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Turbulence Intensity normalisation of power curves and large-scale fleet validation

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Abstract

Turbulence Intensity (TI or I) **affects wind turbine power curve** analysis when performed using 10-minute datasets. This influence has been well documented, its mathematical component is understood and its influence on the Power Curve (PC) characterised.

Over the years, **methods have emerged to counteract the resulting bias** on PC and, since its update in 2017, the **IEC 61400-12-1** [1] has also added a method for turbulence intensity correction, annex M. Although informative, this annex provides a common ground to deal with this issue that should be used by the wind industry.

Unlike air density normalisation of the wind speed, the approach for **TI correction** can feel **more convoluted**. This perceived high complexity can be seen as a barrier to entry by data analysts and could explain its low adoption by the community.

In this study, we assess the effect of the IEC annex M methodology when applied to wind **measurement from SCADA**, rather than undisturbed met mast or lidar measurements.

Fundamentals: Turbulence Intensity Normalisation

The global aim of the turbulence normalisation, or normalisation, is to correct the power signal and to reduce the bias induced, in part, by the mathematical averaging process of the dataset over a 10min period. The process can't be fully described here but is publicly accessible [2], [1]. The correction is applied as follow:

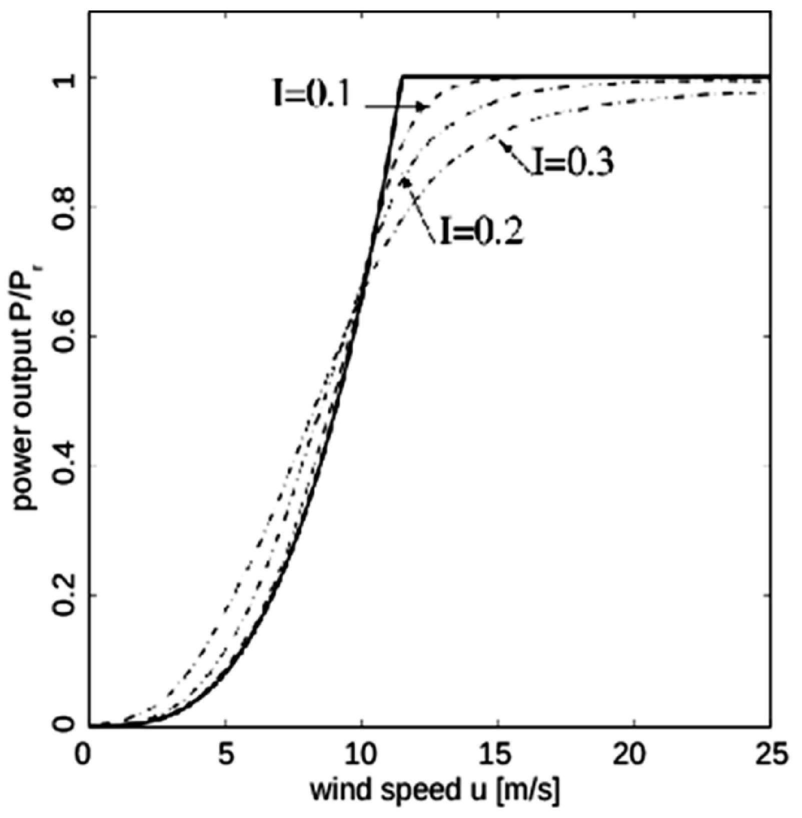
$$\overline{P_{I_{ref}}(v)} = \overline{P(v)} - \overline{P_{sim,I}(v)} + \overline{P_{sim,I_{ref}}(v)}$$

Where $\overline{P_{I_{ref}}(v)}$ is the normalised power output, $\overline{P(v)}$ is the mean measured power output, $\overline{P_{sim,I}(v)}$ and $\overline{P_{sim,I_{ref}}(v)}$ are the power outputs for, respectively, the measured TI and the reference TI. These P_{sim} are derived using:

$$\overline{\mathrm{P_{sim}(v)}} = \int_{v=0}^{\infty} \mathrm{P_{I=0}}(v).\mathrm{f}(v)dv$$

Where $\mathrm{P_{I=0}}(v)$ is the Zero-Turbulence PC function and $\mathrm{f}(v)$ is the wind distribution within the 10min period. As the latter is never stored, $\mathrm{f}(v)$ is almost always approximated by $\mathrm{g}(v)$, a standard gaussian function.

The determination of the $\mathrm{P_{I=0}}(v)$ itself is an iterative process that involves the computation of an initial PC, its binned wind speed and TI as well as prior knowledge about the studied wind turbine. The TI correction is applied after the air density normalisation on each 10min point of the dataset.



The main expected effect of the normalisation on the dataset is obviously to correct the power signal as if the TI was constantly equal to I_{ref}.
The method typically results in lower power values in the lower windspeed range, and higher power values at higher windspeeds close to the "knee" of the curve. This is because TI tends to be higher than the standard reference value (I_{ref}), often set to 10% (or 0.1). The well-known visualisation of this effect can be seen o the left [4]:

Implementation

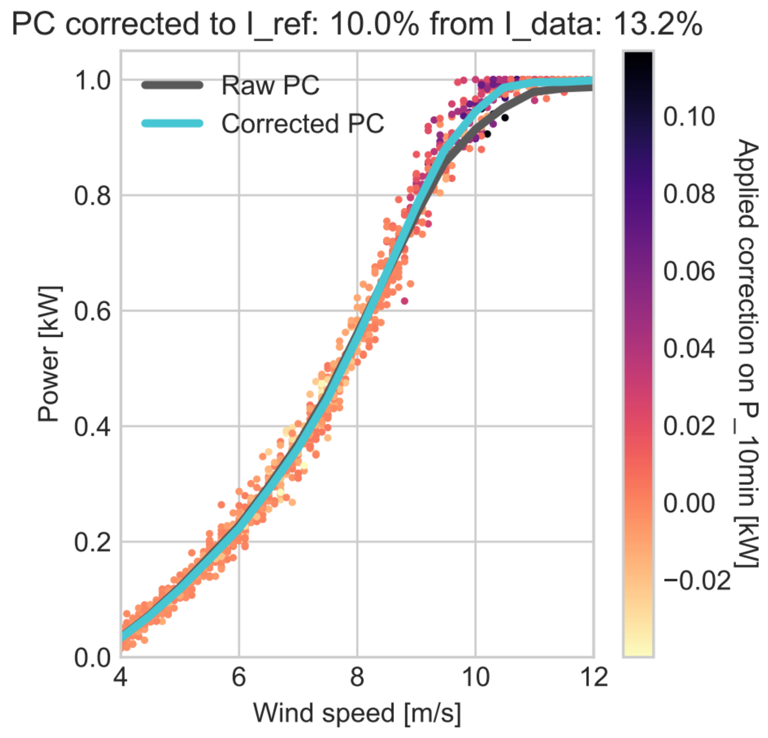
When implementing the algorithm with the intention of performing monthly analysis on a >3000 WTGs portfolio, computational efficiency is key. To solve the integration of the TI correction, Monte-Carlo or quadrature implementations are simply too costly when deployed at this scale.

Fortunately, as long as the $\mathrm{f}(v)$ is simplified by $\mathrm{g}(v)$ or another defined fitted function, and $\mathrm{P_{I=0}}(v)$ remains a function defined by part, **an analytical solution** to the process **can be found**. This closed solution is **several orders of magnitude faster** to run than any other implementation.

Assessing the effect on the Power Curve

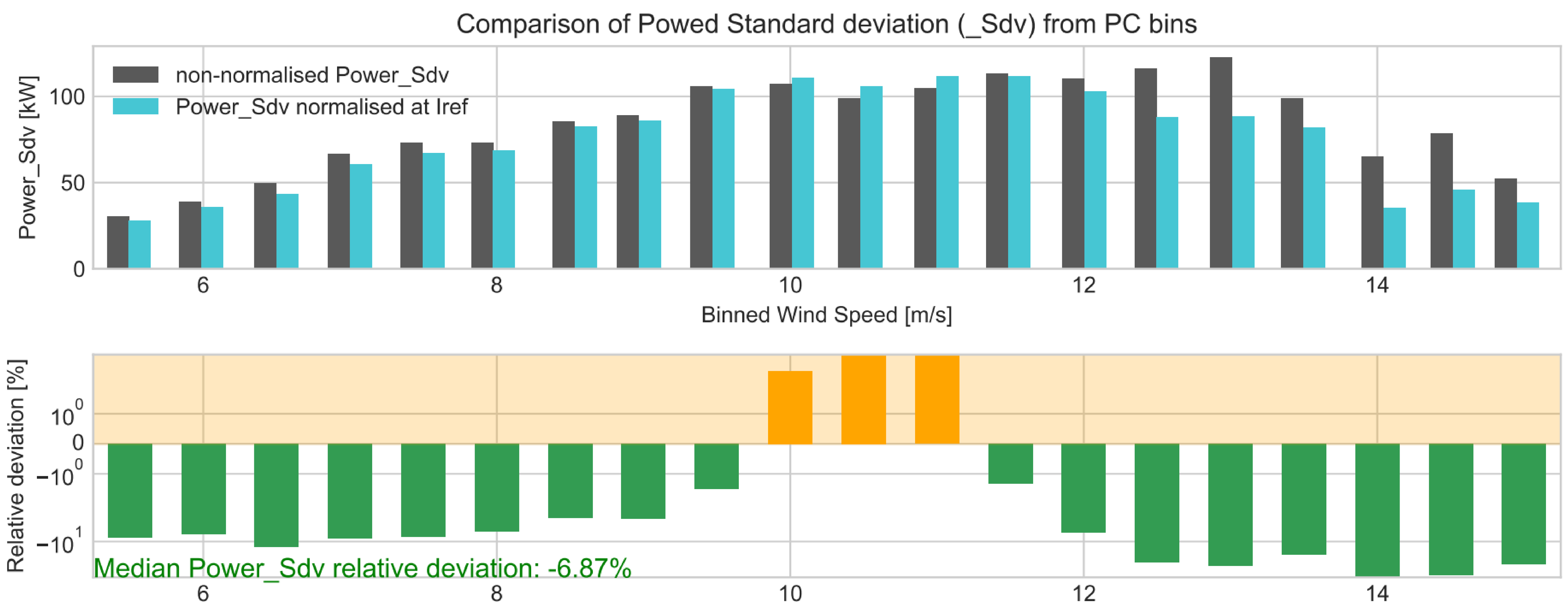
As stated above, we are here testing the TI normalisation using wind measurement from SCADA rather than the preferred met mast or lidar sources.

Although deviation from the standards [2, 3], we perform careful filtering of the dataset to remove wake periods, icing, curtailment and faults, and we assume that TI derived from nacelle anemometry correlates with undisturbed TI.
Since met masts are not available for all WTGs in our portfolio, we cannot automatically check the quality of data provided by the nacelle anemometry of each WTGs.
However, we can **check that the correction behaves as the theory dictates**. An example of that verification can be seen on the right:



An **additional benefit** of the method is also the **reduction of the scatter** of the PC when observed across a period where TI had varied. Checking that this reduction did occur is an effective way to verify if the process had a positive impact or not . If that scatter remains the same or increases, it implies that the method had either no effect or a negative one on the dataset. On the other hand, any significant **reduction on the scatter would indicate that the normalisation reduces uncertainty.**

The graphs below compares the standards deviation (Power_Sdv) of the raw power and the corrected power for one of the WTGs in the portfolio.



When analysing the monthly PC, the Power_Sdv is slightly but consistently reduced (-6.9% in the analysis above). When **deploying that metric on** whole **portfolio**, we found an **average reduction** of the binned Power_Sdv of **about -5%.**

Conclusions

- When undisturbed wind measurements are not available, **the pragmatic solution** for fleet scale performance analysis **is to use nacelle-based anemometry** from SCADA, despite the known influence of the blades.
- Given the results of this pragmatic approach, it was deemed **suitable for immediate deployment** and used for regular, automated analysis of the performance of over 3000 WTGs.
- The inclusion of **TI correction has reduced** the perceived deviation from expected performance, therefore reducing the number of **"false alarms"** raised by automated analysis.
- The quantity of monthly analysis performed forced us to implement the methodology in the most **efficient way**, in the form of its **analytic solution**. Computation time and power required for Monte-Carlo or integration algorithm implementations was shown to be unfeasible for a large-scale deployment.

References

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2. *Albers, A., 2010. Turbulence and shear normalisation of wind turbine power curve. In: European Wind Energy Conference and Exhibition 2010, EWEC 2010. Vol. 6. pp. 4116–4123.*
3. *Electrotechnical Commission (IEC). Power performance of electricity-producing wind turbines based on nacelle anemometry; IEC 61400-12-2; International Electrotechnical Commission: Geneva, Switzerland, 2013*
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