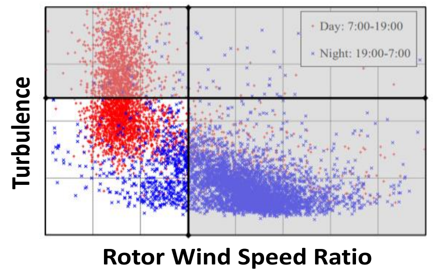
Power Curve Working Group 2016 Roadmap

WWW.PCWG.ORG

Background: Reasons For Action

- **Real world wind conditions** are composed of both inner range and outer range wind conditions:
  - **'Inner range conditions'** refers to moderate rotor wind speed ratio†, moderate turbulence intensity, moderate upflow etc.
  - **'Outer range conditions'** refers to high turbulence, low turbulence, high rotor wind speed ratio, low rotor wind speed ratio, large upflow etc.
- **Outer range conditions are relatively frequent** and therefore the calculation of turbine power output in outer range conditions is an important consideration in wind energy resource assessment. There are **no industry consensus methods** for predicting wind turbine power output in outer range conditions for the purposes of resource assessment. Corrections can be subdivided into:
  - **Type A Corrections**: describing variations in the amount of energy available for conversion at a given wind speed (in outer range conditions).
  - **Type B Corrections:** describing variations in the conversion efficiency of a wind turbine at a given wind speed (in outer range conditions).
- The industry holds **many isolated proprietary datasets** with the potential to help unlock a greater understanding of wind turbine performance in outer range conditions.



† rotor wind speed ratio is defined as:

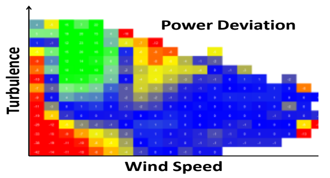
- RSWR = U(z_H+ ¾R) / U(z_H- ¾R), where U(z) is the wind speed profile as a function of height, z_H is the turbine hub height and R is the turbine rotor radius.

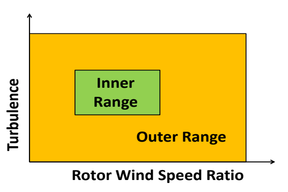
Current Wind Industry State

- There are no industry consensus methods for predicting wind turbine power output in outer range conditions for the purposes of resource assessment.
- The lack of a validated industry consensus methods for predicting power output in outer range conditions (for resource assessment applications) increases the risk perceived by wind energy investors.
- The existing PCWG data sharing initiatives (PCWG-Share-01), while promising, contains some erroneous outlying results which somewhat obscure the impact of outer range conditions on wind turbine performance.
- **Power curve** documentation is often ambiguous with respect to turbine performance in outer range conditions which hampers efforts to model outer range performance.
- Power performance tests and associated warranties are normally limited to a relatively narrow range of idealised conditions i.e. inner range conditions.
- Investors often do not appreciate which conditions are warranted and which are not. This ambiguity combined with the failure to consider outer range conditions in power performance tests increases the risk perceived by wind energy investors.

Target Wind Industry State

- Well document and validated consensus methods for predicting wind turbine power output in outer range conditions for the purposes of resource assessment. These methods should have been communicated to, and are understood by, the investment community.
- Improvements in modelling and understanding will have reduced outer range modelling uncertainty by half (relative to the baseline set by PCWG-Share-01). Consensus methods embedded in real world resource assessment industry practice. Reduced resource assessment risk perceived by wind energy investors.





- Harmonised communication of power curve information so that corrections for outer range conditions can be unambiguously applied.
- Enhanced sharing of data through multiple PCWG initiatives (PCWG-Share-X) and improved methodology/processes to eliminate/correct erroneous outlying datasets.
- Power performance tests routinely make some consideration of outer range conditions.
- Investors understand which conditions are warranted and which are not. This improved understanding has reduced power performance risk perceived by wind energy investors.

Reasons for gap between current and target

- Several empirical (proxy) methods are available which tie observed turbine performance to key (frequently measured) parameters such as turbulence intensity and rotor wind speed ratio. However, there is a lack of industry consensus regarding which proxy methods are best.
- Current power curve documentation can make the application of corrections for outer range conditions difficult e.g. it can be hard to tell if a power curve is defined for hub wind speed, rotor equivalent wind speed or both.
- The existing data sharing initiative (PCWG-Share-01), while promising, has certain failings (e.g. influence of erroneous datasets) which obscure the effect on outer range conditions on wind turbine performance.
- Confusion over contractual and resource assessment contexts inhibits progress on is of turbine performance in non-standard conditions.
- There are no industry standard tools for applying existing methods for modelling power output in outer range conditions.

PCWG 2016 Actions

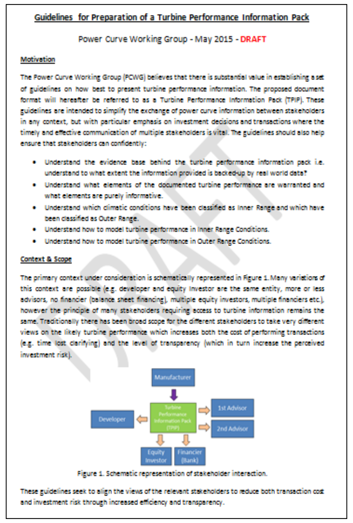
Improved Understanding of Outer Range Performance:

- Examine new engineering methods for predicting wind turbine output in non-standard conditions e.g. 3D Power Deviation Matrix Methods, Production by Height, Machine Learning
- Define the uncertainty associated with modelling outer range conditions.
- Explore new and/or novel methods which address Type B effects.
- Use aero-elastic models to examine the physical reasons for observed performance in outer range conditions.
- Try and close the gap between engineering models, full aero-elastic models and observations.
- Examine the performance of the IEC 61400-12-1 density correction method.

Improved Understanding of Inner Range Performance:

- Examine Inner Range Performance as well as Outer Range Performance
- Define the uncertainty associated with modelling Inner Range Performance
- Define an adjustment framework for Inner Range Performance

- Continue to develop a document to harmonise the communication of power curve information



Guidelines for Preparation of a Turbine Performance Information Pack

Power Curve Working Group - May 2015 - DRAFT

Motivation

The Power Curve Working Group (PCWG) believes that there is substantial value in establishing a set of guidelines on how best to present turbine performance information. The proposed document format will hereafter be referred to as a Turbine Performance Information Pack (TPIP). These guidelines are intended to simplify the exchange of power curve information between stakeholders in any context, but with particular emphasis on investment decisions and transactions where the timely and effective communication of multiple stakeholders is vital. The guidelines should also help ensure that stakeholders can confidently:

- Understand the evidence base behind the turbine performance information pack i.e. understand to what extent the information provided is backed-up by real world data?
- Understand what elements of the documented turbine performance are warranted and what elements are purely informative.
- Understand which climatic conditions have been classified as Inner Range and which have been classified as Outer Range.
- Understand how to model turbine performance in Inner Range Conditions.
- Understand how to model turbine performance in Outer Range Conditions.

Context & Scope

The primary context under consideration is schematically represented in Figure 1. Many variations of this context are possible (e.g. developer and equity investor are the same entity, more or less advisors, no financier (balance sheet financing), multiple equity investors, multiple financiers etc.), however the principle of many stakeholders requiring access to turbine information remains the same. Traditionally there has been broad scope for the different stakeholders to take very different views on the likely turbine performance which increases both the cost of performing transactions (e.g. time lost clarifying) and the level of transparency (which in turn increase the perceived investment risk).

Manufacturer → Turbine Performance Information Pack (TPIP) → Developer, 1st Advisor, 2nd Advisor, Equity Investor, Financier (Bank)

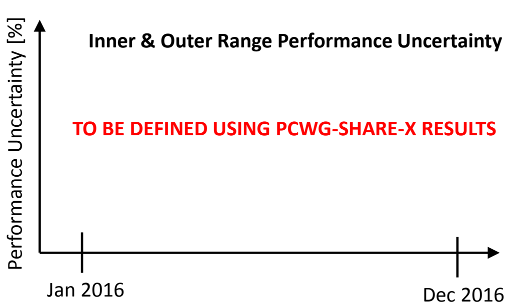
Figure 1. Schematic representation of stakeholder interaction.

These guidelines seek to align the views of the relevant stakeholders to reduce both transaction cost and investment risk through increased efficiency and transparency.

- Build upon PCWG-Share-01 and perform additional intelligence sharing initiatives (PCWG-Share-X). **Expand to 100 datasets, including 20 remote sensing.**
- Develop the PCWG Analysis Tool to help members explore their data and support future intelligence sharing initiatives (PCWG-Share-X).
- Continue to develop the Analysis Tool so that it becomes a power performance tool which is compliant with IEC61400-12-1
- The PCWG should perform a round robin of the uncertainty methods in IEC614-12-1
- Prepare a summary document/paper of the PCWG work to date to help disseminate its conclusions throughout the wind industry

Confirmed State

This box will be updated over the course of 2016.



Guidelines Document Status:

- **DOCUMENT IN DRAFT**
- **DOCUMENT TO BE RESTRUCTURED AS A CHECKLIST**

PCWG-Share Status:

- **50/100 Datasets, 4/20 Remote Sensing**
- **Erroneous Datasets**
- **Unresolved Interpolation Issue**

IEC 61400-12-1 Uncertainty Round Robin Status: **NOT STARTED**

Summary Document Status: **NOT STARTED**

Observations & Follow Up Actions

- The PCWG seeks to act in harmony with both the IEC61400-12 and IEC61400-15 groups. The PCWG seeks to facilitate complimentary activities to support the development of both standards e.g. publication of worked examples of the methods defined in the standards, development of tools which implement the methods defined in the standards, feedback to and dialog with the standards committees etc.
- No metric for describing both the energy context and 'bending' of a shear profile.

Possible future work (for 2017):

- Extend models for predicting outer range performance from the 'turbine scale' to the 'wind farm scale'
- Extend models for predicting outer range performance from 'free stream' to 'waked flow'
- Examine the impact of instrument response (e.g. anemometer response) on the analysis of wind turbine performance.
- Examine methods for determining long term representativeness of measured shear, turbulence etc.