lucky or unlucky, whereas rotor equivalent wind speed offer more certainty. One developer said that rotor equivalent wind speed and the 'two-range' warranty are not mutually exclusive concepts; in fact they could be combined so that the inner region is expanded if it is defined using rotor equivalent wind speed.

A developer and a consultant said that it's important to make the benefit of remote sensing measurements tangible to encourage people to make them. A manufacturer said that it can be difficult to make the benefit completely black and white.

The following conclusion was proposed as a group consensus 'Manufacturers should supply power curves with an explicit range of values outside of which corrections and/or further site specific dialog are required'. One manufacturer said that if you measure the rotor profile with a LiDAR/SoDAR you neutralise the problem due to abnormal shear. One consultant that that it would be beneficial for

manufacturers to explicitly state that power curves have a sensitivity to five[1] parameters so that those interpreting power curves have a clearer understanding about the need to apply corrections e.g. this power curve should be used in conjunction with a measurement of rotor equivalent wind speed. One manufacturer said that it's important for consultants to make clear what use they will make of the additional information. One manufacturer questioned the need for power curves to explicitly state these limitations given that they are well known. One consultant said that the current ad hoc corrections being applied to power curves were introduced against a background of people interpreting power curves as 'valid for all conditions'. A manufacturer queried how this might be possible given that the warranty clearly limits the range of conditions. A developer replied that there has always been disconnect between the turbine supply agreement/warranty and resource assessment analysis. Another consultant and developer agreed that site assessment people tend to use the power curve as given without corrections (apart from density). A consultant said that he agreed that power curves should be supplied with a well-defined range of conditions for which they are representative and/or a way to correct outside of these conditions. One manufacturer reasserted that the issue can, at least in part, be neutralised by measuring the full rotor profile with a LiDAR/SoDAR. One developer proposed the following statement could be attached to power curves: 'this power curve assumes that the hub height wind speed is representative of the rotor, but it is recommend that this is confirmed via measurement'.

One consultant questioned the true benefit of warranties asked how it would be possible for the industry to step away from the adversarial focus on 'lawyers and small print', adding that in practice payment of liquidated damages on power curve warranties is extremely rare.

One developer asked of the consultants: "what's the ideal situation from your perspective i.e. if you had some measurements and they fall outside of the normal range what should be done (if we are not worried about warranties)? What else do you need?" It was suggested by a developer that you may need to make remote sensing measurements to do a good assessment. However one manufacturer said that he thought it was not clear that remote sensing measurements are always going to be beneficial as was the case in one of the presentations. The presenter in question said that for the site in his presentation the hub height measurements were representative of the rotor, however he believed that this is not necessarily always the case and other sites may be different. A consultant added that his experience in the Great Plains in the US is rotor equivalent wind speed is generally below hub height wind speed. One consultant added that 'without a measurement above hub height we don't know if we need it' i.e. it's very difficult to know what's going on across the rotor without a measurement of the rotor equivalent wind speed. The consultant added that the combination of hub height measurements and rotor measurements is also very useful e.g. the measured hub height wind speed from an anemometer can be adjusted to a rotor wind speed by multiplying by the hub to rotor ratio calculated from a remote sensing measurement.

One manufacturer raised the practical point that the use of the rotor equivalent wind speed is made more difficult by the fact that the power performance standard in which it is defined is currently still in draft. Other members of the group did not perceive this as an issue.

[1] The five parameters being referred to are; wind speed, density, vertical wind shear, vertical wind veer, turbulence intensity. Note that in the first meeting two additional parameters were identified (directional variation and inflow angle), however these were deemed of secondary important at the Brande meeting.

Finally the following consensus conclusion was reached: **'The developer, consultant and manufacturer community agree that it would be helpful if the dependency of power curves on five parameters (wind speed, density, wind shear, wind veer and turbulence intensity) was made more explicit'.**

**Discussion Point #2: Benefit of Tip Height Measurements.**

The group proceeded to further discuss the value of tip height measurements. One consultant commented that if such information is available it should not just be used in a traditional way (to verify mast measurement wind shear), instead it should form a core part of the resource assessment strategy. Another consultant commented that provision of tip-height remote sensing measurements removes quite a bit uncertainty. Finally the group agreed to conclude that **'Tip-height measurements have a big role to play in improving energy yield predictions'.**

**Discussion Point #3: Sensitivity to Parameters**

It was proposed that although seven power function parameters were identified in the first meeting, the focus should be on only five; wind speed, density, wind shear, wind veer and turbulence intensity. The two remaining parameters directional variation and inflow angle are potentially less important. One developer commented that they were happy with this in principle, but was unsure as to whether there was evidence to say conclusively that the impact of directional variation and inflow was negligible. One consultant said that he consider the impact of inflow to be modest and well represented by the $\cos^2\theta$ treatment. Another consultant commented that if a power curve is truly only dependent on horizontal wind speed then it should be insensitive to inflow angle, hence any impact on inflow angle should be a secondary effect.

**Road Map**

It was agreed that an outline roadmap for the group would be helpful. Peter Stuart from RES agreed to prepare a draft roadmap and circulate to the group.

**Round Robin Exercise**

A round robin exercise was proposed using a RES dataset from a site in Sweden including tip height measurements from a LiDAR. The purpose of the exercise will be to determine how to make best use of tip height measurements in resource assessment analysis. The exercise will be focused of the key points of relevance to the group and hence will be designed so that participants don't need to bother with certain steps which are not relevant e.g. Data QC'ing, MCP analysis, Wind Flow Modelling etc.

**Next Meeting**

It was agreed that the next meeting would be hosted by REPower in Hamburg. The main focus of the meeting will be a comparison of the results and experiences emerging from the round robin exercise.