GLOBAL SOLUTIONS
IN ENGINEERING

Power Performance Testing

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Why Power Perfomance Testing?

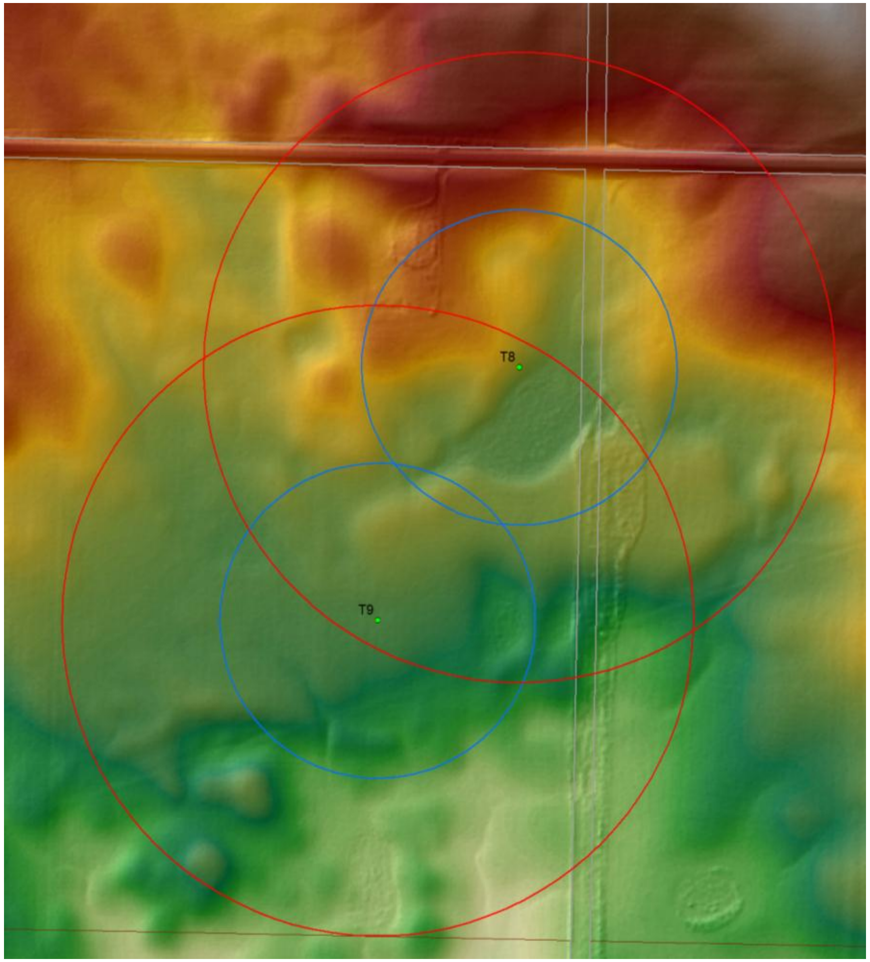
- Identification of turbine performance issues
  - Operational issues
  - Turbine losses
- Standardized way to compare measured power curve to warranted power curve
- Project wide performance
- Higher value for resale or project financing

Outline: Critical Issues

- Following the IEC 61400-12-1 Standard
- Proper tower positioning and instrumentation
- Data filtering techniques
- Measurement uncertainty
- Turbine Supply Agreement Conditions

IEC 61400-12-1 Testing Standard: Tower Siting

- Within 2 to 4 rotor diameters
- 2.5 rotor diameters optimum
- Prevailing wind directions



IEC 61400-12-1 Testing Standard: Terrain Criteria

Criterion	Description*	Distance†	Sector (deg)
1	Maximum slope of best fit plane < 3%	< 2L	360^0
2	Maximum terrain variation from best fit plane < 0.04(H+D)	< 2L	360^0
3	Maximum slope of best fit plane < 5%	2L – 4L	Measurement sector
4	Maximum terrain variation from best fit plane < 0.08(H+D)	2L – 4L	Measurement sector
5	Steepest slope maximum < 10%	2L – 4L	Outside measurement sector
6	Maximum slope of best fit plane < 10%	4L – 8L	Measurement sector
7	Maximum terrain variation from best fit plane < 0.13(H+D)	4L – 8L	Measurement sector

IEC 61400-12-1 Testing Standard: Site Calibration

- In complex terrain

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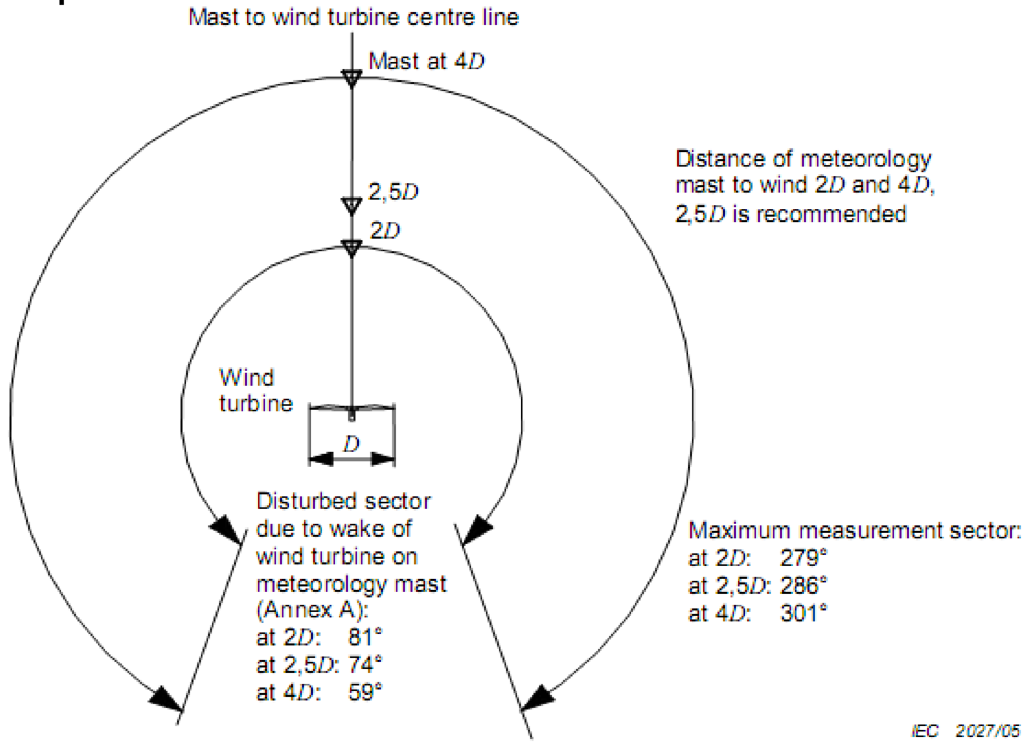
IEC 61400-12-1 Testing Standard: Measurement Sector

- → Flow distortion relevant up to 20 rotor diameters



IEC 61400-12-1 Testing Standard: Sensor Accuracy

Instrument	Specification
Wind Speed Anemometer	Class 1.7A or better for Standard tests
	Class 2.5B or 1.7S or better for tests requiring a site calibration
Wind Direction Sensor	Orientation uncertainty should be less than 5°
Power Transducer	Class 0.5 or better based upon standard IEC 60688
Data Acquisition System	Data acquisition system must be calibrated onsite. The system must be designed such that uncertainty should be negligible compared to the uncertainty of the sensors

Cup Anemometer (Requirement IEC 61400-12-1)	Class A (1.7)	Class B (2.5)
NRG max 40	2.4	7.7
Risø P2546	1.9	8.0
Vaisala WAA151	1.7	11.1
Vector L100	1.8	4.5
Thies "First Class"	1.5	2.9
Thies "First Class" Advanced	0.9	3.0

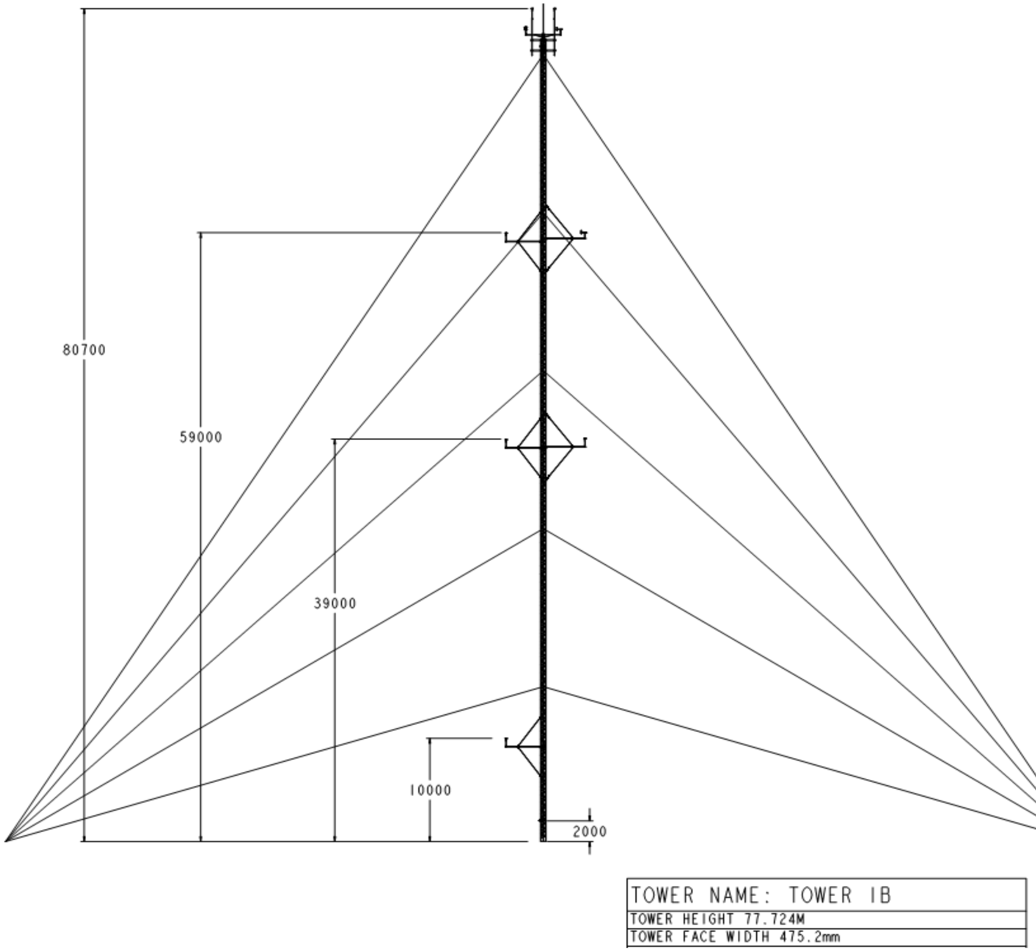
Tower Configuration

→ Over and above the IEC standard to minimize uncertainty

Tower Configuration

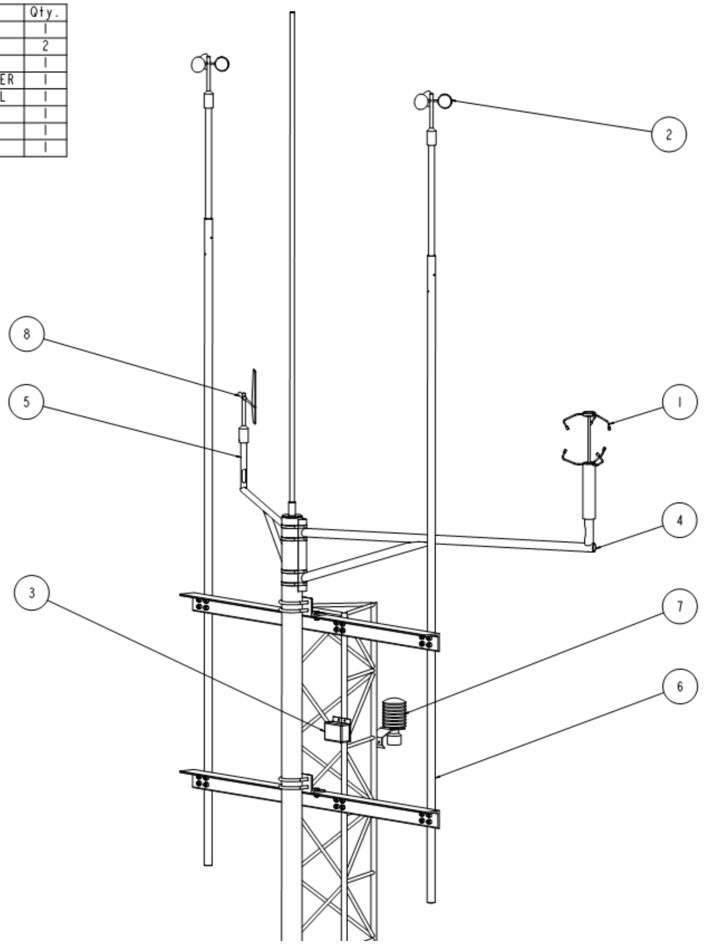
Instrument	Height (m)	Model No.	Mounting
Anemometer (2)	80	Thies First Class Advanced 4.3351.00	goal post boom
Sonic Anemometer (1)	78.3	Thies 4.3830.21.310	post mounted horizontal boom
Wind Vane (1)	78.3	Thies 4.3150.10	post mounted horizontal boom
Temp/Humidity Probe (1)	77	RM Young 41382 , 41003	mounted on tower
Barometric Pressure	77	RM Young 61302	mounted on tower
Anemometer (1)	59	Thies First Class Advanced 4.3351.00	tilt down boom
Wind Vane (1)	59	Thies 4.3150.10	tilt down boom
Anemometer (2)	39	Thies First Class Advanced 4.3351.00	tilt down booms (2)
Temperature Sensor (1)	2	RM Young 41342, 41003	mounted on tower
Anemometer (1)	10	Thies First Class Advanced 4.3351.00	tilt down boom
Precipitation Sensor (1)	2	Thies 5.4103.20.041	short custom boom

Tower Configuration



Tower Configuration

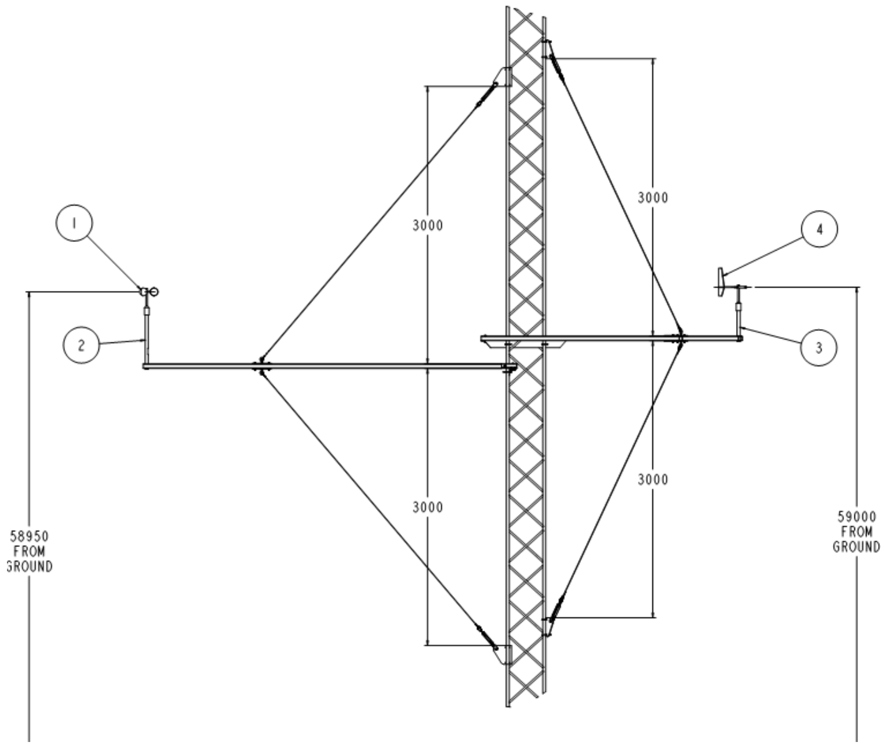
Index	Part No.	Description	Qty.
1	ANEMOM_ULTRA_THEIS	THEIS ULTRA SONIC 3D ANEMOMETER	1
2	ANOMOM_THIES	THIES 1ST CLASS ADVANCED ANEMOMETER	2
3	BARO_PRESS	BAROMETRIC PRESS SENSOR	1
4	GBM-1510	1.7M BOOM THEIS ULTASONIC 3D ANEMOMETER	1
5	GBM-1511	1.7M BOOM THIES WDIR TRNS+WTRNS 1ST CL	1
6	GBM-1716	GOAL POST ASS'Y	1
7	TMP_HMD_PROBE	TEMP + TEMP/RH SENSOR RM YOUNG 41003	1
8	WIND_VANE	WIND VANE THEIS 1ST CLASS	1

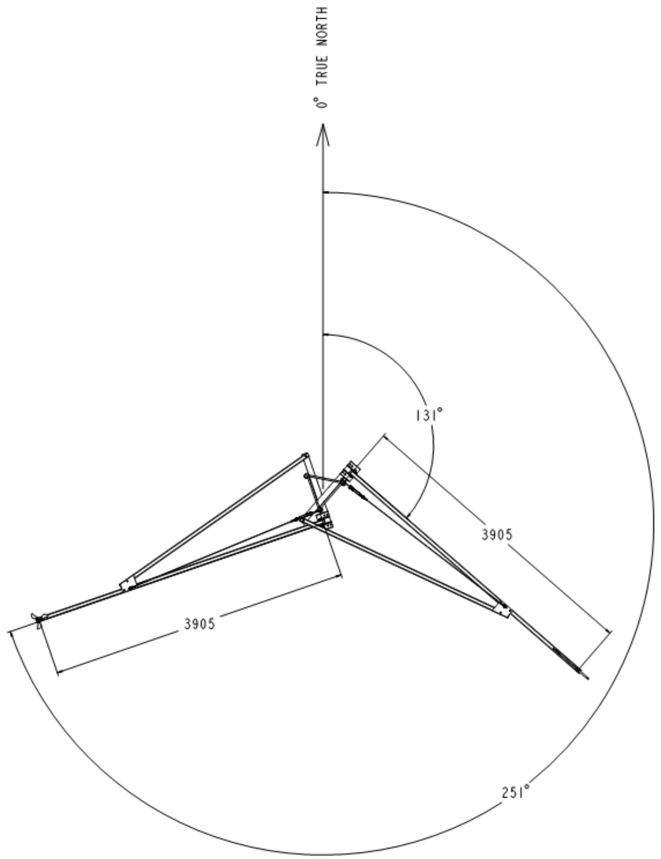


- Sufficient separation between sensors and tower
- Clean configuration

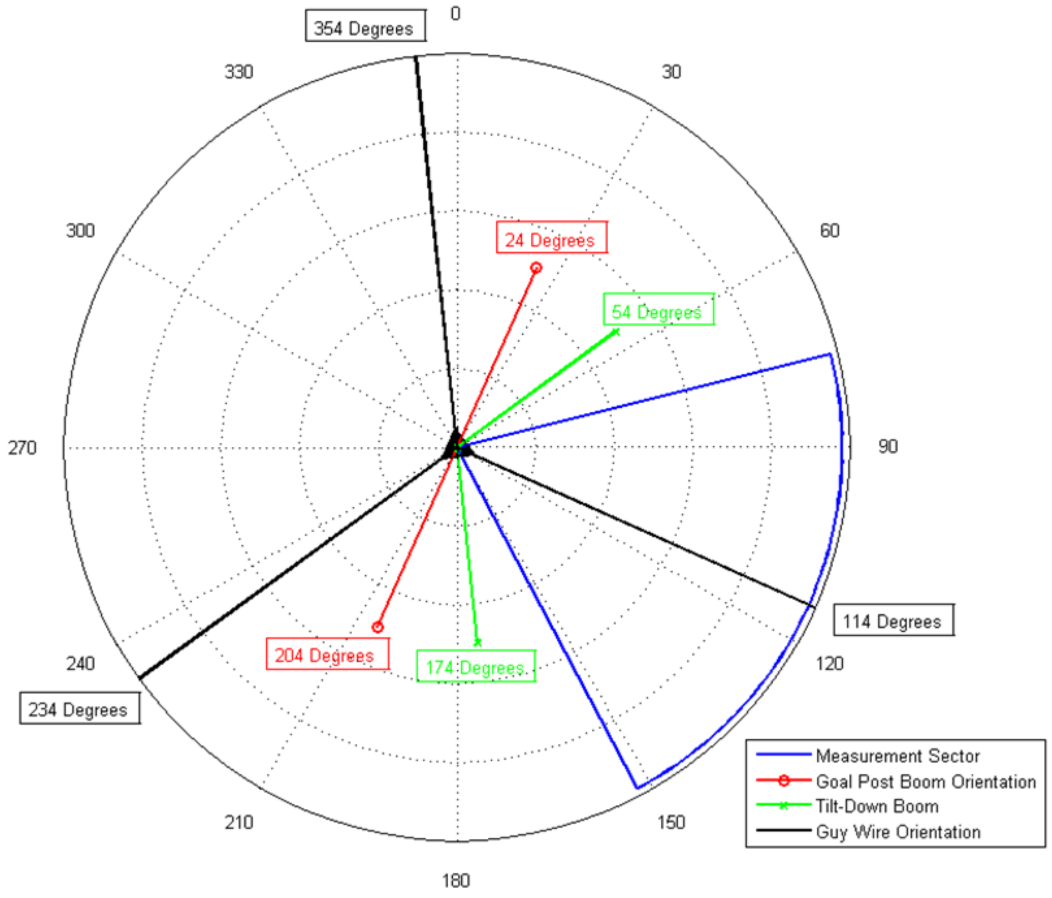
Tower Configuration

Index	Part No.	Description	Qty.
1	ANOMOM_THIES	THIES 1ST CLASS ADVANCED ANEMOMETER	1
2	GBM-1701_2_18_1_344_AN_0	4M BOOM ASSEMBLY	1
3	GBM-1701_2_18_1_344_WV_0	4M BOOM ASSEMBLY	1
4	WIND_VANE	WIND VANE THEIS 1ST CLASS	1





Tower Orientation



Data Filtering: Turbine Operational Envelope

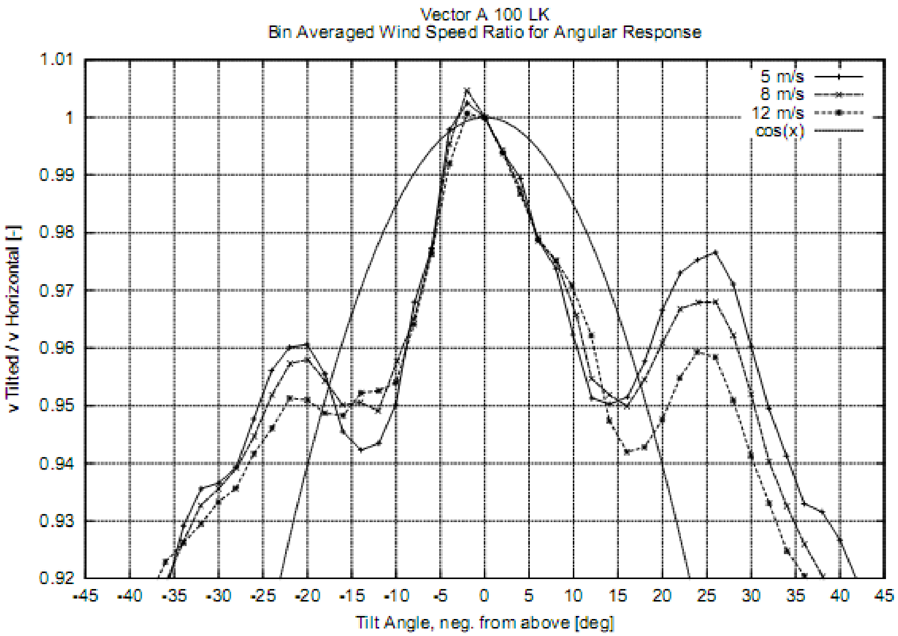
- Inflow Angle (8 degrees)
- Shear (0.2)
- Turbulence Levels (IEC Standard Class)
- Temperature
- Precipitation
- Blade Soiling
- Icing
- Turbine status codes

Data Collection

- 1-second data
- Detailed turbine status data
- Thorough data monitoring program (calibration and test)

Measurement Uncertainty: Anemometer Accuracy

→ Conditions specified in anemometer documentation



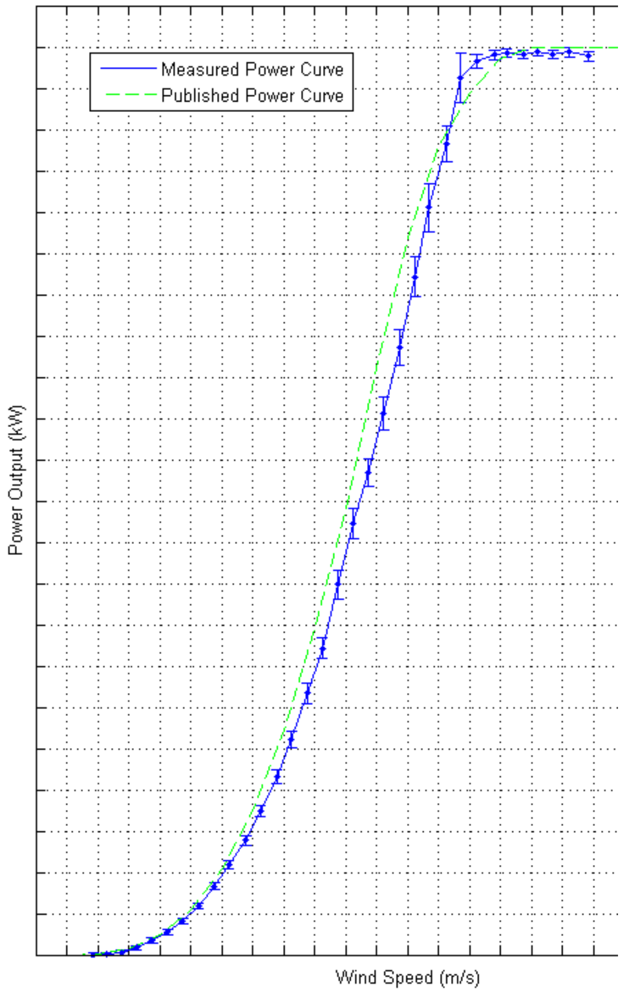
Mean flow inclination	Valid turbulence intensity range	
[deg]	Ti min [%]	Ti max [%]
-20	n.f.	n.f.
-15	11	25
-10	19	25
-5	23	25
-4	>0	7
-3	>0	10
-2	>0	11.5
-1	>0	12.5
0	>0	13
1	>0	13
2	>0	13
3	>0	12.5
4	5	9.5
5	19.5	25
10	15	25
15	9.5	25
20	n.f	n.f.

negative angle: inflow from above

Class 1 conditions for the Vector A 100L2

Turbine Supply Agreement

- IEC Standard is not comprehensive and is open to interpretation
- Deviations are common and an open line of communication should be established
- Treatment of Uncertainty
- Filtering conditions should be specified
- Special tower siting conditions
- Data treatment
- Representativeness of nominated turbines
- Representative wind speed
- Process for implementing test results established
- Methods of calculating availability prescribed



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Conclusions

- Following IEC standard
- Instrumentation and Tower positioning
- Data collection
- Data filtering conditions: minimizing uncertainty
- Turbine supply agreement considerations

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