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

3rd Meeting Minutes: REPower Hamburg, 30th May 2013

Theme: The 1st meeting gave a clear statement of the problem. The 2nd meeting examined possible solutions. The 3rd meeting aimed at putting some of those solutions into practice.

Attending: Andrew Tindal (GLGH), Erik Tuxen (GLGH), Richard Whiting (GLGH), Rozenn Wagner (DTU), Anna Marsh (DNV KEMA), Lesley Dubois (AWS True Power), Ralph Torr (Sgurr), Michael Pram Nielsen (Vestas), Ioannis Antoniou (Siemens), Peder Bay Enevoldsen (Siemens), Jochen cleve (Siemens), Tomas Blodau (Repower), Daniel Bendel (Repower), Katharina Neumann (Repower), Joerg Wanink (GE), Janna Lindenberg (GE), Peter Stuart (RES), Alan Derrick (RES), Anabel Gammidge (RWE), Axel Albers (WindGuard), Julia gottschall (IWES), Jørgen Højstrup (Romo Wind), Jesus Pinedo (Barlovento), Herbert Schwartz (Anemos-Jacob).

Key Outcomes:

- **The 1st round robin demonstrated good agreement on the application of the equivalent wind speed concept, although further work is needed to align estimates. The turbulence normalised results showed a greater spread, but were nonetheless an encouraging start.**
- **The real world consideration of how best to combine a relatively short LiDAR dataset (containing gaps) with a longer met mast dataset warrants further investigation.**
- **The 1st round robin demonstrated that there is substantial merit in the inner/outer range proposal. There was broad agreement that this concept warrants further investigation through future round robin exercises and detailed consideration within individual organisations.**
- **There was a consensus from all manufacturers present that test site 'well-behaved' power curves are suitable for use with both hub wind speed and rotor equivalent wind speed.**
- **Additional round robin exercises will be organised to explore different datasets e.g. North American dataset, forest dataset etc.**

Presentations:

- "01 Introduction/Welcome". Tomas Blodau (Repower)
- "02 Review of Previous Meetings". Andrew Tindal (GLGH)
- "03 Overview of Round Robin Results". Peter Stuart (RES)
- "04 Round Robin Exercise 1 Introduction (Shear)". Anna Marsh (DNV KEMA)
- "05 Round Robin Exercise 2 Introduction (Turbulence)". Anabel Gammidge (RWE)
- "06 Review of Inner/Outer Range Proposal". Tomas Blodau (Repower)
- "07 Round Robin Exercise Introduction (Inner/Outer Range)". Daniel Bendel (REPower)

- "08 Power curve measurements using the spinner anemometer". Jørgen Højstrup (ROMOWind)
- "09 Use of LiDARs to measure non-standard flow effect on power curve measurement and resource assessment in the IEA Task 32". Rozenn Wagner (DTU Wind Energy)
- "10 Round Robin contrast to North American Experience". Richard Whiting (GLGH)

Minutes of Discussion

Round Robin Exercise 1: Shear

The first round robin exercise was to perform a resource assessment calculation considering rotor equivalent wind speed using data from a co-located mast and LiDAR. An introduction to the exercise was presented by Anna Marsh of DNV KEMA (see *'04 - Round Robin Exercise 1 Introduction (Shear)'* for further details) who highlighted the differences between the round robin site and the typical wind profiles at a mid-west US site. A comparison of the results of the participants was presented (relative to a base case of a hub height wind speed assessment). This plot is shown in Figure 1.

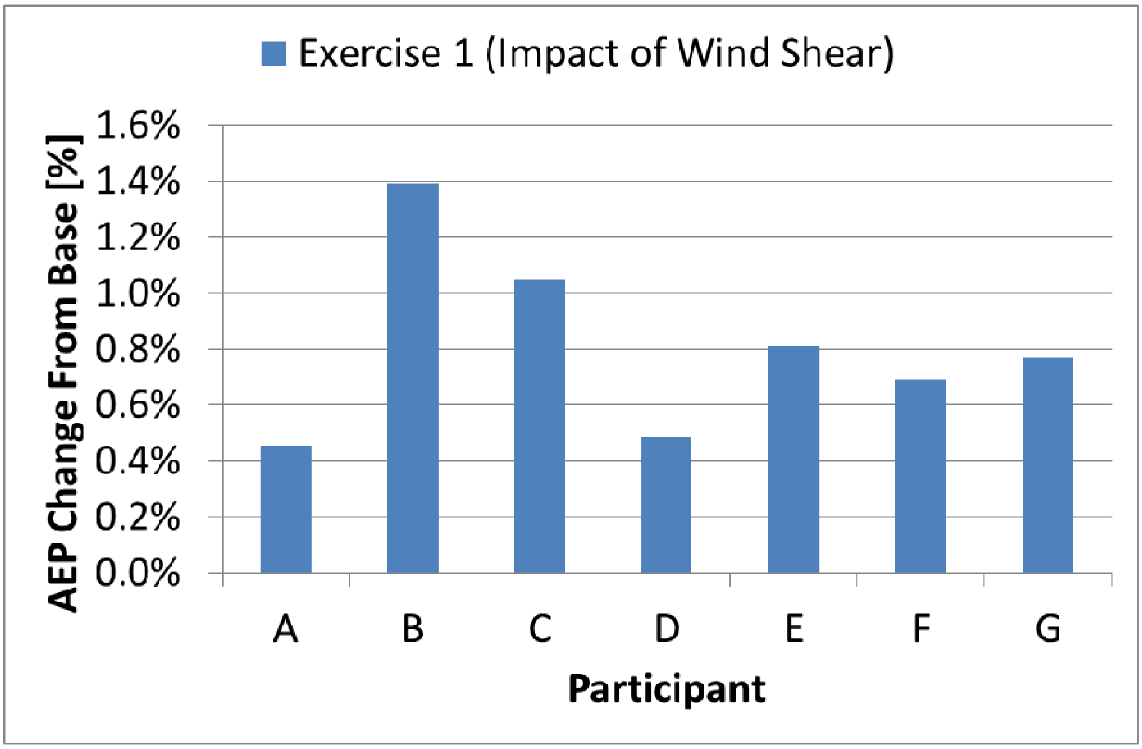

Figure 1. Comparison of participant results for Exercise 1

It was noted that the results were broadly consistent with all participants calculating a small increase in yield relative to the base case. The spread in results was primarily attributed to different filtering and gap filling methods (the exercise did not prescribe what should be done for these steps).

The experiences of the participants of the first round robin exercise were discussed. Most participants used a time series based approach instead of a frequency distribution approach. Most participants combined the mast and LiDAR measurements by deriving the 'equivalent wind speed to hub wind speed ratio' from the LiDAR data and then scaling the mast wind speed by this value. The practical consideration of gap-filling the LiDAR time series was discussed. As there are periods in the LiDAR dataset with data from some or all heights missing some participants opted to fill in the gaps by synthesizing LiDAR data using the co-located mast as a reference. It was noted that other participants did not perform any gap filling as they considered it beyond the scope of the exercise. One consultant commented that real world data coverage means there are inherent difficulties dealing with LiDAR data. Another consultant agreed stating that having to work with a limited amount of data is a common situation. The group acknowledged the need to find effective methods for using longer term mast measurements to extend shorter term co-located remote sensing measurements. It was agreed that although this type of gap filling is potentially appropriate for resource assessment applications it would be unsuitable for power performance applications.

The group discussed whether or not it is right to expect to have two distinct power curves (one for hub height wind speed and one for rotor equivalent wind speed), or whether a single power curve can be used for both types of input wind speed. One consultant commented that they would expect to see two distinct power curves. A manufacturer stated that rotor equivalent wind speed is just a 'fairer way of measuring wind' and therefore a single power curve should be valid for both approaches. Another consultant said that in order to introduce the effect of site specific shear it is essential to understand the shear built into the power curve. A manufacturer replied that it's important to consider the variation of shear during the power curve measurement period (e.g. di-urnal and seasonal variations) and hence there is no single shear value built into the power curve, but rather a range of shears. Another consultant said that in their experience they have found that assuming one power curve is fine as long as the data analysis is performed appropriately by calculating the rotor equivalent wind speed to hub wind speed ratio per wind speed bin (and applying a separate turbulence correction). A manufacturer added that on a 'well behaved' site hub wind speed and rotor equivalent wind speed are very similar and that tests sites (where power curves are measured) are well behaved while real sites are different. The manufacturer said that this supported the idea that it's valid to use a single power curve for both hub wind speed and rotor equivalent wind speed i.e. power curves are derived that sites where hub wind speed and rotor equivalent wind speed are effectively the same. The manufacturers in the room who had not joined in the discussion were as to comment and all agreed that their power curves were suitable for use with both hub wind speed and rotor equivalent wind speed. There was therefore consensus from all manufacturers present that test site 'well-behaved' power curves are suitable for use with both hub wind speed and rotor equivalent wind speed.

The group discussed the fact that the concept of rotor equivalent wind speed only deals with the available energy for conversion and assumes that the conversion efficiency remains the same (Type 1 correction). One consultant said that they believed that the 'Type 1' effects normally dominant, but that there are cases where the change in conversion efficiency ('Type 2' effects) may become significant.

Round Robin Exercise 2: Turbulence

The second round robin exercise was to perform a resource assessment calculation considering the turbulence re-normalisation scheme proposed as an informative in the draft IEC power performance standard. Exercise 2 was introduced by Anabel Gammidge of RWE (see presentation *'05 Round Robin*

Exercise 2 Introduction (Turbulence)' for details). A comparison of the results of the participants was presented (relative to a base case of no adjustment for turbulence). This plot is shown in Figure 2.

The participants agreed that the methods in Exercise 2 were more challenging to apply than those in Exercise 1. The results of the participants for Exercise 2 were compared and shown to have a greater spread that those of Exercise 1. Some key differences between participants were identified:

Difference value of reference turbulence intensity for power curve (exercise was not explicit). Most participants used either 10% or 11%. This demonstrates the need for manufacturers to state this value explicitly on power curves.

- Differences in the time series analysed and gap filling strategies.
- Use of time series approach by some participants and frequency distribution approach by others.
- Some participants submitted results which were included the compound effect of both shear and turbulence.

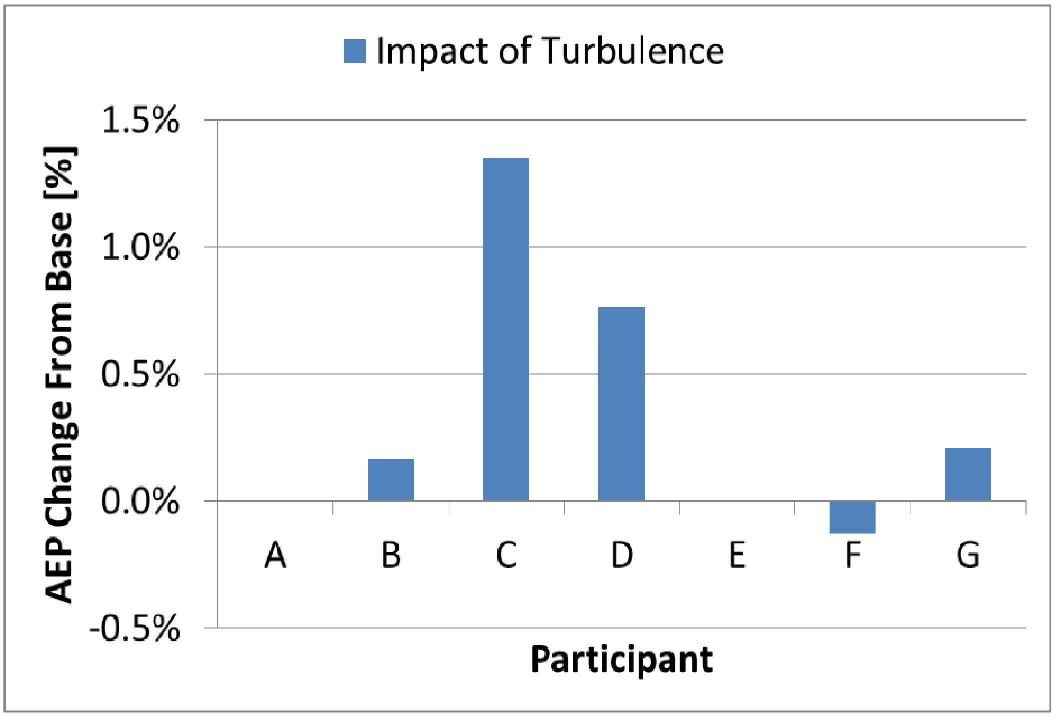

Figure 2. Comparison of participant results for Exercise 2

The treatment of cut-out wind speed was discussed. One developer stated that the basic correction can give a reduction in power about rated at high wind speed (due to the cut out wind speed). Several participants said that they forced the power in this region to be rated power.

One consultant commented that he did not like the turbulence correct method (which is an informative section of draft power performance standard). The group discussed the merits of the approach with substantial differences in opinion. One developer commented that there is definitely an effect related to turbulence which is clearly visible in the data. One consultant said that the method describes an effect related to the ten-minute averaging of data (Type 1 correction) and that the magnitude of the correction is similar to that associated with rotor equivalent wind speed. One consultant commented that it's possible to verify the method by separating a power performance dataset into high turbulence and low turbulence and then correcting each dataset to a reference turbulence intensity (the correction should give a consistent result for both cases). One manufacturer made the comment that a possible issue with the method is that the 'zero-turbulence' curve is in practice site dependent whereas in theory it should not be.

The group discussed the coupled nature of atmospheric turbulence/shear and the implications for applying two separate correction methods. One manufacturer stated that although the two atmospheric variables were coupled this did not preclude the use of two separate corrections. One consultant agreed stating that the rotor equivalent wind speed correction should be used in conjunction with turbulence re-normalisation correction adding that the methods 'solve two different problems'.

It was commented that the method relies upon the assumption that the hub height turbulence is representative of the rotor. One participant commented that the rotor should have the effect of 'averaging out' some turbulence intensity. It was commented that the impact of these considerations on the correction method is possibly offset by the 'built-in' turbulence in the power curve.

One consultant made the point that on very turbulent sites (e.g. forests) with extremely high turbulence intensity (e.g. 18-20% mean TI) the turbulence re-normalisation may reach its limits and the analysis would be 'in Type 2 territory'.

In summing up the group agreed that more working is needed to developing understanding and standardise use of the turbulence correction. There was consensus that further round robin exercises and validation data would be of benefit.

Round Robin Exercise 3: Stakeholder Interaction and the Inner/Outer Range Proposal

The third round robin exercise related to the application of the inner/outer range concept proposed in meeting two. The inner/outer range proposal was briefly reviewed by its proposer Tomas Blodau of REPower (see *'06 - Review of Outer Range Proposal'* for more details). The exercise was then introduced by Daniel Bendel of REPower (see *'07 Round Robin Exercise Introduction (Inner/Outer Range)'* for more details). The results of the participants are compared in Figures 3a and 3b. The results between participants show good agreement, with some differences due to data filtering strategies. The participants commented that they found the exercise relatively simple to complete.

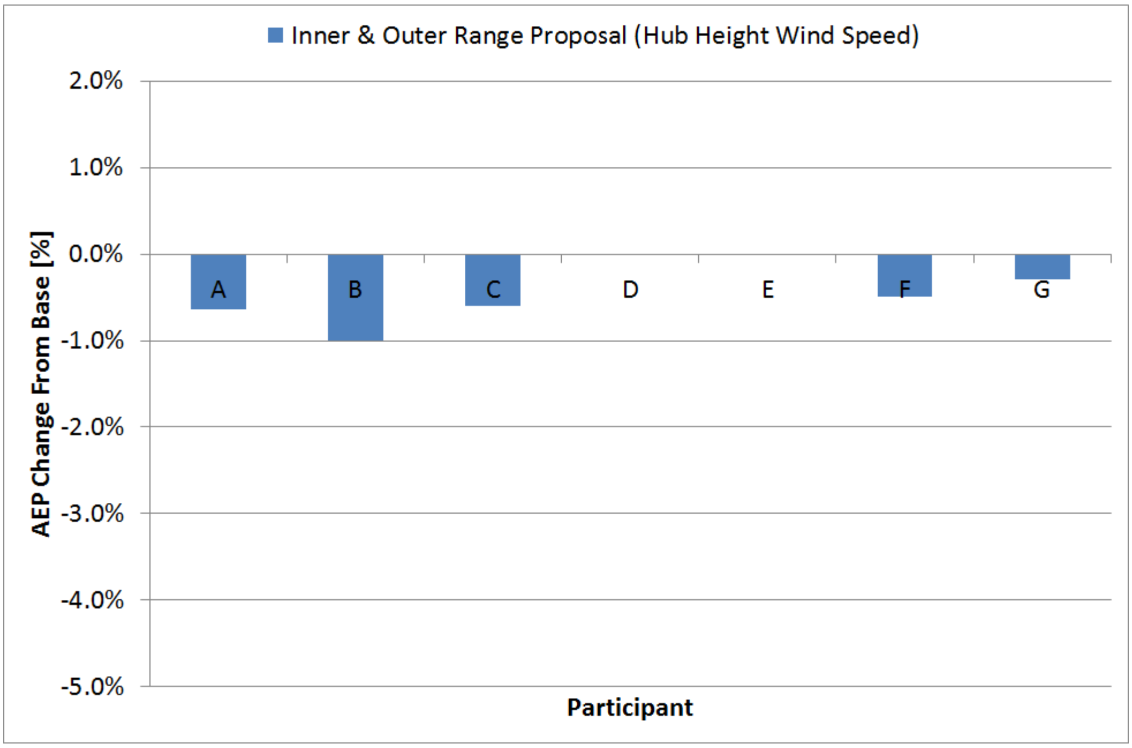

Figure 3a. Comparison of participant results for Exercise 3a

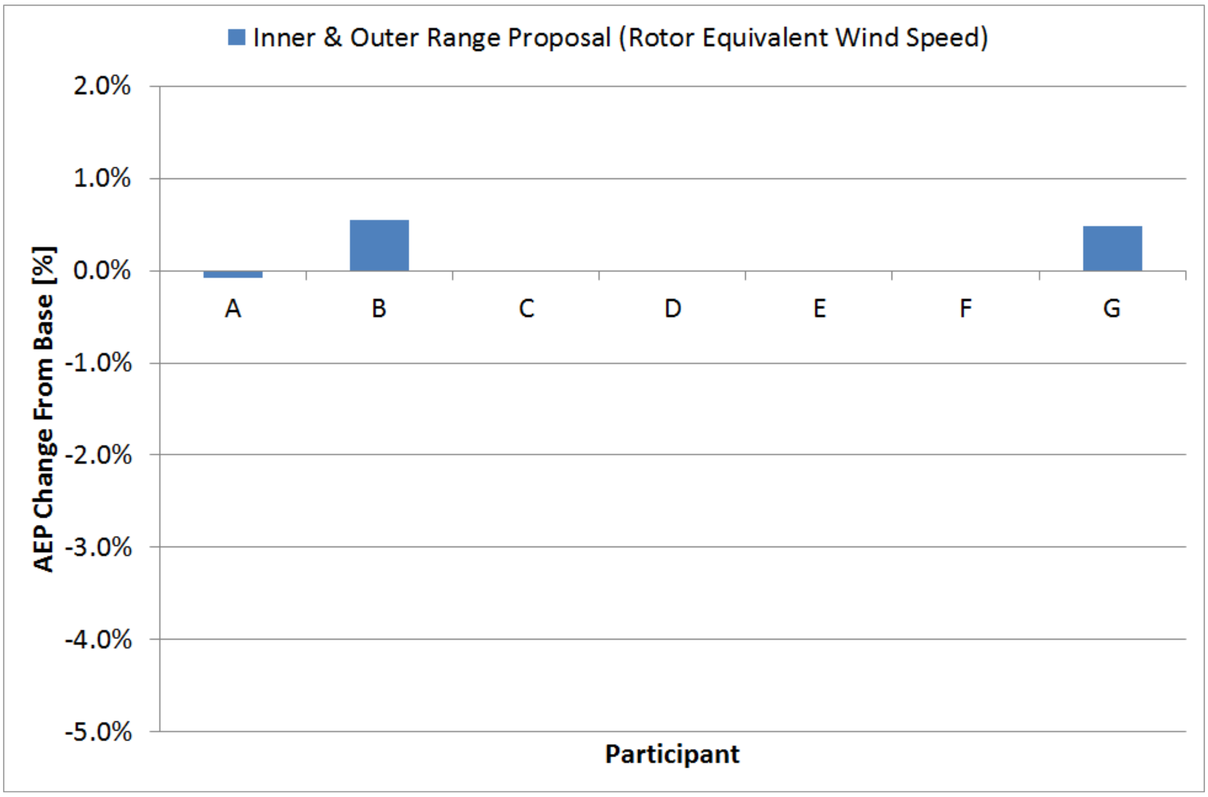

Figure 3b. Comparison of participant results for Exercise 3b

The issue was raised as to whether the inner/outer range concept should be applied in combination with the other corrections (equivalent wind speed and turbulence renormalisation). The proposer of the inner/outer range concept said that he believed it should be applied in combination with equivalent wind speed, but not in combination with turbulence normalisation. The proposer remarked that the inner/outer range concept can only ever reduce the yield and should be regarded as a first pass which can be refined using site specific information. A consultant agreed that the concept provides a valid starting point for analysis. The proposer added that if manufacturers do not provide a guideline like the inner/outer range then consults and developers will end up applying some other correction. One developer commented that he liked the proposed inner/outer range concept as the industry has historically suspended its disbelief with regard to the impact of 'real world' conditions on power curves and the inner/outer range concepts makes it explicit that people should expect to see a change in behaviour. A consultant commented that the reduction in yield derived from using the inner/outer range concept should be coupled with a reduction in uncertainty i.e. the P50 reduces, but the P90/P50 ratio increases. Another consultant added that the inner/outer range concept was evidence of industry movement which he considered a very good thing. In response to a question from a consultant the proposer confirmed that there are no limits on the outer range. One developer made the point that the reduction in the outer range includes periods above rated power where no actual power reduction is expected. The proposer commented that he is aware of this and that this is taken into account in deriving the aggregate energy reduction in the outer range. One manufacturer commented that an advantage of the inner/outer range concept is that a broader range of data could be considered for power performance tests which would allow tests to complete faster. A manufacturer asked whether power performance tests would be required to have data both in the inner and outer ranges. The proposer responded that the concepts allows the power performance test to use data from both inside and outside and that dialogue with the customer should help determine if there is enough data. In summing up the group agreed that there is merit in the inner/outer range approach and it warrants further investigation by the group.

Afternoon Presentation Session

A presentation was made by Jørgen Højstrup (an independent consultant working for ROMOWind) on spinner anemometers (see *"08 Power curve measurements using the spinner anemometer"* for more details). After the presentation the sensitivity of power curves to inflow and directional variation was discussed. One consultant raised the issue that he disagreed with the focus of the group on shear and turbulence as he felt that the impact of inflow and directional variation was not insignificant. The group broadly agreed that they expected some impact from inflow and directional variation, but the consensus was that, for the time being, the focus of the group should be on determining the impact of shear and turbulence.

A presentation was made by Rozenn Wagner of DTU on IEA Task 32 on LiDAR (see *"09 Use of LiDARs to measure non-standard flow effect on power curve measurement and resource assessment in the IEA Task 32"* for more details). IEA Task 32 addresses the application of LiDARs for resource assessment calculations including the use of equivalent wind speed. The working group agreed that it needed to address the issue of collaboration with IEA Task 32, but at the same time the group must retain its industry focus, organisational flexibility and work within the relatively short timescales of its roadmap.

Afternoon Discussion Session

The afternoon session was opened by a presentation by Richard Whiting of GLGH (see *'10 Round Robin contrast to North American Experience'* for more details). The presentation contrasted the Swedish dataset used in the round robin exercise with the strongly stable conditions observed in the

US mid-west. The presentation also described GLGH's current methods which involve using low turbulence intensity as a proxy for stability. GLGH's results suggested that the drop off in performance at low turbulence intensity (stable atmosphere) could not be explained by rotor equivalent wind speed alone. A manufacturer commented that it may be necessary to consider the compound impact of multiple effects associated with a stable atmosphere to fully explain the observations e.g. wind shear, wind veer and turbulence renormalisation. The group agreed that the current round robin dataset was in no means representative of all sites and that it would be good to secure additional datasets for future exercises e.g. a north American dataset, a forested dataset etc. The group agreed that future datasets would need to have both mast and LiDAR data. Siemens and RWE said that they would check if they could provide datasets. RES agreed to check if it can release the power data associated with the Swedish round robin dataset.

The inner/outer range proposal was discussed further. The manufacturers within the group were firstly invited to give further feedback on the inner/outer range proposal. One manufacturer said that they had met with the same customer requirement for site specific power curves and liked the pragmatic approach of the inner/outer range. Other manufacturers said that they saw merit in the proposal, but would need to discuss further and consider internally. One developer commented that they were happy with any approach as long as it is bringing the industry closer to the truth. A consultant commented that the scheme was elegant and simple while also being practical in a commercial sense, adding that it's still worth thinking beyond the concept to establish the mechanisms behind performance degradation. Another consultant agreed saying that they saw the proposal as a big step forward but still wanted to 'go further'. Another consultant added that the scheme allowed the industry to do something simple now. A developer agreed that a key advantage of the scheme is that it can be used now, but also agreed that there is to investigate the underlying mechanisms further and 'keep pushing on all fronts'. One developer added that it's important to consider the uncertainty implications of applying the inner/outer range approach e.g. what is the uncertainty associated with the outer range reduction.

One consultant said that he believed that the normalisation procedures in the draft IEC power performance standard are already robust i.e. we have methods that go beyond the inner/outer range concept already available. The consultant added that it was possible to do a good assessment without using the time series approach by determining; rotor equivalent wind speed to hub ratio per wind speed bin, turbulence per wind speed bin and performing turbulence renormalisation on the power curve. This allows the power curve supplied by the manufacturer to be normalised to the site conditions which should be sufficient in the majority of cases, although there are limits to the ranges over which these corrections can be applied.

The group briefly discussed the magnitude of performance degradation in 'non-standard' conditions (also referred to as 'real world' conditions) relative to other uncertainties. It was suggested by one consultant that the effects are potentially insignificant relative to other uncertainties e.g. wind flow modelling, MCP uncertainty etc. A developer responded by saying that the performance degradation issue was a bias of the order of a few percent and was certainly worth considering.

The group briefly discussed the fact that the power curves supplied by manufacturers to developers/consultants should be a P50 power curve i.e. it should give a central estimate of the performance that can be expected to be observed in the 'real world'. The inner/outer range concept has the potential to bridge the gap between current sales curves (performance in 'ideal world' conditions) and the required P50 curves (central performance in 'real world' conditions). It was noted that the current public evidence base is currently focused on the 'ideal world' conditions defined by the power performance test filters i.e. the current evidence base is much stronger in the inner region. Re-analysis historic power performance data with the filters removed has the potential to build understanding in the outer region. One manufacturer suggested that if a power curve was based on modelling (instead of measurements) then a narrow inner range could be defined.

In summing up the group agreed to the consensus that the inner/outer range proposal has merit and warrants further investigation. Individually organisations should consider the proposal internally to determine how it affects them. Although the inner/outer range is a pragmatic approach that can be rolled out quickly, members felt strongly that the group shouldn't stop at this proposal and should investigate further the underlying mechanisms. The group strongly supported further round robin exercises.

The 'real world' power curve session at the upcoming EWEA technology workshop in Dublin (25-26th June) was discussed. The session will be chaired by Tomas Blodau with a presentation on the working group by Peter Stuart. The group agreed that the minuted key outcomes from previous working group meetings and the results of the round robin should form the basis of the presentation.

Future Round Robin Exercises

The group agreed to the merit of future round robin exercises. RWE, Siemens and RES agreed to attempt to secure additional datasets. The group agreed that attempts should be made to align results e.g. by designing an exercise around a simple 'ideal' dataset where gap filling is not an issue.

Next Meeting

It was agreed that the next meeting would be hosted by Vestas in Aarhus in September. The December meeting will be hosted by SSE in Glasgow.