Power Curve Working Group Meeting Minutes

Impact of Outer Range Conditions on Wind Turbine Power Performance
16th Meeting Minutes, Thursday 10th March 2016, Hamburg, Germany

Attending: Rebeca Rivera Lamata (Dong), Anders Sommer (Vattenfall), Daniel Marmander (Natural Power), Joerg Wanink (GE), Erik Tuxen (DNV GL), Gil Lizcano (Vortex), Andreas Stolten (Siemens), Axel Albers (WindGuard), Francisco Ariza (Barlovento), Carlos Andre Niederbacher Silva (Nordex), Herbert Schwartz (anemos-jacob), Tom Hall (EON), Iñaki Lezaun Mas (Gamesa), Gert Cool (AXYS Technologies), Harald Hohlen (Romo Wind), Nils Schlüter (Wind Consult), Frank Scheurich (Siemens), Alex Woodward (Zephir), Thomas Blodau (Senvion), Gaetan Martellozzo (EDF), Bert Gollnick (Senvion) & Peter Stuart (RES).

Objectives: To follow-up on the results of PCWG-Share-01

Presentations

01 PCWG Update and 2016 Roadmap, Peter Stuart (RES)
02 PCWG-Share-01 Current Status, Peter Stuart (RES)
03 Understanding the Power Curve Interpolation Issue, Axel Albers (WindGuard)
04 Power Curve Interpolation, Daniel Marmander (Natural Power)
05 Validation of Turbulence Enable Modelled Time Series & Mapping Inner and Outer Range, Gil Lizcano (Vortex)
06 Impact of the distance between mast and wind turbine on power curve measurement results, Herbert Schwartz (Anemos-Jacob)

Discussions

PCWG-Share-01

During the presentation *'PCWG-Share-01 Current Status'* the group co-ordinator stated that the PCWG-Share-01 results exhibited unexpectedly large baseline inner range normalised mean errors (NME). For convenience Figure 1 shows an adapted form of one the key slides from the presentation *'PCWG-Share-01 Current Status'.*

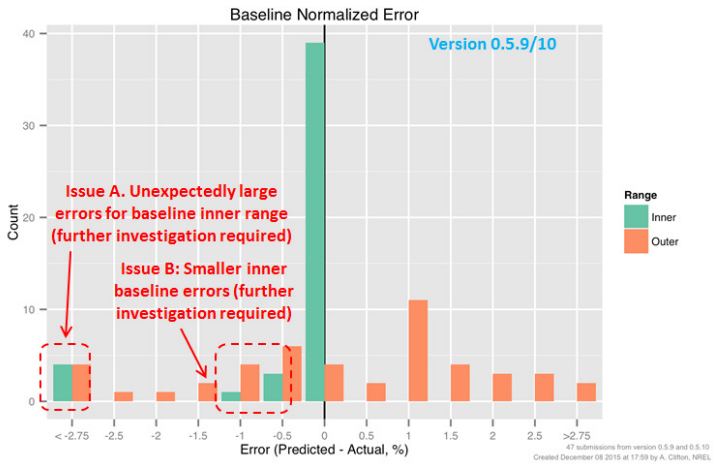

Figure 1. Unexpectedly large baseline inner range errors.

The group co-ordinator said that it had been expected that the baseline inner range NME values would be close to zero. The group co-ordinator stated that the unexpectedly large baseline inner range NME values were understood to be associated with two distinct categories:

A. **Erroneous Outliers**: Unexpectedly large errors for 4 datasets (left-hand peak in histogram). These outliers are understood to be related to a distinct issue affecting an isolated group of datasets (see presentation *'PCWG-Share-01 Current Status'* for further details).

B. **Interpolation Issue:** Smaller, though still unexpected, errors in the region of -0.5%. These values are understood to be related to the method used to interpolate the inner range power curve (see presentation *'PCWG-Share-01 Current Status'* for further details).

PCWG-Share-01 > Interpolation Issue

Two further presentations were then made by PCWG members on the 'Interpolation Issue':

02 'Understanding the Power Curve Interpolation Issue', Axel Albers (WindGuard)
03 'Power Curve Interpolation', Daniel Marmander (Natural Power)

Following the presentations the group discussed the interpolation issue. The core concepts are illustrated in Figures 2a and 2b.

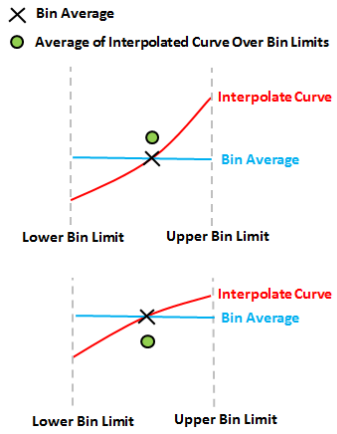

Figure 2a. Illustration of 'Interpolation Issue' at power curve ankle (top image) and power curve knee (bottom image)

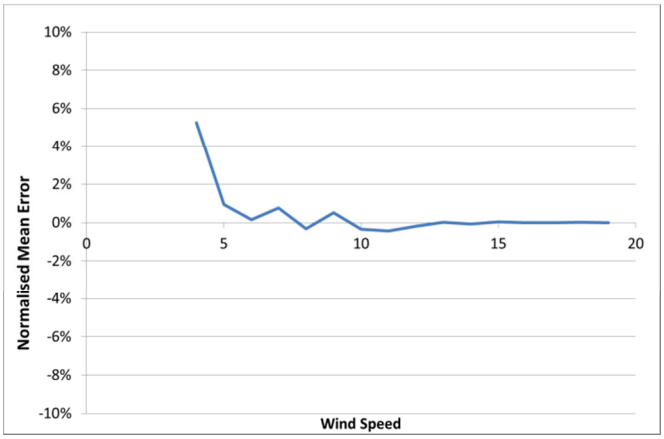

Figure 2b. Typical NME by wind speed signature of the interpolation issue.

One working group member commented that it should be possible to eliminate the issue by reducing the bin size. A developer member responded by saying that PCWG-Share-01 has been designed to maximise participation and that the 1m/s bin size had made it easier for participants to achieve sufficient data counts in each bin. A manufacturer commented that large errors near cut-in are unavoidable. A developer added that the current 'NME by wind speed' plots potentially over-represent the importance of low wind speeds in terms of energy content. A consultant commented that the interpolation issue could be avoided by working in the frequency-domain, however they also acknowledged the broader benefit of finding a solution that works in the time-domain.

The group discussed the merits of the potential solutions proposed in the presentations. The group agreed that the solution proposed in the presentation *'03 Power Curve Interpolation'* is preferable. The proposed method uses an iterative procedure to determine an adjusted set of points which when integrated from each bin start to the associated bin end will give a value equal to the bin average. The adjusted interpolated curve does not necessarily pass through the bin averages. The core concept of the proposed method is illustrated in Figure 3.

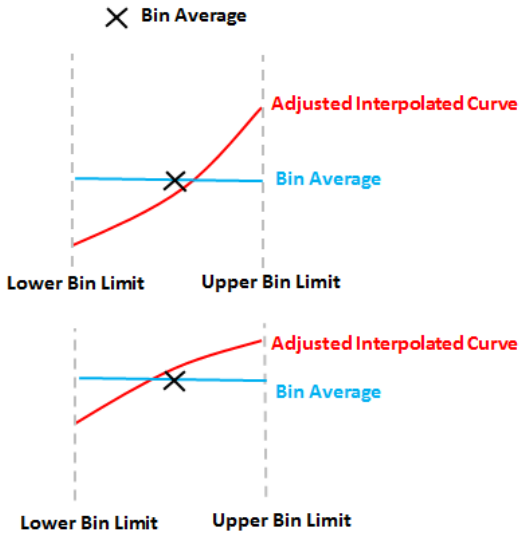

Figure 3. Proposed solution to the interpolation issue.

The group discussed the steps required in order to adopt the proposed solution to the interpolation issue in PCWG-Share-01. The follow sequence of actions was agreed:

1. **Excel Example**: Create an example calculation of the proposed method in Excel.
2. **PCWG Analysis Tool Implementation**: Implement the proposed method in the PCWG analysis tool and benchmark against the Excel example.
3. **Beta Release**: prepare a Beta Release of the revised Tool. Seek feedback on the new method from existing PCWG-Share-01 participants (have conference call to discuss). Target for feedback cycle to be completed by the May PCWG meeting.
4. **Re-run PCWG-Share-01**: once the new method is stable and tested re-run PCWG-Share using the new method.

One developer stated that it would be valuable to communicate the outcome of the interpolation issue investigations to MT12-1 at the May meeting (joint meeting between IEC61400-12-1 and IEC61400-15). The same developer added that the presentation should draw a distinction between the PCWG-Share-01 interpolation issue (resource assessment context) and the part of the draft power performance standard which concerns interpolation (adjustment of measured power curve to bin centres). The group co-ordinator agreed to propose an agenda item for this topic on the May meeting agenda.

PCWG-Share-01 > Erroneous Outliers

The group discussed the erroneous outlier results. For convenience Figure 4 is reproduced from the presentation *'02 PCWG-Share-01 Current Status'*. The group noted that the erroneous outliers are all

associated with large negative NME errors at high wind speeds. The group co-ordinator stated that the anonymous nature of the sharing initiative made it somewhat difficult to establish the reasons behind the erroneous outliers. The group co-ordinator agreed to work with the PCWG-Share-01 data aggregator (NREL) to investigate the reasons behind the erroneous outliers without compromising the anonymous principles of PCWG-Share-01.

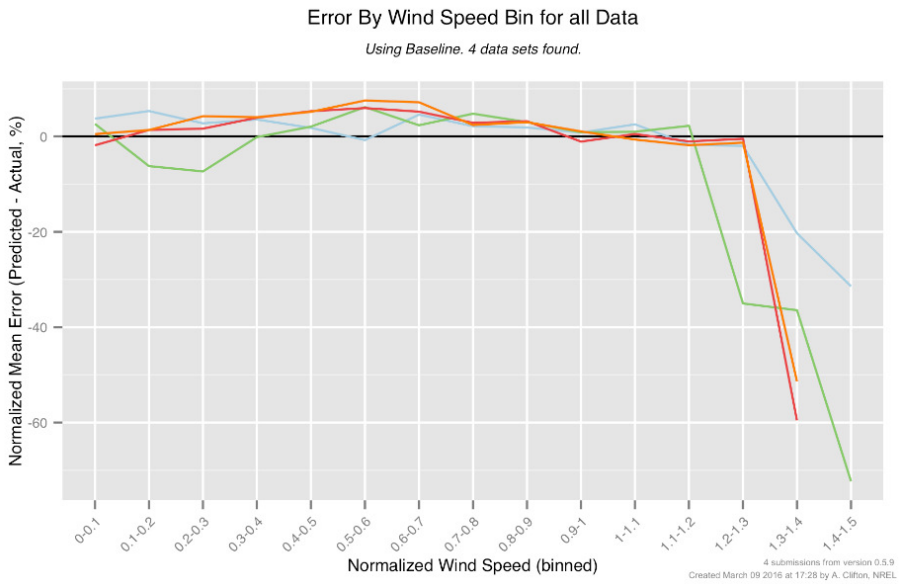

Figure 4. NME by wind speed for Erroneous Outlier datasets (the same datasets contributing to peak on the left hand side of Figure 1).

The group discussed how to avoid erroneous results in future sharing initiatives (PCWG-Share-X). The group agreed that future sharing initiatives should include additional quality checks so that erroneous outliers do not obscure the overall results. One manufacturer suggested that participants should still be encouraged to submit results datasets with erroneous results, however the data aggregator should partition the datasets into 'quality checks compliant' and 'erroneous' categories. The same manufacturer added that this would ensure that any important lessons were not lost by rejecting datasets. The group agreed with the suggested approach. The following criteria were proposed as defining 'quality checks compliant' submissions:

- Baseline Inner Range NME < 0.5%
- Baseline Inner Range by Normalised Wind Speed < 2% (for each individual wind speed bin)

The group agreed that the above criteria should be refined following feedback on the next Beta release of the PCWG Analysis Tool.

PCWG-Share-01 > Efficiency of Participation

The group discussed the efficiency of participation in PCWG-Share-01. Participants noted that, while efforts had been made to minimise the effort required to participate, it still took several minutes to re-run a portfolio of datasets. The group agreed that the PCWG Analysis Tool should be adapted so that a portfolio of PCWG-Share-X submissions can be re-run using 'one click'. The group also agreed that automated process should output a single zip file of the anonymous results and an overview spreadsheet containing the quality checks for all component datasets.

PCWG-Share-01 > Datasets Without Shear

The group discussed if the definition document for PCWG-Share-01 should be modified to allow datasets without shear to be submitted. The group co-ordinator estimated that relaxing the submission requirements in this way would expand the number of datasets submitted by around 10%. Several members expressed concern about aggregating results derived from a mixture of shear and no-shear datasets, in particular the fact that inner range definition would not have a consistent number of parameters. One member stated that in order to allow datasets without shear it would be necessary to analyse datasets consistently i.e. to execute a 'parallel approach' whereby datasets with shear were analysed as if they did not contain shear (in addition to the standard process). The group co-ordinator said that this was possible, but added that the group should be conscious of the effort required to implement such an approach and that the group needs to prioritise its efforts. After some discussion the group agreed that datasets without shear should not be admissible to PCWG-Share-01 for the time being. Nonetheless it was agreed that, where possible, the Analysis Tool should be adapted to allow datasets without shear to be investigated (outside of PCWG-Share-01). These amendments to the tool would support the inclusion of 'shearless' datasets in future sharing initiatives (PCWG-Share-X).

As an aside one working group member reminded the group that the inner range can be defined with any number of parameters i.e. the PCWG Inner-Outer Range Proposal does not mandate the use of any particular parameter or set of parameters. The working group agreed that the treatment of the Inner Range in the PCWG Analysis Tool should be made more flexible so that it can be defined with any parameter or set of parameters.

PCWG-Share-01 > Next Steps

The group agreed to work to resolving the outstanding issues ahead of the May PCWG meeting with a view to re-running PCWG-Share-01 (with solutions in place) after the May meeting.

PCWG-Share-02 > Next Steps

The group discussed the actions required to prepare new methods for inclusion in PCWG-Share-02. The group agreed the following actions:

Method	Action	Responsible
Rotor Equivalent Wind Speed with Upflow	Obtain LiDAR data which includes Upflow (an extended form of PCWG Dataset 1)	Peter Stuart
	Extend existing PCWG REWS consensus analysis for Dataset 1 to consider Upflow.	Iñaki Lezaun Mas
3D Power Deviation Matrix Method	Prepare draft consensus analysis and circulate for comment	TBC
Machine Learning	Obtain an open source training dataset (suitable for both machine learning and other statistical methods).	Peter Stuart
	Prepare simple Python code example and circulate for comment.	TBC

The group agreed that the methods in Annex E and F (Modified Turbulence Correction and Empirical Turbulence Correction) of PCWG-Share-X definition document should be removed for now. These

methods should not be included in a sharing initiative until they have been properly introduced to the group via a meeting presentation. Similarly the group agreed that the Analogue Ensemble method should be presented to the group before it can be progressed within PCWG-Share-X.

Using Modelled Data to Map the Inner and Outer Range

Gil Lizcano from Vortex made a presentation to the group entitled *'Validation of Turbulence Enable Modelled Time Series & Mapping Inner and Outer Range'*. The presenter stated that Vortex would like to share WRF LES modelled data with the PCWG purpose of modelling turbine performance in Outer Range Conditions.

Proposed Round Robin on IEC Uncertainty Methodology

The group discussed the PCWG 2016 roadmap action entitled *'The PCWG should perform a round robin of the uncertainty methods in IEC614-12-1'*. The group co-ordinator stated that a member of IEA Task 32 had been in touch regarding a planned round robin on uncertainty within IEC Task 32. The group agreed that it would be most productive for the PCWG to co-ordinate with IEC 32 and avoid duplication. The PCWG members agreed to focus on a producing a set of publically available worked examples on specific subcomponents of the IEC 61400-12-1 uncertainty methodology. The group agreed that these worked examples would serve as useful building blocks and help educate the wind industry on how to apply the IEC 61400-12-1 standard successfully.

One working group member expressed concern that round robins and work examples on the IEC Uncertainty methodology was a deviation from the primary objective of the PCWG (i.e. modelling turbine performance in Outer Range conditions). A different working group member said that they also felt these activities were somewhat of deviation, but said that the PCWG should work on these issues given that the 2016 roadmap was now finalised. The group co-ordinator stated that it has been previously agreed by the PCWG that the IEC uncertainty related activities should be 'minor actions' and should not dominant the group's work.

In conclusion the group agreed to focus on preparing a set of worked examples of the IEC 61400-12-1 uncertainty methodology and to leave the round robin to IEA Task 32. The group co-ordinator said that he would inform IEA Task 32 of the PCWG planned activities. The group agreed that it would be used for IEC Task 32 to present their results to the PCWG.

Rebeca Rivera Lamata agreed to prepare a high-level overview (e.g. flow chart) of uncertainty elements of IEC 61400-12-1 to help identify sections of the standard which would benefit from the PCWG preparing worked examples.

Working Examples of Non-Uncertainty Elements of IEC 61400-12-1

The group agreed to appraise if there are non-uncertainty elements of IEC61400-12-1 that would benefit from the PCWG preparing work examples showing how to correctly apply them.

Bert Gollnick agreed to prepare a high-level overview (e.g. flow chart) of non-uncertainty elements of IEC 61400-12-1 to help identify sections of the standard which would benefit from the PCWG preparing worked examples.

Proposed 'Reference Yield' Round Robin

The group discussed the potential to have a 'reference yield'[1] round robin, with the following inputs and outputs:

Inputs	Output
• Power Curve • Wind Frequency Distribution • Air Density	'Reference Yield' in MWh

One working group member stated that, while in principle it should be trivial to calculate reference yield, they had observed differences of around ±0.5%. The group agreed that members should be advised to use their normal software for the purposes of the round robin (as opposed to performing the calculation form first principles in excel or similar).

The group agreed to target the circulation of a draft exercise in advance of the May meeting and completion of the exercise by the September meeting.

[1] The group co-ordinator will confirm the correct IEC61400-15 term for 'reference yield'.