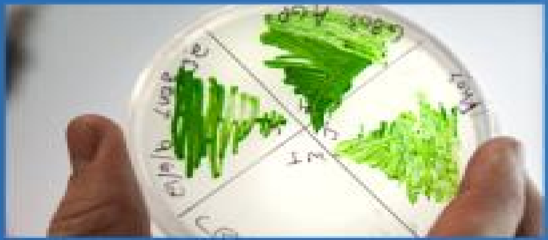




Competitiveness Improvement Project Informational Workshop

December 17, 2019

PR-5000-76082

Session 1: Overview of the Competitiveness Improvement Project (CIP)

Ian Baring-Gould

The CIP Challenge

The Challenge

The distributed wind industry is struggling to compete with lower-cost distributed generation technologies (e.g., photovoltaics [PV]), and consumer confidence is limited from past deployments of untested wind turbines. Industry requires rapid innovation to reduce costs and increase consumer confidence, but many companies are small and limited by available resources.

Through the CIP, the Wind Energy Technologies Office/National Renewable Energy Laboratory offers a competitive, cost-shared solicitation for manufacturers of small and medium wind turbines to optimize their designs, invest in advanced component development, implement advanced manufacturing processes, and help certify turbine models.

CIP Objectives

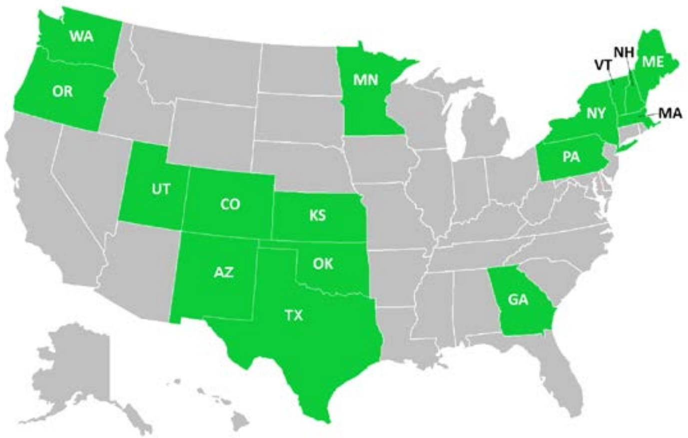
To expand U. S. leadership in the domestic and international distributed wind turbine sector by:

- Lowering the levelized cost of energy, through improved components, overall system optimization, and manufacturing process upgrades
- Increasing the number of certified distributed turbines through testing of turbines <1,000-m^2 rotor swept area (RSA).

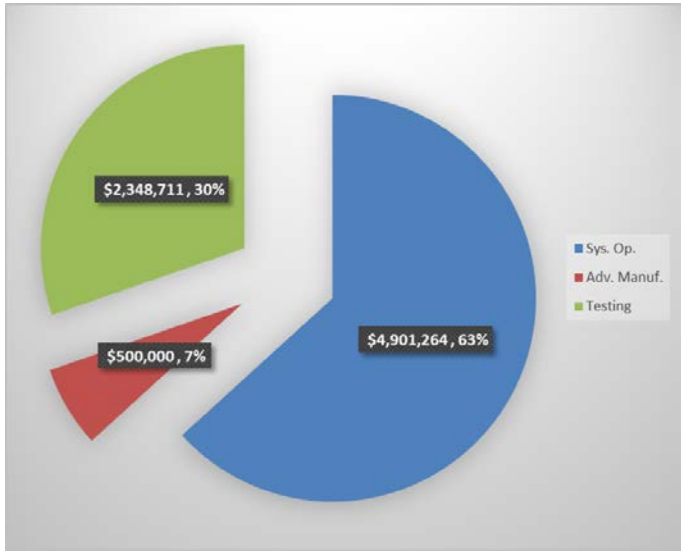
History of the CIP

The history of the CIP includes the following:

- CIP initiated in 2012
- Seven annual solicitations have been implemented
- Thirty-six awards have been issued to 20 manufacturers in 16 states
- Not all projects ultimately completed as originally scoped due to range of issues (eight to date)
- Total original U.S. Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) funding was $9.1 million; due to rescoping DOE/NREL investment reduced to $7.35 million, leveraging $3.6M in additional cost share.
- NREL manages the projects through a defined period of performance subcontract, providing oversight and technical assistance as needed.



CIP manufacturer distribution (Through 2018)



CIP budget breakdown, after descoping (Through 2018)

CIP Technical Approach

The CIP technical approach includes the following:

- Competitively selected with cost-share requirements
- Short, normally 21-month, period of performance to make sure that the projects are manageable and can be completed in a timely manner, typically 24 months
- Focused on high technology readiness level efforts
- The CIP has provided a sustained solicitation process to go from improvements to ultimately a certified turbine
- NREL works with awardees to end contracts if it is determined that the original scope is not achievable
- Technical assistance (see session 3) provided by NREL to help companies achieve the intended goal.

CIP Topics

Previous CIP topics have included:

- Pre-prototype Development
- Prototype testing
- Overall system optimization
- Component innovation
- Certification testing (<200-m^2 RSA)
- Type certification (>200-m^2 and <1,000-m^2 RSA).
- Manufacturing process innovation

Not all topics have been offered each cycle.

If you are unsure, reach out. We can't tell you what to do but prior to the release of the request for proposal we can provide guidance on what might be the best approach.

Examples of Past Projects Within Scope

Previous CIP projects within scope included:

- Pre-prototype turbine assessments
- Overall system optimization, looking how to optimize a combination of components
- Improvement of components, such as inverters, blade designs, and towers to reduce costs
- Projects that support all types of turbines < 1,000-m^2 RSA, including:
  - Micro
  - Small
  - Midsize
  - Horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines (VAWTs)
- Turbine testing, including:
  - Prototype testing, with plan towards certification
  - Certification testing (<200-m^2 RSA)
  - Type certification (>200-m^2 and <1000-m^2 RSA).
- Manufacturing process upgrades, such as injection molding blades to reduce costs

Examples of Past Projects Outside of Scope

Criteria for CIP projects that were considered outside of scope included:

- Lacking technical merit, such as:
  - Violation of Betz limit
  - Insufficient preliminary work to assess the turbine viability or probability of success
  - Turbines that don’t consider basic wind dynamics, such as changing wind direction
  - Not addressing significant topics identified within the proposal (incomplete proposal)
- Only technical information is a website or marketing brochure
- Stand-alone component not partnered with turbine manufacturer
- Turbines > 1,000-m^2 RSA
- Not a U.S. manufacturer or defined collaboration if required in request for proposals
- More than one topic area included in proposal (component improvement, leading to a prototype testing that feeds into a certification test)
- Does not match a specific topic being solicited
- Multiple proposals submitted into different topical areas for ostensibly the same turbine

Addressing Changes in Project Scope

The CIP has been designed to allow for some flexibility in scope once award has been issued but not ones that substantially change the focus of the work.

Potential modifications considered can include:

- Shift in project focus based on initial project work, such as a different approach to improve a specific component
- Shifting between specific subtier vendors
- Project schedule to plan for staffing and other unexpected challenges.

Modifications that are likely not to be allowed

- Shifting work between topic areas, such as shifting from a turbine certification to prototype testing
- Change in primary vendor
- Change in project cost

Questions?

Ian Baring-Gould
Ian.Baring-Gould@nrel.gov

www.nrel.gov

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Session 2: Merit and Scoring Criteria

Robert Preus

Guidance on Context

- The specific merit criteria discussed are from past CIP RFPs and may not be the same in future offerings
- A proposal should be intended to provide confidence that a project is worthwhile and likely to succeed
- The proposal should address EVERY merit criteria in the RFP
- If making incredible claims, interested parties must provide strong evidence or risk losing credibility
- Technical expertise should be demonstrated with a team that covers all the bases.

Component Improvement vs. Certification Testing

Component Improvement

- Technically feasible and commercially attainable
- Will result in reduction in levelized cost of energy (LCOE)
  - Must be justified and credible
- Sound development plan that includes plans for certification
- Sufficient human resources are available.

Certification Testing

- Likely to succeed in the market
- Impact on the U.S. market
- Ready for certification
  - Prototype testing almost necessary to demonstrate
- Sufficient human resources are available.

Important to Make Complete Responses

- If a merit criteria is ignored ZERO points are received
- For example, if late in the past:
  - Ignoring the history of on-time and on-budget criteria = **0** points
  - Acknowledging some late history and describing what has changed to improve = some points
- Evidence that turbine is ready for certification
  - If the turbine has an operating history provide that information
  - A good prototype testing history can be better than history from an unmonitored fleet.

More on Complete Responses

- Proposal should include response to all sub-bullets in merit criteria. Missing information receives a zero score
- A response of “none” for turbine sales history is fine especially if there is a history of prototype testing
- All of the answers are considered for a section and scored based on the whole set of information
- It is perfectly fine to not have done some things, as long as it is clear that the product and company are ready to meet contract requirements (if a different timeline is needed, please indicate that).

Critical Complete Responses

- Team qualifications
  - Explain qualifications to design wind generators
  - If the team is heavy on marketing and light on technical expertise explain what outside expertise is needed and who or how it will be obtained
  - While a name with credentials is best, simply “we need a consultant to run FAST models and are talking to several” lets NREL know that the proposer knows what is needed and is working it out.

Prototype Testing is Critical

- Certification testing consumes time and money
- Prototype testing results may indicate readiness for certification testing. The key is to avoid problems during certification testing
  - Safety and function testing should show that controls are rock solid with no surprises
  - Loads analysis should be complete even though preliminary (will be checked before testing starts)
  - Performance should not reveal surprises
    - Even if not testing to technical standards, there should be a measured power curve.

What is Not Acceptable

- Claiming all information in the proposal is proprietary
- Applying for a contract when the turbine is not going to be ready and available in the contract timeline
  - Small timeline changes can be proposed that are justified (provide justification)
  - Not finished with development is not justification, wait for the next round
- Combining more than one topic area in one proposal
- Inclusion of standards not applicable in the United States in the certification contract (CSA, CE, and so on) may not be allowed. It was allowed in the most recent RFP. Read the whole RPF! Then check your proposal against the RFP.

Questions?

Robert Preus
Robert.Preus@nrel.gov

www.nrel.gov

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Session 3:
Deliverables and Outreach Materials

Robert Preus

Project Management

Technical monitor requirements include the following:

- Initial kickoff meeting
- NREL communication protocols
- Monthly status check-in calls; NREL monthly reporting to DOE
- Reporting requirements:
  - Quarterly reports (template to be provided)
  - Topic-specific/technical reports
  - LCOE (Session 5)
  - Conformity statements (if required for certification)
  - Close-out summary
  - Other reports as identified in RFP/statement of work (such as final project report)
- Direct NREL contract management (contract modifications; invoicing)
- Accounting: estimate of work to be performed (for budget accrual).

Deliverable/Occurrence Schedule Example

Occurrence	Deliverable	Description	Due Date	Delivered Date	Status	Notes	Timeline Based on Subcontract
1	6.1	Summary of work planned					30 days after contract execution
2	6.2						
3	6.6	QR #1					2 weeks after end of previous quarter
4	6.4						
5	6.6	QR #2					2 weeks after end of previous quarter
6	6.3						
7	6.6	QR #3					2 weeks after end of previous quarter

Note: Awardee can negotiate subcomponents of a complex deliverable, which would result in more occurrences but also provide more opportunities for payments throughout the duration of the project period. Clock starts once subcontract is fully executed.

Outreach Materials

DOE/NREL use a number of methods to distribute information on CIP projects to the public, including:

- Press releases
- Fact sheets
- Articles
- Success stories
- Retrospective summary (NREL technical report)–expected to be published FY20
- Accomplishments report–key Fiscal Year accomplishments for DOE
- Progress alert (DOE).

Note: materials that are not for public dissemination include subcontractor project reports and any material marked as confidential or proprietary.

Outreach Materials

Sources of information for outreach materials (nonproprietary) come from:

- Summary of subcontracted effort (outlined in statement of work)
  A. Company name
  B. Company contact/principal investigator
  C. Project title
  D. Start date/duration
  E. Project budget (total, NREL, subcontractor)
  F. Statement of problem
  G. Solution
  H. Project deliverables and milestones
  I. Work to be preformed
  J. Anticipated benefits
  K. Collaborating entities
- Photos contributed to NREL's image gallery.

Note: Subcontractor will generally be requested to review/edit proposed text to ensure it is void of any errors or proprietary information before NREL/DOE distribute to the public.

Questions?

Robert Preus
Robert.Preus@nrel.gov

www.nrel.gov

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Session 4: Standards for Grid Connected Equipment

Robert Wills & Robert Preus

Standards That Apply to Distributed Wind

- IEC 61400 or AWEA 9.1 / SWT1 (Sessions 5 & 6)
  - 61400 -1 for swept area > 200 m^2
  - 61400 -2 or SWT1 for “small wind” swept area < 200 m^2
- Underwriters Laboratories (UL) 6141 & 6142
  - References UL1004-1 (rotating machines), UL1741, etc.
- Institute of Electrical and Electronics Engineers (IEEE) 1547
- National Fire Protection Association 70 National Electric Code (NEC)
- State standards (California Rule 21,

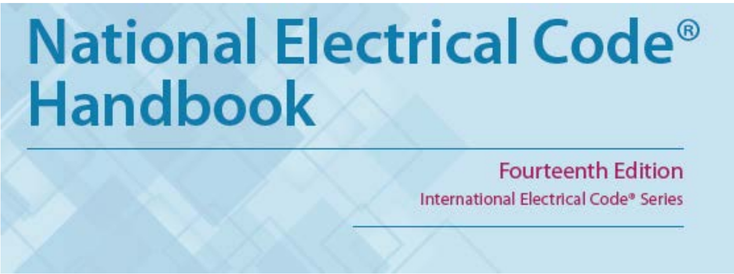
UL1741

STANDARD FOR SAFETY

Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources

1547™

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems



Why So Many? Are They Really Necessary?

Different areas, cross reference and support:

- IEEE 1547 - grid interconnection
- NEC – installation / wiring
- UL Standards – equipment
- IEC61400-2 - design, performance, and structural issues
- UL6141 and UL6142 – electrical & mechanical safety
- State standards for special cases

How Standards Weave Together for an Inverter

- Interconnection behavior to IEEE1547
- Inverter is type tested to UL1741 and IEEE1547.1
- Software verified to UL1998
- Turbine “front end” to UL6142
- Installation to NEC Article 694

ARTICLE 694 Wind Electric Systems

Contents

Changing State Requirements & Opportunities

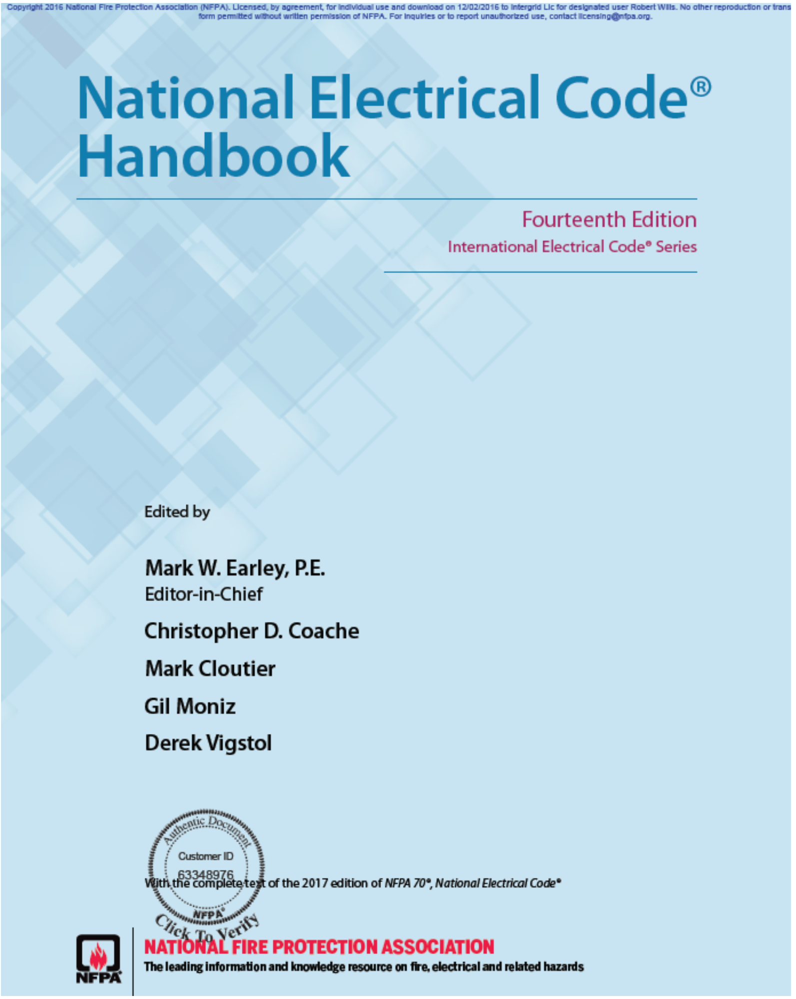
Hawaiian Electric

- **Customer Grid-Supply Plus (CGS Plus)** systems must include grid support technology to manage grid reliability and allow the utility to remotely monitor system performance, technical compliance and, if necessary, control for grid stability.
- **Smart Export** customers with a renewable system and battery energy storage system have the option to export energy to the grid from 4 p.m. – 9 a.m. Systems must include grid support technology to manage grid reliability and system performance.
- **Customer Self-Supply (CSS)** is intended only for private rooftop solar installations that are designed to not export any electricity to the grid. Customers are not compensated for any export of energy.
- **Customer Grid-Supply (CGS)** participants receive a PUC-approved credit for electricity sent to the grid and are billed at the retail rate for electricity they use from the grid. The program remains open until the installed capacity has been reached.

National Electric Code (NEC)
NFPA 70

National Electric Code

- Applies to electrical installations unless exempted (utility equipment and boats (Article 90)
- IPP’s are technically *not* exempt
- Requires listing for the application (ties to UL standards)
- There are general sections, Chapters 1–4, and special sections, Chapters 5–8; Chapter 6 is special equipment including 694 Wind Electric Systems
- Special sections override the general sections



Why a Special Section for Wind?

- With no wind specific guidance Authorities Having Jurisdiction, were using :
  - General section rules
  - PV special rules
  - Sometimes this did not work, and it left installers uncertain what would be required.
- There are issues that are specific to wind generators
  - Cannot ground the center of the Wye in a generator feeding a rectifier to a DC link (it just doesn’t work but is otherwise required)
  - Grounding some metal parts on a small wind generator (tail boom) serves no purpose and is difficult
  - Requiring a disconnect on a PMA wind generator with a remote brake load is dangerous

NEC Covers Requirements for a Safe Installation

Equipment

- All equipment must be listed and approved for the application
- Option for field labeling
- Disconnect and protection rating
- Labeling.

Methods and Practices

- Wiring practices and support
- Disconnect and protection required when and where
- Grounding requirements
- Wiring methods
- Raceway use and size requirements.

Special Use Chapters

- Chapter 6 Special Equipment:
  - 690 PV Systems
  - 694 Wind Systems
- Chapter 7 Special Conditions:
  - 705 Interconnected Electric Power Production
  - 706 Energy Storage Systems
  - 710 Stand Alone Systems
  - 712 Direct Current Micrograms.

IEEE 1547 Revision

IEEE 1547 Interconnection Standard

- IEEE 1547 is the standard for the interconnection of distributed energy resources (DERs) to the utility grid
- Original version was completed in 2003
  - DERs were insignificant to grid stability
  - Only allowed DER response to grid event was tripping
- DER penetration on the grid is now high in some places
  - DER support of grid stability is becoming essential.
- IEEE 1547 2018 officially adopted
  - IEEE 1547.1 for testing requirements is nearing completion

IEEE1547 Revision Interconnection Requirements

DERs are required to provide grid support in the form of:

- Ride-through capability
  - Over and undervoltage
  - Over and underfrequency
- Several modes of power factor control are required
- Anti-island protection is still required
- Several categories of capability are allowed
  - 1547 does not specify what category required
  - Grid operator determines required category
  - Allowed category may vary by feeder or even location on the feeder.

Large and Small Wind Turbines Electrical System Compliance

Listing of Wind Generators

- Wind turbine electrical system compliance (Listing or field evaluation) required by Article 694 of NEC.
- UL 6142 – Small wind turbines where entry of personnel in the tower or nacelle is not possible (mainly because of the size of the turbine).
- UL 6141 – Large wind turbines where entry of personnel in the tower or nacelle is allowed for assembly, installation, operation, and maintenance.
- Personnel access was the only inherent specific difference that UL could find for large and small wind generators

Compliance Options

- Listing of the wind generator as a system
  - Includes safety evaluation of each component and overall system
  - Review of manufacturing QA process and consistent with tested product
  - Involving the certification body during the design phase is recommended

- Field labeling evaluation (mostly used for large turbines)
  - The main aim of field labeling evaluation is to demonstrate essential compliance with the same standards that are used for Listing or certification
  - On-site testing, such as continuity tests and insulation tests, are generally required for proving essential compliance

Documentation Needed by Certification Bodies for Electrical System Assessment

OEMs/certification applicants are typically requested to provide the following **product design documentation** to a certification body:

- Drawings: electrical components and connections, and dimensional drawings of enclosures
- Electrical one-line diagram and wiring schematics, including circuit ratings
- Bonding grounding one-line diagram, including component descriptions
- Electrical bill of materials
- Material flammability, temperature, and electrical ratings
- Drawings of all caution, warning, ratings, and terminal markings
- Component photos and inside views of enclosures
- Installation & operation manual
- Type test plan and test data.

Slide provided by Anant Jain of Intertek

Communications

Communications

- Requirements in California, Electric Rule 21, Generating Facility Interconnections, Phase 3.
- Regulatory deadline - 22 January 2020
- Uses:
  - IEEE Standard for Smart Energy Profile Application Protocol, IEEE 2030.5-2018
  - SunSpec Common Smart Inverter Profile (CSIP)
  - Draft Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces, P1547.1/D9.6, October 2019

Questions?

Robert Wills
rwills@intergrid.us

Robert Preus
Robert.preus@nrel.gov

www.nrel.gov

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Session 5: Certification Testing

Windward Engineering

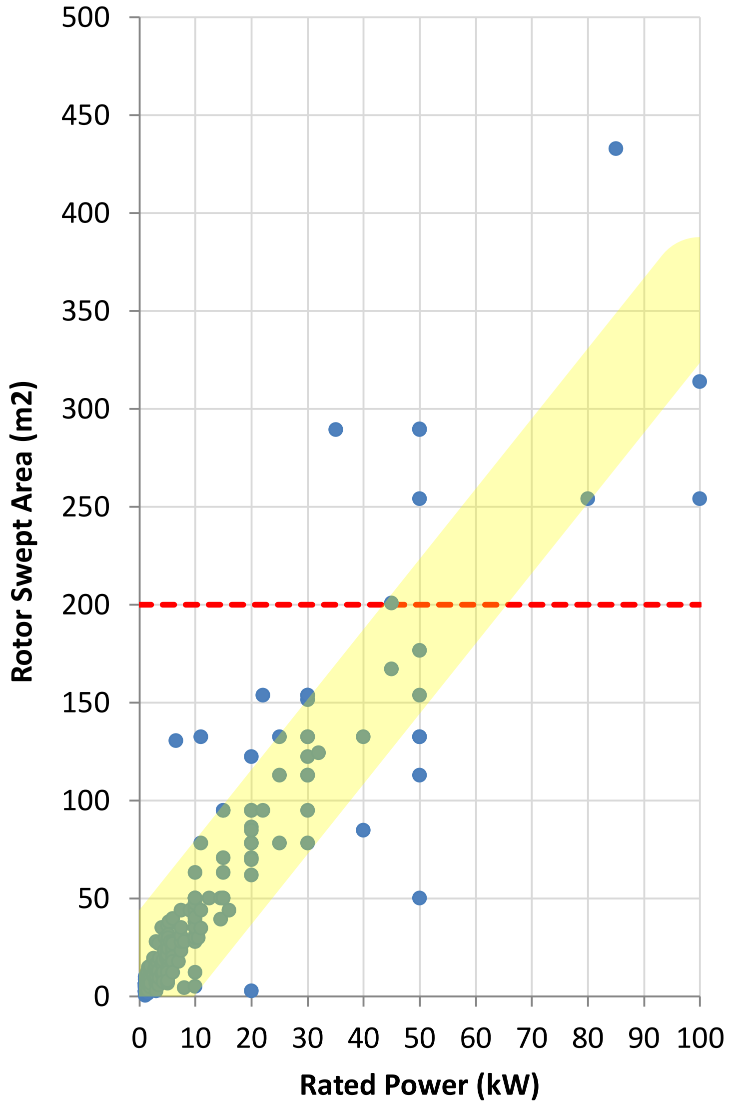
Background


Assumed Audience
• Product needing field or certification testing
• What's involved?
o Should self-test?
o Should hire consultant?
o What's involved in a CIP testing project?

CIP and Testing

- Prototype Testing (PT)
- Certification Testing (CT)
  - $< 200\ m^2$ Rotor Swept Area (RSA)
- Type Certification (TC)
  - $200\ m^2 < (RSA) < 1{,}000\ m^2$

Test	NREL (2019)	20% Price Participation	Project Cost
PT	$250k	$62.5k	$312.5k
CT	$170k	$42.5k	$212.5k
TC	$800k	$200k	$1,000k



Certification Requirements

Certification Testing (CT)

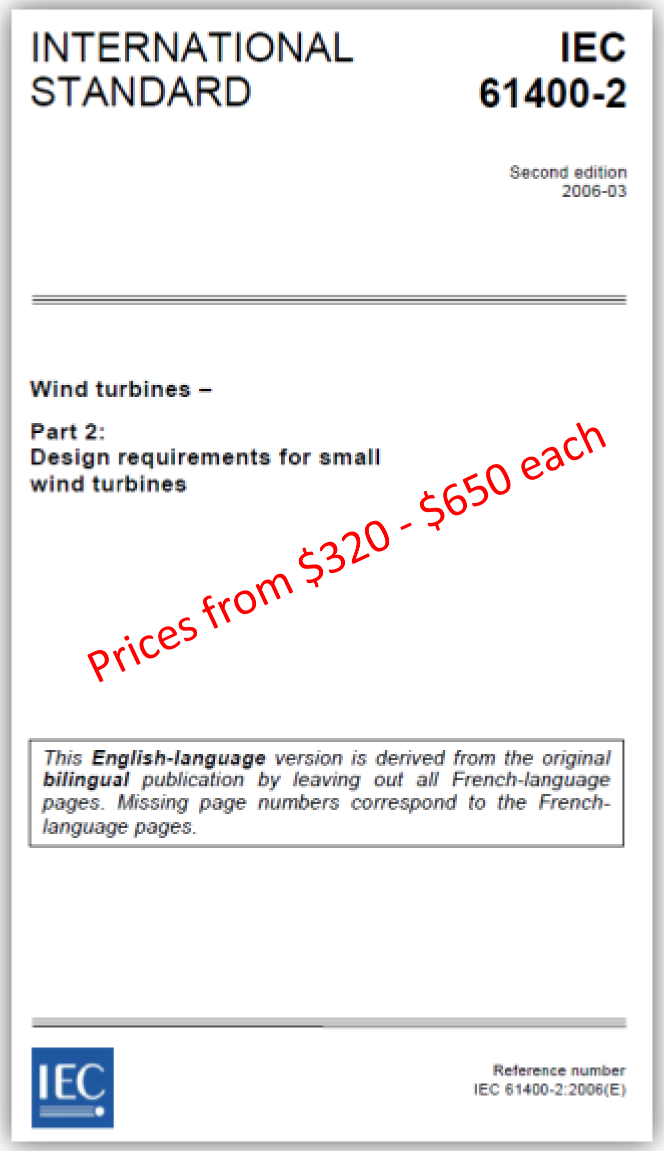
- Design Evaluation
- Required Field Tests
  - Power Performance
  - Acoustic
  - Safety and Function
  - Duration

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

- Conformity testing & certification (IEC 61400-22)
- Power Performance (IEC 61400-12-2)
- Acoustics (IEC 61400-11 ed3)
- Small wind turbine design (IEC 61400-2)
- AWEA certification for small wind turbines (AWEA SWT-1)
  - Duration test
  - Safety and function
- Large wind turbine design (IEC 61400-1)
- Mechanical loads (IEC 61400-13)
- Structural testing of rotor blades (IEC 61400-23)
- 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

- Intertek
- ICC-SWCC
- UL (Underwriters Laboratory)
- TUV SUD NEL
- DNV-GL
- Others…

Engage early to avoid surprises

Existing Test Facilities

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
- Goal is to make sure the data from the test facility meets their standards as well as the guidelines set forth in ISO 17025

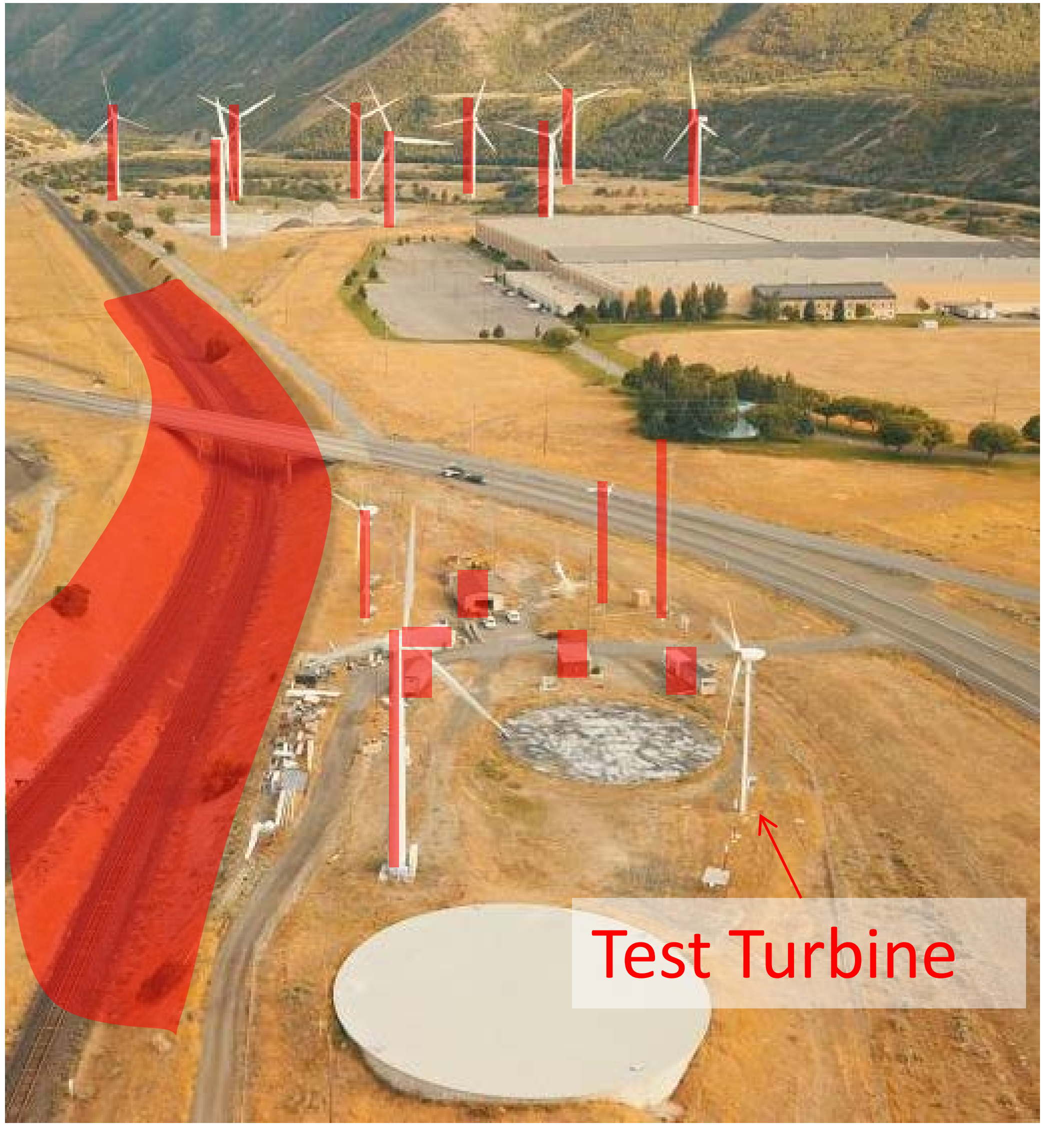
Ideal Test Site Attributes

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

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

Power Performance (test site evaluation)

- Met tower placement
    - 2 to 4 rotor diameters away
- Nearby turbines
- Nearby obstacles
- Flatness of terrain

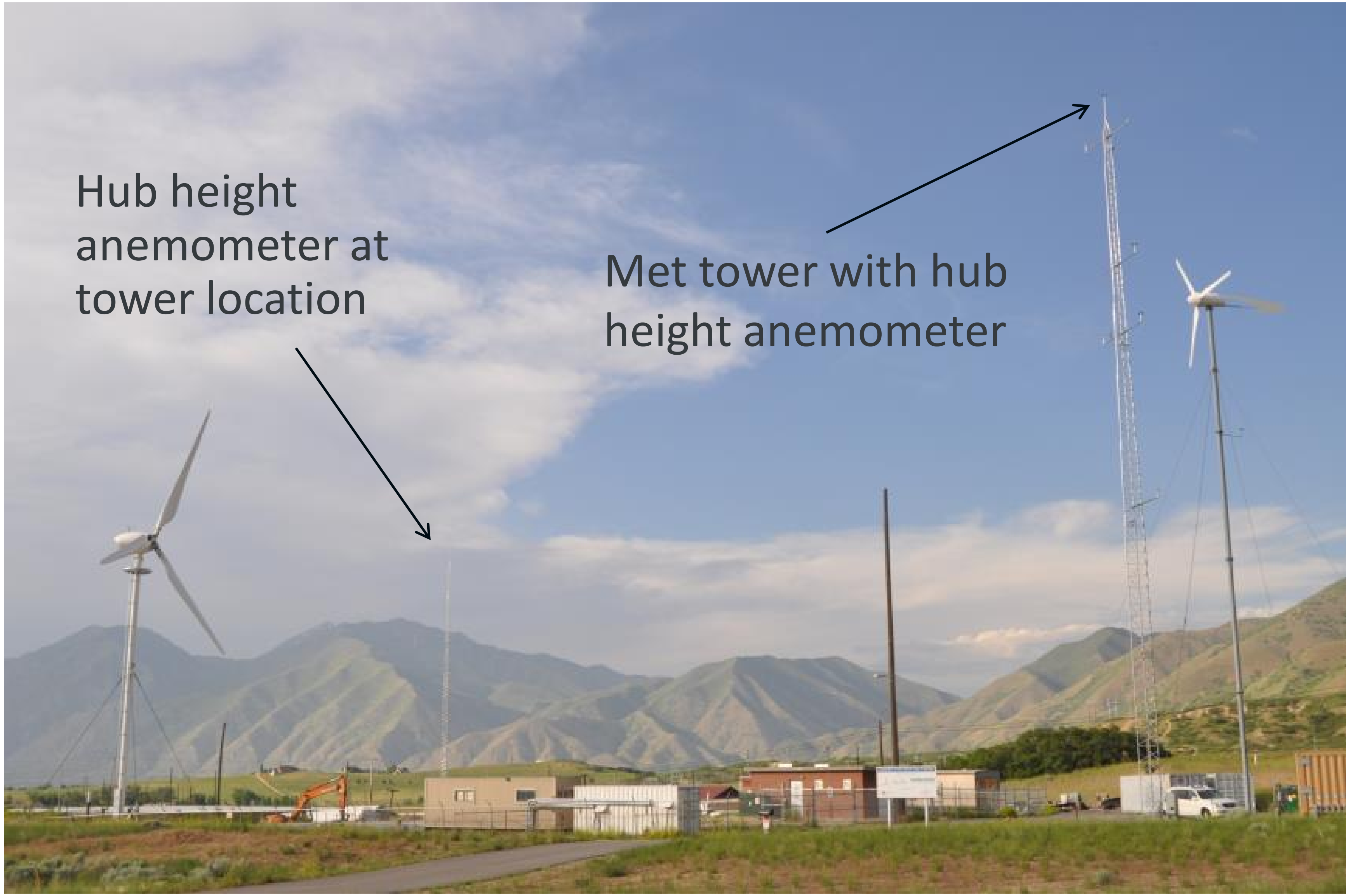


Power Performance (test site evaluation)

- Some sites will pass all requirements easily

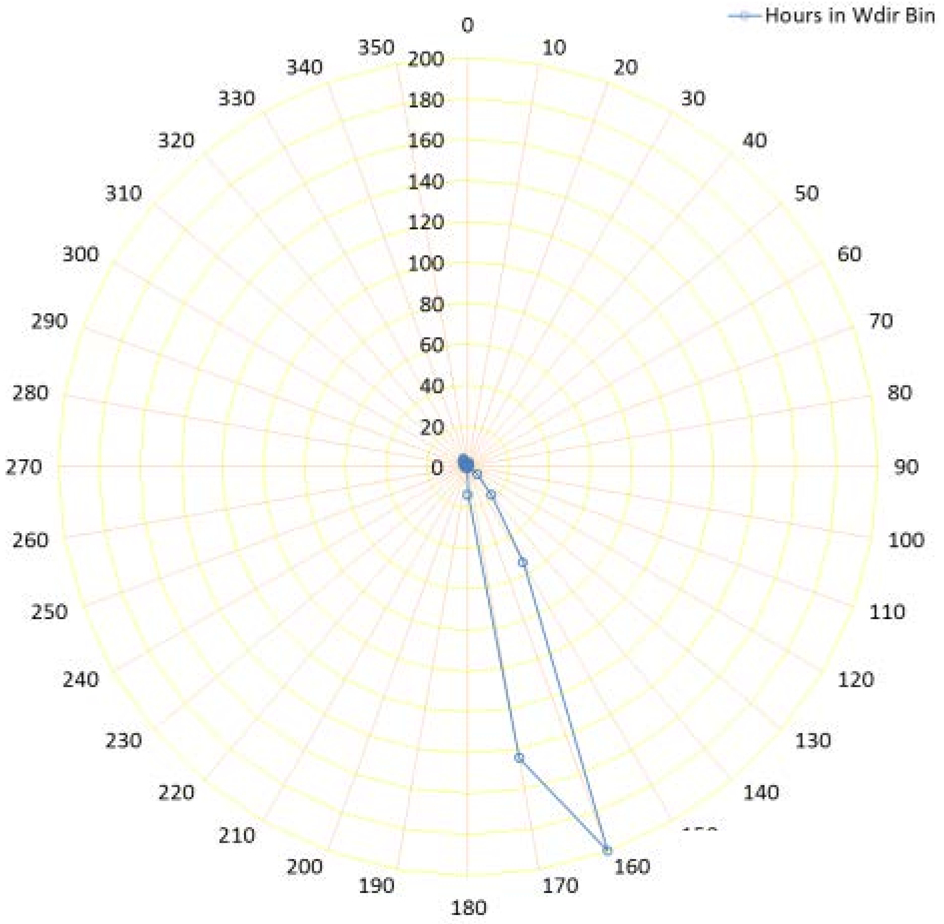
- Some will require a bit of analysis but will pass
- Others (like ours) will require a site calibration

Power Performance (site calibration)



Power Performance (site calibration)

- Performed prior to installation or after removal of turbine
- Data requirements (for each 10° wind direction sector)
  - 24 hours (between 4 and 16 m
  - At least 6 hours above 8 m/s
  - At least 6 hours below 8 m/s
  - Data must converge

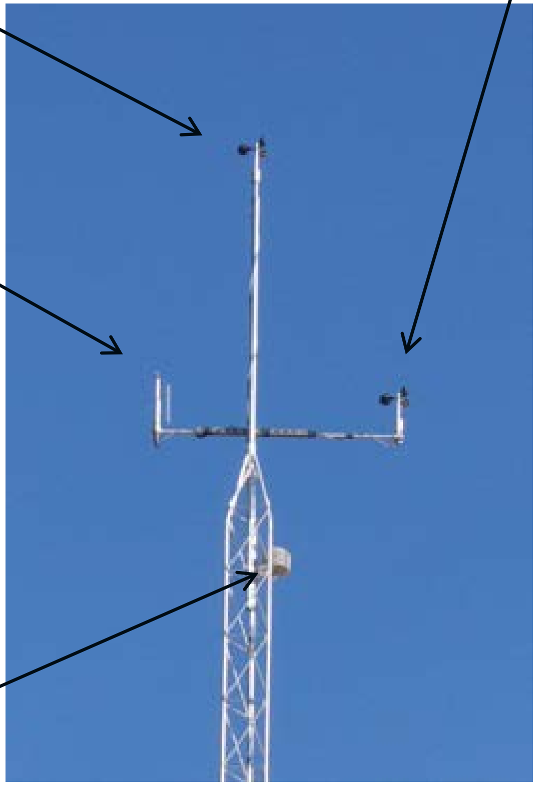


- Not too difficult if unidirectional site (like ours)

Much harder and longer for a site like this

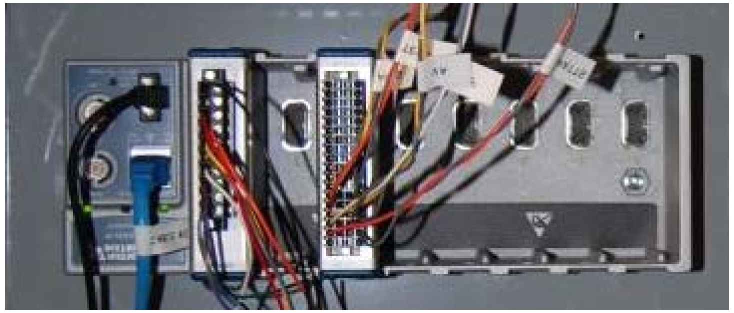
  - In our last site calibration:
    - 4 days to calibrate 1 sector
    - 6 days to calibrate 2 sectors
    - 11 days to calibrate 3 sectors

Power Performance (met. tower instrumentation)



Power Performance (down tower instrumentation)

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

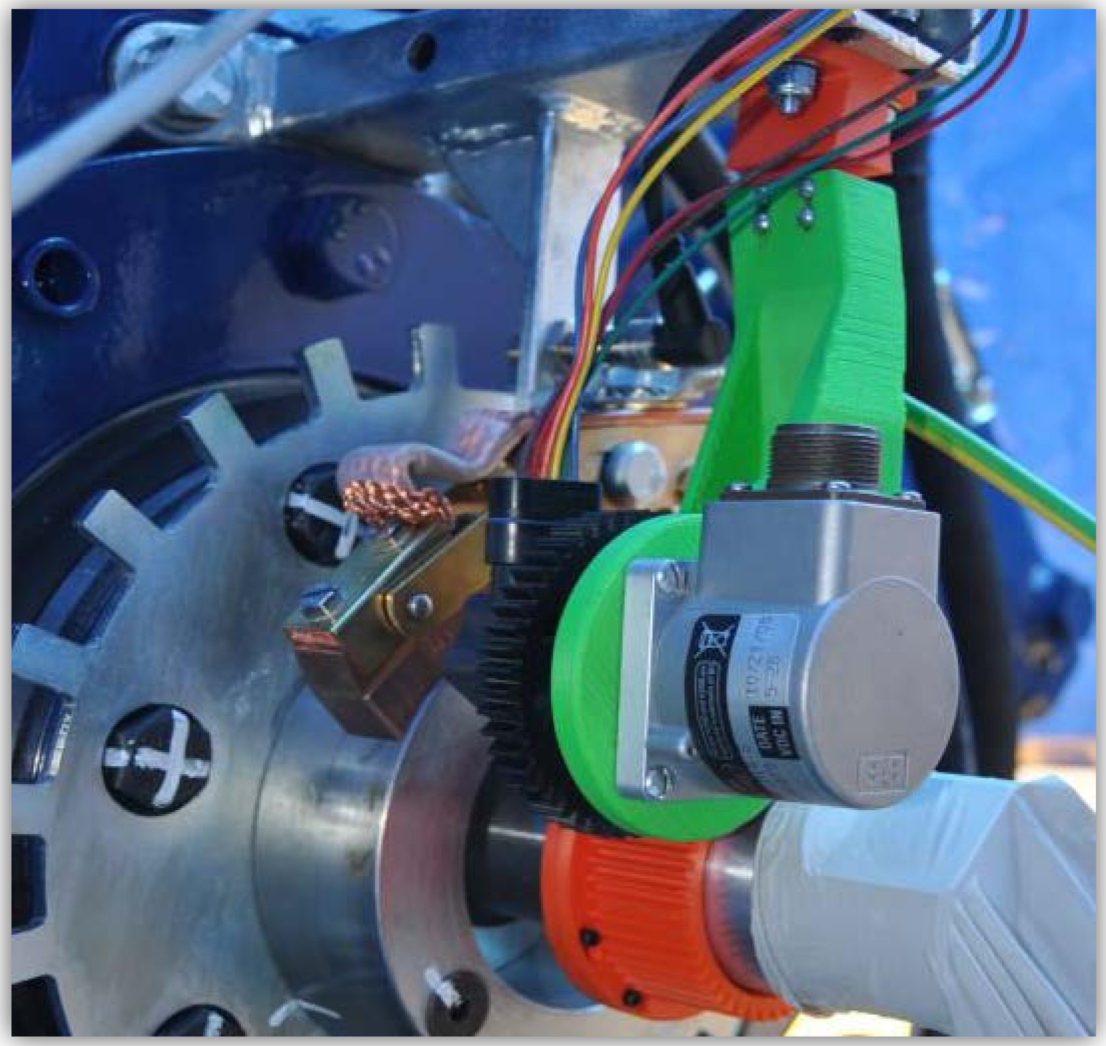


Data Acquisition (chassis and modules)

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)

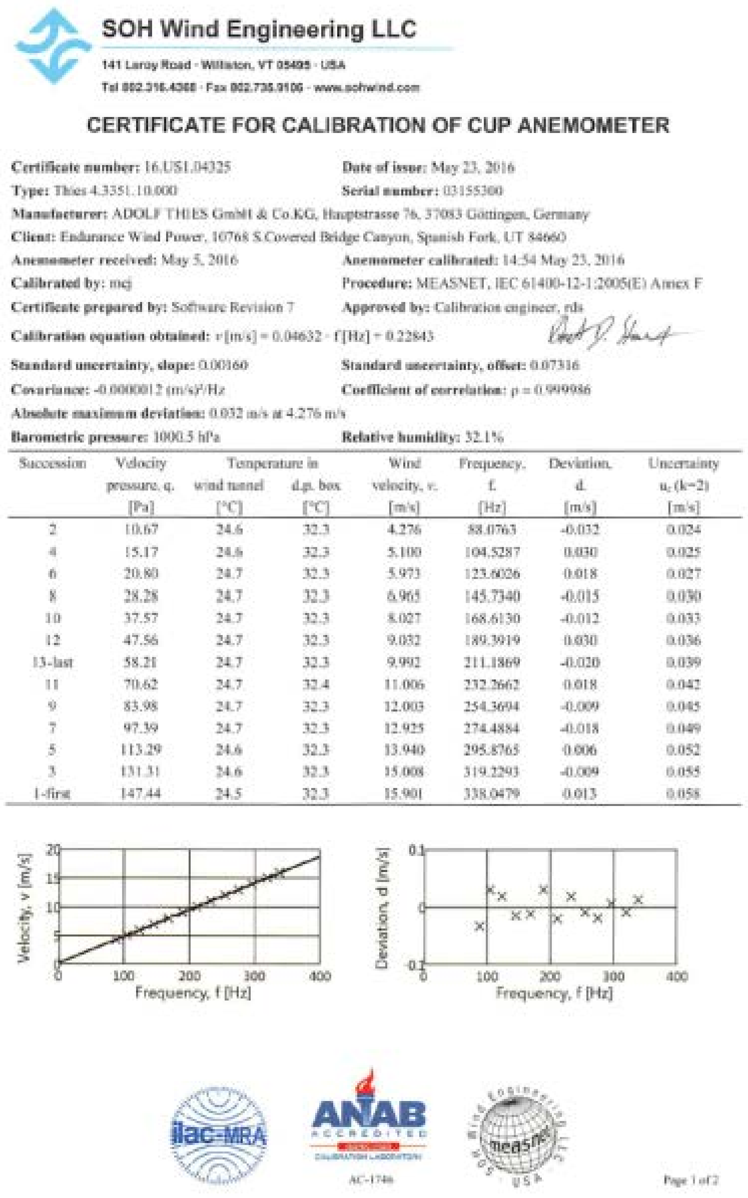
Subsystem	Description	Instrumentation type or detailed description	Qty	price/ea	Total Cost
Rotor	Rotor speed	Gen voltage or encoder	1	$ 250	$ 250
Electrical	Power, VA, Volts	Ohio Semitronics DWV	1	$ 1,284	$ 1,284
Ambient	Wind speed (primary & secondary)	Thies First Class Anemometers	2	$ 1,530	$ 3,060
	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.

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: mcj **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%

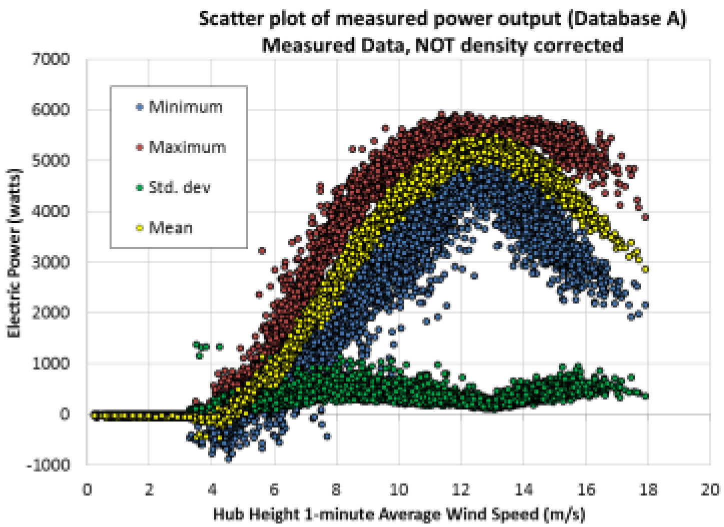
Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in d.p. box [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	10.67	24.6	32.3	4.276	88.0763	-0.032	0.024
4	15.17	24.6	32.3	5.100	104.5287	0.030	0.025
6	20.80	24.7	32.3	5.973	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

Power Performance (database requirements)

- Minimum data requirements (IEC)
  - Each 0.5 m/s bin has more than 30 minutes of data
  - Bins cover 1 m/s below cut-in to 1.5x wind speed where 85% of rated power is reached
  - Database contains more than 180 hours
- AWEA (above requirements plus)
  - Requires 10 minutes for all wind speeds at least 5 m/s beyond 95% of maximum power

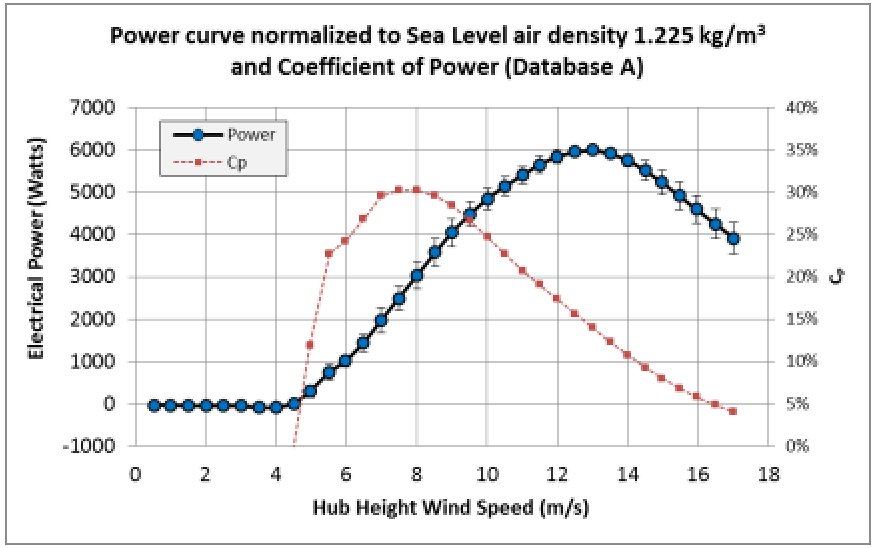
Rated = 5 kW
85%*5 = 4.25 kW
4.25 kW @ ~10 m/s
1.5*10 m/s = **15 m/s**

Max Power = 5 kW
95%*5 = 4.75 kW
4.75 kW @ ~11 m/s
11 m/s + 5 m/s = **16 m/s**



Power Performance (how long does it take)

- Timing dependent on:
  - Percent of time blowing from valid wind direction sectors
  - How long to get high winds
  - Turbine which hits rated power at high winds can require very high winds to be captured
- NREL suggests:
  - 3-6 months
- Can be performed in parallel with Duration Testing



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
- Our reports:
  - ~90 pages total length
  - ~35 pages of report
  - ~55 pages in appendices
- Example NREL report:
  - ~50 pages total length
  - ~27 pages of report
  - ~23 pages in appendices

TABLE OF CONTENTS

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)

- Wind speed range
  - 0.8 to 1.3 times wind speed at 85% maximum power
    - e.g.: 85% max power at 10.0 m/s then:
      - Range is 8.0 to 13.0 m/s
  - “As broad a wind speed range as practically possible”
- Measurements are 10 seconds each
- Overall
  - At least 180 measurements (turbine operating)
  - At least 180 measurements (background)
- In each wind speed bin
  - At least 10 measurements (turbine operating)
  - At least 10 measurements (background)
- Not a ton of data but can be challenging to get!
- Likely weeks not months

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
  - 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, 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
- Data analysis absolutely needs to be validated
- Tonality is laborious and requires lots of manual clipping of recordings
- Significantly more difficult than Power Performance

Duration Testing (only RSA < 200 m^2)

- 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 hours of power production
  - 250 hours operating in winds above $1.2V_{avg}$
  - 25 hours operating in winds above $1.8V_{avg}$
  - AWEA (25 hours greater than 15 m/s regardless of turbine class)
- "Major failure" will restart test

Use Power Performance instrumentation

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

where

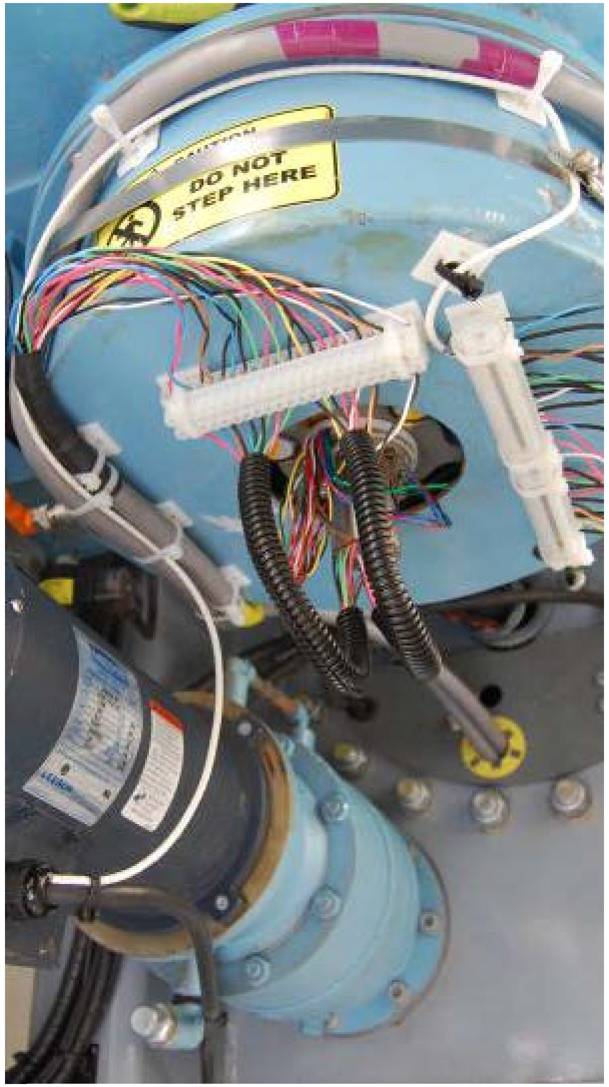
- the values apply at hub height, and
- I_{15} is the dimensionless characteristic value of the turbulence intensity at 15 m/s,
- a is the dimensionless slope parameter to be used in equation (7).

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)

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.)



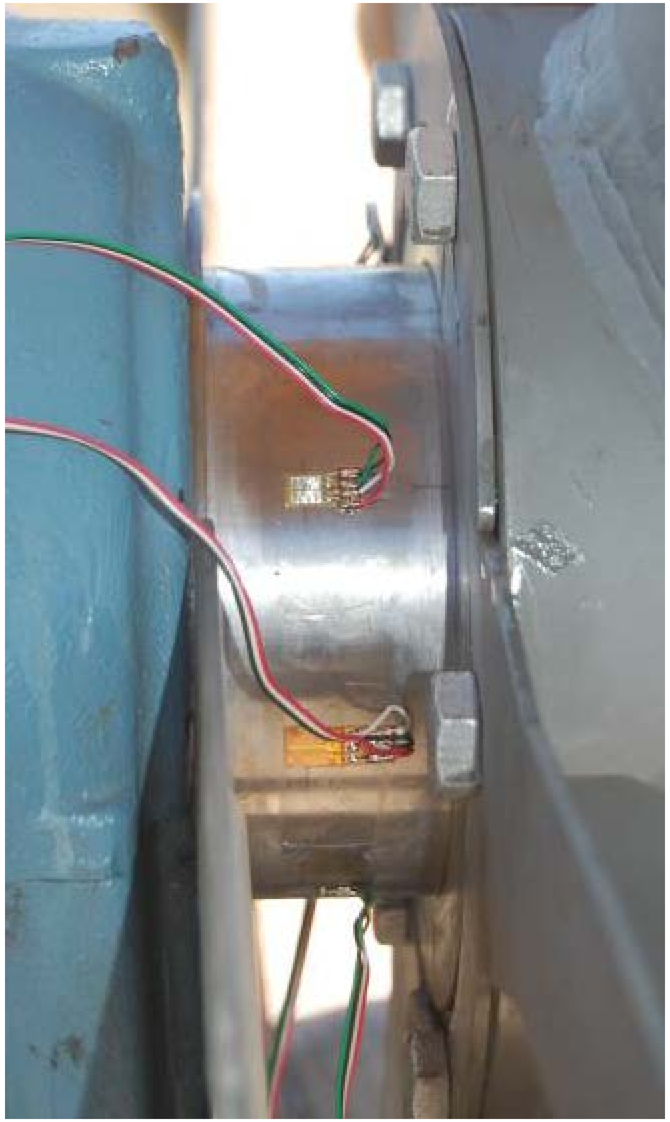
Slipring transmitting data from rotor through main shaft

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

Questions?

Dean Davis
ddavis@windwardengineering.com
1-801-372-9251

Session 6: Design Evaluation

Robert Preus
Modified slides from Rick Damiani

Design Evaluation for NREL go/no go vs for Certification

- Contracts for certification have a go/no go design review
  - Not the same as done by the certifying body
  - Primarily used to confirm (not guarantee) that design is likely to get certified if field tests completed successfully
- Design review for certification done by certifying body and using official test results and as built drawings
  - They will check design drawings vs shop drawings used in production
  - They will confirm that inputs match test results for Simplified Loads or
  - That model is validated to field test results for aeroelastic model loads

Small Wind Turbine (less than 200 m2) Loads Approaches

- Three options
- Simplified loads equations (only for <200 m2)
  - HAWT with 2 or more blades and fixed hub
  - Needs some measured data input
- Aeroelastic modeling (all sizes)
  - Needs to be validated
  - Few models for VAWTs
- Full scale load measurement (all sizes)
  - Most difficult, expensive and time consuming

Notes on Simplified Loads Approach

- Valid only for: HAWTs, rigid hub, cantilevered blades, collective—not individual—blade control
- Provides *key loads for key components*
- *Does not cover all of the loads explicitly* but the designer should use good judgment
- Crude approximation of the loads, especially for fatigue
- Must be *fairly conservative*
- Does not guide toward the understanding of the key dynamic aspects of the turbine
- **Assumes turbine data verified by tests** (to follow-12,-13).

Notes on Simplified Loads Approach: Inputs

- Design rotational speed: n_{design} -From test
- Design wind speed: V_{design} -From IEC $1.4V_{ave}$
- Design power: P_{design} -From test

- Design shaft torque: Q_{design} -From test
  - Drivetrain efficiency, η (use IEC or test)

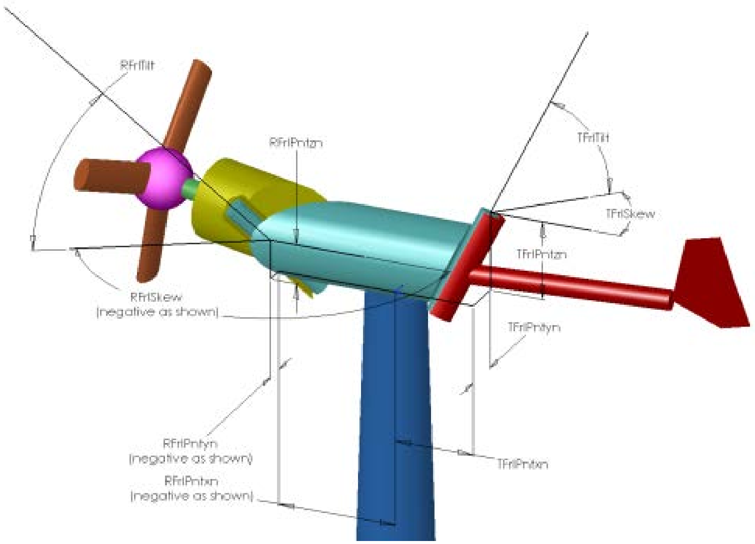
- Maximum yaw rate, $\omega_{yaw,max}$ FROM IEC (except for active yaw)

- Maximum rotational speed: n_{max} -From test (2 hours with 30 minutes at 15+m/s and loss of load + extrapolation to Vref).

Aeroelastic Modeling

- Three-dimensional effects on blade aerodynamics, stall, and tip losses
- Unsteady aerodynamics and aeroelastic effects
- Structural dynamics and vibration mode coupling issues
- Control system effects
- Realistic load distribution on components
- Can explore other features (independent pitch, hinged hub, and so on)
- More accurate representation of fatig
  Equivalent Loads (DELs)
- Comprehensive view of loads and dynamic behavior of turbine—easy to postprocess and automate
- Remove unnecessary conservatism.

URL:Github.com/OpenFast



Alternative Approach: Full-Scale Load Measurements

- Load measurements should be taken under conditions as close as possible to the aeroelastic model DLCs [61400-2] (this is difficult at most sites)
- Load measurements for large turbines almost exclusively used for model validation; determination of design loads is then done with the validated model
- Extrapolation of measured loads shall occur in compliance with IEC/TS 61400-13.

Design Analysis Report (1/3)

TITLE/REV NO./DATE/AUTHOR and CONTACTS

1. List of symbols/acronyms
   1.1 list of tables
   1.2 list of figures
2. List of referenced drawing/document numbers
3. Introduction/overview (the who, what, when, why, and so on)
4. System description
   4.1 System description (discuss protection principles, operation principles, modeling assumptions, testing assumptions, and validation efforts, identify critical load path from rotor to foundation, identify components to be mechanically and structurally verified, and so on)
   4.2 Turbine specifications (add tables, drawings, pics, graphs)
5. Control and protection system details (algorithms, hardware descriptions, setpoints, logic, fault analysis, condition monitoring, overspeed sensing, vibration sensing, test plan)
6. Modeling approach description (methods and computer-aided engineering tools used for the analysis, verification/validation data, coordinate systems, simplifications, standards of reference.)

Design Analysis Report (2/3)

7. Modal analysis and Campbell diagram for the system (eigenfrequencies for all the major components [blade, drivetrain, tower], mass schedule for all components)
8. Design Load Cases (tables and description)
9. Load results for all components
    - *9.1 ultimate limit states (ULS)*
    - *9.2 fatigue limit states (FLS)*
    - *9.3 service and other limit states (*deflections/clearance calculations)
10. FEA or equivalent analysis to verify integrity and serviceability of components
    - 10.1 Blade (verification of ULS/FLS strength, buckling, deflection, bolted connection, pitch drive and bearing)
    - 10.2 Hub/main shaft (verification of: ULS/FLS strength, buckling, deflection, bearing, bolted connection)
    - 10.3 Yaw system/bedplate (verification of ULS/FLS strength, buckling, deflection, bolted connection, bearing, drive)
    - 10.4-10.w Gearbox […] HSS […] brake […]
    - 10.x Tower
    - 10.y Foundation (Geotech, pile, reinforcement, anchors, and so on)
    - 10.z Electrical components (one-line diagrams, emergency disconnects, inverter/converter, load banks, lightning protection, and so on.)

Design Analysis Report (3/3)

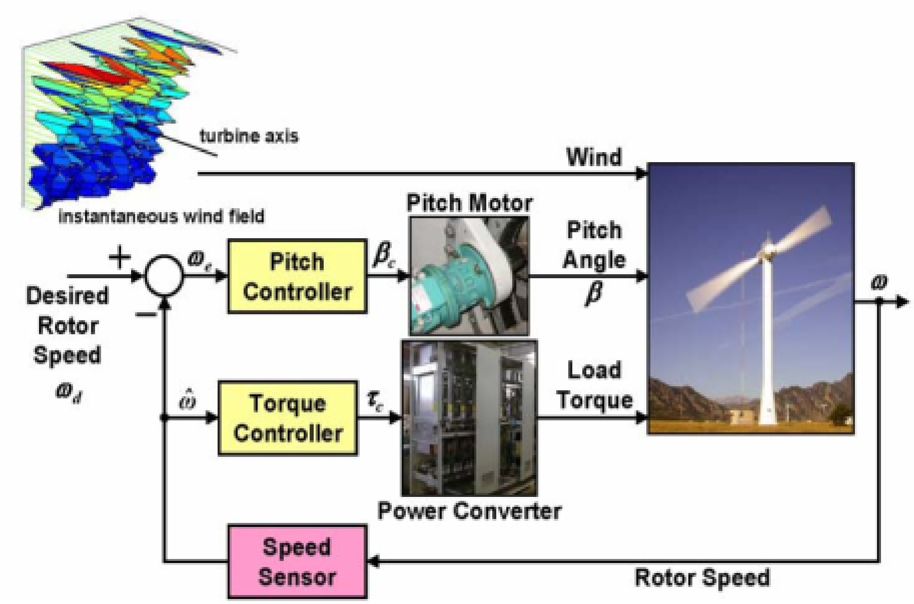
11. O&M provisions
12. Transportation/installation provisions:
    - 13.1 Requirements for tower loads/deflections/clearance
    - 13.2 Interconnection electrical requirements
13. Manufacturing process (quality assurance/quality control)
14. Safety and functioning and emergency procedures
15. Conclusions (summary tables, safety margins, utilization)

Appendices

- Installation instructions
- Cable connections
- Tower options and loads for tower design.

What to Include

- Control system
  - Description of operation modes
  - Fail-safe, redundancy of protection system
  - Algorithm (software) and hardware
  - Condition monitoring
  - Test plan for safety and functioning tests.



Pao L. Y., Johnson K.E. (2009): A tutorial on the dynamics and control of wind turbines and wind farms. ACC 2009, St. Louis, MO.

What to Include

- Design Load Cases
  - Take the time to understand all of the wind/fault conditions
  - List of assumptions and aerostructural parameters used (e.g., Cl, Cd, yaw rates)
  - Provide clear commentary with references to any assumptions made
  - Modeling description.

IF IEC 61400-2 (<200 m^2): three ways to determine design loads:

1. Simplified loads methodology
2. Simulation model
3. Full-scale load measurement

Loads to consider:

- Aerodynamic
- Inertial
- Vibrational
- Seismic
- Gravitational
- Operational (e.g., due to yawing/furling/grid faults, and so on)

- Other (e.g., transportation, ice, wake, maintenance).

What to Include

- Design Load Cases
  - Provide a CLEAR and ORGANIZED table of load cases analyzed.

Minimum set of DLCs given by the standards!

Design situation	DLC	Wind condition		Other conditions	Type of analysis
1) Power production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		F, U
	1.2	ECD	$V_{hub} < V_{design}$		U
	1.3	EOG_{50}	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		U
	1.4	EDC_{50}	$V_{in} < V_{hub} < V_{out}$ or $3 \times V_{ave}$		U
	1.5	ECG	$V_{hub} = V_{design}$		U
2) Power production plus occurrence of fault	2.1	NWP	$V_{hub} = V_{design}$ or V_{out} or $2{,}5 \times V_{ave}$	Control system fault	U
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Control or protection system fault	F, U
	2.3	EOG_1	$V_{in} < V_{out}$ or $2{,}5 \times V_{ave}$	Loss of electrical connection	U
3) Normal shutdown	3.1	NTM	$V_{in} < V_{hub} < V_{out}$		F
	3.2	EOG_1	$V_{hub} = V_{out}$ or $V_{max,shutdown}$		U
4) Emergency or manual shutdown	4.1	NTM	To be stated by the manufacturer		U
5) Extreme wind loading (standing still or idling; or spinning)	5.1	EWM	$V_{hub} = V_{e50}$	Possible loss of electrical power network	U
	5.2	NTM	$V_{hub} < 0{,}7\ V_{ref}$		F
6) Parked and fault condition	6.1	EWM	$V_{hub} = V_{e1}$		U
7) Transport, assembly, maintenance and repair	7.1	To be stated by the manufacturer			U

e.g., IEC 61400-2

What to Include

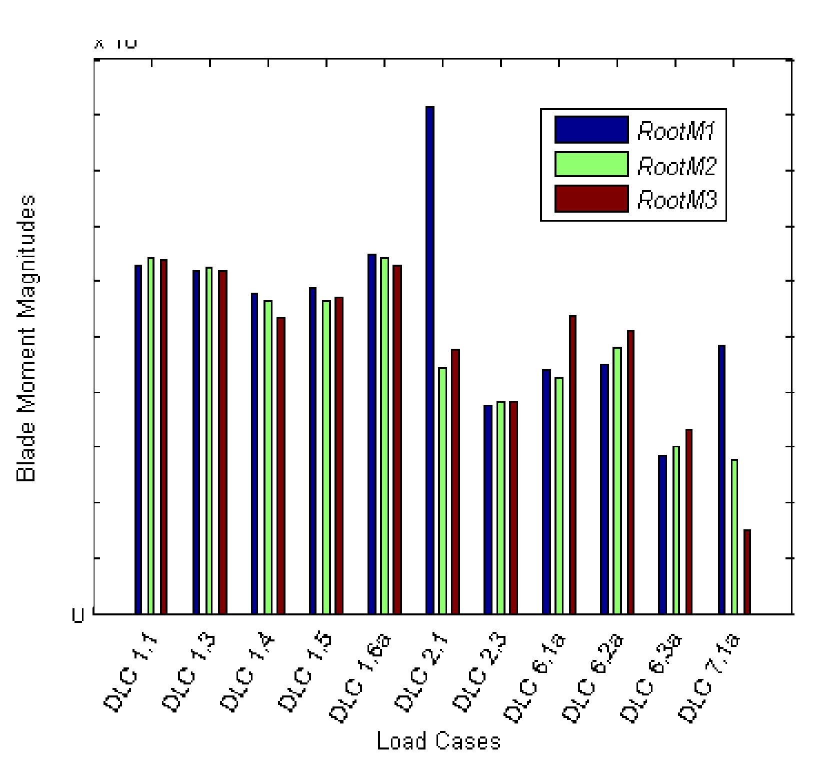
- DLCs loads analysis results
  - Simultaneous load component tables for all system parts of relevance Ultimate Limit States (ULS) loads/ deflections/strains, and Fatigue Limit States (FLS) DELs
  - Partial Safety Factors applied.

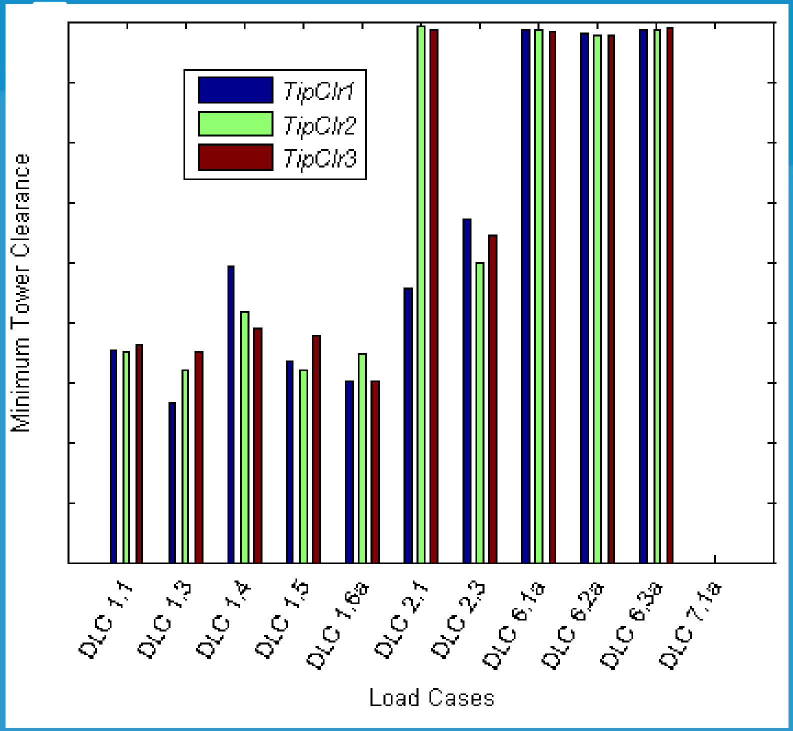
TOWER BASE ULS LOADS	TwrBsFxt	TwrBsFyt	TwrBsF	TwrBsFzt	TwrBsMxt	TwrBsMyt	TwrBsM	TwrBsMzt	Time	HorWindV	NacYaw Err	RotThrust
File Name/DLC	kN	kN	(kN)	kN	kN·m	kN·m	(kNm)	kN·m	s	(m/s)	(deg)	kN
DLC1.6\DLC16_61_24.0V0_S01.outb	- 6.32E+02	3.54E+02	7.25E+02	- 1.01E+04	- 1.81E+04	- 6.31E+04	6.57E+04	- 1.02E+04	2.33E+03	2.70E+01	3.11E+00	1.9096E+02
DLC6.1b\DLC61b_03_API_61.86V0_015YE_S1.outb	2.31E+03	- 2.33E+02	2.32E+03	- 9.90E+03	3.94E+04	7.50E+04	8.47E+04	1.17E+04	3.14E+03	6.19E+01	3.45E+02	1.3828E+03
DLC6.1b\DLC61b_03_API_61.86V0_015YE_S1.outb	- 1.87E+02	- 1.20E+03	1.22E+03	- 9.85E+03	9.24E+04	- 2.67E+04	9.61E+04	2.63E+04	1.43E+03	6.19E+01	3.45E+02	- 3.7063E+02
DLC6.2a\DLC62a_010_API_48.71V0_020.0YE_S1.outb	5.78E+02	1.23E+03	1.36E+03	- 8.25E+03	- 9.62E+04	1.17E+04	9.69E+04	- 5.97E+03	3.00E+03	5.14E+01	1.83E+01	1.7297E+02
DLC1.6\DLC16_02_04.0V0_S02.outb	2.22E-02	2.79E-01	2.80E-01	- 1.03E+04	- 6.37E+01	- 2.92E+04	2.92E+04	- 6.74E+01	1.93E+03	3.63E+00	3.48E+02	4.1482E+02
DLC6.1b\DLC61b_03_API_61.86V0_015YE_S1.outb	2.28E+03	- 5.58E+02	2.35E+03	- 9.97E+03	6.27E+04	7.20E+04	9.55E+04	- 7.64E+02	3.27E+03	6.19E+01	3.45E+02	1.3268E+03
DLC1.6\DLC16_62_24.0V0_S02.outb	5.30E+02	2.50E+02	5.86E+02	- 1.08E+04	- 1.00E+04	6.12E+02	1.01E+04	4.01E+03	2.08E+03	2.78E+01	4.86E+00	7.4295E+02
DLC6.2a\DLC62a_108_API_48.71V0_340.0YE_S1.outb	7.30E+02	- 3.80E+02	8.23E+02	- 7.73E+03	3.54E+04	2.20E+04	4.16E+04	7.61E+03	2.80E+03	6.00E+01	3.35E+02	4.1493E+02
DLC6.2a\DLC62a_010_API_48.71V0_020.0YE_S1.outb	6.18E+02	1.22E+03	1.37E+03	- 8.24E+03	- 9.68E+04	1.29E+04	9.77E+04	- 3.96E+03	3.00E+03	5.64E+01	1.43E+01	1.4866E+02
DLC6.2a\DLC62a_101_API_48.71V0_320.0YE_S1.outb	1.18E+03	- 1.16E+03	1.66E+03	- 8.12E+03	1.04E+05	5.17E+04	1.16E+05	9.97E+03	2.22E+03	6.35E+01	3.18E+02	1.3975E+02
DLC16_61_24.0V0_S01.outb	- 6.32E+02	3.54E+02	7.25E+02	- 1.01E+04	- 1.81E+04	- 6.31E+04	6.57E+04	- 1.02E+04	2.33E+03	2.70E+01	3.11E+00	1.9096E+02
DLC1.6\DLC16_31_14.0V0_S01.outb	1.99E+03	- 8.66E+01	1.99E+03	- 1.03E+04	1.30E+04	1.20E+05	1.21E+05	2.11E+03	2.18E+03	1.31E+01	3.55E+02	2.1095E+03
DLC1.6\DLC16_64_24.0V0_S04.outb	3.49E+02	1.11E+02	3.66E+02	- 1.03E+04	- 7.51E+00	1.98E+01	2.12E+01	- 1.14E+02	3.24E+02	2.86E+01	3.55E+02	7.9330E+02
DLC6.2a\DLC62a_096_API_48.71V0_300.0YE_S1.outb	1.73E+03	- 7.01E+02	1.86E+03	- 8.20E+03	7.51E+04	9.56E+04	1.22E+05	1.23E+04	2.78E+03	6.40E+01	2.97E+02	2.7779E+02
DLC6.2b\DLC62b_18_API_61.86V0_340YE_S1.outb	7.30E+02	4.68E+02	8.68E+02	- 8.12E+03	- 5.01E+04	2.12E+04	5.44E+04	- 6.15E+04	3.96E+02	6.19E+01	2.00E+01	2.4802E+02
DLC6.1b\DLC61b_03_API_61.86V0_015YE_S1.outb	6.96E+02	- 6.80E+02	9.73E+02	- 1.04E+04	6.51E+04	6.23E+03	6.54E+04	4.87E+04	6.96E+02	6.19E+01	3.45E+02	2.4635E+02

TOWER TOP FLS LOADS	YawBrgFx	YawBrgFy	YawBrgFz	YawBrgMx	YawBrgMy	YawBrgMz
File Name/DLC	kN	kN	(kN)	kN	kN·m	kN·m
DEL	10.2	5	2	0.5	4	0

What to Include

- Design Load Cases loads analysis results
  - Simultaneous load component tables for all system parts of relevance Ultimate Limit State loads/deflections/strains and Fatigue Limit State Damage Equivalent Loades
  - Partial Safety Factors applied.

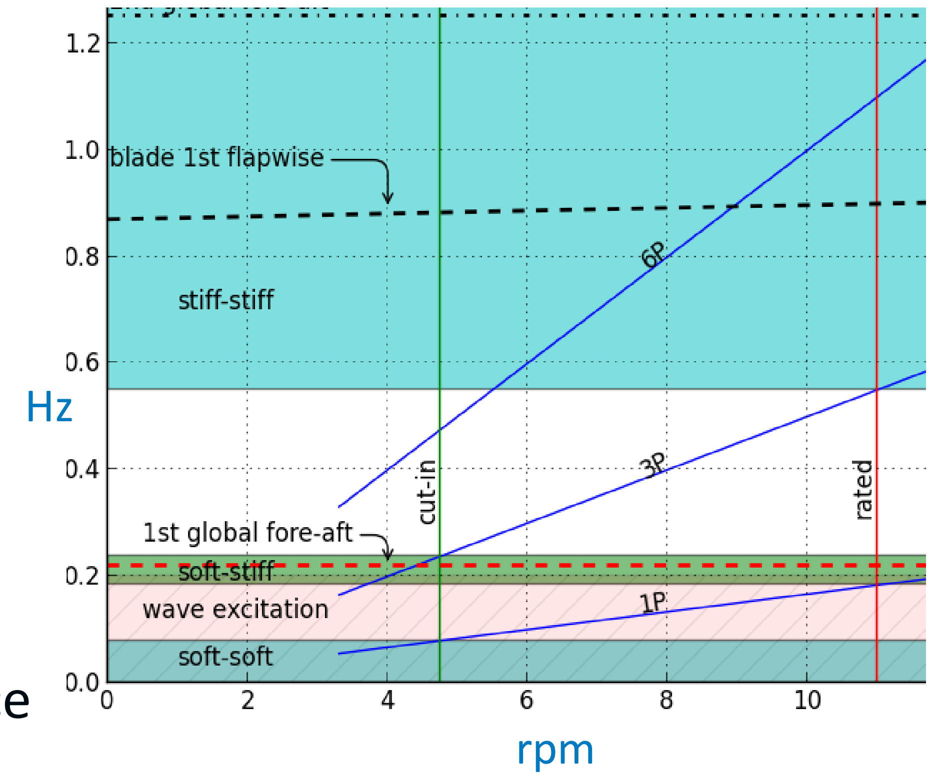




Component Verification: What to Include

"It shall be verified that limit states are not exceeded"
➔(FEA or equivalent analysis to assess utilization)

- Modal assessment and resonance avoidance (Campbell diagram)
- Include all components of relevance
  - AWEA (blade root, yaw axis, main shaft) vs. IEC (all)
- Structural design
  - Safety and service
    - Ultimate, Fatigue, and Service Limit States.



Component Verification

For all components of relevance include:

- Eigenanalysis
- FEA; at a minimum equivalent static loading
- Explanation of adopted boundary conditions
- Load distributions (including thermal effects as applicable, e.g., brakes, gear lubrication)
- Material properties (subcomponent and coupon test data)
- Partial Safety Factors (loads and materials)
- Manufacturing process and quality assurance/quality control protocols
- Standards of reference (e.g., VDI 2230 for bolted connections, ASTM A311 for steel properties, AGMA.ISO81400/IEC61400-4 for gearboxes, and so on).
- **Static load test required for blade.**

Takeaways

This presentation is by no means exhaustive. Therefore, it is important to:

1. Read and understand the standards or find somebody who does

2. Be scientifically rigorous, convince reviewers of the choices made and prove it is a safe and reliable design

3. Pay attention to the documentation format (version control, figure and table numbering, diagrams, and so on)

4. Use best engineering judgement

5. Be prepared to be asked for more clarification, tests, proofs

6. This is required by NREL for a go-/no-go on certification.

Questions?

Robert Preus

Robert.preus@nrel.gov

www.nrel.gov

Session 7: Procurement/Contracting

Kyndall Jackson
Subcontract Administrator

Proposal Submittal

- Request for Proposal (RFP)
  - Posted on FedBizOps
  - Instructions for submittal (contact info, requirements, due date, etc.) will be identified in RFP
- Technical Questions
  - Date for submitting questions will be specified in RFP
  - Amendment(s) will be issued to all who submitted a proposal
- Proposal Review
  - Best Value Selection (qualitative merit and price)
  - Evaluated on Merit Criteria (weighted)
  - Evaluation Process
    - Initial evaluation for acceptability (clarifications)
    - Proposal evaluation against SOW and merit criteria (discussions)
    - Successful and unsuccessful offerors notified (negotiations)
    - Award(s)

Proposal Requirements

- Price Participation Criteria
  - Identified in RFP
    - Example: Minimum 20% subcontractor price participation of the total subcontract amount required in previous rounds
    - Built into payment schedule
    - Common types of price participation include labor, equipment and supplies
- Allowable Costs
  - Reasonable and allocable under the terms of the Federal Acquisition Regulations and DOE Acquisitions Regulations (FAR Part 31.201-2)
- Specifying proprietary/intellectual property
- Forms
  - Price Cost Proposal
  - Organizational Conflict of Interest (OCI) forms (Representation OR Disclosure)
  - New Vendors (W-9, ACH Banking Information)
  - Representations and Certifications
    - SAM.gov registration (System for Award Management)

Payment Schedule

- Sample Deliverable Table

Occurrences/Deliverables - Description	NREL Portion	Subcontractor Portion	Total
6.1	$0.00	$0.00	$0.00
6.2	$0.00	$0.00	$0.00
6.3	$0.00	0.00	$0.00
6.4	$0.00	$0.00	$0.00
6.5	$0.00	$0.00	$0.00
6.6	$0.00	$0.00	$0.00
Total Price	$0.00	$0.00	$0.00

- Invoicing (Post-Award)

Questions?

Kyndall.Jackson@nrel.gov

Session 8: NREL's Technical Support Opportunities

Scott Dana

Flatirons Campus/NWTC Facilities

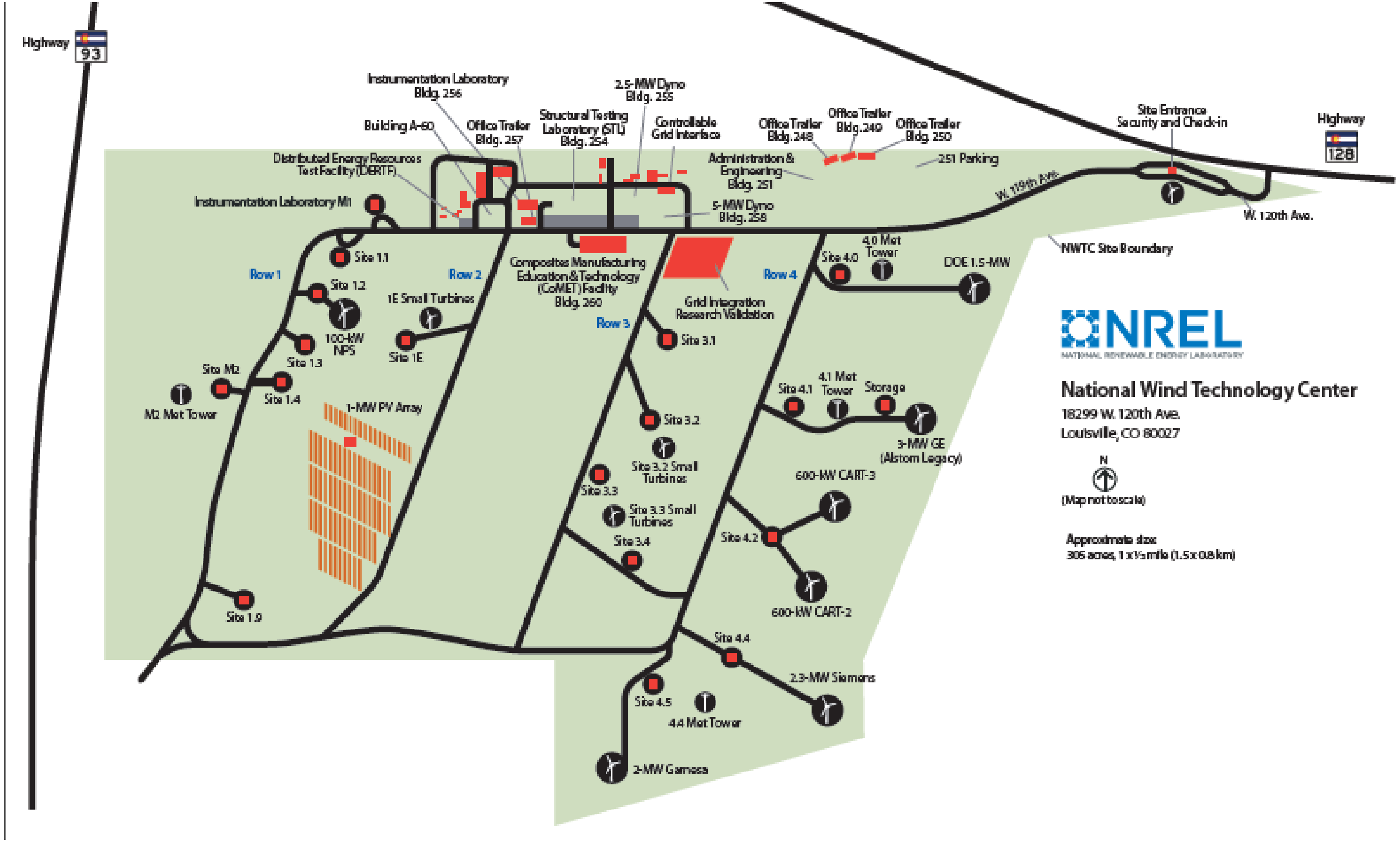
- Numerous small- and midsized field test sites
  - NWTC Row 1 and Row 3
  - Adaptable sites
    - Meteorological towers
    - Data sheds
    - Customizable to meet test needs

- Extreme wind speeds (>90mph) are a regular occurrence
- Test design limits

Photo by Scott Dana, NREL

Photo by Dennis Schroeder, NREL 36245

Flatirons Campus Layout



https://www.nrel.gov/about/assets/pdfs/nwtc-site-map.pdf

NWTC Facilities

- Structural research facilities include:
  - Fully equipped high bays
  - Basic load
  - Force
  - Strain sensing
  - Nondestructive research systems:
    - Modal, acoustic emission, thermography, and digital image correlation systems
  - Examples
    - Blade static and fatigue testing
    - Tower static and fatigue testing

Photo by Mike Jenks

Photo by Mike Jenks

NWTC Facilities

The NWTC offers:

- A 225-kW dynamometer facility, which:
  - Is ideal for smaller turbines
  - Includes a 300-hp variable-speed motor
  - Allows gearbox and generator testing.

Photo by Lee Jay Fingersh, NREL 15004

NWTC Facilities

- Micro-Grid testing
- Distributed Wind focused Controllable Grid Interface (CGI) to come
  - Connection to Row 1
  - Ability to create numerous grid events
- Grid Compliance testing
- Solar array/tracker testing (hybrid systems)

Photo by Dennis Schroeder, 18660

NWTC Facilities

- 5MW Dynamometer and CGI capability
- Can be configured for smaller systems
- Ability to create numerous wind events within laboratory conditions (remove wind component)

Photo by , Mark McDade 28218

Discussion of Opportunities for Technical Support

NREL Technical Support

- Design review
- Component testing
- FAST
- Standards interpretation/navigation
- Cost modeling and analysis
- Instrumentation
- Test site requirements
- Controls
- Structural analysis
- Component analysis
- Electrical (Energy Systems Integration Facility)

QUESTIONS?

Scott Dana
scott.dana@nrel.gov

www.nrel.gov

NRÉL
NATIONAL RENEWABLE ENERGY LABORATORY

Session 9: Levelized Cost of Energy

Robert Preus

Purpose of Levelized Cost of Energy Calculation

- Provide a level comparison for different turbines
- Show if the turbine has the potential to have a competitive cost to the customer
- Determine if the claims being made are reasonable and consistent with physical reality
- Show that there is reasonable expectation for improvement in LCOE
  - No improvement expected for certification contracts.

What Goes into the Calculation

$$LCOE = \frac{(FCR \times ICC) + AOE}{AEP_{net}}$$

- Installed capital cost (ICC)
- Fixed charge rate (FCR) provided
- Net annual energy production (AEP_{Net})
  - Annual energy production (AEP)
  - Deductions from annual energy production
- Annual operating expense
  - Levelized O&M cost
  - Levelized replacement cost.

Initial Capital Cost: Turbine System Costs

- Component cost either purchased or manufactured
- Manufactured cost includes labor and manufacturing overhead but not general overhead
- Other covers everything else to get to cost to customer (overhead, profit, etc.)
- Provide baseline (as it is today) and proposal as it is expected to be after the proposed improvement
    - Justify the expectation for cost reduction
- Do **not** fill in end of project, this is for the final actual result
- Add lines to have the cost breakout follow your accounting.

Turbine System Costs

Turbine System Costs	Baseline	Proposal	End of Project
Turbine rotor assembly			
Turbine nacelle assembly (includes generator)			
Electrical system (inverter/controller and related electronics)			
Tower and tower hardware			
Shipping and delivery			
Extended warranty (define # of years)			
Other (difference between costs above and cost to customer)			
Total Cost to Consumer	**$ -**	**$ -**	**$ -**

- Baseline is current costs before the proposed project effort
- Proposal is the expected cost after the proposed project effort
- End of project is **not** filled in now
- If a contract is won, then report LCOE at the end of the project
- Also report the cause of any difference between expected and actual LCOE
- If it is green, fill it in (except end of project); otherwise, leave it to calculate.

Initial Capital Cost: Balance of System

- Include everything expected in a normal installation billing
- Show baseline (current) costs and expected improvement
  - Justify improvement
  - If performance increases, then higher cost can still give lower LCOE
- Again, "Other" covers the difference between costs and sales price to the customer
- Real installed costs for many turbines are available so please be real with the ICC.

Initial Capital Cost: Balance of System

Balance of Station Costs	Baseline	Proposal	End of Project
Wind resource and site assessment and feasibility studies			
Zoning approval, permits and licenses, including environmental assessments			
Project engineering and design			
Site preparation, including roads, grading, and fences			
Electrical infrastructure including wire run (labor, materials, and equipment)			
Foundation cost (labor, materials, and equipment)			
Installation including assembly, erection, and commissioning costs (includes crane)			
Wind turbine monitoring equipment (if applicable)			
Other project construction costs			
Sales tax			
Construction contingency			
Other (difference between costs above and cost to customer)			
Total Cost to Consumer	**$ -**	**$ -**	**$ -**

Annual Energy Production

- In the past, the RFP specified an average wind speed, distribution, sheer, and height
- A spreadsheet is provided
- Provide the power curve and hub height
  - Provide source of the power curve (calculated or measured)
  - Do **not** exceed the Betz limit
- Provide baseline (as it is today) and proposal as it is expected to be after the proposed improvement
  - Justify expectation for performance improvement
- Do **not** fill in end of project, this is for the final actual result
- Take deductions for availability, blade soiling, controls, and grid availability (it is all in the spreadsheet).

AEP Calculation

	Baseline			Proposal		
Wind Speed Bin (m/s)	Rayleigh Probability	Turbine Power Curve (kW)	Gross AEP	Rayleigh Probability	Turbine Power Curve (kW)	Gross AEP
0.5	0.0217		0.00	0.0217		0.00
1.5	0.0623		0.00	0.0623		0.00
2.5	0.0952		0.00	0.0952		0.00
3.5	0.1169		0.00	0.1169		0.00
4.5	0.1262		0.00	0.1262		0.00
5.5	0.1240		0.00	0.1240		0.00
6.5	0.1128		0.00	0.1128		0.00
7.5	0.0959		0.00	0.0959		0.00
8.5	0.0767		0.00	0.0767		0.00
9.5	0.0579		0.00	0.0579		0.00
10.5	0.0413		0.00	0.0413		0.00
11.5	0.0280		0.00	0.0280		0.00
12.5	0.0180		0.00	0.0180		0.00
13.5	0.0111		0.00	0.0111		0.00

- The difference should be justified (not in the spreadsheet)
- Doubling swept area is expected to nearly double power
- Doubling power with no increase in swept area must be supported to be credible
- This example is for 6 m/s at hub height
- It will adjust if a different hub height is entered.

Adjustments to AEP

	Baseline	Proposal	End of Project	Notes
30 m windspeed (m/s)	6.00	6.00	6.00	windspeed in column C is not locked, the default is 6.0
Hub height (m)	30	30	30	
Power law shear exponent	0.250	0.250	0.250	Alpha in column C is not locked, the default is 0.25
Hub height windspeed	6.00	6.00	6.00	
Availability				
Soiling Losses				
Controls Losses				
Grid Availability Losses				
Other Non-Drivetrain Losses				

- Loss figures used will depend on power curve source
- Calculated power curve will have a controls loss, measured will not
- It is important to establish credibility as much as show good results
- Some entries, such as grid availability, may have guidance in the RFP.

Annual Operation and Maintenance (Levelized)

Annual Operation and Maintenance Costs	Baseline ($/yr)	Proposal ($/yr)
Labor, parts, and supplies for scheduled turbine maintenance		
Labor, parts, and supplies for unscheduled turbine maintenance (include expenses covered by warranty)		
Labor for administration and support (zero for most small turbines)		
Other (define)		
Total Cost to Consumer	$ -	$ -

- Be realistic on O&M costs
- If the manual calls for annual maintenance, the cost should be based on that
- Things are going to break (it is an estimate, do not put zero)
- If replacement is expected in 10 years, the expense goes in "replacement cost," not here.

Levelized Replacement Cost

- Anything that is expected to be replaced periodically during the turbine design life but not consumables such as brake pads or oil
- Enter the cost and mean time for replacement and the spreadsheet will calculate the annual cost.

Baseline Levelized Replacement Cost (LRC)	Mean Time Between Replacements (years)	Replacement Cost (2017 Dollars)	LRC ($/yr)
Item #1			$ -
Item #2			$ -
Item #3			$ -
Item #4			$ -
Item #5			$ -

Proposed Levelized Replacement Cost	Mean Time Between Replacements (years)	Replacement Cost (2017 Dollars)	LRC ($/yr)
Item #1			0
Item #2			$ -
Item #3			$ -
Item #4			$ -
Item #5			$ -

LCOE Rollup Calculation

- It all rolls up into an LCOE result
- Proposal should be better than baseline
- This table is all made up numbers so no significance.

LCOE Summary	Baseline	Proposal	End of Project
Turbine Component ($)	55,000	48,000	0
Balance of Station ($)	15,000	10,500	0
Annual Operating Expenses ($/kWh)	0.008777522	0.005066782	#DIV/0!
Annual Energy Production (kWh/yr)	30561.01787	39867.51126	0
Fixed Charge Rate	7.4%	7.4%	7.4%
LCOE ($/kWh)	0.178274494	0.113651438	#DIV/0!

Questions?

Robert Preus
Robert.preus@nrel.gov