Power curve measurements using the ROMO Wind Spinner Anemometer

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WIND FARM OWNER'S ADVOCATE
AND CONTRACT DEVELOPER

ROMOWind

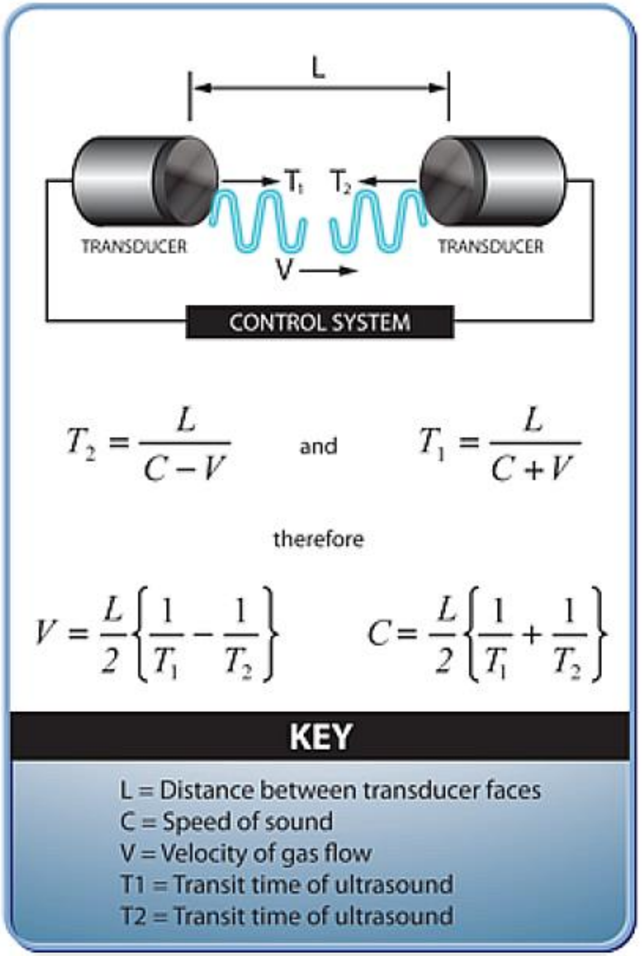
Spinner anemometer

- Description of spinner anemometer
- The spinner anemometer for relative power curve measurements (measure improvements of power curves).
- Power curve of test turbine.
- IEC 61400-12-2
- Advantages of spinner anemometer over conventional nacelle anemometer and mast based measurements
- Plans for documentation and tests. Timeschedule.

ULTRASONIC ANEMOMETER

- Ultrasonic anemometers
- Well-known basic technology
- Used for wind measurements > 40 years

Time of Flight Theory



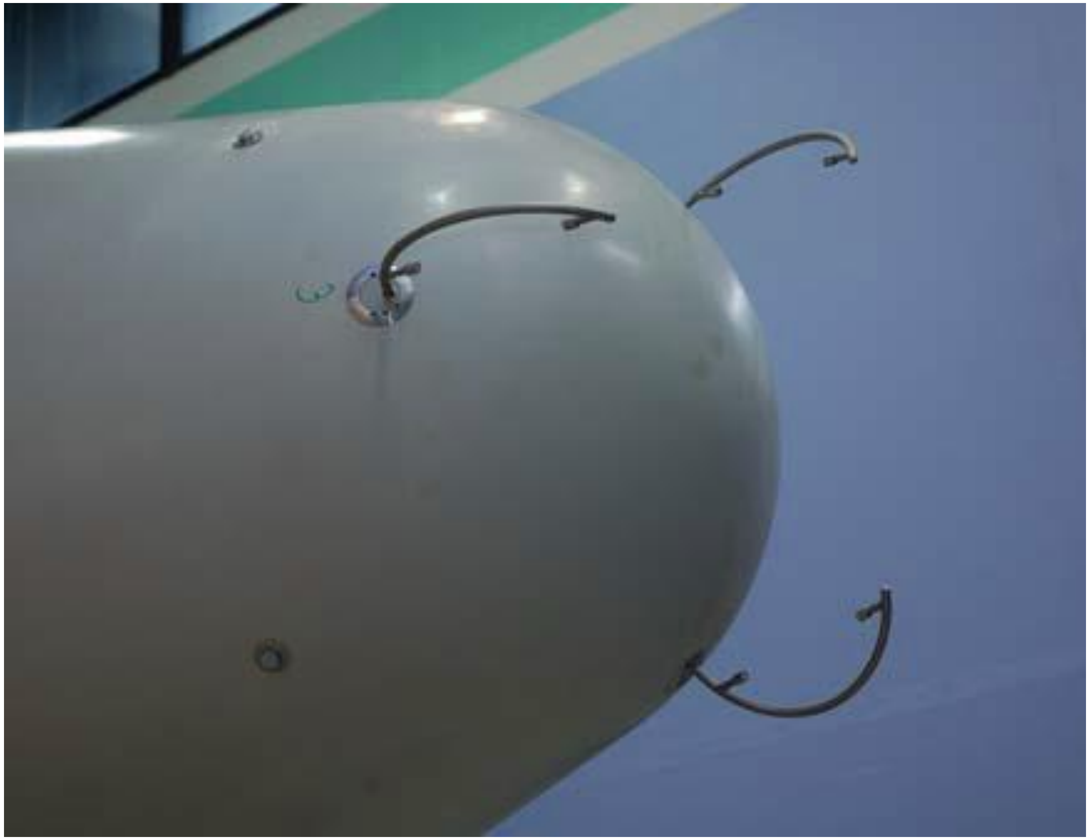
Source of fig: http://www.gill.co.uk

SPINNER ANEMOMETER HISTORY

- **1970 ies** — Sonic anemometer developed
- **2004** — RISØ files patent for SA and first prototype tested on 0.3 and 3.6 MW Siemens turbines
- **2006** — Patent granted
- **2007** — New SA prototype produced by Metek
- **2008** — Tested on Høvsøre off-shore Vestas turbine
- **2009-2011** — Tested on Vestas turbine in Tjæreborg
- **2011** — ROMO Wind acquires global patent from RISØ
- **2012** — Spinner Anemometer enter commercial phase

THE SPINNER ANEMOMETER

- Innovative application (Troels Friis Pedersen, DTU)
- Three single-path sonics rotating with the spinner



MEASUREMENTS, ROTATING SPINNER

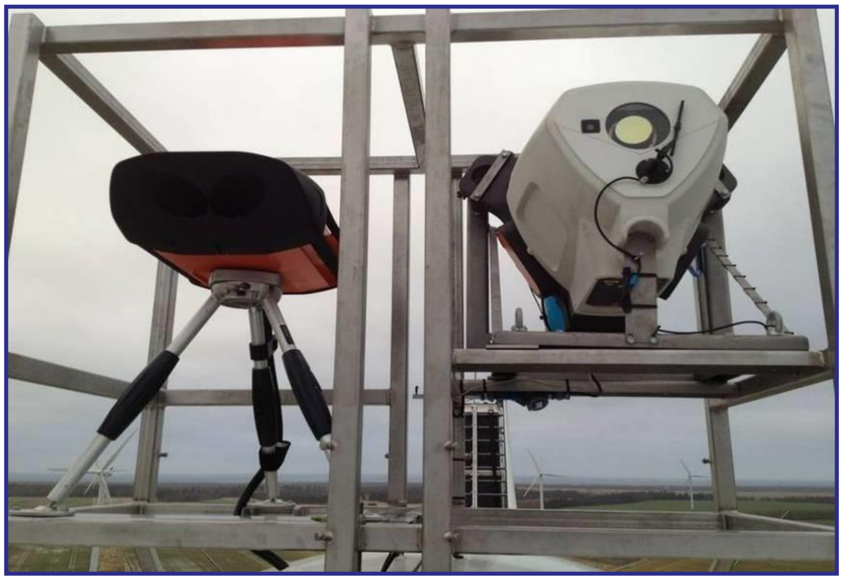
- Output: Wind vector, i.e. wind speed, yaw angle, tilt angle
- Simple calibration procedures to account for flow distortion.
- DTU has made extensive tests in windtunnel, and field test comparison with mast mounted instruments.

ORIGINAL APPLICATION OF SPINNER ANEMOMETER

- Measure yaw misalignment
- Measure improvement of power curve after correction of yaw misalignment

TEST TURBINE WITH TWO LIDARS AND SPINNER ANEMOMETER

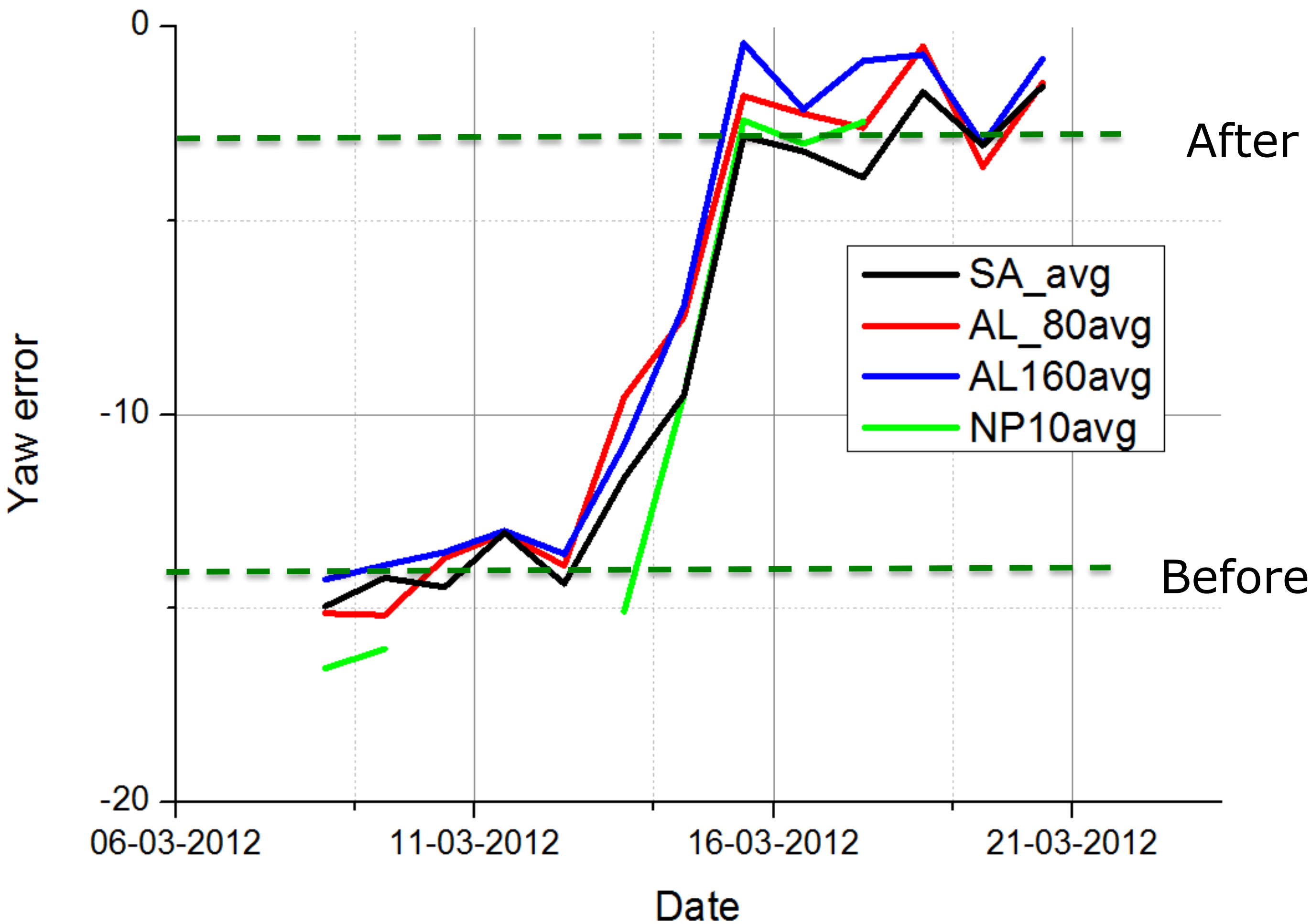
Nacelle based LiDAR		Spinner anemometer



AventLidar	Natural Power	ROMO Wind (patented)

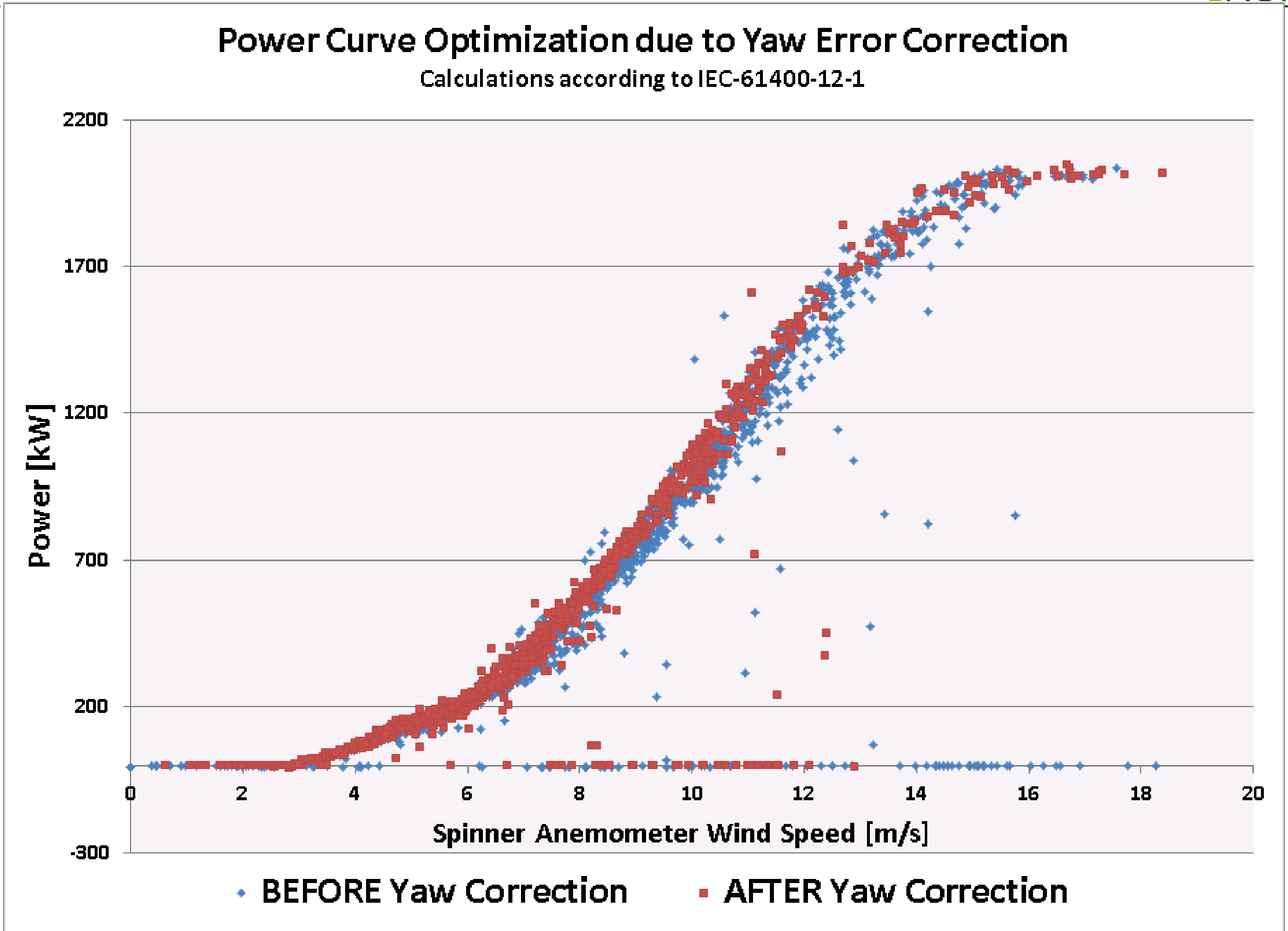
Source: ROMO Wind

CORRECTION OF YAW MISALIGNMENT USING THE SPINNER ANEMOMETER

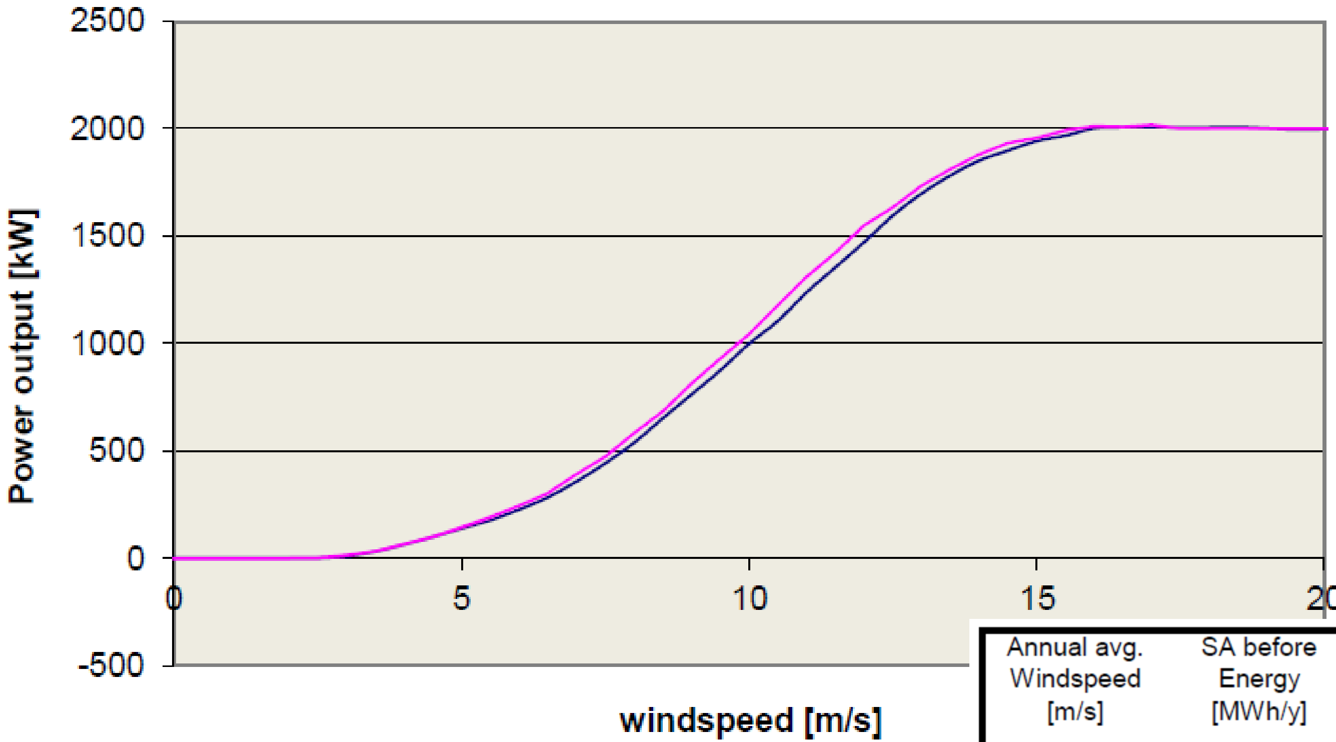


Source: ROMO Wind

POWER CURVES – BEFORE AND AFTER VANE ADJUST

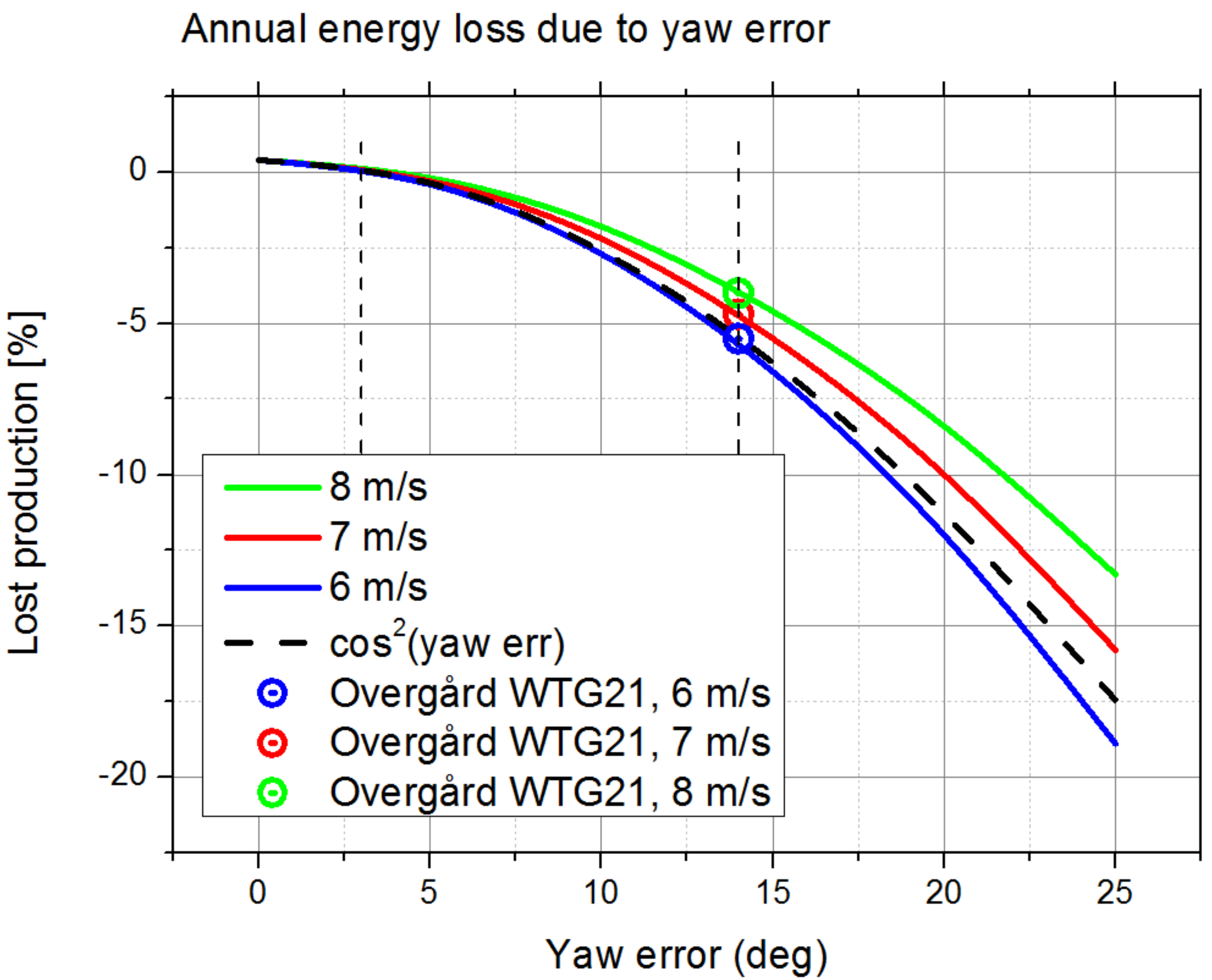


POWER CURVES MEASURED BY SPINNER ANEMOMETER BEFORE/AFTER YAW ERROR CORRECTION



Annual avg. Windspeed [m/s]	SA before Energy [MWh/y]	SA after Energy [MWh/y]	Improvement [%]
5,00	2037	2163	6,1%
6,00	3261	3439	5,5%
7,00	4607	4824	4,7%
8,00	5951	6189	4,0%
9,00	7196	7441	3,4%
10,00	8288	8530	2,9%

POWER CURVES – COMPARISON WITH SIMPLE MODELLING OF POWER LOSS BY YAW ERROR



GL – GH REVIEW OF SPINNER ANEMOMETER

GL Garrad Hassan's main conclusions:

- The Spinner Anemometer is capable of measuring yaw error such that this yaw error can be corrected to an insignificant level.
- ROMO's calculations of magnitude of energy loss caused by yaw error are confirmed by GL GH calculations using the GH-Bladed model.
- Relative power curve measurements using the Spinner Anemometer can be made to within 10% accuracy (i.e.10% of the measured difference in AEP)

Compare measured power curve with manufacturer’s data

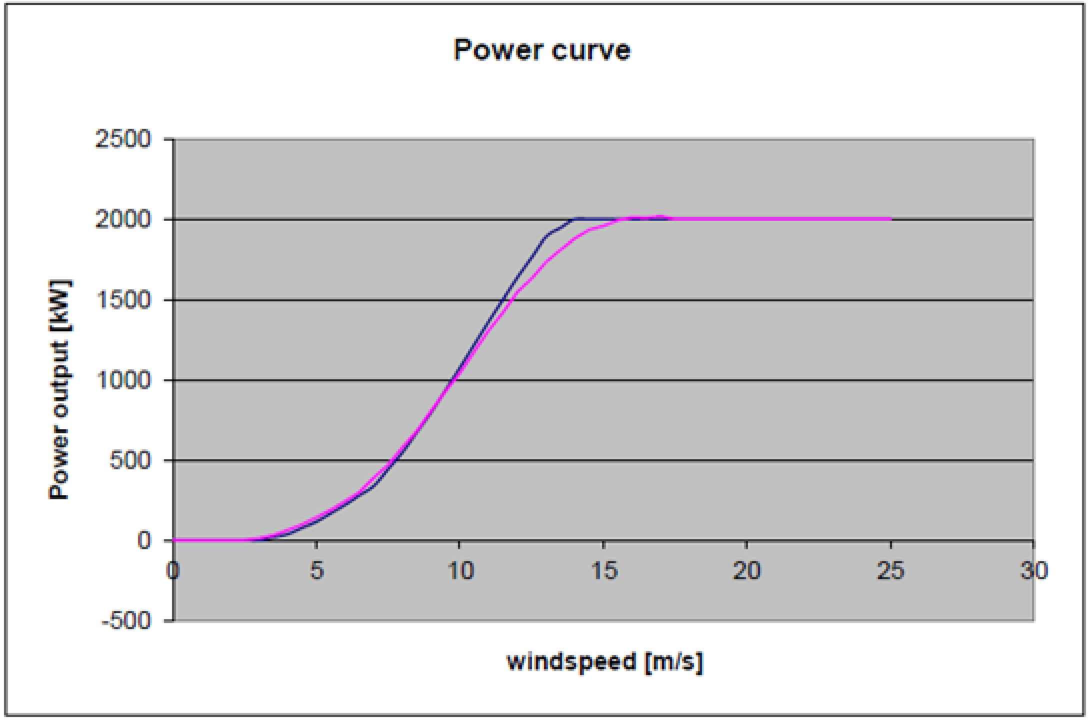
- Original level of ambition: Measure power curve relative improvement after correction of yaw error with sufficient accuracy. √
- We measured the power curve of the test turbine.
  It is obvious to compare with manufacturer’s power curve

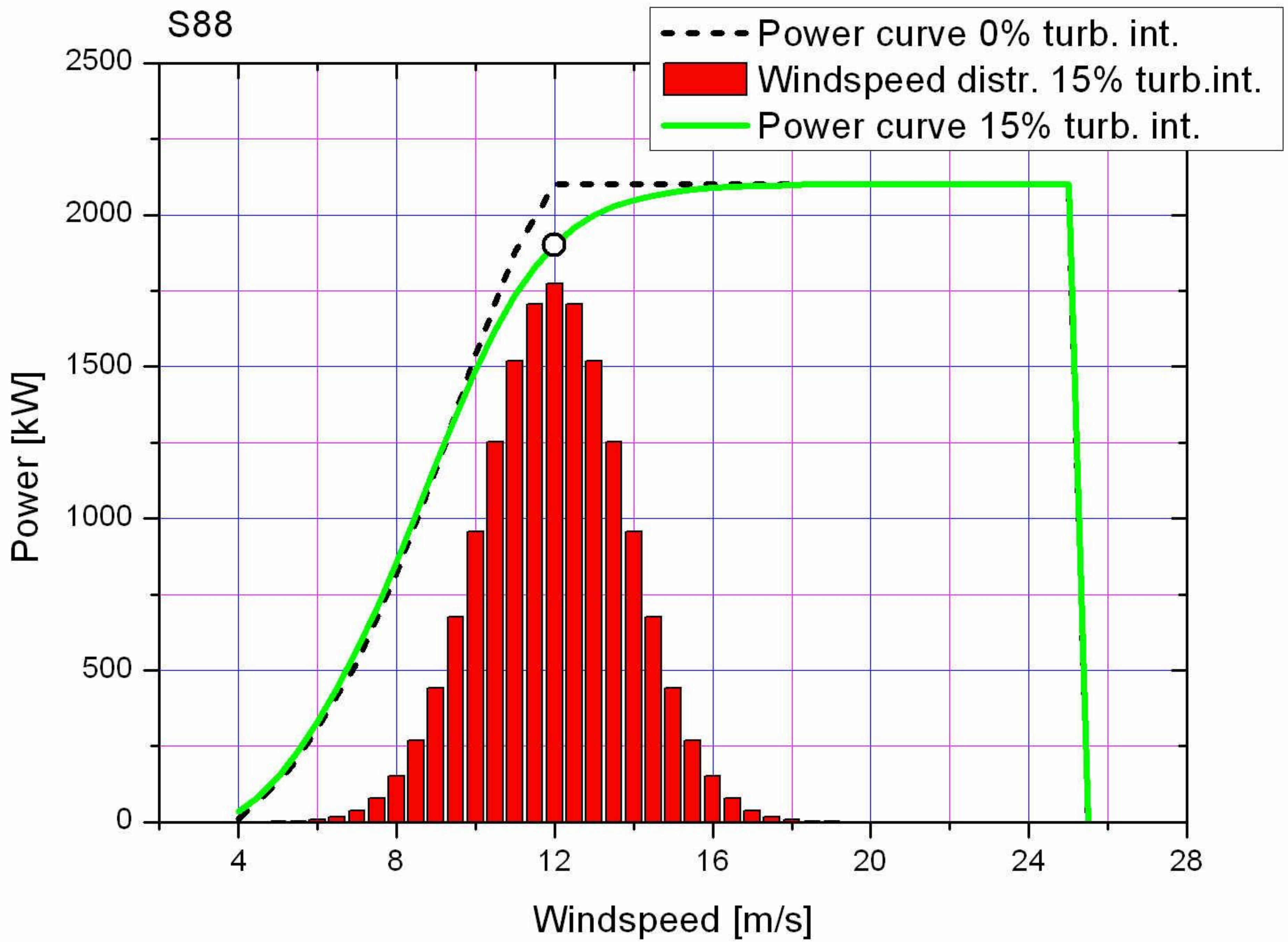
Spinner Anemometer weeks 12-15 (after adjustment of vane) compared with std curve

Jørgen Højstrup 29/05/2012

Rayleigh wind distributions

Annual avg. Windspeed [m/s]	SAbefore Energy [MWh/y]	SAafter Energy [MWh/y]	Ratio After/before
6,00	3375	3439	1,019
7,00	4828	4824	0,999
8,00	6255	6189	0,989
8,50	6920	6829	0,987

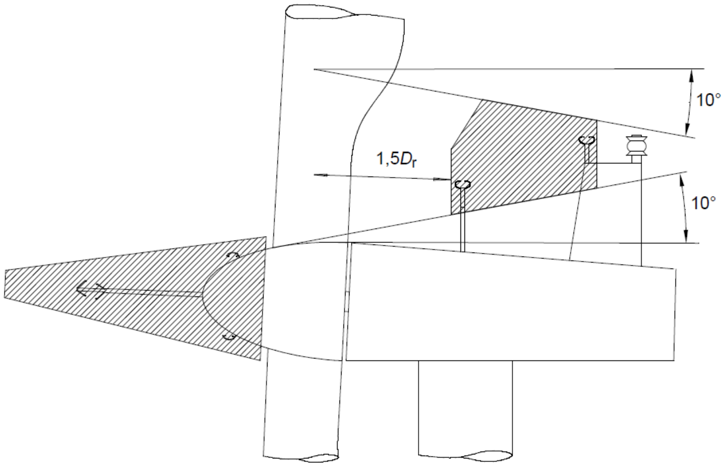




S88
Power curve 0% turb. int.
Windspeed distr. 15% turb.int.
Power curve 15% turb. int.
Power [kW]
0
500
1000
1500
2000
2500
4
8
12
16
20
24
28
Windspeed [m/s]

Power curve measurements according to IEC 61400-12-2

- In the new IEC 61400-12-2 there is the possibility of using the spinner anemometer for power curve measurements.



NOTE The anemometer should be mounted inside the hatched areas.

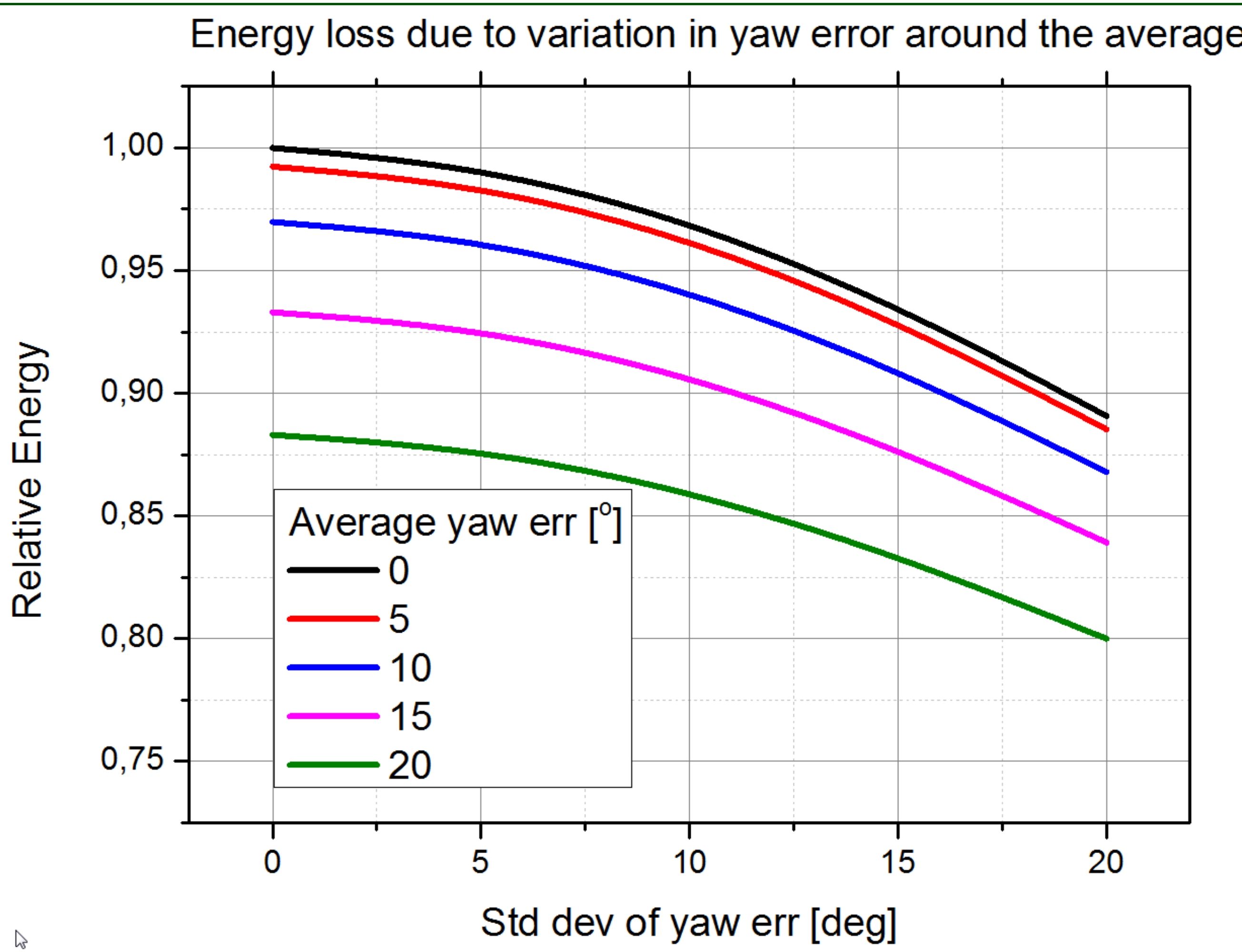
- Status: We looked at the standard and planned how to go about getting the spinner anemometer documented, tested and accepted for power curve measurements,

Power curve measurements according to IEC 61400-12-2

The power curve depends on seven parameters, all of which can be derived from the Spinner Anemometer:

1. Wind speed – measured by SA
2. Air density – temperature measured by SA. Only need to measure pressure additionally.
3. Turbulence intensity – measured by SA
4. Directional variation – measured by SA
5. Inflow angle – measured by SA
6. Wind shear – Indirect measurement by SA by advanced turbulence analysis (not yet developed)
7. Vertical wind veer – Indirect measurement by SA by advanced turbulence analysis (not yet developed)

Reduce yaw error variations => Less energy loss
Std.dev. 10 deg to 5 deg => 2% more energy



Power curve measurements according to IEC 61400-12-2

The power curve depends on seven parameters, all of which can be derived from the Spinner Anemometer:

1. Wind speed – measured by SA
2. Air density – temperature measured by SA. Only need to measure pressure additionally.
3. Turbulence intensity – measured by SA

4. Directional variation – measured by SA.
   1. RMS_dir=10deg => -3% energy
5. Inflow angle – measured by SA
   1. Inflow=5deg (upwards) => -2% energy
   2. Inflow=10deg (upwards) => -6% energy

6. Wind shear – Indirect measurement by SA by advanced turbulence analysis (not yet developed)
7. Vertical wind veer – Indirect measurement by SA by advanced turbulence analysis (not yet developed)

Power curve measurements according to IEC 61400-12-2
To be documented

- The spinner anemometer provides a much higher quality of wind speed measurement than conventional nacelle anemometer in terms of accuracy and turbulence measurements.

- Because of position of spinner anemometer in front of rotor, the necessary corrections to the measured wind speed are much simpler and more reliable than for nacelle anemometer.

- Corrections for spinner anemometer are not dependent on yaw misalignment – corrections for nacelle anemometer are very much dependent on yaw misalignment.

Power curve measurements according to IEC 61400-12-2
To be documented

- The uncertainties on the mean wind speed due to turbulent variations of wind speed are small – in contrast to conventional anemometers.

- Because of symmetry of corrections, no need to measure spinner anemometer corrections in "site-similar" terrain (which is required for nacelle anemometer), but it is sufficient to measure (or calculate) the correction for flow around the spinner once and for all.

- No need for site calibration when measuring power curves with spinner anemometer.

CONCLUSIONS Power Curve Measurements
To be documented

- The spinner anemometer will be able to make an accurate power curve measurement at a very reasonable cost on any turbine in a wind farm.
- Much more accurate than conventional nacelle anemometers
- Much less expensive than IEC 61400-12-1 power curves

- Planned timeschedule for documentation and tests:
  7 months.

Thank you!

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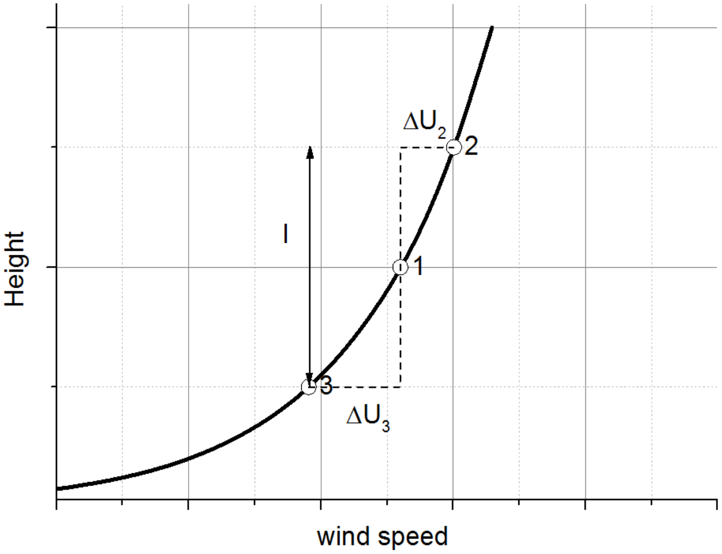
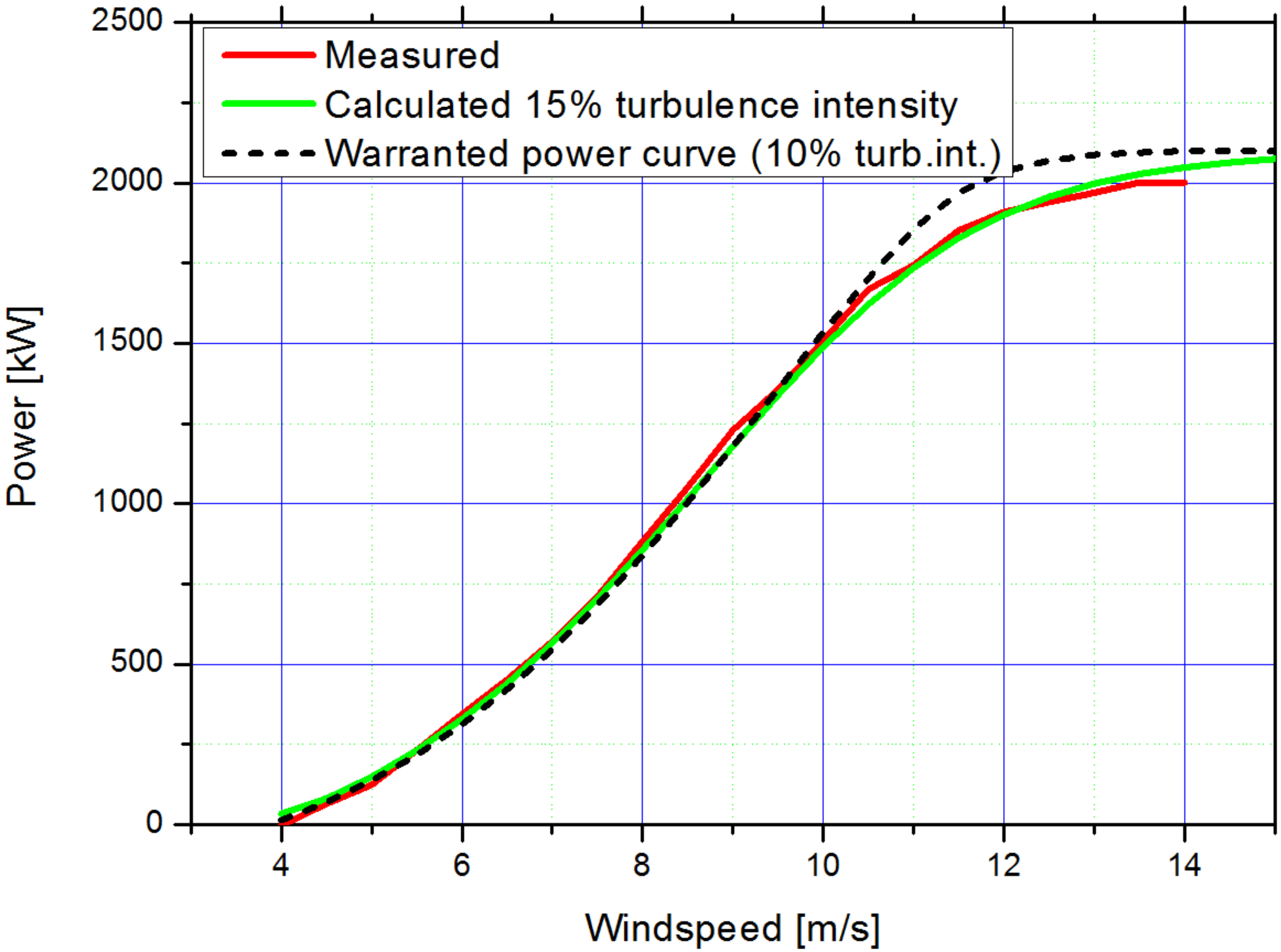
How to measure the wind shear 1

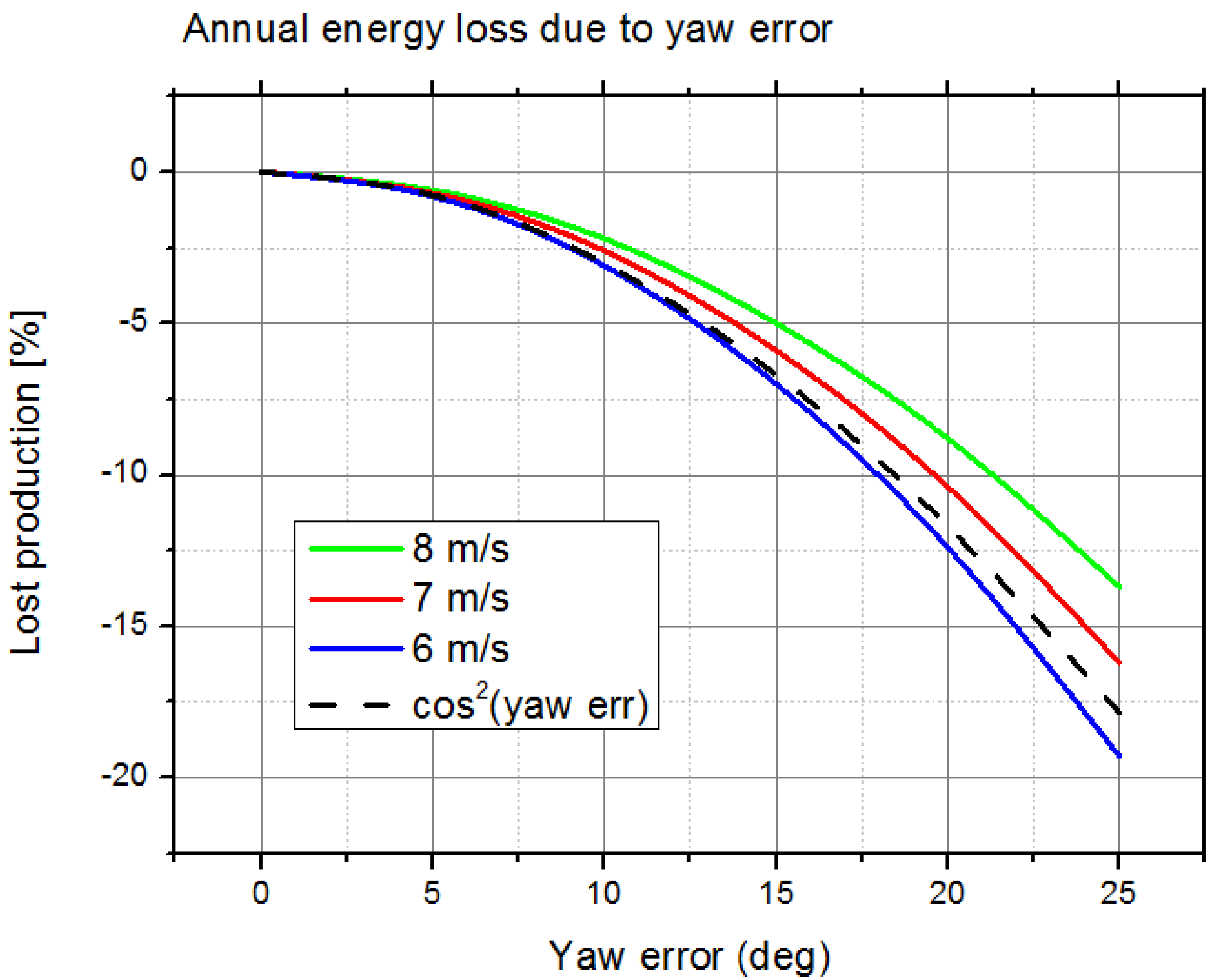
- The main observation is that in a turbulent flow with air parcels moving up and down, the air parcel will ”remember” what the horizontal windspeed was at other heights.
- The air parcel arriving from ”3” to ”1” will arrive with a lower windspeed than the local windspeed at ”1”.



Turbulence effects => Deviations from Manufacturers Power curves (measurements and theory for a different turbine)



YAW MISALIGNMENT = LOWER PRODUCTION AND HIGHER LOADS



THE SPINNER ANEMOMETER PROVIDES 3.7-5,5% MORE POWER WHEN CORRECTING AN AVERAGE 14 DEGREE YAW ERROR

LIDAR (Zephir) at 180m compared with Spinner Anemometer

	Additional Power Production Obtained After Yaw Error Correction (%)			
Annual Average Wind Speed	6m/s	7m/s	8m/s	8,5m/s
NP180	4,9	4,4	3,8	3,5
SA	5,5	4,7	4	3,7

Source: ROMO Wind