Test Site & Certification Testing Requirements

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NREL CIP Workshop

29 November 2023

Background - Dean

CIP Topic Areas

- Prototype Design Development
- Prototype Manufacture & Installation
- Prototype Testing
- Component Innovation
- System Optimization
- Small Wind Testing & Certification
  (<200 m^2 RSA or up to 150 kW for ACP 101-1)
- Type Certification
  (>200 m^2 RSA or > 150 kW)
- Manufacturing Process Innovation

CIP and Testing

- Prototype Testing (PT)
- Small Wind Certification Testing (CT)
- Type Certification (TC)

Before: <200 m^2
Now: up to 150 kW

Before: >200 m^2
Now: >150 kW

Or if extra effort/cost warranted for specific reason or market

Test	Project Cost	NREL (2022)	20% Price Participation
PT	$312.5k	$250k*	$62.5k
CT	$250k	$200k**	$50k
TC	$1,000k	$800k	$200k

*or $150k for testing plus $20k + $1/W for installation (<80 kW units)
**Additional $80k for loads, $80k for UL 6142, $200k for inverter listing

Certification Requirements

Certification Testing (CT)

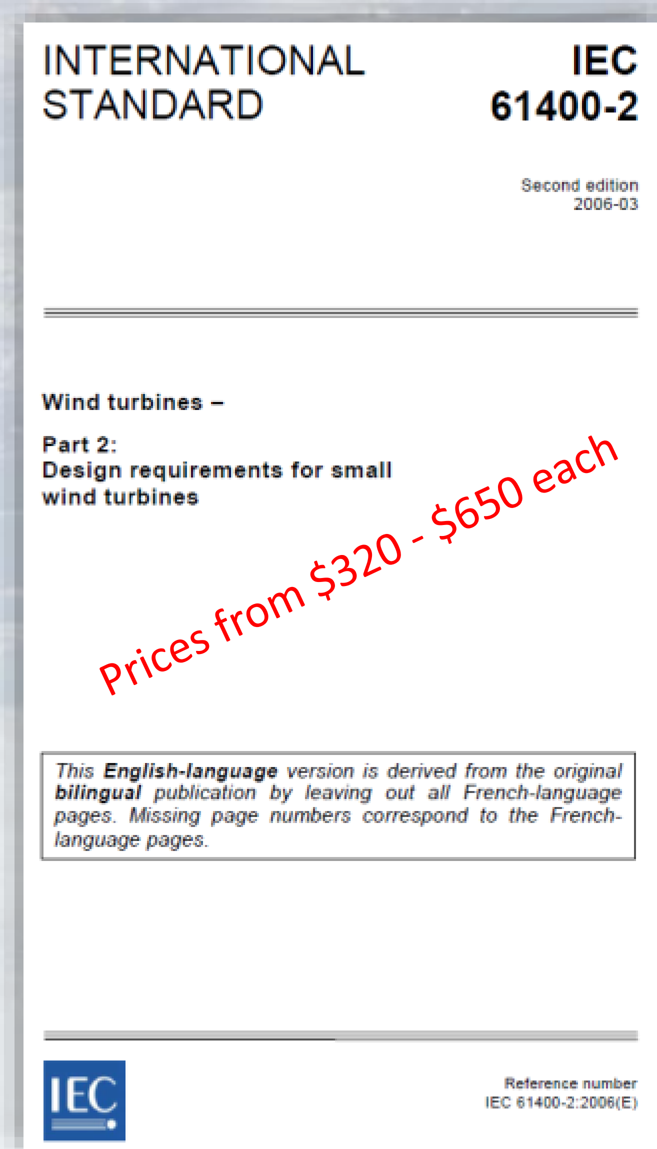
- Design Evaluation
- Required Field Tests
  - Power Performance
  - Acoustic
  - Safety and Function
  - Duration

Type Certification (TC)

- Design Basis Evaluation
- Design Evaluation
- Required Tests
  - Power Performance
  - Safety & Function
  - Mechanical Loads
  - Blade Structural
- Optional Tests
  - Acoustics
- Manufacturing Evaluation
- Final Evaluation

Standards

- Power Performance (IEC 61400-12-1 ed 2.0)
- Acoustics (IEC 61400-11 ed 3)
- Small wind turbine design (IEC 61400-2)
- AWEA 9.1-2009 (up to 200 m^2)
- ACP-101-1_2021 (Up to 150 kW)
- Large wind turbine design (IEC 61400-1)
- Mechanical loads (IEC 61400-13)
- Structural testing of rotor blades (IEC 61400-23)
- Conformity testing & certification (IECRE ODs)
- Competence of testing and calibration laboratories (ISO/IEC 17025)
- Quality management system (ISO 9001)
- Others if needed (gearbox, electrical, lightning, power quality, low voltage ride through, etc.)



INTERNATIONAL STANDARD

IEC 61400-2

Second edition 2006-03

Wind turbines –

Part 2: Design requirements for small wind turbines

*This **English-language** version is derived from the original **bilingual** publication by leaving out all French-language pages. Missing page numbers correspond to the French-language pages.*

Reference number IEC 61400-2:2006(E)

Prices from $320 - $650 each

Certification Bodies

- ICC-SWCC
- Intertek
- UL (Underwriters Laboratory)
- DNV
- BSI (UK)
- SGS
- ClassNK (Japan)
- Accredited to ISO 17065

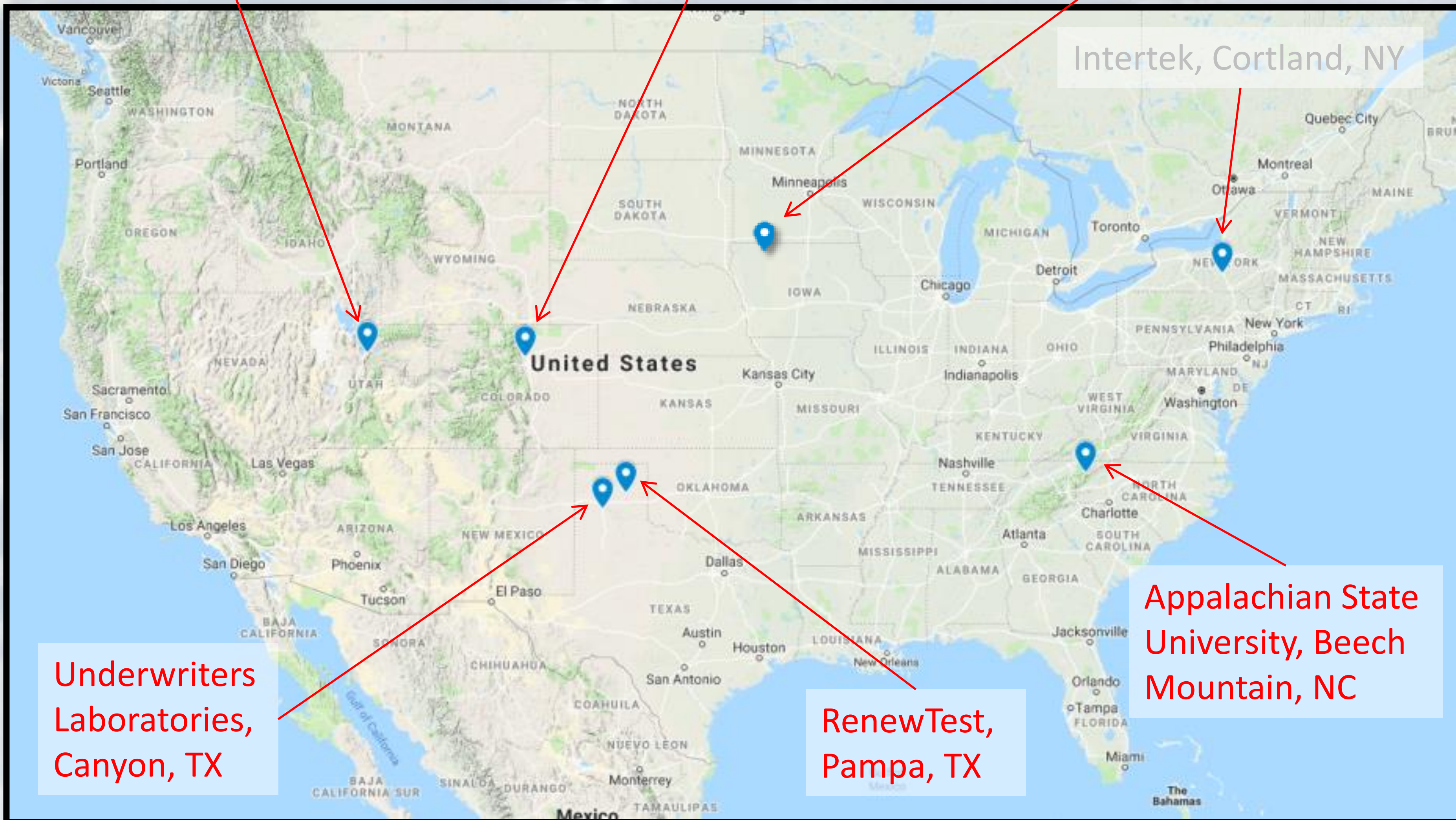
Engage early to avoid surprises

Existing Test Facilities

Windward Engineering, Spanish Fork, UT

NREL Flatirons, Arvada, CO

windtest North America, Estherville, IA



Certification Body Due Diligence

- If an accredited testing laboratory:
  - Review paperwork
- If not accredited, they will need to review:
  - Quality assurance procedures/manuals
  - Testing related procedures/manuals
  - Interviews of personnel
  - Round robin (or other method) for evaluation of data processing
  - Test site visit (witnessing)
- Goal is to make sure the data from the test facility meets their standards as well as the guidelines set forth in ISO 17025

Ideal Test Site Attributes

- All Field Tests
  - Regular & non seasonal winds
  - Favorable zoning and permitting laws
  - Nea…
    equ…
    etc.
- Power …
  - Unobstructed ground
  - Flat terrain
  - Occasional high winds

The ideal site may not exist, but most shortfalls can be mitigated with ingenuity, time and money

- Acoustics
  - Quiet site
  - Unidirectional winds
  - No nearby reflective surfaces
  - Unchanging ground cover
  - …ducing winds
  - …s
  - … ambient temperature
- Loads
  - Occasional high winds
  - Regular times of calm (for calibrations)
  - Variability in turbulence

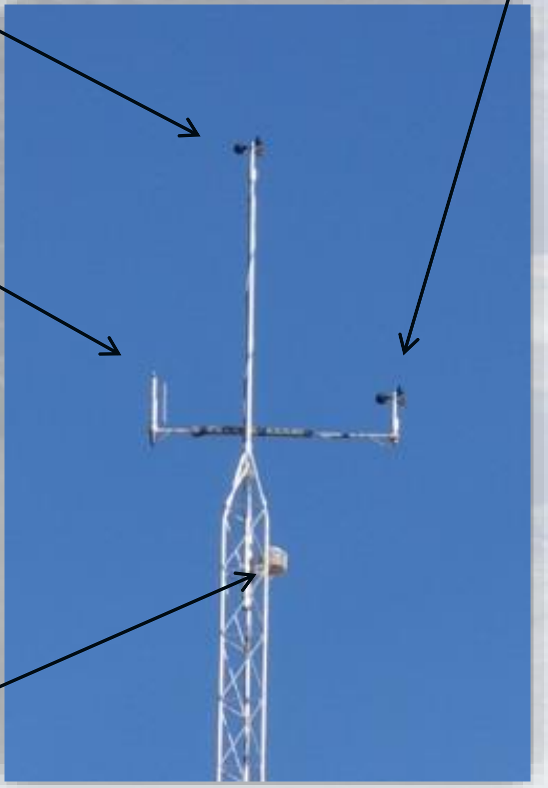
Power Performance

Power Performance (test site evaluation)

- Some sites will pass all requirements easily

- Some will require a bit of analysis but will pass
- Others (like ours) will require a site ~~calibration~~ ACP 101-1

Power Performance (met. tower instrumentation)



Met. tower

Primary Anemometer

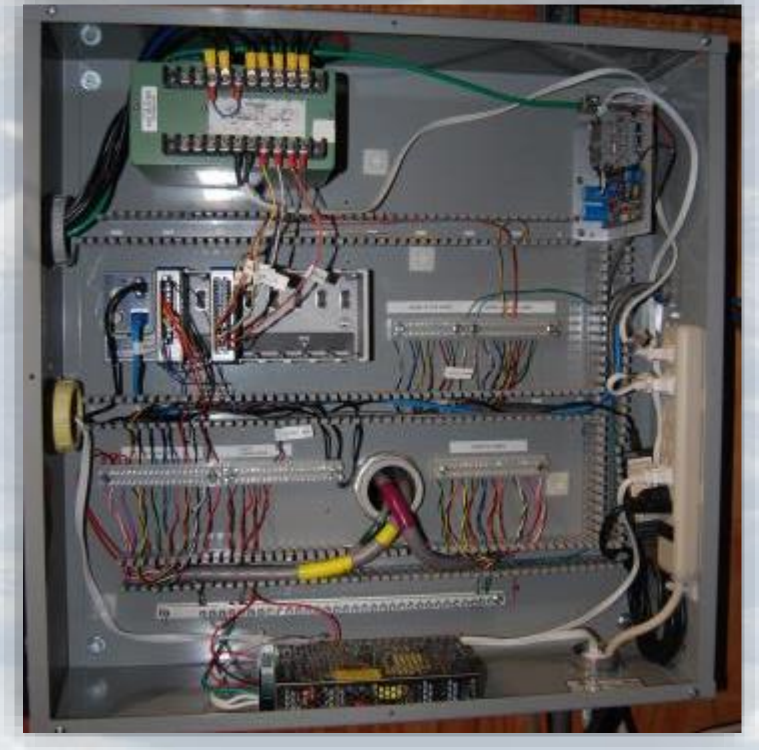
Secondary Anemometer

Wind Direction

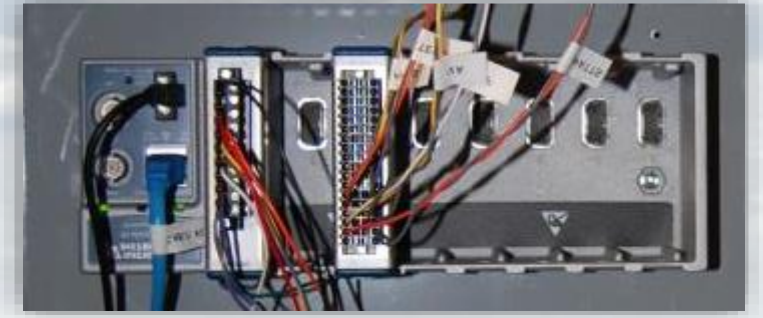
Air Pressure

Air Temperature

Power Performance (down tower instrumentation)



Power, VA, Volts transducer (external CT's)

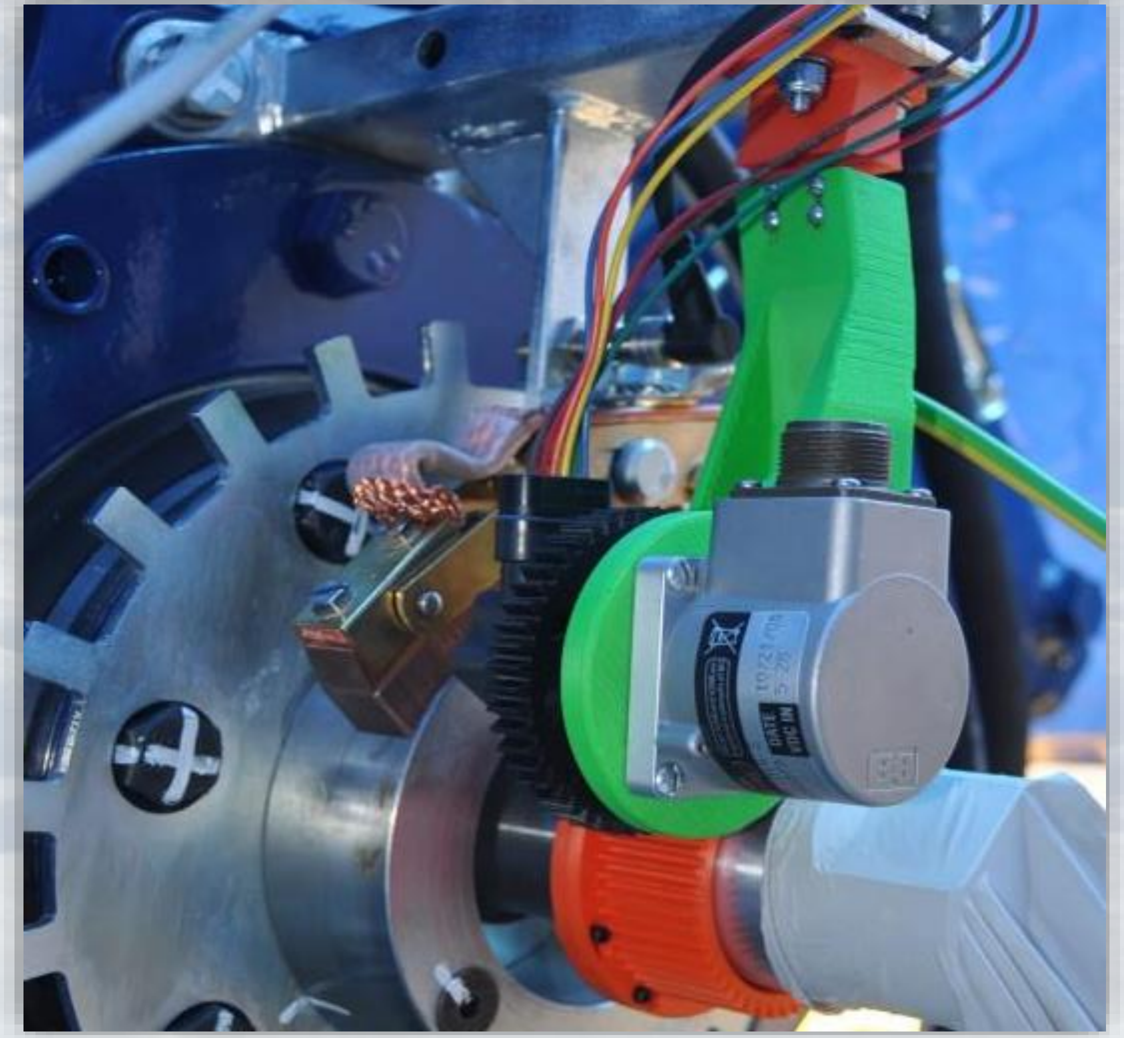


Data Acquisition (chassis and modules)

Data Acquisition Computer

Power Performance (other instrumentation)

- RPM
- Turbine status
- Pitch angle
- Wetness
- Rotor Azimuth
- etc…



Example of RPM and Azimuth sensors (3D printed mounts)

Power Performance (instrumentation costs)

Subsystem	Description	Instrumentation type or detailed description	Qty	price/ea	Total Cost
Rotor	Rotor speed	Gen voltage or encoder	1	$ 250	$ 250
Electrical	Power, VA, Volts	Ohio Semitronics DWV	1	$ 1,284	$ 1,284
Ambient	Wind speed (primary & secondary)	Thies First Class Anemometers	2	$ 1,530	$ 3,060
	Wind direction	Met One 020C	1	$ 1,080	$ 1,080
	Temperature	Met One T-200	1	$ 855	$ 855
	Barometric pressure	Vaisala PTB101B	1	$ 620	$ 620
	Wetness	Wetness sensor	1	$ 145	$ 145
Ancillary	Data shed	Construction trailer	1	$ 3,600	$ 3,600
	Met tower	Climatronics	1	$ 2,985	$ 2,985
	Instrumentation Wire	Belden 12 pair, 24 AWG	1	$ 1,500	$ 1,500
	Power Supply, DC-DC	12V, 24V	2	$ 150	$ 300
Data Collection	LabView software	National Instruments (NI)	1	$ 2,800	$ 2,800
	Data acquisition computer	Dell	1	$ 700	$ 700
	Uninterruptable power supply	APC	1	$ 120	$ 120
	DAQ CompacDaq chassis	NI cDAQ-9188	1	$ 1,399	$ 1,399
	Voltage module	NI 9229	2	$ 1,328	$ 2,656
	RTD module	NI 9217	1	$ 500	$ 500

Total estimated cost $ 23,854

Power Performance (calibration sheets)

- All instrumentation requires current calibrations sheets
- Calibration constants used in data acquisition system
- Uncertainty required in data processing
- Calibration sheets included in final report
- Ask certifying body if specific details are required – such as ISO 17025 accredited.

ANAB
ACCREDITED
CALIBRATION LABORATORY
AC-1746

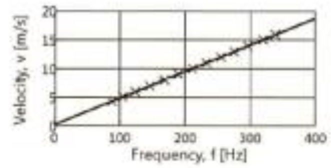
SOH Wind Engineering LLC

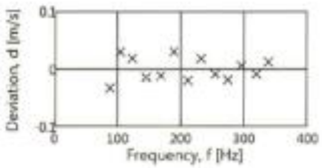
141 Leroy Road · Williston, VT 05495 · USA
Tel 802.316.4368 · Fax 802.735.9106 · www.sohwind.com

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 16.US1.04325 **Date of issue:** May 23, 2016
Type: Thies 4.3351.10.000 **Serial number:** 03155300
Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany
Client: Endurance Wind Power, 10768 S.Covered Bridge Canyon, Spanish Fork, UT 84660
Anemometer received: May 5, 2016 **Anemometer calibrated:** 14:54 May 23, 2016
Calibrated by: mej **Procedure:** MEASNET, IEC 61400-12-1:2005(E) Annex F
Certificate prepared by: Software Revision 7 **Approved by:** Calibration engineer, rds
Calibration equation obtained: $v[m/s] = 0.04632 \cdot f[Hz] + 0.22843$
Standard uncertainty, slope: 0.00160 **Standard uncertainty, offset:** 0.07316
Covariance: -0.0000012 $(m/s)^2/Hz$ **Coefficient of correlation:** $\rho = 0.999986$
Absolute maximum deviation: 0.032 m/s at 4.276 m/s
Barometric pressure: 1000.5 hPa **Relative humidity:** 32.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in d.p. box [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	10.67	24.6	32.3	4.276	88.0763	-0.032	0.024
4	15.17	24.6	32.3	5.100	104.5287	0.030	0.025
6	20.80	24.7	32.3	5.973	123.6026	0.018	0.027
8	28.28	24.7	32.3	6.965	145.7340	-0.015	0.030
10	37.57	24.7	32.3	8.027	168.6130	-0.012	0.033
12	47.56	24.7	32.3	9.032	189.3919	0.030	0.036
13-last	58.21	24.7	32.3	9.992	211.1869	-0.020	0.039
11	70.62	24.7	32.4	11.006	232.2662	0.018	0.042
9	83.98	24.7	32.3	12.003	254.3694	-0.009	0.045
7	97.39	24.7	32.3	12.925	274.4884	-0.018	0.049
5	113.29	24.6	32.3	13.940	295.8765	0.006	0.052
3	131.31	24.6	32.3	15.008	319.2293	-0.009	0.055
1-first	147.44	24.5	32.3	15.901	338.0479	0.013	0.058





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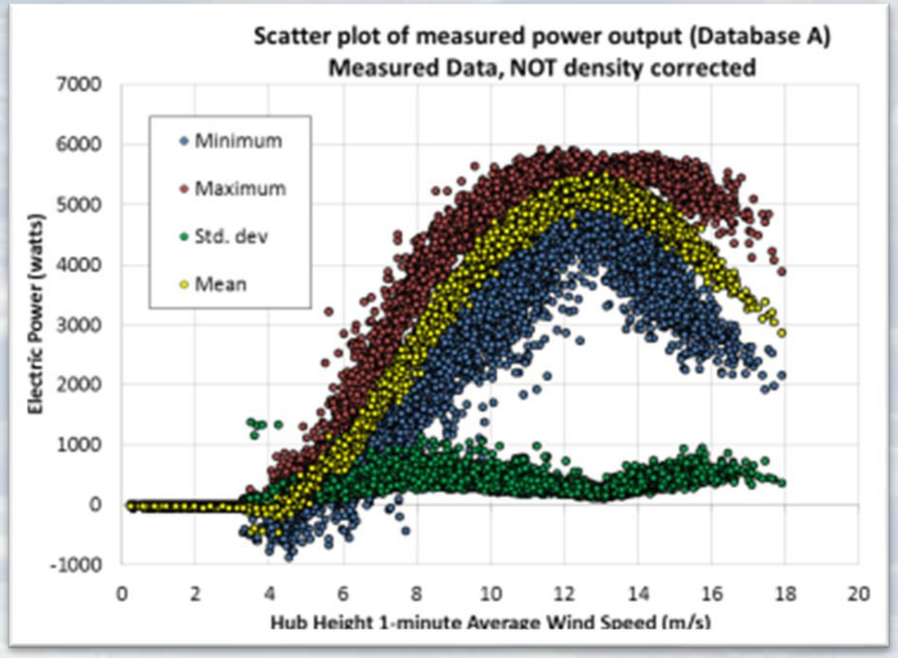
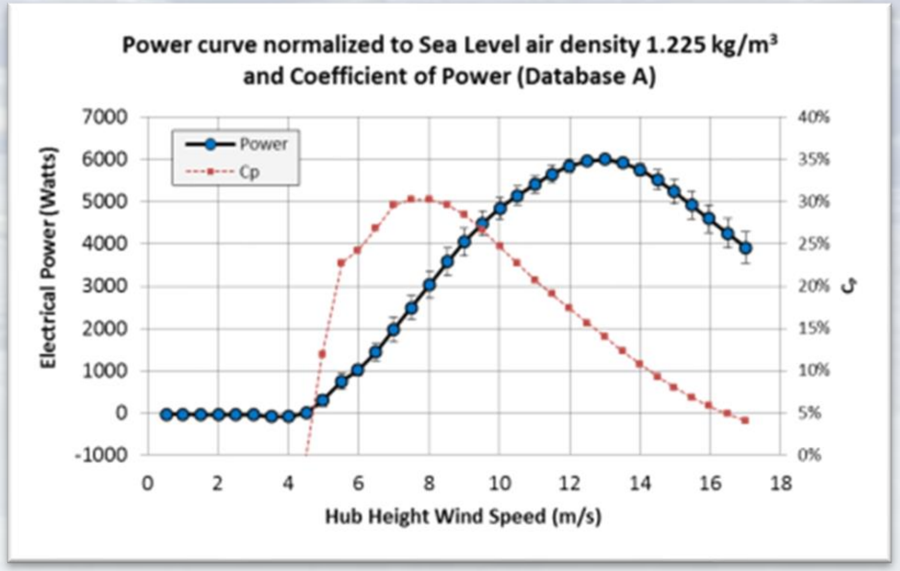
Power Performance (database requirements)

- IEC 61400-12-1 ed2.0 (Annex H - SWT)
  - Minimum of 10 minutes in each bin
    - 1-minute data sets
    - Bin width is 0.5 m/s
  - Bins range to fill
    - 1 m/s below cut-in to 14 m/s
  - Total database at least 60 hours
- IEC 61400-12-1 ed2.0
  - Minimum of 30 minutes in each bin
    - 10-minute data sets
    - Bin width is 0.5 m/s
  - Bins range to fill
    - 1 m/s below cut-in to
    - 1.5x WS at 85% of rated power
  - Total database at least 180 hours



Power Performance (how long does it take)

- Timing dependent on:
  - Percent of time blowing from valid wind direction sectors
    - ACP 101-1 exclusion sectors allowed if anno not affected
  - Time to capture higher winds
- NREL suggests:
  - 3-6 months
- Can be performed in parallel with <u>Duration Testing</u>



Power Performance (data processing)

- Can be performed in Excel
  - Need array functions
  - Could be slow on some computers
- Standard uses clear and well-defined equations

$$C_{P,i} = \frac{P_i}{\frac{1}{2}\rho_0 A V_i^3}$$

where

$C_{P,i}$	is the power coefficient in bin i;
V_i	is the normalized and averaged wind speed in bin i;
P_i	is the normalized and averaged power output in bin i;
A	is the swept area of the wind turbine rotor;
ρ_0	is the reference air density.

- Lots of details – Difficult to imagine not having errors in equations or interpretation if not reviewed by more than one person
- Uncertainty portion not trivial
  - Old NREL reports have details on their uncertainty analysis
  - Old NREL presentations are also a useful resource

Power Performance (reporting)

- Standard has a section on what must be reported
- NREL reports – great template
- Example NREL report:
  - ~50 pages total length
  - ~27 pages of report
  - ~23 pages in appendices

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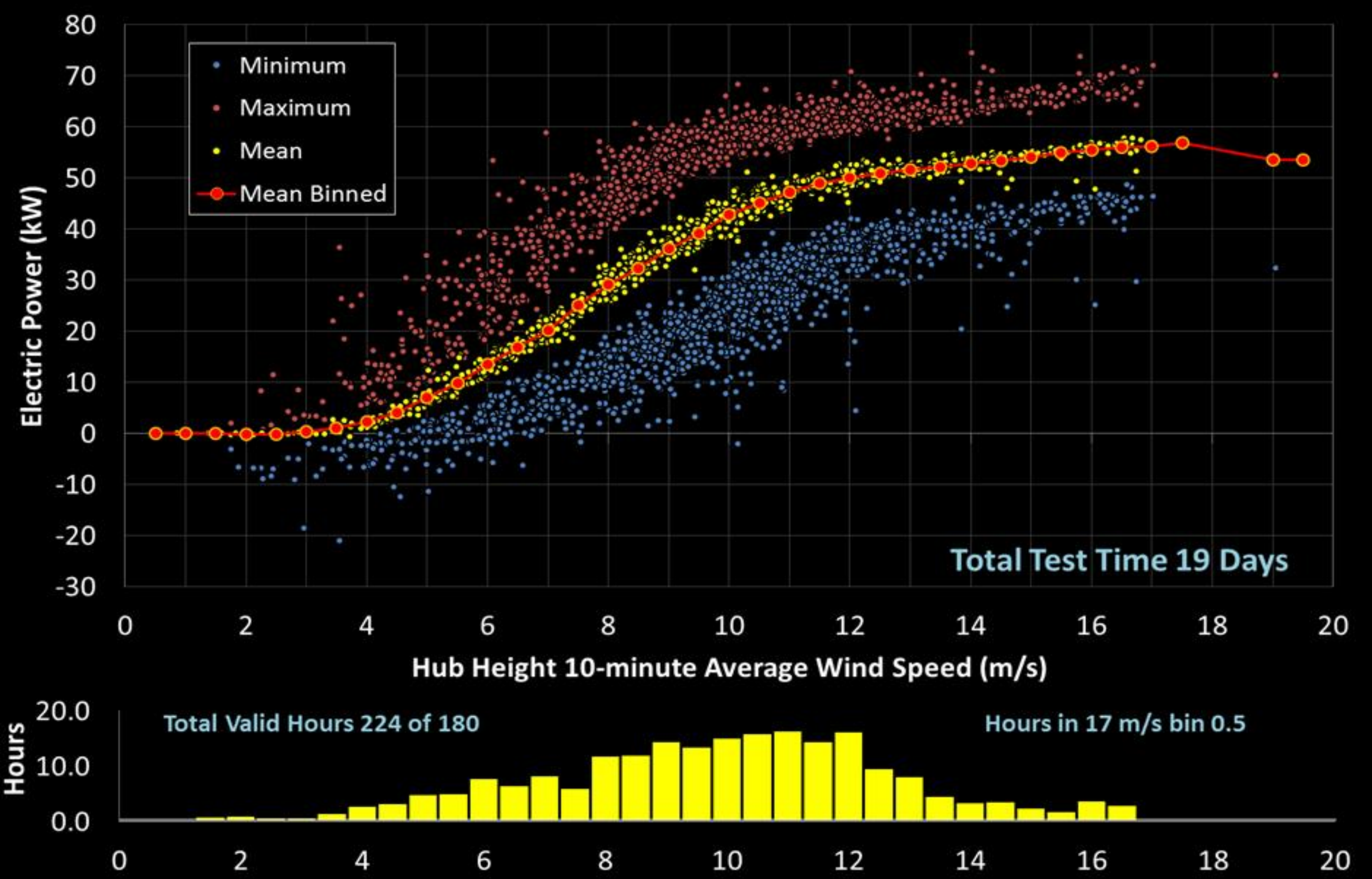
Power Performance



Acoustic Testing

Acoustic Testing

- The good news:
  - Most of the instrumentation is now in place (from PP test)
  - Test times are much shorter
- The bad news:
  - There are significant challenges in data collection
  - Data post processing is much more difficult and time consuming
  - New and expensive instrumentation is required
    - We spent more than $11,000 on microphone, calibrator, Noiselab software, and DAQ equipment

Acoustic (data requirements Power < 100 kW)

- See Annex F (Small Wind Turbine) [<100 kW]
- Wind speed range
  - Cut-in to 11 m/s minimum
  - If possible up to cut-out (especially for speed control mechanisms)
- Measurements are 10 second each
- In each wind speed bin (1 m/s bin widths)
  - At least 12 measurements (turbine operating)
  - At least 12 measurements (background)
- Not a ton of data but can be challenging to get!
- Likely weeks not months

Acoustic Testing (data collection challenges)

- Microphone has to be +/-15° from downwind (> 100 kW)
- Microphone has to be +/-45° from downwind (< 100 kW)
- Measurement chain needs to be calibrated before and after measurement
- In the same conditions the background noise needs to be measured
- It has to be quiet with few other noises:
  - People, traffic, birds, planes, trains, grass, crickets, etc.
  - You soon realize what a noisy world we live in

Acoustic Testing (data post-processing)

- Software
  - Noiselab (or other software) to process the recorded data
  - For full automation need something more powerful than Excel
  - Can use Excel (complicated spreadsheets) with manual manipulations
  - I built a powerful desktop computer to help speed-up Excel
- Standard uses clear and well defined equations but…
  - Equations are complicated and easy to make errors
  - Interpretation of words can be challenging
  - Most of us won't have a strong background for this analysis

$$u_{L_{WA,k}} = \frac{\sum_{i=1}^{28}\left(u_{c,i,k}10^{\left(\frac{L_{WA,i,k}}{10}\right)}\right)}{\sum_{i=1}^{28}10^{\left(\frac{L_{WA,i,k}}{10}\right)}}$$

- Data analysis absolutely needs to be validated

ACP 101-1

- ~~Tonality is laborious and requires lots of manual clipping of recordings~~
- Significantly more difficult than Power Performance

Duration Test

Duration Testing (simplified in ACP 101-1)

No new instrumentation needed

- Purpose
  - Structural integrity
  - Material & performance degradation
  - Quality of environmental protection
  - ~~Dynamic behavior~~
- Requirements
  - Reliable operation ~~(>90% availability)~~
  - ~~At least 6 months of operation~~
  - ~~2,500~~ 1,000 hours of power production
  - ~~250 hours operating in winds above 1.2V_{avg} (10.2 m/s for Class II)~~
  - ~~25 hours operating in winds above 1.8V_{avg} (15.3 m/s for Class II)~~
  - ~~15~~ 10 hours greater than 15 m/s
- "Major failure" will restart test
- Operational Time Fraction & Analysis of power degradation not required

SWT Class		I	II	III	IV	S
V_{ref}	(m/s)	50	42,5	37,5	30	Values to be
V_{ave}	(m/s)	10	8,5	7,5	6	specified
I_{15}	(-)	0,18	0,18	0,18	0,18	by the
a	(-)	2	2	2	2	designer

Safety & Function

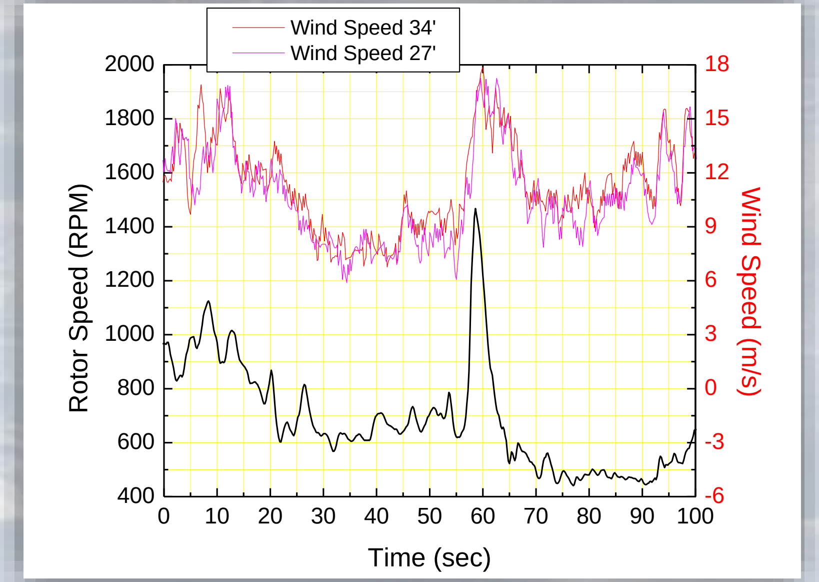
Safety & Function

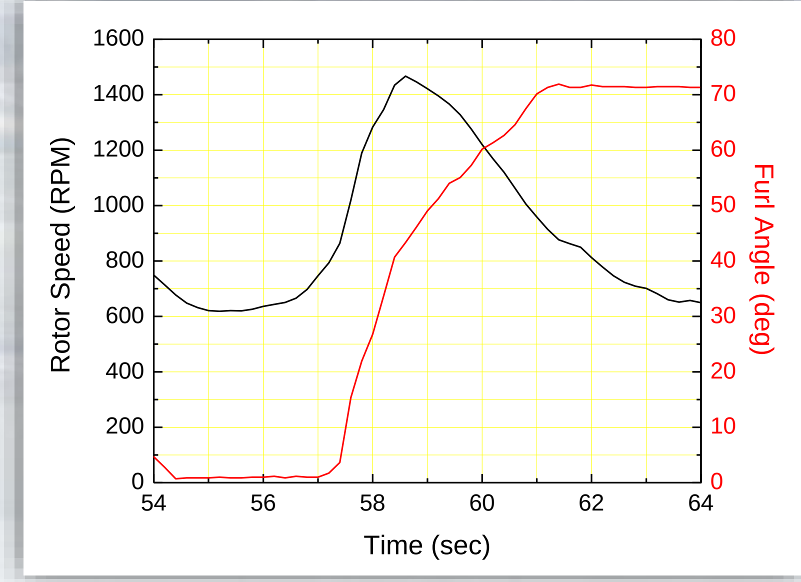
Safety

- Review of O&M procedures and other manuals
- Review of personnel safety topics
  - Warnings, safety labels
  - Climbing related safety

Function

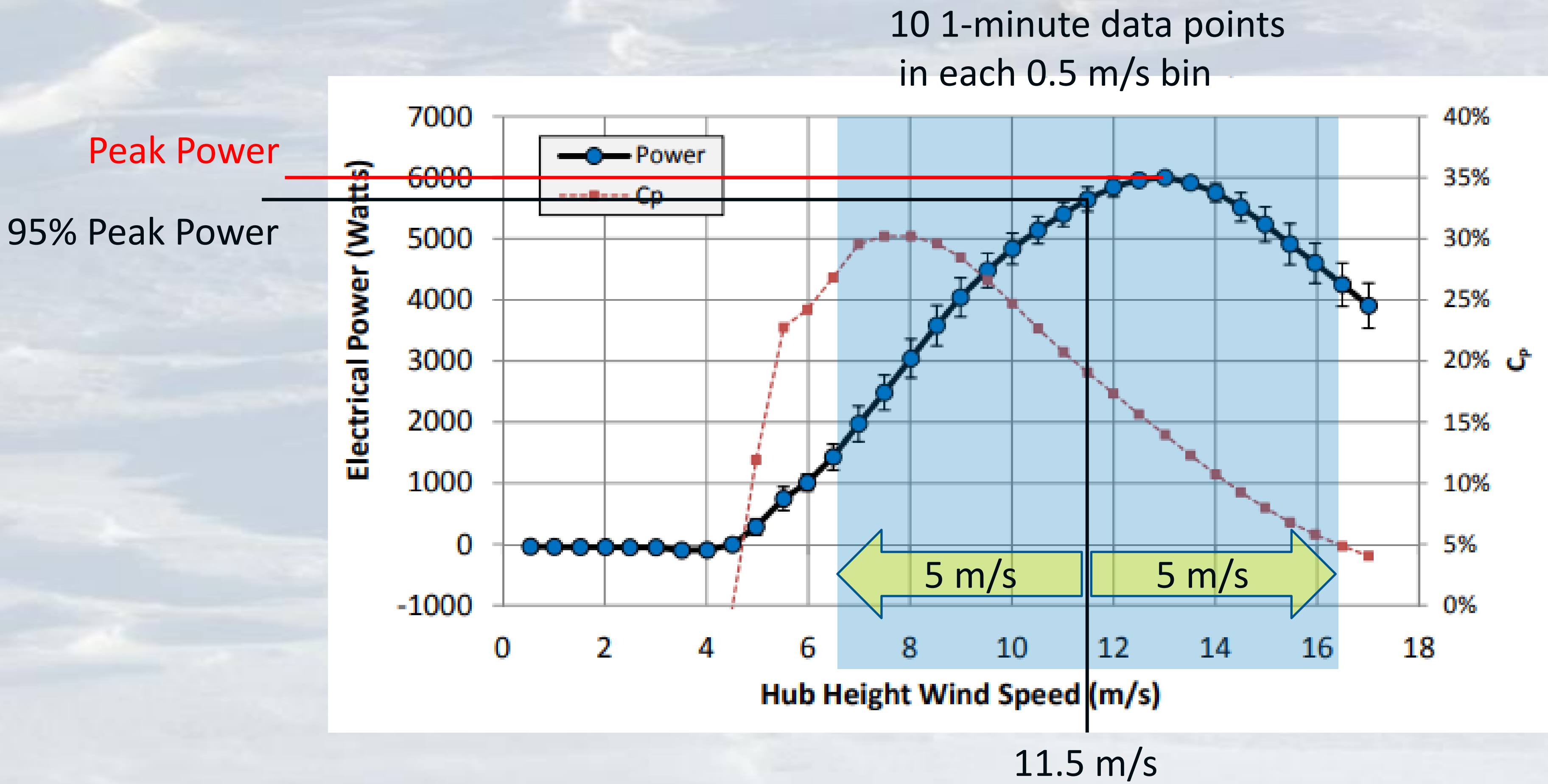
- Similar to a commissioning procedure but with some instrumentation available
- Includes some fault condition testing
  - Grid fault
  - But also may include things such as loss of critical sensors
- May include some specific events
  - Condition related (example: high wind startup or shutdown)
- Demonstrate
  - Peak Power
  - Power limitation
  - Rotor speed limitation





Safety & Function – Peak Power

ACP-101-1

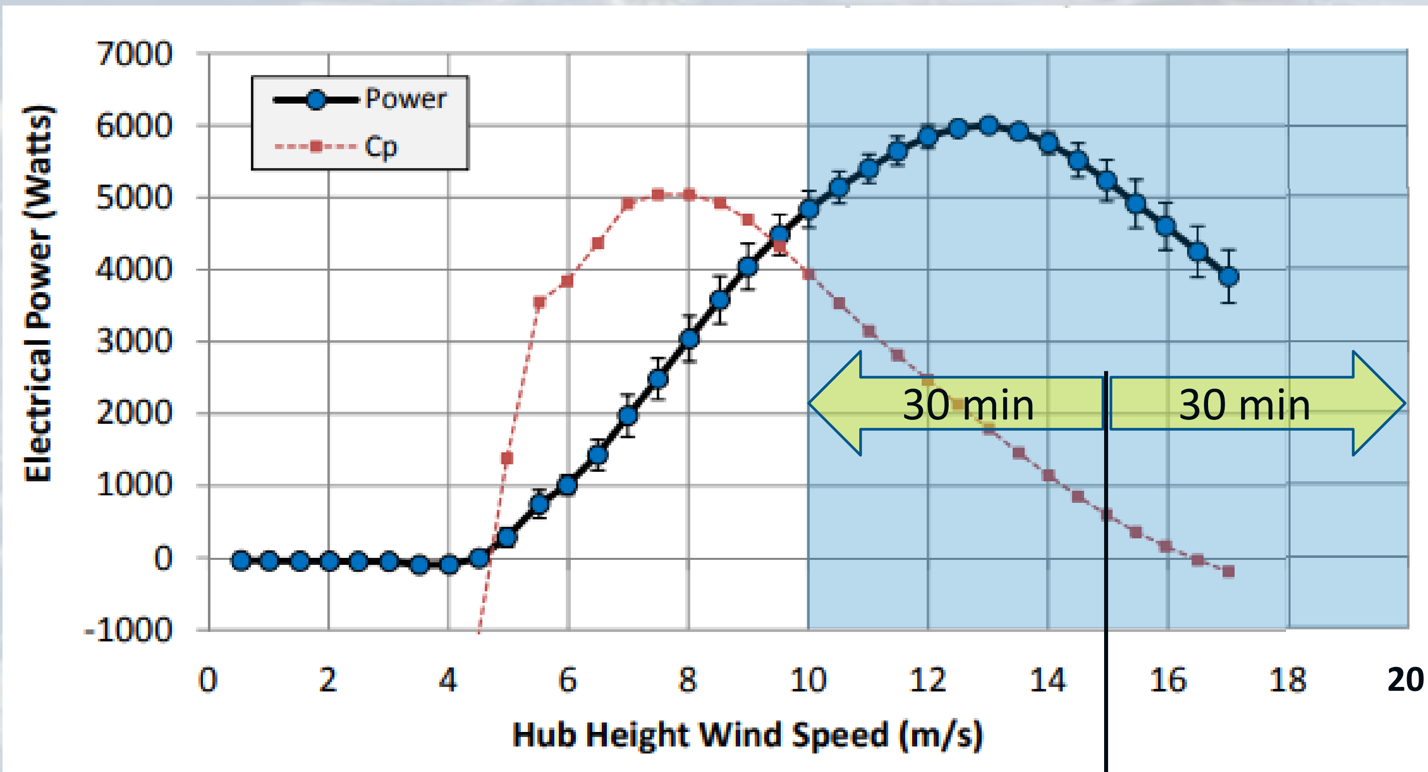


This will also demonstrate Power Limitation

Safety & Function – Max Rotor Speed

IEC 61400-2 section 13.2.4

2 hours of winds between 10 & 20 m/s



15 m/s

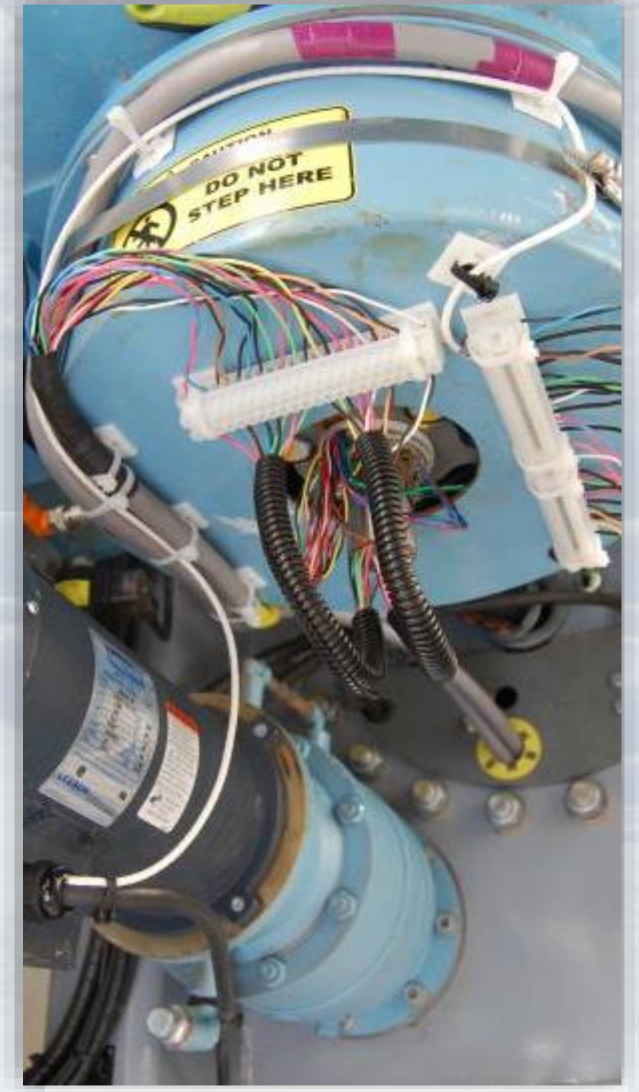
interpolation or extrapolation to V_{ref}

SWT Class	I	II	III	IV	S
V_{ref} (m/s)	50	42,5	37,5	30	Values to be
V_{ave} (m/s)	10	8,5	7,5	6	specified
I_{15} (-)	0,18	0,18	0,18	0,18	by the
a (-)	2	2	2	2	designer

Mechanical Load Testing

Mechanical Loads (overview)

- Not typically needed for small wind (CT)
  - Unless validated load model does not exist (VAWT, ducted, etc.)
- Necessary for large wind (TC)
- Significant undertaking (time, money and effort)
  - >$100,000 and many months
- Use Power Performance instrumentation but add…
  - Tower moments
  - Rotor moments
  - Blade moments
  - Sliprings or telemetry for rotating measurements
  - Anti-aliasing modules required
  - Others (such as rotor azimuth, yaw angle, etc.)



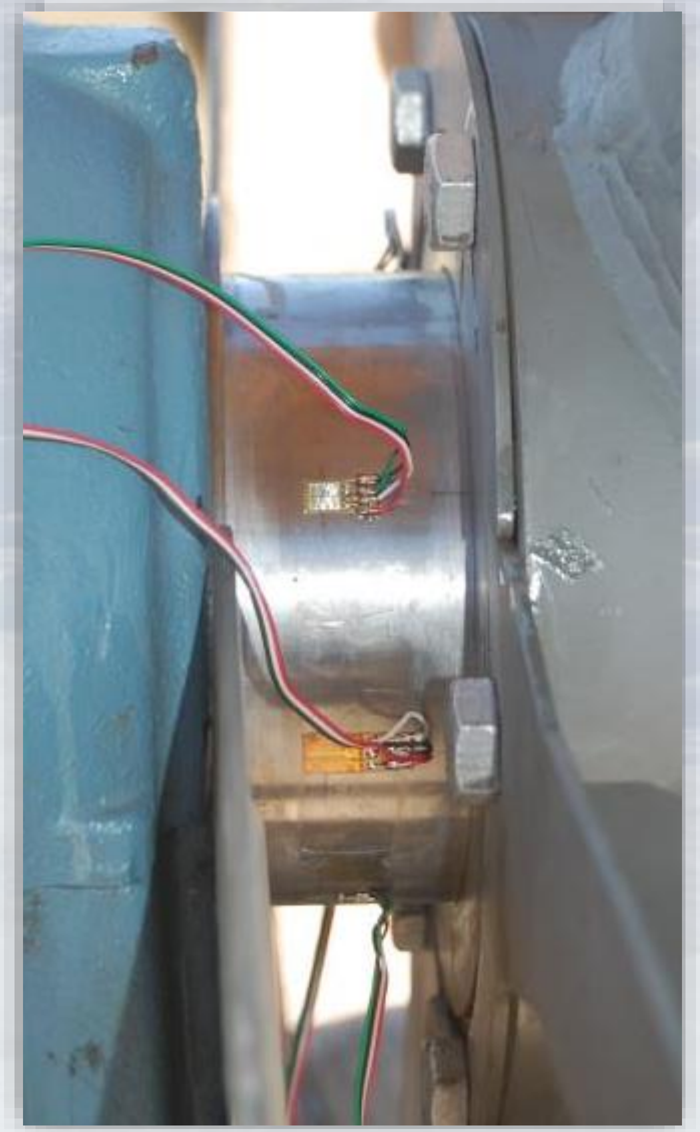
Slipring transmitting data from rotor through main shaft

Mechanical Loads (guidance)

Standard IEC 61400-13 defines:

- Minimum required data channels
- Recommended additional data channels
- Transient load cases
  - Braking
  - High wind shutdown
  - Grid loss
  - Start-up, etc.
- Normal operating load conditions
  - Number of datasets per wind speed bin
  - Range of required wind speed bins
  - Turbulence variability in wind speed bins
- In-situ calibrations
- Data processing and reporting

Main shaft strain gauges



Summary

Test	Time	Cost	Additional Equipment Costs
Field test setup	few months	$20k	$25k
Power Performance	3 – 6 months	$30k	
Acoustic	1 – 2 months	$50k	$10k
Safety & Function	weeks – months	$15k	
Duration testing	6 – 12 months	$25k	
Mechanical Loads	5 – 12 months	$140k	$20k
Blade testing	6 months	$235k	
Manufacturing Evaluation	weeks – months	$65k	

Time and costs could vary significantly

Summary

Certification Testing (CT)

Description	Costs
Field testing	$175k
Certification body	$35k
TOTAL	$210k

Time and costs could vary significantly

Type Certification (TC)

Description	Costs
Field testing	$250k
Other tests	$300k
Certification body	$350k
TOTAL	$900k

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