ACHIEVING PERFORMANCE TRANSPARENCY USING SPINNER ANEMOMETRY

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Summary

Determining the true performance of each turbine in a wind farm is extremely difficult but not impossible. Nowadays performance measurements in wind farms are limited to single turbines with free wind sectors fulfilling strict criteria and using dedicated met masts. Although remote sensing devices have the potential to replace met masts, especially in offshore applications they are limited to the same constraints. Hence the only wind measurement source available on each turbine over the entire turbine life time is the nacelle anemometry, which provides neither meaningful nor trustworthy input for a performance characteristic measurement. Here the spinner anemometer technology iSpin can provide more transparency and insights into the turbine performance. The unique position and measurement principle in front of the rotor enables to overcome the limitations of conventional nacelle anemometry in two ways: By measuring the main aspects which define the wind input and by showing high robustness for local flow conditions, different from those where the Nacelle Transfer Function (NTF) was derived.

A method and field test results will be discussed showing the spinner anemometer capabilities for performance monitoring and comparisons of wind farm turbines. Special focus will be given to the introduction of a large iSpin based Performance Transparency Project (PTP) - recently started by ROMO Wind and funded by the Danish government.

1. A common problem with wind farms

Wind turbines are energy producing devices. Hence it is important for the customer as well as the manufacturer to know how efficiently a turbine converts the kinetic energy from the given wind conditions into power. This power performance characteristic is commonly expressed as electrical power (output) versus wind speed (input) measured under free inflow conditions at a distance of 2 to 4 rotor diameters in front of the turbine [1][2]. Here is where the big dilemma in the wind industry lies so far. On the one hand it should be monitored that every turbine's performance characteristic is within the specification, but on the other hand it is almost impossible to measure the wind quantities at all turbines and at all sites. This is a known fact and the current way to handle it is to use nacelle anemometry wind speed measurements for performance monitoring of each individual turbine. Additionally - in certain, limited cases - the input-output relationship is determined by using met-masts or remote sensing devices (RSD). Those power curve measurements are performed at prototype sites or at dedicated turbines in a wind farm to verify that the turbine power curve is fulfilling contractual obligations. The results from the verification measurements are considered representative, not only for the individual turbine, but for all turbines of the evaluated wind farm.

2. Changing the game: Precise and comparable individual measurements

Up to now the existing nacelle based wind speed measurements – although considered as not really meaningful and trustworthy – are often the only sources of information for the input quantity “wind” in relation to the output quantity “power”. Here the spinner anemometer technology iSpin can change the game and provide more accurate and precise wind input measurements to analyse the turbine performance. By using the iSpin technology with its three ultrasonic sensors at the spinner and the unique measurement principle in front of the rotor, it is possible to overcome the limitations of conventional nacelle anemometry.

Table 1: Measurement capabilities of nacelle anemometry versus iSpin spinner anemometer

Quantity	Nacelle anemometry	iSpin
Wind speed	NTF sensitive to different inflow condition	Robust iSpin NTF - even in wake
Turbulence intensity	No possibility to measure	Key capability
Flow inclination	No possibility to measure	Key capability
Yaw misalignment	Indirect measurement, sensitive to sensor location	Key capability

Table 1 shows the aspects of the wind field affecting the turbine performance and which of those can be measured with conventional nacelle anemometry and with the advanced wind measurement capabilities of the iSpin system. Except for wind shear and veer all relevant factors describing the wind input to a turbine for a performance evaluation can be measured directly with the iSpin system.

Another important iSpin capability is its robustness against flow conditions differing e.g. from those of the prototype site. Tests at wind farms in different terrains have shown that even when considering 360° inflow – this means also including wake situation caused by other turbines - the scatter and the characteristic of the power curve remain nearly the same as for the free inflow sector. Figure 1 shows as an example a result of the Nørrekær Enge test experiment. Here the scatter and power curve characteristics are almost similar for free inflow and 360° inflow conditions.

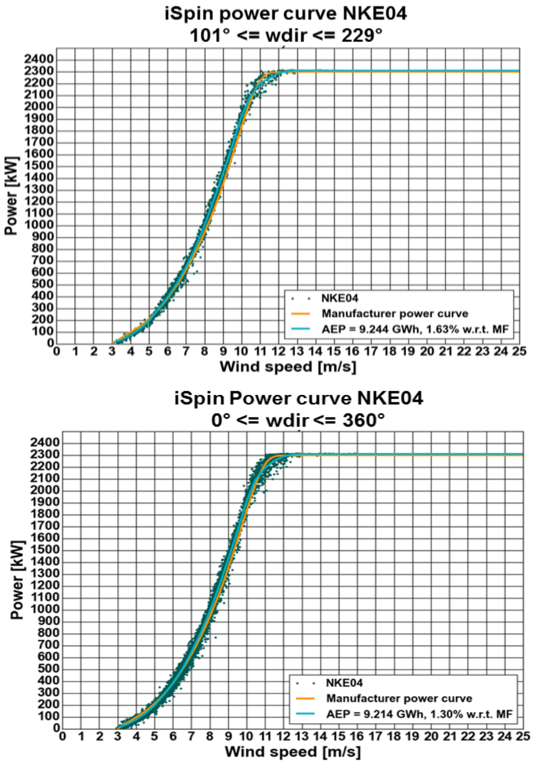

Figure 1: iSpin power curves at turbine no. 4 of the wind farm Nørrekær Enge: Free inflow (upper diagram) and 360 degree inflow (lower diagram)

3. Field test results

What does it mean to use iSpin measurement data to generate power curves and get an idea about the performance of each individual turbine or a complete wind farm? Examples of two different case studies from field experiments will be discussed in the following section. The case studies do show current findings for a simple wind farm layout in flat terrain and for an area distributed wind farm layout in semi-complex terrain [5].

3.1. Simple farm layout and terrain example

Figure 2 is showing the power curves of 9 2.3MW turbines using 360° inflow and being measured with iSpin systems (iSpin based power curves) and the nacelle anemometry (SCADA based power curves). In addition to this power curves the IEC 61400-12-1 compliant power curve - measured with a met mast in front of turbine number 4 - is shown as well. For this evaluation 9 of the 13 wind farm turbines have been used (T2 to T6 and T10 to T13), noise de-rated turbines were excluded.

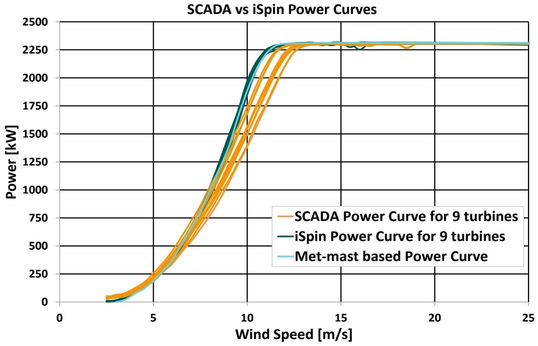

Figure 2: Comparison of power curves based on iSpin and nacelle anemometer measurements

From the graph at least four observations can be made: First of all none of the SCADA power curves does match the IEC power curve. This means that both, the calibration factor and the nacelle anemometry NTF having been established once for the turbine type are no longer applicable and definitely not usable for 360° inflow. Secondly, a very large variation in power curves between the different turbines can be seen. In contrast the iSpin based 360° power curves do match the IEC power curve very well - the average difference between the 360° iSpin power curves and the IEC power curve was -0.7% - and all power curves show similar characteristics [3].

The previously shown variation of the iSpin and SCADA based power curves can also be expressed as variation in Annual Energy Production (AEP). The graphs in Figure 3 show the resulting AEP values using the binned power curves and a wind Rayleigh wind speed distribution for an annual average wind speed of 7m/s. The grey bands cover the variation of +/-2% around the average AEP values of all observed turbines.

What can be concluded from comparing the iSpin and SCADA based power curves and AEP results? In general the SCADA based results underestimate the power curves whereas the iSpin based results are near to the IEC power curves (measured at turbine T04) and the warranted power curve. iSpin based power curves and finally AEPs do fall very close together, i.e. allow a small variation band and therefore are very suitable for identification of turbines with underperformance issues.

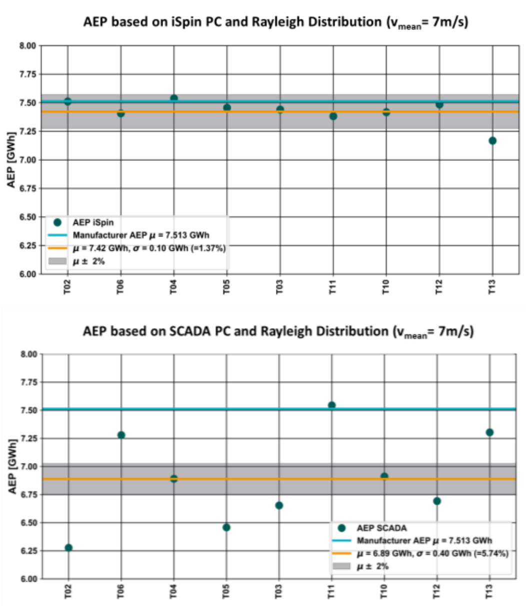

Figure 3: Comparison of AEP results using power curve measurements based on iSpin (upper diagram) and on SCADA data (lower diagram)

For turbine T13 - for which a yaw misalignment of 6.8° was detected using the iSpin system - the power curve and consequently the AEP differed from the average power curve and AEP band significantly. Contrary to this the SCADA based power curve and AEP analysis shows an indistinct picture, finally leading to a much higher AEP variation band. An operator, only looking at the SCADA based power curves and AEPs, might conclude that certain turbines are underperforming (e.g. T02, T03, T05, T12) and might start to invest in optimization measures, where none are necessary. On the other hand turbines which do have an underperformance issue like T13 are not classified as such.

3.2. Semi-complex terrain example with area distributed wind farm layout

For a semi-complex terrain case, the iSpin and SCADA based power curves of 29 2 MW turbines, arranged in a forested area and in a distributed layout, have been evaluated and transferred into AEP values for an annual average wind speed of 8m/s (see Figure 4).

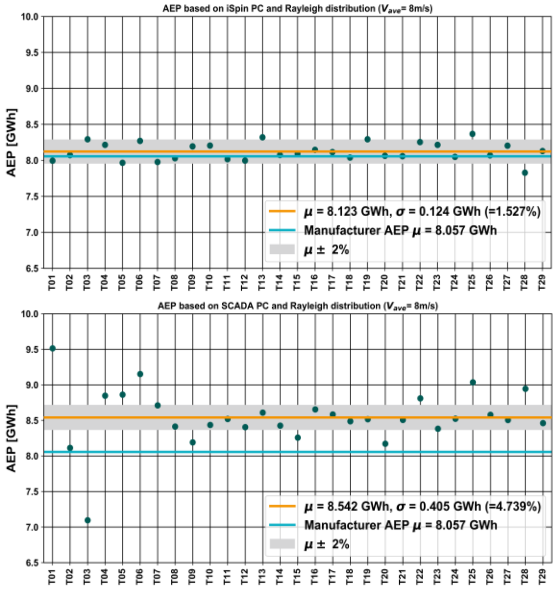

Figure 4: AEP comparison based on iSpin based power curves (upper diagram) and conventional anemometry based power curves (lower diagram)

Following findings can be made: Beside significantly higher variation of the SCADA based AEPs, the individual and the average AEP is in general higher than the AEPs based on iSpin measurements. Reason for this is that the SCADA power curves are far too optimistic. This becomes obvious seen when looking at the power coefficiency values. These values are greater than 57%, i.e. are near to the Betz-maximum of 59%. Contrary to this the maximal power coefficients based on iSpin measurements are with 47% in the range of the warranted power curve.

Again the interpretation of performance behaviour using SCADA data is very difficult: on the one hand turbines appear underperforming although they aren't (see turbines T03 and T09), on the other hand turbines which do have a real performance issue cannot get identified (see turbines T05 and T28).

Here the iSpin based AEPs show again a very low variation. Although the iSpin free flow calibration factor k1 and the iTF (iSpin NTF) for this turbine type was developed at a flat terrain site in Southern-Europe, the power curves and AEP values for the 29 turbines are almost confined by the ±2% interval band around the mean value.

4. The iSpin Guardian approach

The presented case studies demonstrated the capabilities of iSpin to measure wind speeds accurately and precisely. iSpin allows generating an average performance characteristic including a variation band for the wind farm. To transfer this approach systematically to other wind farms, iSpin systems should be installed on all turbines in the wind farm, but only at one as IEC compliant reference measurement to generate the iSpin free wind speed calibration factor and the iTF. Preferably after commissioning an accredited 3rd party consultant should perform power curve verifications according IEC 61400-12-1 and -12-2 on one wind turbine in the wind farm, using an IEC compliant met-mast set-up and calibrated iSpin equipment. After some plausibility checks the free flow calibration factor and iTF, derived at this reference turbine, can then be applied to the other turbines to determine the power curves. Figure 5 shows the process flow to generate a site and turbine specific reference performance characteristic including a tolerance band.

5. The Performance Transparency Project (PTP)

The presented case studies, the process flow and the description of the iSpin Guardian approach have already been reviewed by the Energy research Center of the Netherlands (ECN). In [4] ECN confirmed that the iSpin Guardian approach "based on the presented cases is well-suited to monitoring the relative performance of the turbines in a wind farm, which can be used to identify potential performance issues and which needs to be further validated".

In October 2016 ROMO Wind and DTU Wind Energy have also been awarded funding from

EUDP (an energy technological development and demonstration program from the Danish government) to run a large performance comparison and demonstration project. The setup and the general work packages of the PTP can be derived from figure 6.

From all in all 90 planned Spin installations 59 have been already been performed covering 6 wind farms and two turbine types. In total it is planned to install iSpin systems on 9 different wind farms. 3 different turbine types - each of them installed at 3 different terrain classes (flat, semi-complex and complex or offshore) – will be evaluated. At each of the wind farms one met mast or RSD will be used for a time period of at least 12 months to validate together with acknowledged independent 3rd parties the iSpin measurement capabilities on a broad scale. I.e. it shall be proven that the iSpin transfer function is stable in all terrain classes, and that consequently the iSpin power curves can be used to directly compare wind turbine performances regardless of their location.

6. References

[1] IEC 61400-12-1:2017; Power performance of electricity producing wind turbines

[2] IEC 61400-12-2:2013; Power performance of electricity producing wind turbines based on nacelle anemometry

[3] Holistic performance monitoring of wind farms – the iSpin Guardian approach; Hohlen; VGBPowerTech Journal; September 2016

[4] Evaluation of the ROMO Wind iSpin Guardian approach; Wouters, Wagenaar, Warnaar; ECN report ECN-E--16-050; September 2016

[5] Performance Monitoring on all Wind turbines at any Time; Hohlen; WindTech Journal; November 2016

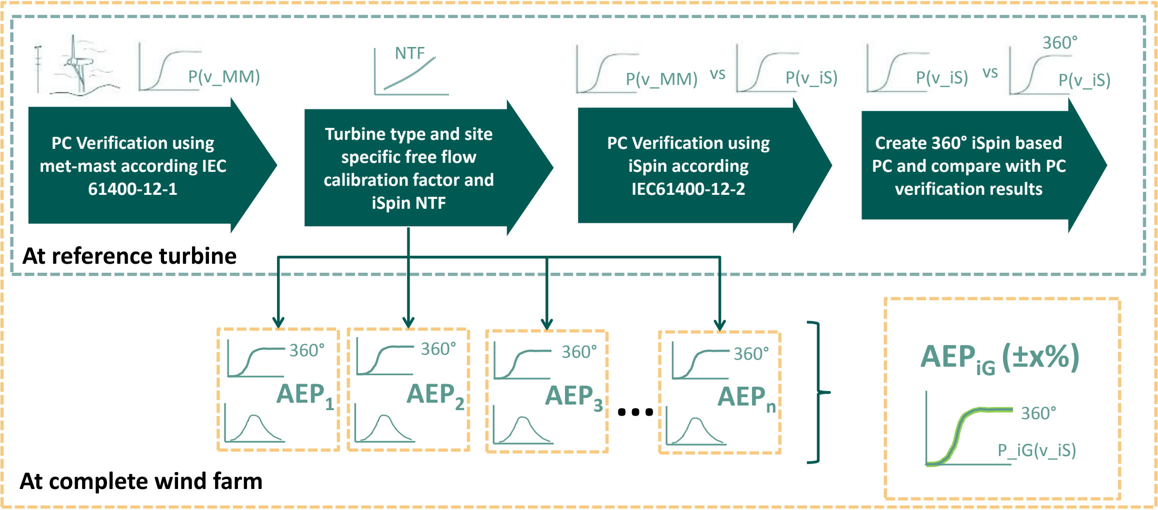

Figure 5: Process flow for iSpin Guardian approach

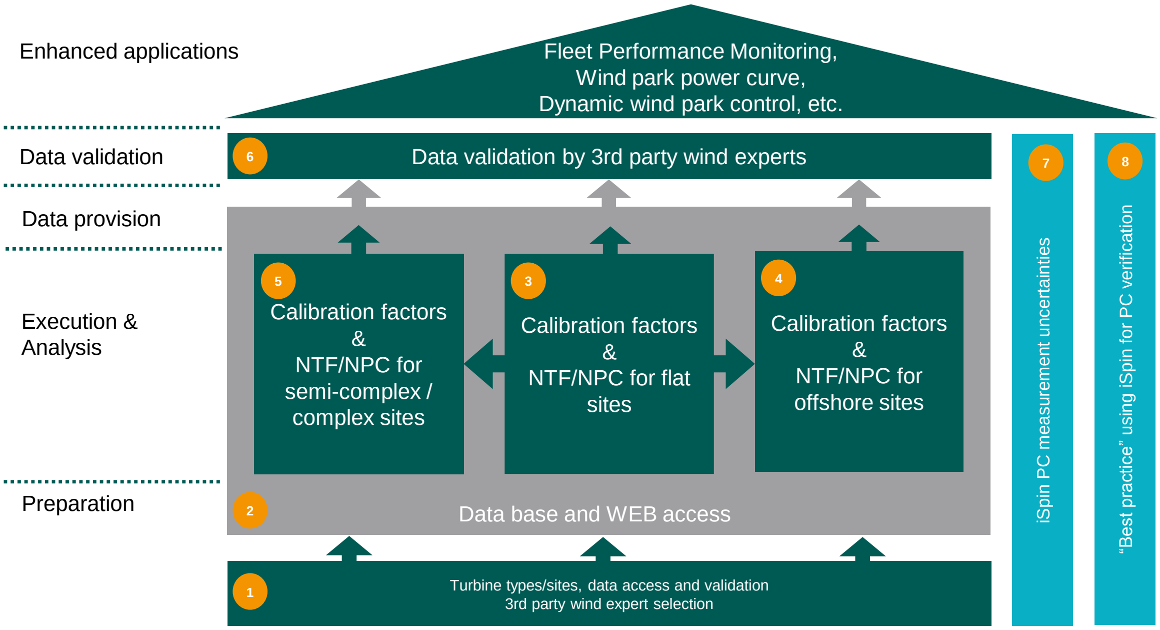

Figure 6: Work Packages of iSpin Performance Transparency Project (PTP)