From real wind to actual power output – adjusting IEC TI and REWS correction

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Motivation and goals

Deliver accurate predictions of wind turbine power performance in all environmental conditions.

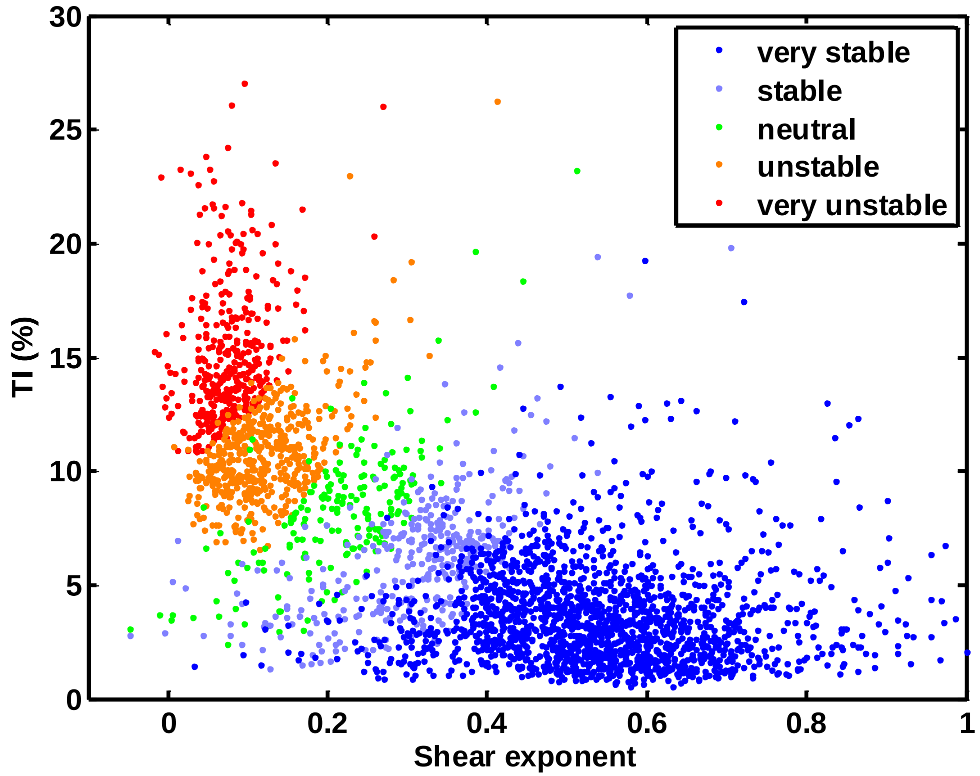
Present work will:

- ✓Illustrate typical variation of wind parameters for a flat terrain site and their impacts on measured power performance
- ✓Evaluate and improve industry standard methods for prediction/correction of power performance variations
- ✓Leverage updated methods to assess typical power performance questions

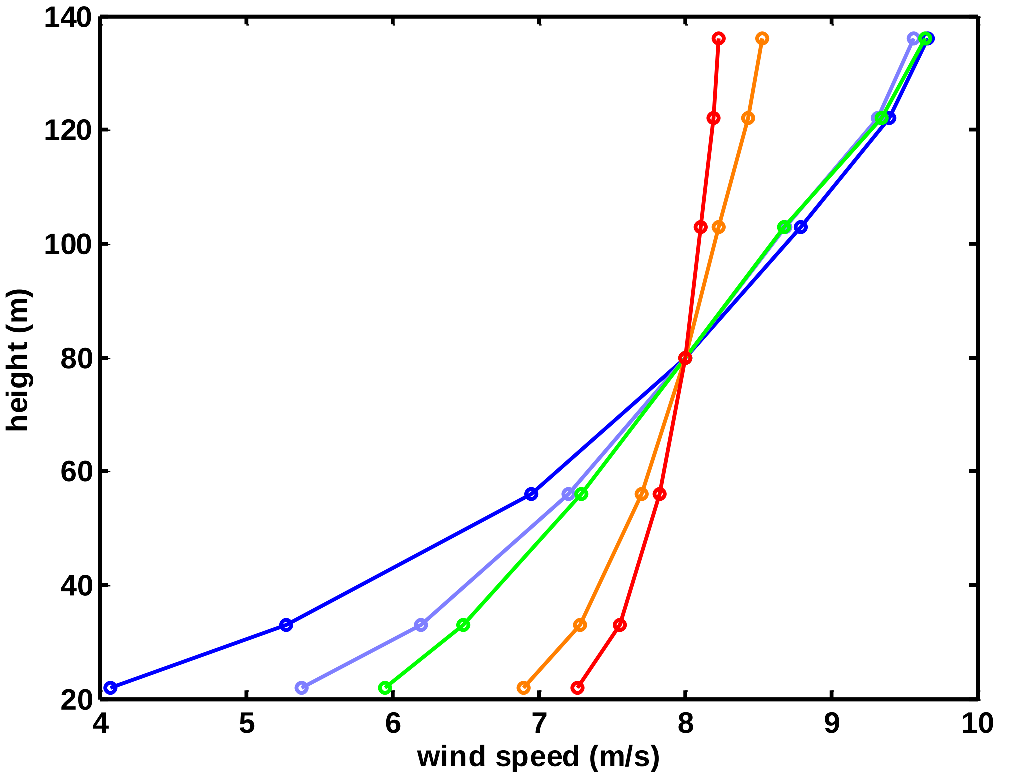
Wide variation of wind parameters…

Observations from 3 month of winter wind conditions during a power curve test at a flat US site

Turbulence intensity vs shear exponent (all wind speeds)



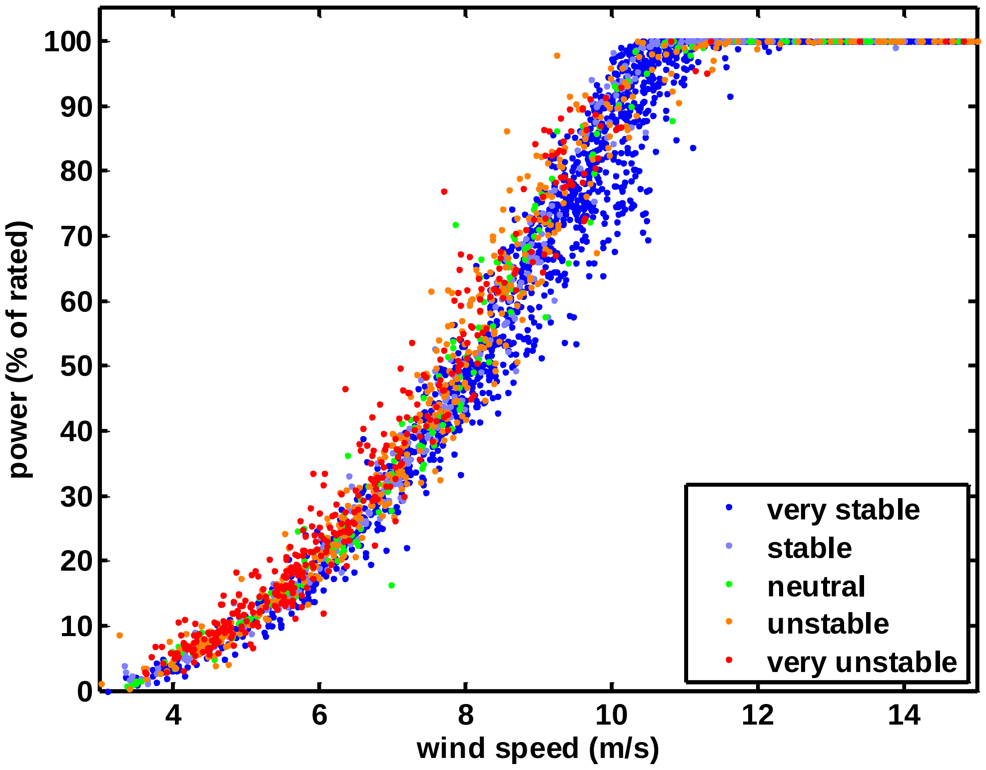
Stability classified wind profiles (all data in 8m/s bin)



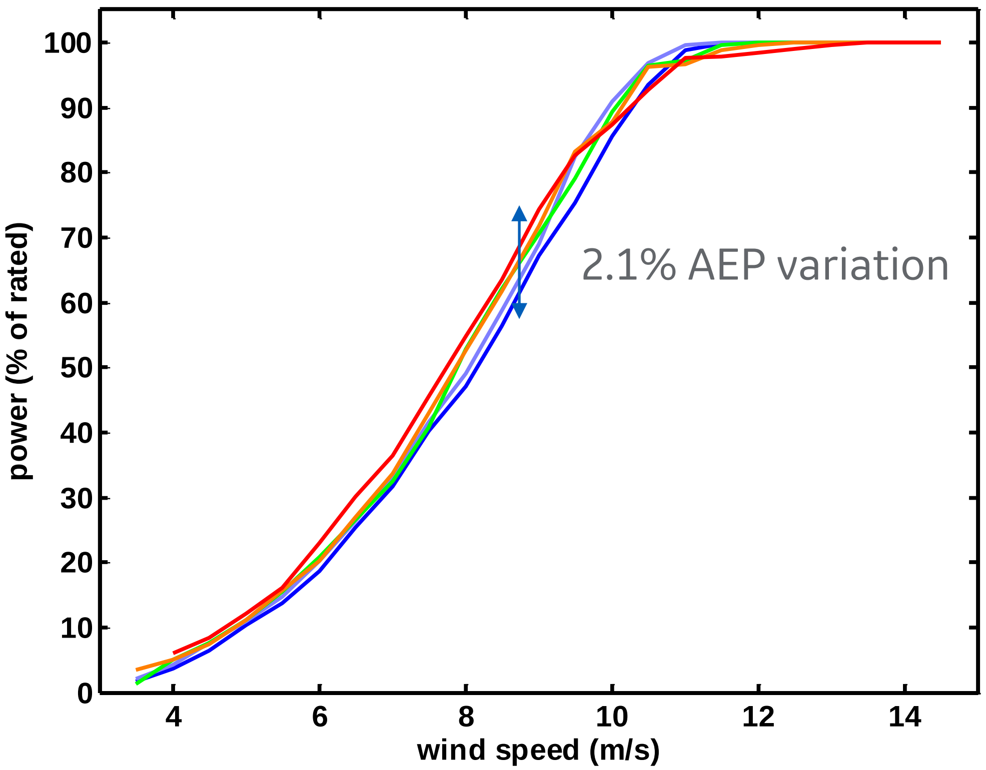
… results in power performance variations

Observations from 3 month of winter wind conditions during a power curve test at a flat US site

10min averaged power curve scatter plot



Bin average power curves per stability class



IEC standard normalisations

Air density

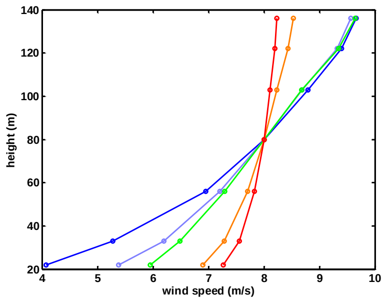
- Wind speed normalization based on first principle that the incoming energy flux is proportional to air density.

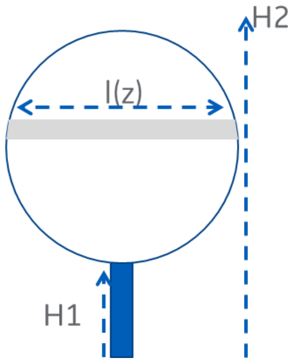
$$v_i^{\,n} = v_i \left(\frac{\rho_i}{\rho_{\mathrm{ref}}}\right)^{\frac{1}{3}}$$

- Air density correction is broadly used and was introduced in the 12-1 Edition 1. It is known that it is accurate enough only for small air density variations around the reference.

Wind shear (Annex P, 12-1 Ed. 2)

- Extrapolation of first principle to non-homogeneous flow. Assumes turbine extracts energy as per the average of cubed wind speed accross rotor disk.



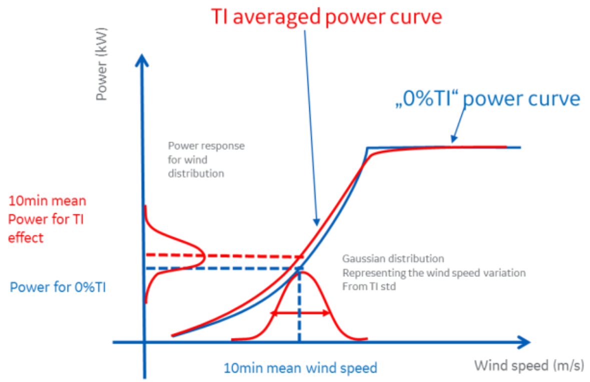


$$f_{meas} = \left[\frac{\int_{H1}^{H2} l(z)\left(\cos(Phi(z))\frac{v_i(z)}{v_i(z_0)}\right)^3 dz}{\int_{H1}^{H2} l(z)\, dz}\right]^{1/3}$$

$$v_i^{\,n} = v_i \frac{f_{meas}}{f_{ref}}$$

Turbulence intensity (Annex M , 12-1 Ed. 2)

- Models turbulence effect as the averaging of a 0%TI steady wind power curve. Assumes turbine tracks all the turbulence scales.

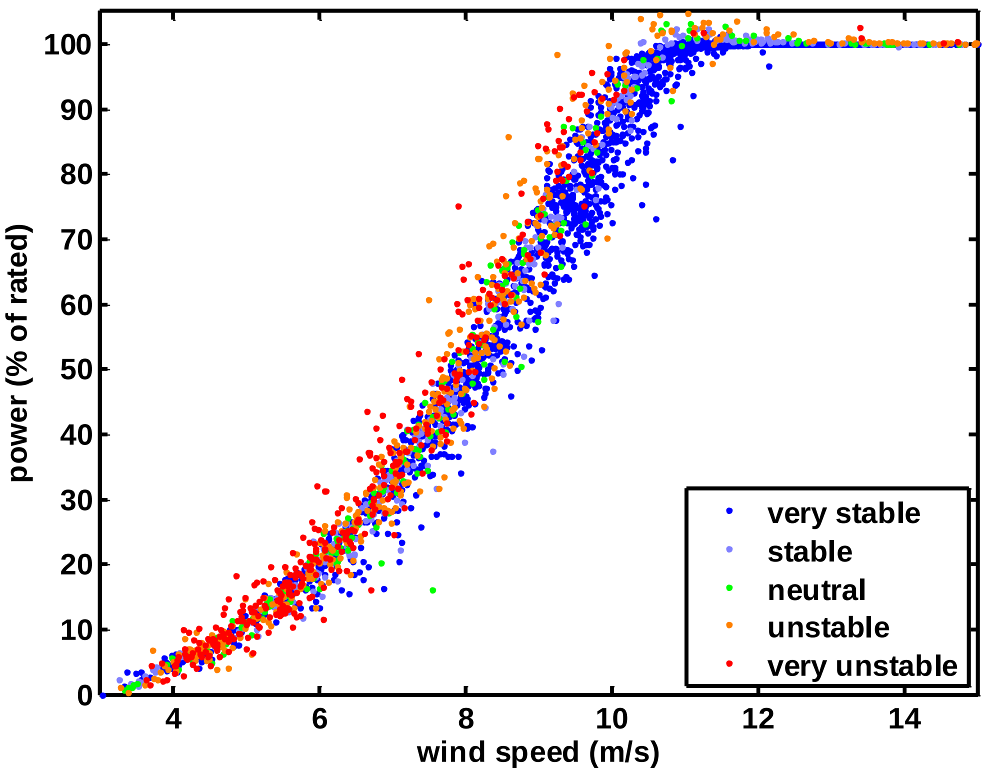


$$P_{meas,cor} = P_{meas,uncor} - P_{est,meas\ TI} + P_{est,ref\ TI}$$

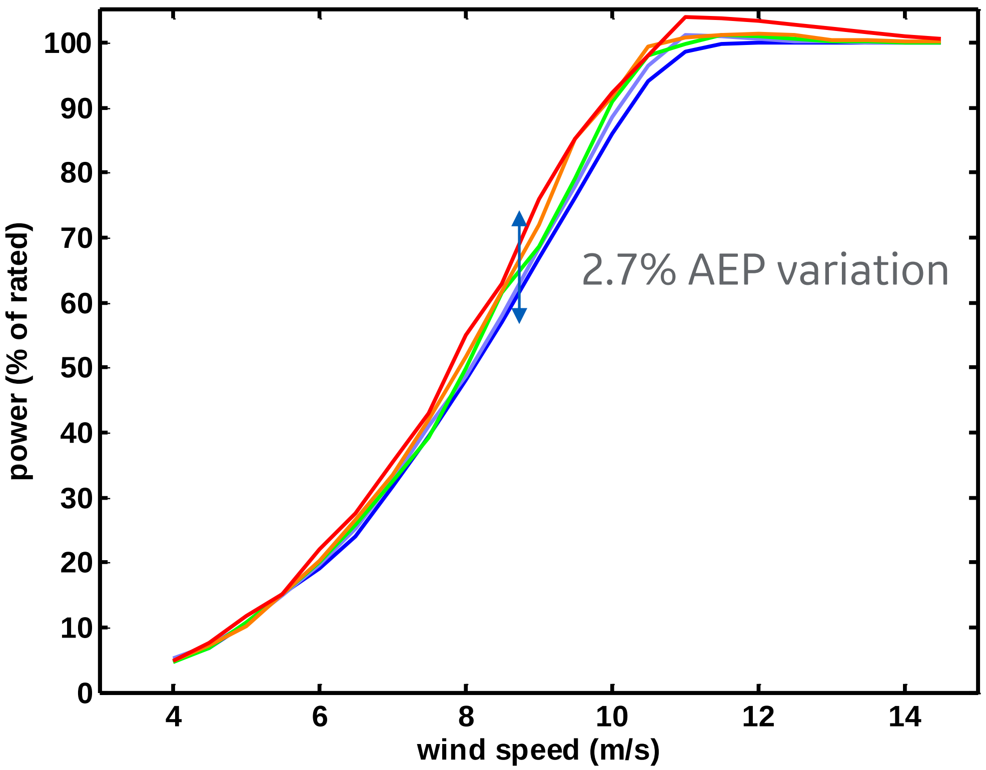
How well do they work?

Result of IEC wind shear and turbulence normalisation

10min averaged power curve scatter plot



Bin average power curves per stability class

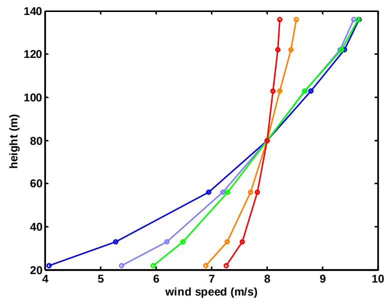


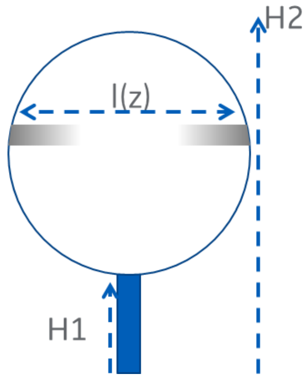
We do not observe that the IEC-12-1 Ed.2 normalisations reduce power performance variations

How can we improve this?

Adjusted wind shear normalization

- Each turbine has a specific ability to convert a wind profile into power, which can be modeled (e.g. depends on blade section contributions to power production).



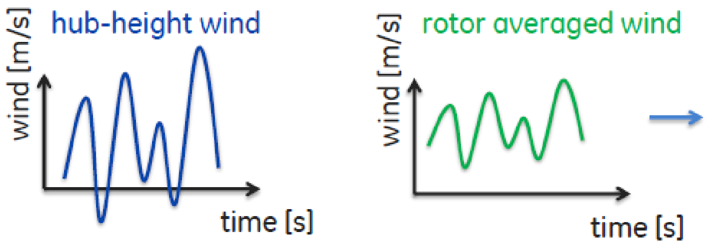


$$f_{meas} = \left[\frac{\int_{H1}^{H2} l(z) \left(\cos(Phi(z)) \frac{v_i(z)}{v_i(z_0)} \right)^n dz}{\int_{H1}^{H2} l(z)\, dz} \right]^{1/n}$$

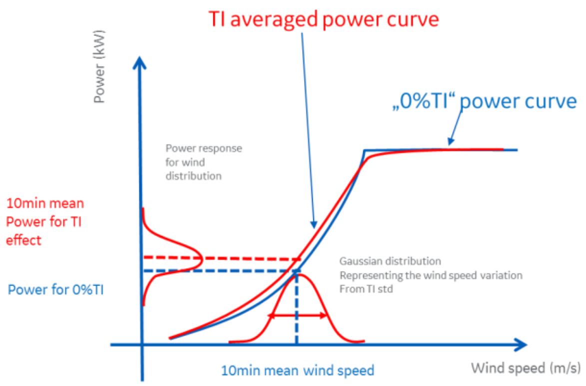
$$v_i{}^n = v_i \frac{f_{meas}}{f_{ref}}$$

Adjusted turbulence intensity normalization

- Small turbulence scales are not spatially correlated and averaged by the rotor. This reduces the turbulence intensity which drives the turbine‘s response.



$$\rightarrow \quad TI_{RA} = \alpha\, TI_{HH}$$

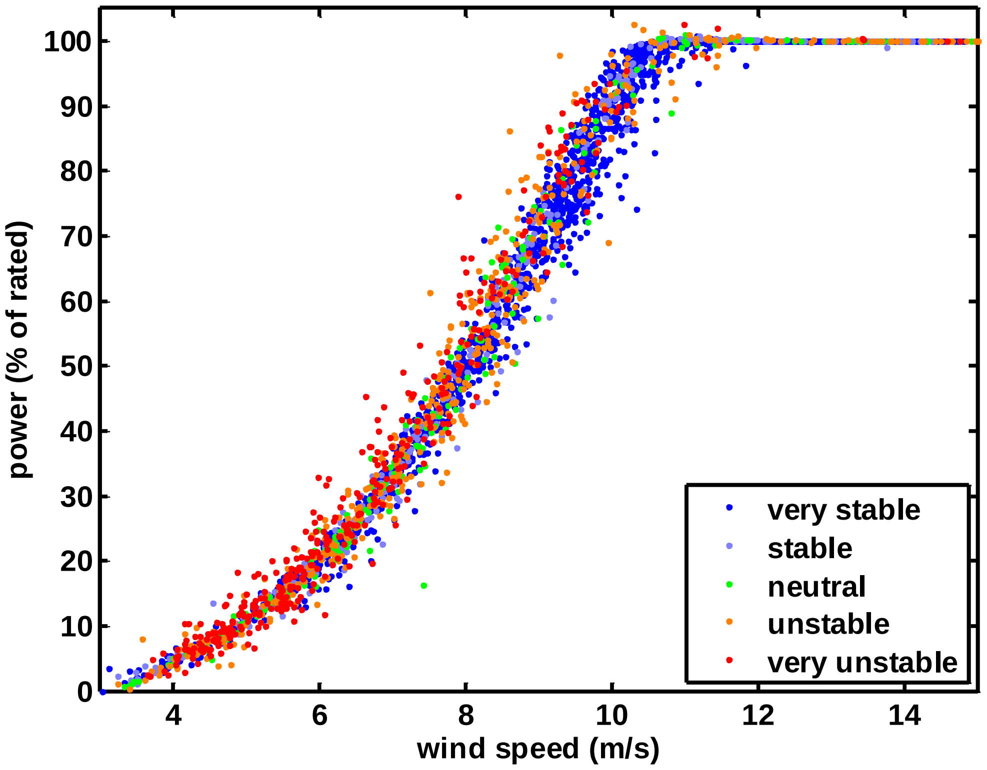


$$P_{meas,cor} = P_{meas,uncor} - P_{est,meas\ TI_{RA}} + P_{est,ref\ TI_{RA}}$$

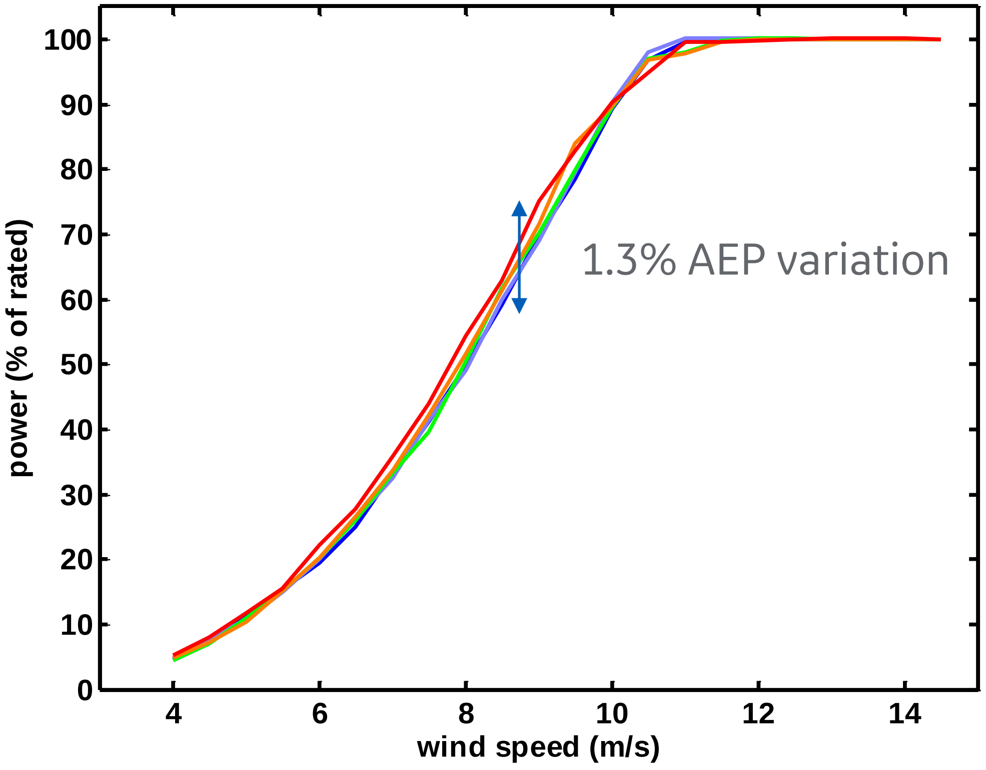
And now…

Result of application of adjusted REWS normalization and TI corrections

10min averaged power curve scatter plot



Bin average power curves per stability class



After this update, these normalisations greatly reduce power performance variations

Answering typical power performance questions

Leveraging these methods allows to evaluate variations on a longer data sets and broader range of conditions

1. How to estimate a site specific power curve from WRA?
2. How important is it to conduct WRA above hub-height?
3. What is the uncertainty of short IEC PC tests for a given site?
4. What are the pros/cons of different power curve definitions?

1. How to estimate a site specific power curve from WRA?

Simplified description – not accounting for variations of some key environmental parameters (wakes, upflow, etc). We presently only consider the effects of horizontal wind speed and direction vertical profiles.

WRA input data

10 min time series for:

- ρ_i (air density)
- v_i (hub-height wind speed)
- TI_i (hub-height TI)
- $f_{meas,i}$ from wind speed and direction profile
- etc

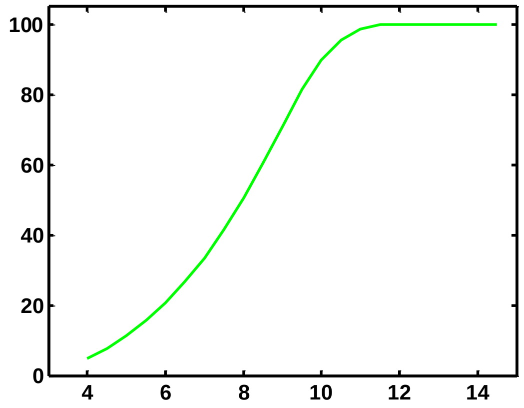
Initial power curve (Provided for reference shear and TI conditions) → Power distribution adjusted for shear and air density → Power distribution adjusted for shear, density and TI → Site specific power curve

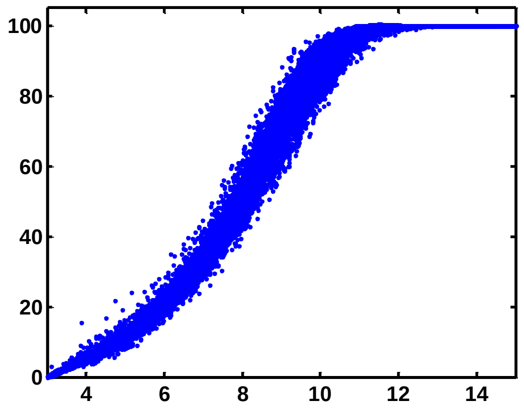
$$P = PC_{ref}(v)$$

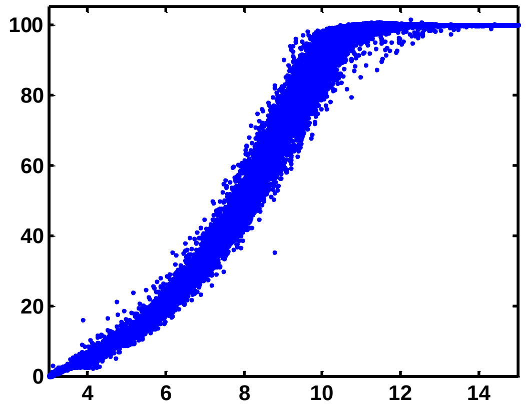
$$v_i{}^n = v_i \frac{f_{meas,i}}{f_{ref}} \left(\frac{\rho_i}{\rho_{\mathrm{ref}}}\right)^{\frac{1}{3}}$$

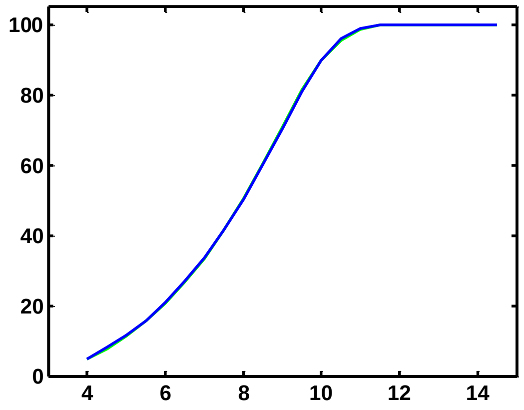
$$P_{cor,i} = PC(v_i{}^n) + P_{est,\alpha TI_i} - P_{est,\alpha TI_{ref}}$$

$$P = PC_{site}(v)$$



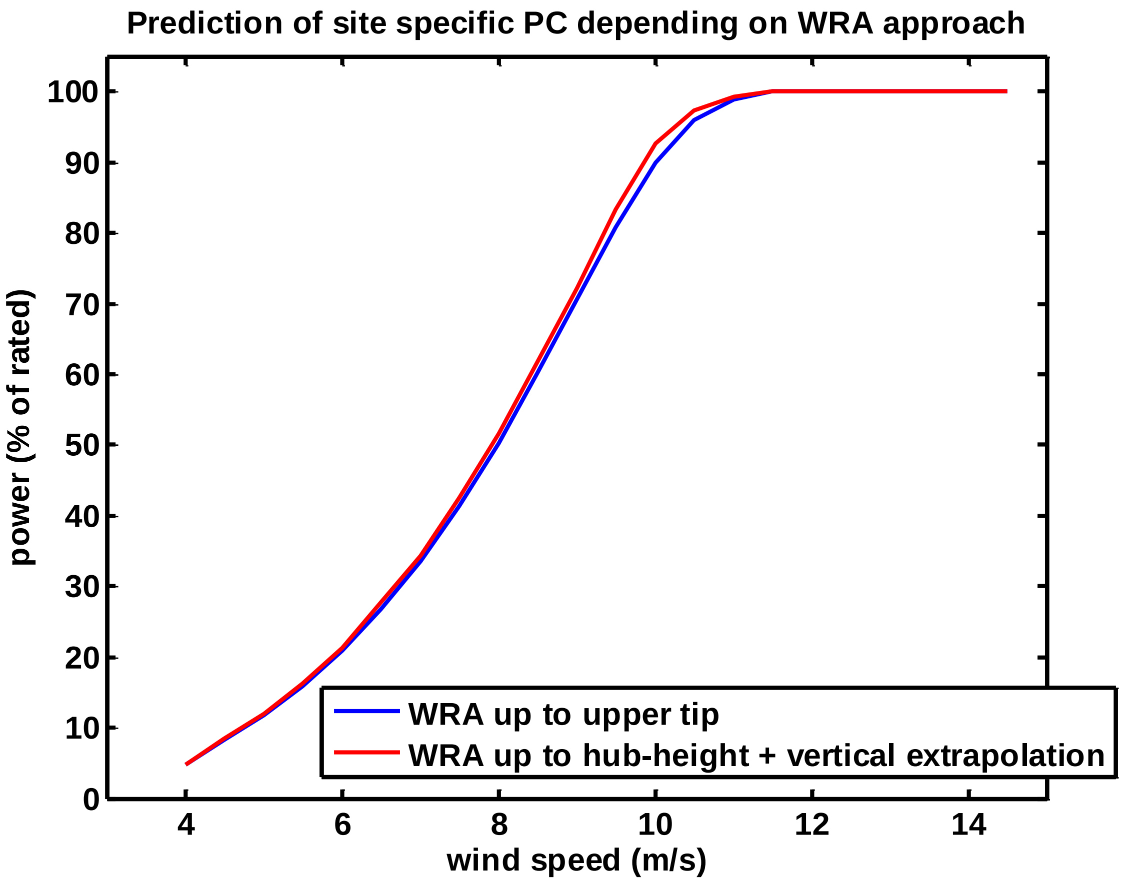






2. How important is it to conduct WRA above hub-height?

Application to one flat US site

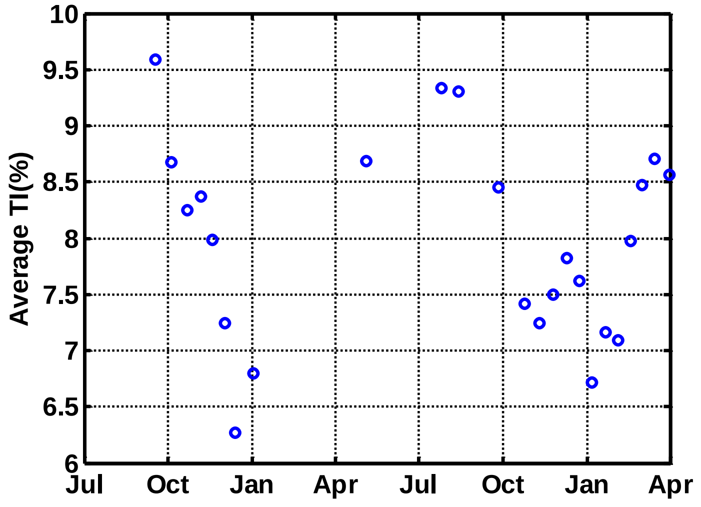


AEP is overpredicted by 1.5% if one assumes a power law shear profile above hub-height

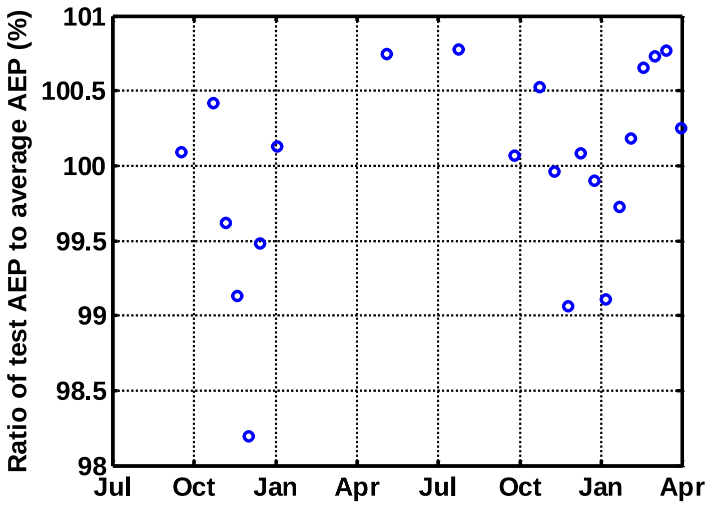
3. What is the uncertainty of short IEC PC tests for a given site?

Split 1.5 year of WRA data into several sub-periods equivalent to one IEC PC test duration.

Average TI during IEC test period



Average estimated AEP during each period



While only accounting for TI and shear effects, this site would result in:

~3% min/max AEP variation between different test periods

~1.5% AEP standard deviation overall

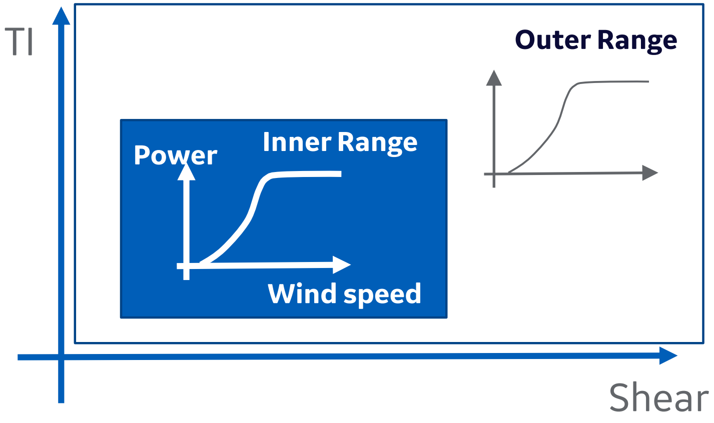
How can we reduce test to test AEP variations?

4. Power curve definition – potential evolutions

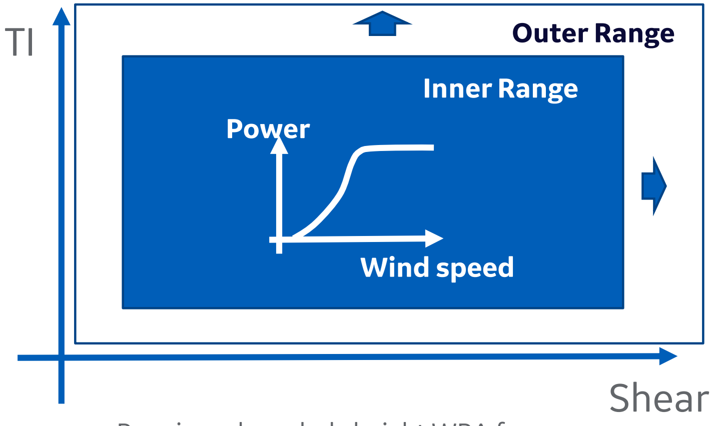
Addressing the need to predict power performance in all conditions (no or fully reducing filtering)

Different approaches can be adopted retaining hub-height wind speed as a reference:

a. Add an „Outer Range“ power curve to account for typical performance in abnormal conditions

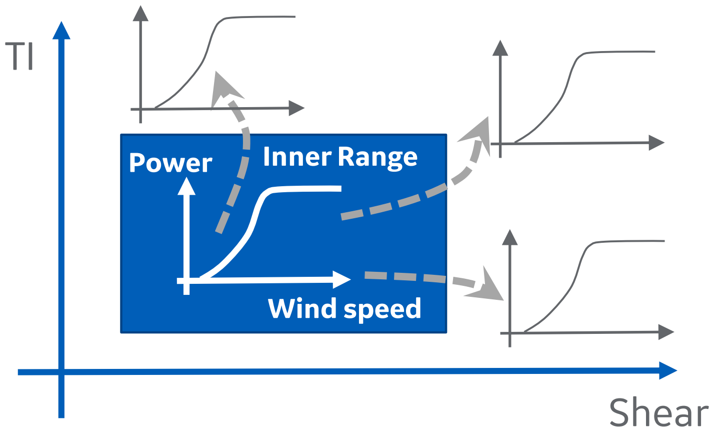


b. Extend the Inner Range by predicting a site specific hub-height average power curve from wind ressource assessment



- Requires above hub-height WRA for power curve prediction

c. Translate the Inner Range PC to any other wind condition using adjusted REWS and TI correction



- Requires above hub-height WRA for energy assessment and during PC testing

4. Power curve definition – performance metrics

Improvements with respect to what matters for power curve definition

	Inner / Outer range	Site specific power curve	Adjusted REWS and TI normalization
Increases AEP accuracy for site	-	++	++
Increases AEP repeatability during PC tests	+	+	++
Increases amount of PC test data (less filtering of test data)	++	+	++
Simple to implement	++	+	-

No method seems perfect so far. Going forward, several approaches can be adopted to meet customers needs.

Take-aways

- Wide variation of wind parameters influencing power performance occurs accross sites, but also within a site.
- New approaches are needed to improve IEC wind shear and turbulence normalization methods
- Wind ressource assessment above hub-height is critical to predict correctly power performance on a specific site
- To reduce power performance uncertainties, power curve publication needs to evolve.