# Spinner anemometer: wind speed and Spinner Transfer Function seasonal robustness in an offshore wind farm

K. Ritter, P. Gómez

Spinner Transfer Function, measurement, robustness, uncertainty, spinner anemometry, lidar, power curve

## Introduction

The “spinner anemometer” is an instrument installed on a wind turbine spinner that measures wind inflow angles and horizontal wind speed in the centre of the turbine rotor. Since it measures inside the turbine induction zone, it requires a Spinner Transfer Function (STF, the equivalent of the NTF for nacelle-mounted sensors [1]) to obtain the “free wind speed”. I.e. a wind speed that (ideally) is not affected by the flow distortion caused by the wind turbine, which is the input to power curves and Annual Energy Production (AEP) calculations.

The Performance Transparency Project (PTP), funded by EUDP (project partners ROMO Wind and DTU Wind Energy), aims to demonstrate the seasonal and terrain wise robustness of the STF in different terrains and turbine types.

PTP has produced 22 months of data from one nacelle lidar and iSpin® (spinner anemometer produced by Romo Wind) in an offshore wind farm. Previously, we presented preliminary results from the reference turbine in this wind farm [2]. In the present work, we reviewed our previous analysis and studied the seasonal stability of the spinner anemometer wind speed and STF in a longer dataset. Moreover, we investigated the reproducibility of the spinner anemometer power curves and the suitability of the STF derived from the reference turbine, which was applied to several turbines in the wind farm.

**This work presents the first, long-term, demonstration case of the use of spinner anemometers for power curve measurements in an offshore wind farm.**

## Objectives

- To analyse the stability, over more than a year, of the spinner anemometer wind speed measurements with respect to the lidar and the nacelle anemometer, using a long-term STF.
- To evaluate the seasonal stability of the STF and its impact on AEP.
- To investigate the reproducibility of the spinner anemometer power curves and AEPs from several neighbouring wind turbines

## Methodology

Database

The dataset consisted of ten-minute iSpin® and turbine SCADA data from several turbines. In the “reference” turbine, a nacelle lidar (Wind Iris v2) provided the reference wind speed measurements used to obtain the STF and $k_1$ corrections that were applied in all turbines.

Spinner Transfer Function

The spinner anemometer wind speed calibration includes two final steps [3]: (1) to correct measurements to free wind speed by applying a calibration factor k1, and (2) to correct the non-linear induction effects at the rotor with a spinner transfer function (STF). An example is given in the next two plots. Figure 1 presents the raw iSpin and lidar wind speed filtered data. First, the data in very low and very high wind speeds in Figure 1 was fitted to a forced-through-zero line (ignoring non-linear effects from the operating turbine rotor induction). The obtained gain coefficient is k1. Next, a STF was obtained using the $k_1$-corrected iSpin data, by computing the average difference between iSpin and lidar speed, in 0.5m/s bins [1] (see example in Figure 5).

As part of the seasonality study, five different $k_1$ calibration factors and STFs were obtained, following the procedure in [4] but using the lidar wind speed (at a distance of 2.3 times the rotor diameter) as the reference ($ws_{ref}$) instead of a mast-mounted cup anemometer. Table 1 summarizes the start and end dates of the selected periods, the number of valid data points, and the $k_1$ calibration factors.



## Methodology (continued)

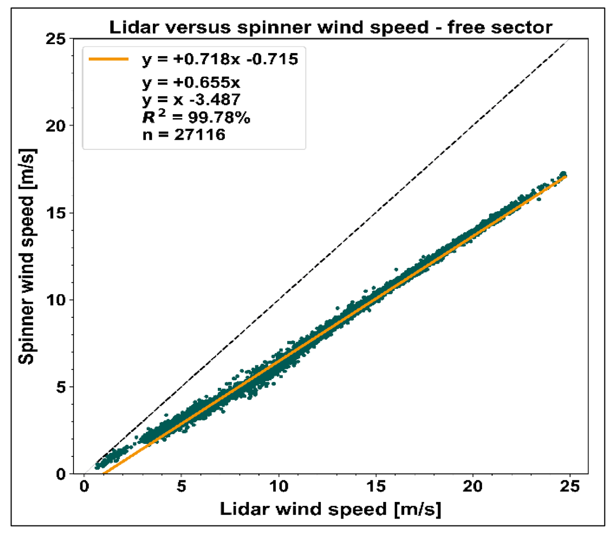


**Figure 1.** Spinner anemometer wind speed before applying the calibration factor $k_1$ and STF, as function of the lidar wind speed.

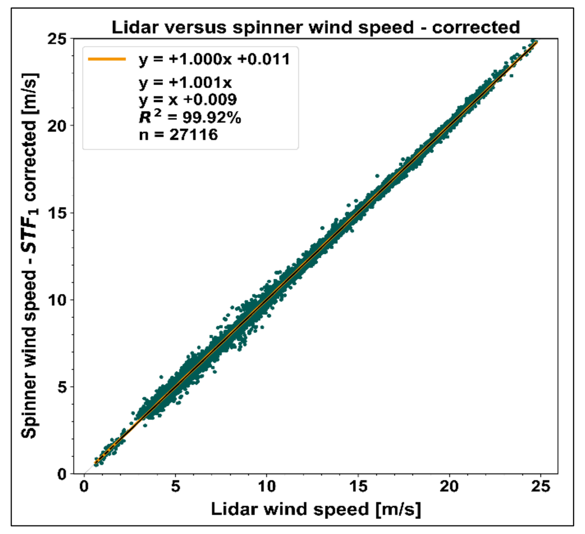


**Figure 2.** Spinner anemometer wind speed corrected with the calibration factor $k_1$=0.69 and STF1 as function of the lidar wind speed.

| Name | Description | Measurement period | | Number of valid data points | $k_1$ factors |
|---|---|---|---|---|---|
| | | *Start date* | *End date* | *Valid for STF* | |
| $STF_1$ | full period | 2018-02-07 | 2019-12-04 | 27116 | 0.69 |
| $STF_2$ | spring | 2018-03-01 | 2018-05-01 | 2394 | 0.69 |
| $STF_3$ | summer | 2018-07-01 | 2018-09-01 | 1984 | 0.68 |
| $STF_4$ | autumn | 2018-09-01 | 2018-11-01 | 3736 | 0.69 |
| $STF_5$ | winter | 2018-11-01 | 2019-01-01 | 2190 | 0.69 |

**Table 1.** Overview of Spinner Transfer Function periods, number of data and calibrations.

Wind speed deviation

The wind speed deviation, $\Delta ws$, was defined as:

$$\Delta ws_x = \frac{ws_x - ws_{ref}}{ws_{ref}} \cdot 100\%$$

where $ws_{ref}$ is the lidar wind speed, and $ws_x$ stands for either the spinner anemometer wind speed (corrected with calibration factor $k_1$=0.69 and $STF_1$), $ws_{iSpin}$, or the nacelle anemometer wind speed (from SCADA), $ws_{nac}$.

AEPs

The lidar and spinner anemometer power curves and AEPs were obtained based on [5].

## Results

**1. Long-term STF analysis (reference turbine)**

In result sections 1.1 to 1.3, $STF_1$ and $k_1$ were applied to correct the spinner anemometer data.

1.1. Wind speed deviations

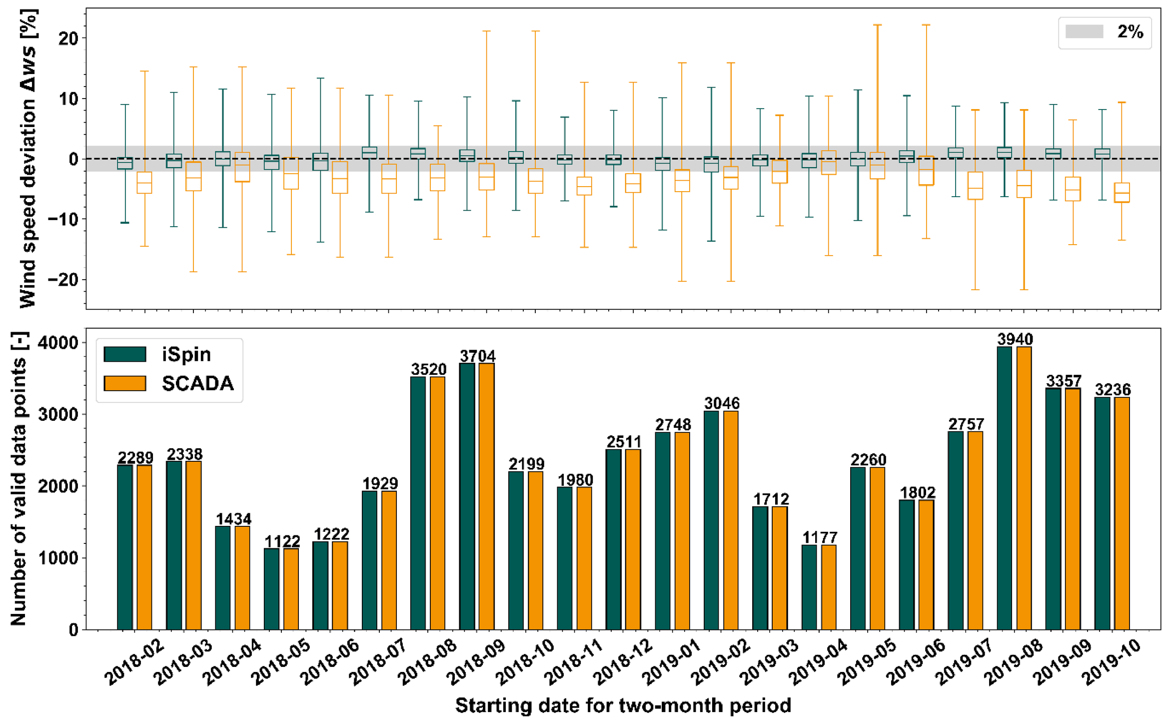


**Figure 3.** Distribution of wind speed deviation (top) and number of valid data points (bottom) for spinner anemometer (iSpin ®) and nacelle anemometer (SCADA) in 21 two-month periods.

## Results (continued)

1.2. Lidar and spinner anemometer AEP and uncertainty comparison

For the lidar and spinner anemometer power curves based on the full dataset:

- The lidar uncertainties were determined following the present IEC draft for the use of nacelle-mounted lidars for wind speed measurements [6].
- The spinner anemometer uncertainties were assessed according to [1]; the inputs and uncertainty method were described in [7].
- Where available, the input values for the assessment were taken from calibration certificates and installation documents. In other cases, we assumed typical values, based on our experience or common practice.

**Table 5.** Measured AEP and uncertainty from full period data set

| | V = 6m/s | | V= 8m/s | |
|---|---|---|---|---|
| | Measured AEP, $AEP_{meas}$ | Standard uncertainty in AEP, $u(AEP_{meas})$ | Measured AEP, $AEP_{meas}$ | Standard uncertainty in AEP, $u(AEP_{meas})$ |
| Lidar | 100.0% | $4.7\% \cdot AEP_{meas,lidar}$ | 100.0% | $3.1\% \cdot AEP_{meas,lidar}$ |
| Spinner anemometer | 100.0% | $6.7\% \cdot AEP_{meas,iSpin}$ | 100.1% | $4.4\% \cdot AEP_{meas,iSpin}$ |

1.3. AEP comparison

Power curves and AEPs were obtained from each two-month data set, from the lidar, spinner anemometer (iSpin®), and nacelle anemometer (SCADA). The method and normalizations used are described in [5]. A Rayleigh probability density function was assumed with a reference annual mean wind speed of 8m/s. Figure 4 presents the AEP values normalized to the AEP of the lidar power curve obtained from the full period (black dashed line).

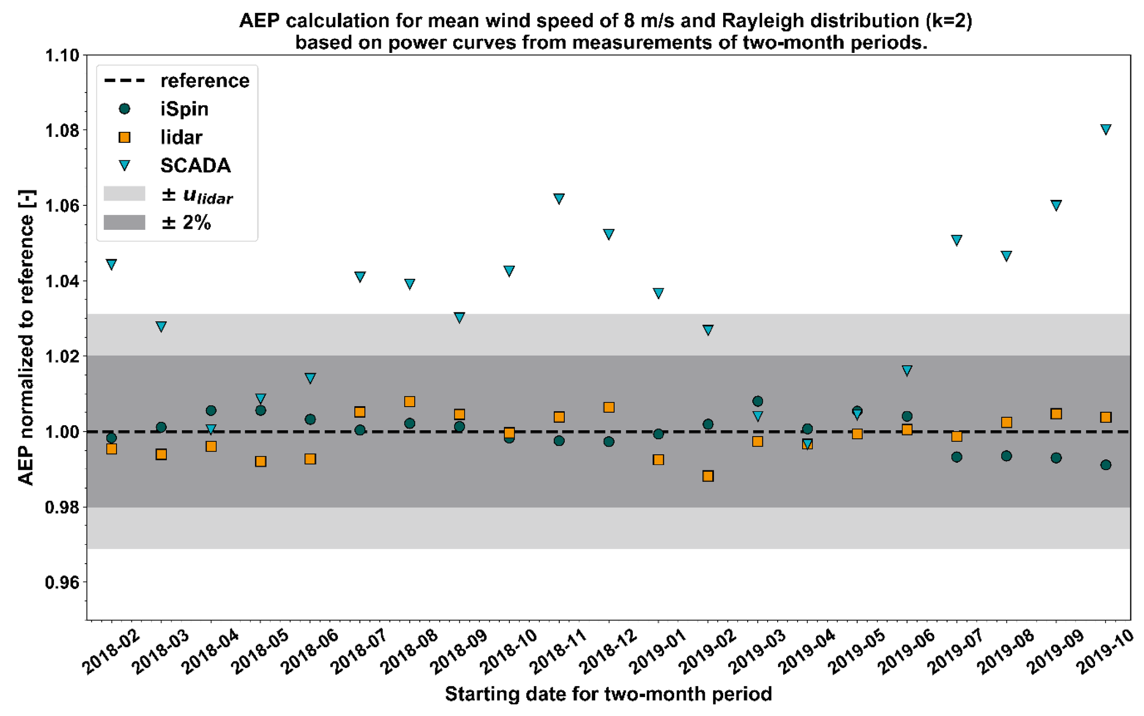


**Figure 4.** AEPs from spinner anemometer (iSpin®), lidar and nacelle anemometer power curves in two-month periods. Normalized by AEP of lidar power curve obtained from the full period (black dashed line).

**2. STF seasonality analysis (reference turbine)**

The STF is expressed as the wind speed difference $ws_{ref,n,i} - ws_{ispin,n,i}$, where “n” indicates the STF period, and “i” indicates the wind speed bin index (Figure 5) .

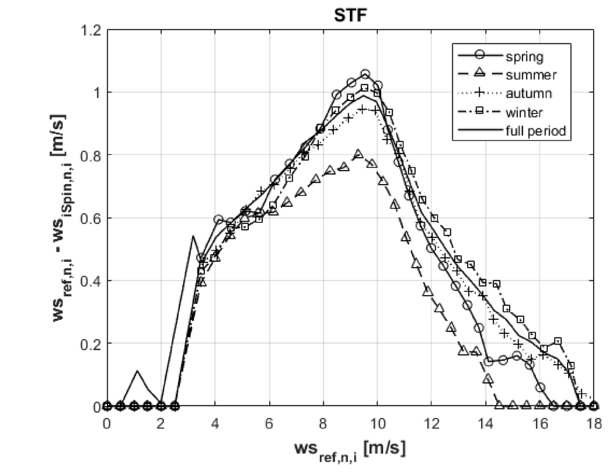


**Figure 5**. STFs from the different periods.

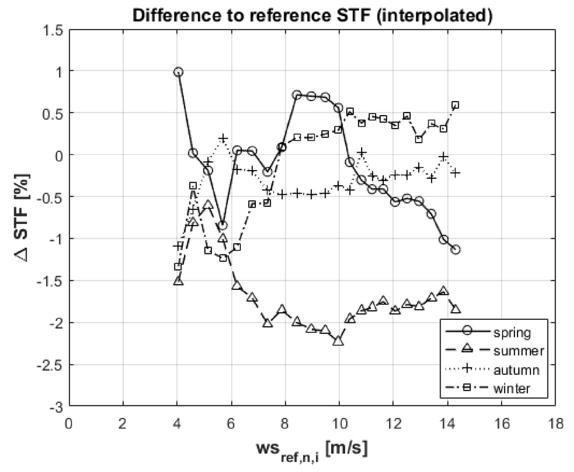


**Figure 6.** Wind speed difference between each STF and the full-period STF, expressed as a function of the wind speed.

## Results (continued)

(Figure 6) The difference between each season STF and the one-year STF ($STF_1$), expressed as $\Delta$STF. Only wind speed bins were there was data in all STFs are plotted.

$$\Delta \text{STF} = \left( (ws_{ref,n,i} - ws_{ispin,n,i}) - (ws_{ref,1,i} - ws_{ispin,1,i}) \right) ws_{ref,1,i}{}^{-1}$$

The values $(ws_{ref,n,i} - ws_{ispin,n,i})$ were interpolated to the abscissa values in $STF_1$ ($ws_{ref,1,i}$).

**3. STF transferability**

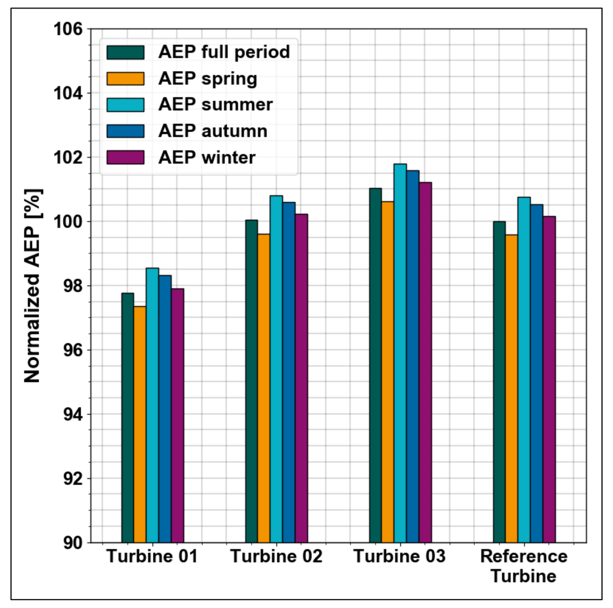


**Figure 7.** AEPs for neighbouring turbines normalized to the AEP obtained at the reference turbine for the full-period STF.

## Conclusions

The analysis using a long-term STF showed that:

- The two-month-average wind speed differences between the spinner anemometer and the lidar were within ±2% of the reference wind speed, over a year.
- The spinner anemometer and lidar power curves and AEPs were consistent, considering their uncertainty intervals (calculated following IEC standards).
- The variation in AEP calculated from short periods of spinner anemometer and lidar wind speeds showed similar results.

The analysis using several STFs from different periods showed that:

- Differences between the one-year STF and the season STFs were within -0.5% and 2.5% of the reference speed.
- The AEPs from season STFs differed from the AEPs based on the one-year STF in less than 1%.

## References

1. IEC 61400 12-2 Ed.1, 2013.
2. Ritter K, Gómez Arranz P. “Long term comparison of spinner anemometer and nacelle lidar data for and offshore wind farm”. Wind Europe Offshore 2019 conference proceedings.
3. “iSpin calibration procedures”. ROMO Wind A/S. December 2018 (Version 12.0).
4. Pedersen T F, Gómez Arranz P. “Spinner anemometry – best practice”. DTU Wind Energy E-0165, April 2018.
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6. CD IEC 61400 50-3. May 2019.
7. Pedersen T F, Gómez Arranz P. “Spinner Anemometer Uncertainty Analysis”. DTU Wind Energy E-0166. April 2018.

## Acknowledgements and Contact

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Katrin Ritter: kri@romowind.com
Paula Gómez: paar@dtu.dk