Power Curve Working Group Meeting Minutes

Impact of Outer Range Conditions on Wind Turbine Power Performance

9th Meeting Minutes, Tuesday 16th December 2015, Glasgow's City Halls, Glasgow, Scotland

Hosted by ORE Catapult

Attending: Ralph Torr (ORE-CATAPULT), Peter Stuart (RES), IÑAKI LEZAUN MAS (GAMESACORP), Alex Clerc (RES), Daniel Marmander (NATURALPOWER), Peter Clive (SGURRENERGY), Stuart Baylis (PREVAILINGANALYSIS), Ivar Rush (PREVAILINGANALYSIS), Jeremy Bass (RES), Alan Derrick (RES), Gaetan Martellozzo (EDF-EN), Tomas Blodau (SENVION), Michael Harris (ZEPHIRLIDAR), Michael Pram Nielsen (VESTAS), Aris Dimopoulos (INFINIS), Florin Pintilie (SGURRENERGY), Richard whiting (DNVGL), Hector Alonso (BARLOVENTO-RECURSOS), Iain Nisbet (SGURRENERGY), Patrick Jones (TUV-SUD), Richard Gale (EON), Erik Tuexen (DNVGL), Herbert Schwartz (ANEMOS-JACOB), Gordon Barr (SSERENEWABLES), Michael Blair (SSERENEWABLES), Julija Tastu (SIEMENS), Anabel Gammidge (RWE), David Robb (SGURRCONTROL), Erik Brown (OLDBAUMSERVICES) and Rodolphe Lebosq (ENERCON).

Motivation: To agree the 2015 roadmap for the PCWG.

Key Outcomes:

- Round Robin on Conditions Specific Power Curves Completed. The exercise demonstrated that the PCWG members can consistently apply multiple conditions specific power curves.
- The Draft 2015 PCWG Roadmap was presented and discussed.
- PCWG data-sharing initiative presented and discussed.

Actions/Outcomes:

- Finalise 2015 PCWG Roadmap
- Launch expression of interest for PCWG data sharing initiative.

Morning Presentations

- 01 Introduction, Agenda and Review of Actions
- 02 PCWG Round Robin 4 Results Overview - Conditions Specific Power Curves
- 03 PCWG 2015 Roadmap - Coffee Break Exercise Result
- 04 PCWG 2015 Roadmap - Survey Results
- 05 PCWG 2015 Roadmap - A3 Report Introduction
- 06 PCWG 2015 Roadmap - Draft Roadmap
- 07 PCWG 2015 Roadmap - Proposed Data Sharing Initiative

Overview of Round Robin 4 Results: Conditions Specific Power Curves

The results from Round Robin 4 (conditions specific power curves) were briefly presented (see '02 PCWG Round Robin 4 Results Overview - Conditions Specific Power Curves). The results are summarised in Figures 1-2.

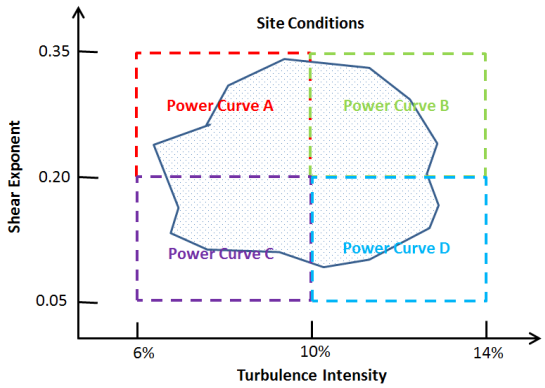

Figure 1a. Schematic representation of Exercise 4a 'Conditions Specific Power Curves'.

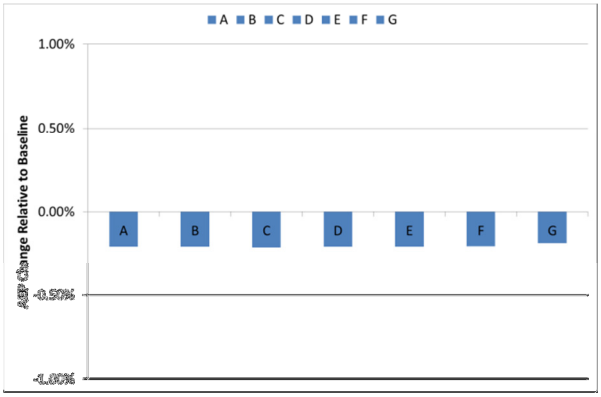

Figure 1b. Results of participants A-G of Exercise 4a 'Conditions Specific Power Curves'.

Exercise 4a sought to determine if a set of conditions specific power curves could be applied consistently in order to calculate the specific energy production (SEP) for a given input time series. For the purposes of Exercise 4a an input time series was defined such that all conditions fell within the range of applicability of one of the conditions specific power (as illustrated in Figure 1a.). A baseline calculation was also performed using a single power curve which only partially covered the conditions in the input time series. The results (Figure 1b) indicate that all participants consistently applied the conditions specific power curves in predicting a small reduction in specific energy production by applying the conditions specific power curves (relative to the baseline of a single power curve).

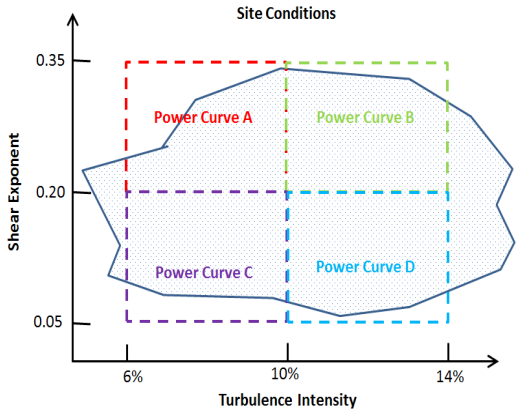

Figure 2a. Schematic representation of Exercise 4b 'Conditions Specific Power Curves & Turbulence Correction'

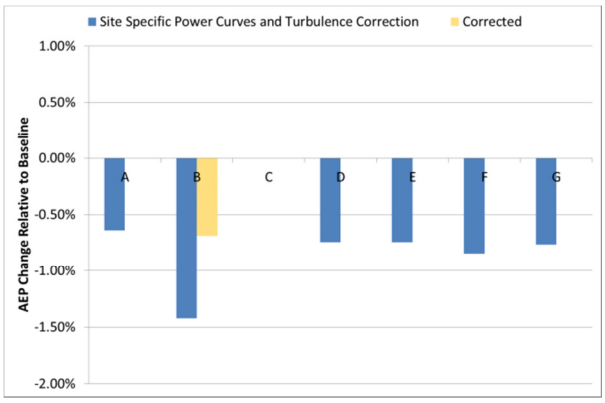

Figure 2b. Results of participants A-G of Exercise 4b 'Conditions Specific Power Curves & Turbulence Correction'

Exercise 4b sought to build upon Exercise 4a by examining the application of conditions specific power curves in combination with the turbulence correction method. For the purposes of Exercise 4b an input time series was defined such that some conditions fell outside the range of applicability of one of the conditions specific power (as illustrated in Figure 2a.). The participants were asked to

use the uncorrected conditions specific power curves within their range of applicability and to apply the turbulence correction for those conditions beyond their range of applicability. The results (Figure 2b) indicate that most participants consistently applied the conditions specific power curves and turbulence correction in predicting a small reduction in specific energy production by applying the conditions specific power curves (relative to the baseline of a single power curve). One participant (B) predicted an appreciably larger negative correction than the others, the group chair agreed to follow up with this participant to determine the reason for this discrepancy.

> ***Addendum**: Following the meeting the group chair contacted participant B to determine why their results differed from the other participants. It was determined that participant B had calculated a different baseline yield to the other participants. Participant B then submitted a corrected result which was in much better agreement with the other participants (shown in Figure 2b as an orange bar).*

Finally participant B submitted an extra calculation whereby they used only the baseline power curve in combination with the turbulence correction. The additional analysis showed very close agreement with Exercise 4b (see Table 1). This indicates that (for the particular power curves used in the round robin) using multiple climatic specific power curves method behaves very similarly to using the turbulence correction method.

Participant B Result	Normalised SEP
Exercise 4b (Climate Specific Power Curves and Turbulence Correction	99.31%
Additional Analysis (Baseline Power Curve only and Turbulence Correction	99.25%

Table 1. Participant B Additional Analysis

Group Discussion of Round Robin 4 Results

One manufacturer commented on the design of the exercise and said that it may have been more appropriate to have had one inner range curve and several outer range curves. Another manufacturer commented that they preferred the phrase 'Conditions Specific Power Curves' as opposed to 'Site Specific Power Curves'. One developer commented that they thought it was encouraging that most participants had obtained consistent results.

Discussion of Conditions Specific Power Curves vs. Power Deviation Matrix Approaches

The relative merits of the Site Specific Power Curve and Power Deviation Matrix approaches were discussed by the group. One manufacturer commented that they were not so keen on the conditions specific power curves and favoured the power deviation matrix approach, adding that only power deviations matrices tended to fully represent the range of behaviour of a wind turbine. One consultant commented that in principle the two methods should be more or less equivalent, however the number of curves shouldn't be limited to 4 i.e. a larger number of curves may be required to fully represent the full range of wind turbine behaviour. The same consultant added that it wasn't sufficient to simply supply conditions power curves they had to stand up to scrutiny i.e. an independent consultant is unlikely to accept conditions specific power curve which imply small deviations that don't match reality. One developer commented that there were similar differences between conditions specific power curves vs. reality and the turbulence renormalisation method vs. reality.

The group briefly discussed if multiple conditions specific power curves could be used to form the basis of a power performance test. One manufacturer commented that they did not think that a warranty based on multiple site specific curves was feasible and the inner/outer range concept was a more practical basis for a contract.

It was acknowledged that there were two schools of thought within the group; some members felt that conditions specific power curves were worthwhile, while others felt that they did not offer much practical benefit.

Group Exercise: Adaptive Problems

During the coffee break the group performed an exercise on adaptive problems based on the work of Heifitz and Linsky (see '03 PCWG 2015 Roadmap - Coffee Break Exercise Result' for details). The group were asked to mark a flip chart with an 'x' to denote where they thought the PCWG stood as a group with respect to the issue of wind turbine perform performance in outer range conditions. The flip chart was a two-dimensional 'problem space' with political and technical dimensions. The digitised results of the exercise are shown in Figure 4 which indicate that the PCWG members on the whole view the issue of wind turbine performance in outer range conditions as an adaptive problem i.e. far from political certainty and far from technical certainty (so much work to do!). A few members thought that the group was close to political consensus, but far from technical consensus. One member thought the group was close to technical consensus, but far from political consensus. No member felt that the group was close to both political and technical consensus.

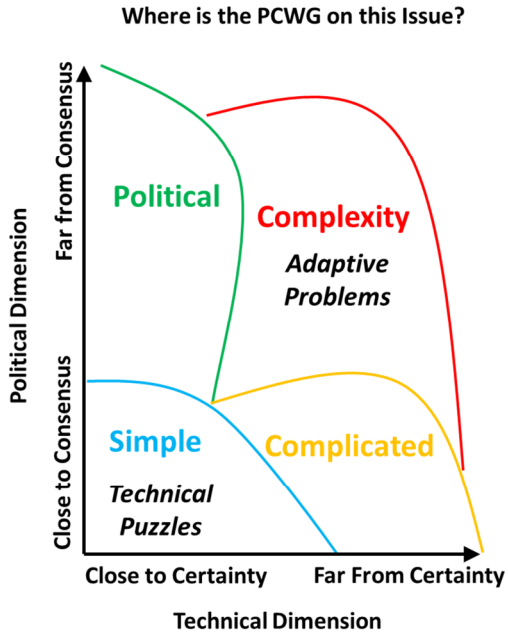

Figure 4a Outline of 'problem space'

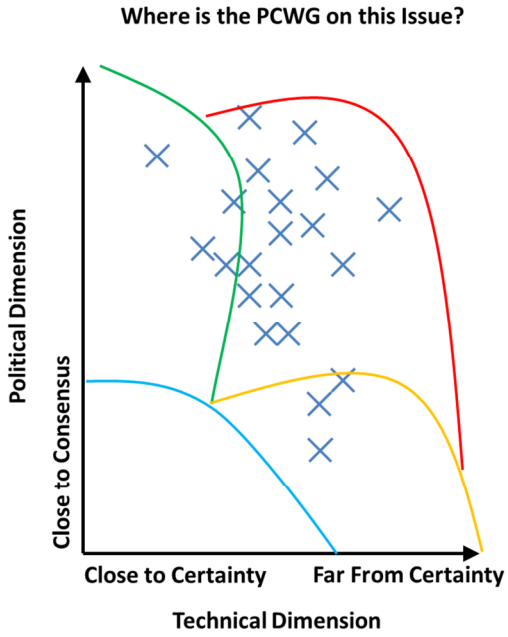

Figure 4b Recorded PCWG member opinions.

Potential for Future Uncertainty on IEC Uncertainty

The group briefly discussed the potential for a future round robin on the IEC Uncertainty methodology. One developer and IEC committee member suggested that a round robin might be a productive exercise in developing industry understanding of the draft standard. A developer suggested that an open benchmark may be a more practical option than a round robin. An IEC working member commented that the IEC working group are very receptive to the role of the PCWG in testing the methodologies proposed in the draft standard. The group agreed to revisit this issue as part of the 2015 PCWG roadmap.

Draft PCWG 2015 Road Map

The results of the recent 2015 roadmap survey were presented (see '04 PCWG 2015 Roadmap - Survey Results'). The format of the roadmap was briefly introduced by the presentation presented (see '05 PCWG 2015 Roadmap - A3 Report Introduction'). Finally the draft roadmap was presented to the group and the subsequent feedback is summarised in Table 1 (see '06 PCWG 2015 Roadmap -

Draft Roadmap'). The working group members are invited to submit further comments to the 2015 roadmap via email (PCWG@res-ltd.com).

Section	Comment	Status
Reasons For Action	Indicate values for inner and outer ranges are misleading and unhelpful e.g. offshore is different. Replace values with schematic/diagrammatic representation of inner/outer range.	Completed
Reasons For Action	Frequencies given for the inner and outer ranges are not meaningful as they will not be representation of all sites. Suggest removing example frequency values.	Completed
Reasons For Action	Change phrase 'power performance tests' to 'Power performance tests and associated warranties.	Completed
Current State	Change phrase 'power performance tests' to 'Power performance tests and associated warranties.	Completed
Target State	Add sentence indicating that consensus methods should present be in 'real world' resource assessment industry practice.	Completed
Gap	Current work has focused on the behaviour of the test turbine (where mast time series data is available). Currently there is currently no consensus method to extrapolate conclusions at the test turbine to all turbines e.g. extrapolation of shear and turbulence to all turbine locations.	Completed
Gap	No existing consensus method for modelling turbine performance in non-standard conditions in wake conditions.	Completed
Action	Develop methods for applying corrections for non-standard conditions across a wind farm in order to reduce 'by turbine errors' and facilitate the design of better wind farms.	Completed
Observations	No clear consensus method for determining long term representativeness of measured shear, turbulence etc.	Completed
Gap	Confusion over contractual and resource assessment contexts inhibits progress on is of turbine performance in non-standard conditions.	Completed
Action	Use power curve communication document to clarify the difference between the contractual and resource assessment context: • **Contractual Context**: Methods should be meaningful, but simple and practical. • **Resource Assessments**: Methods should be whatever gives the best (most accurate) P50 estimate.	Completed
Observations	No objective criteria for evaluating performance of correction methods.	Completed
Action	Develop objective criteria/framework for testing corrections for non-standard conditions.	Completed
Observations	No metric for describing both the energy context and 'bending' of a shear profile.	Completed

Table 2. Comments on Draft PCWG Roadmap

Discussion on Proposed PCWG Data Sharing Initiative

A presentation was made outlining a proposed data sharing initiative (see '07 PCWG 2015 Roadmap - Proposed Data Sharing Initiative'). The data sharing initiative is designed to navigate organisational boundaries by using the PCWG Open Source Tool to consistently analyse many proprietary datasets. It is proposed that the output of the individual participants will be aggregated by two academic institutions who will then share the final results.

The group briefly discussed the content of the data sharing initiative. One developer asked if it was possible to define an objective test for models which could be evaluated via the data sharing initiative. One manufacturer comment on the process of testing models via the data initiative saying that it could be as simple as computing the mean square error for a given model for a given set of conditions. The same manufacturer then commented on the potential to 'over-fit' any model developed via the data sharing initiative and therefore it was important to keep the 'training' dataset separate from the 'testing' dataset. One developer commented that the data sharing initiative should allow some interesting information to be assembled on uncertainties.

Overall the PCWG members were positive on the concept of the data sharing initiative and agreed that it should feature in the 2015 PCWG roadmap. In terms of kicking-off the initiative it was agreed that PCWG members would first be invited to give an expression of interest via a web form. The expression of interest will allow the PCWG to gauge if the level of likely participation is sufficient to justify running the initiative. The expression of interest form will allow prospective participations to outline what data they have (e.g. site classification) and what their level of participation will be (e.g. data only, analysis only, both data and analysis).

One manufacturer commented that it was their strongly held view that the data sharing initiative must distinguish between the behaviour of different turbine manufacturers. It was agreed that at least some results would be shared with all PCWG members right away, however some more detailed results will be restricted to participants who contribute data. This restriction will be lifted after some defined period has elapsed (e.g. one year).

Discussion of Energy Impact of Shear Profile 'Bending'

One manufacturer initiated a discussion on the use of proxy methods to represent wind turbine behaviour. The same manufacturer commented that in their view the Rotor Equivalent Wind Speed (REWS) concept was not sufficient to describe wind turbine behaviour and that some metric was required to represent the amount of 'bending' in the profile e.g. Figure 3 compares two profiles with the same REWS and different 'bendiness'.

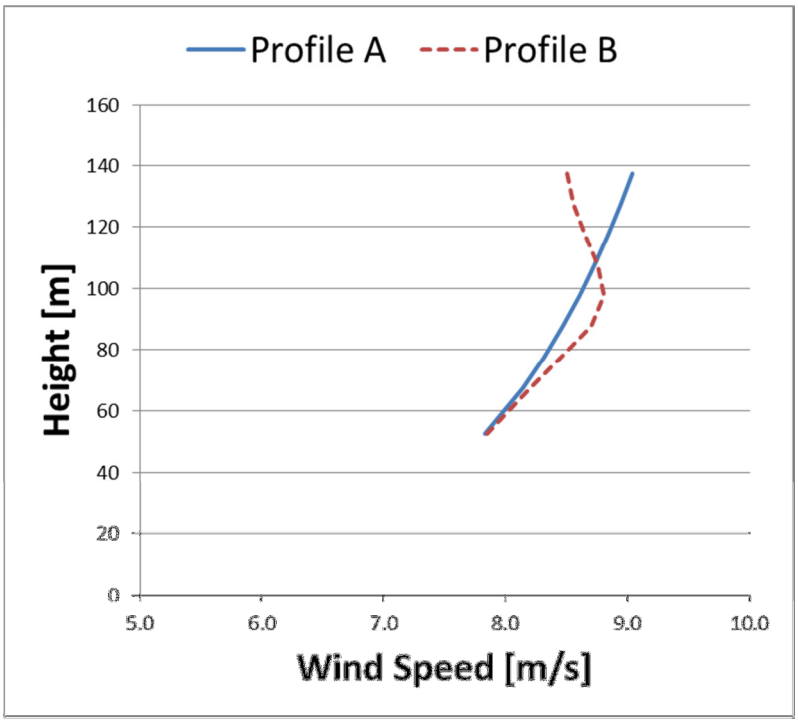

Figure 3. Comparison of two profiles with the same REWS, but different 'bendiness'.

The manufacturer commented that in their view proxy parameters (such as turbulence) can be useful in describing wind turbine behaviour under conditions associated with a stable atmosphere e.g. low turbulence and 'bending shear' (4th quadrant).

Afternoon Presentation Session:

- 08 Modelling type B effects in the 4th Quadrant - Richard Whiting (DNV GL)
- 09 Parameterised Turbine Performance - Stuart Baylis (Prevailing)
- 10 Redefinition of Power Curves Electric vs. Kinetic Power - Erik Tüxen (DNV GL)
- 11 Lidar observations of the compression zone and capabilities as a turbulence instrument - Peter Clive (Sgurr)
- 12 ANALYSIS OF REAL-WORLD TURBINE PERFORMANCE USING FORWARD-FACING NACELLE LIDAR - John Medley (ZephIR)

Proposed 2015 Meeting Schedule:

- May (date TBC): Glasgow (timed with IEC Meeting)
- June (date TBC): Riso DTU, Denmark
- September (date TBC): New Orleans, US (timed with AWEA Resource Assessment)
- October (date TBC): Vestas, Aarhus, Denmark
- December (date TBC): London, UK