Competitiveness Improvement Project 2020 Informational Workshop

Ian Baring-Gould, Robert Preus, Robert Wills, Brent Summerville, Dean Davis, Kyndall Jackson, and Scott Dana

December 8, 2020

Introductions

Patrick Gilman, DOE Wind Energy Technology Office

Ian Baring-Gould, National Renewable Energy Laboratory

Because we don’t have time to do a full around-the-room, using the chat feature, please introduce yourself. Include:

- Name, company, company website
- Contact information
- Short sentence about your company or interest in CIP

Agenda

9:00	Welcome and Introductions
9:15	Session 1: Overview of CIP, Ian Baring-Gould
9:45	Session 2: Electrical Standards for Grid Connected Equipment, Robert Preus (NREL) and Robert Wills (Intergrid)
10:15	Session 3: Review of the AWEA SWT-1 (2020), Brent Summerville (NREL)
10:45	Break
11:30	Session 4: Test Site & Certification Testing Requirements, Dean Davis (Windward Engineering)
12:15	Session 5: Breakout on Potential Topical Areas (NREL)
12:45	Break
1:15	Discussion, Questions and Answers, Ian Baring-Gould and NREL Team
1:45	Session 6: Procurement/Contracting, Kyndall Jackson (NREL)
2:14	Session 7: Design Evaluation, Robert Preus (NREL)
2:45	Session 8: Additional CIP Considerations, Robert Preus (NREL) and Scott Dana (NREL)
3:15	Questions and Answers, Ian Baring-Gould (NREL)

All times are Mountain Standard Time

Housekeeping and Considerations

Please mute your phone.

Please ask questions using the Q&A feature.

- Depending on the number of questions, we will try to unmute you to ask your question
- Please introduce yourself when you ask a question
- Please be quick and to the point; we don’t have a lot of time

Breakout on Potential Topical Areas—choose which session you want to attend.

- Pre-Prototype Development, Robert Preus
- Component Innovation & System Optimization, Ian Baring-Gould
- Prototype Testing, Certification Testing & Type Certification, Scott Dana (NREL) and Jeroen van Dam (NREL)
- Manufacturing Process Innovation, Dave Snowberg (NREL)

When we go into breakout, go to the breakout tab at the top of the screen and select your breakout room.

We regret the inability to allow expanded cross-industry dialogue. If you would like to host a sidebar discussion with another participant, feel free to use the breakout session function or message Rachel Wolford.

Notice

- NREL announced a Notice of Intent on November 9, 2020, stating that it intends to release a request for proposals (RFP) under CIP in early 2021.
- NREL and DOE employees cannot discuss any potential CIP solicitation, but we can provide guidance based on previous releases.
- Any information covered today is relative to past CIP RFPs and should not be assumed to be consistent with any potential future offerings.
- Slides and webinar recording will be published and made available.
- If you are interested in being placed on a distribution list for CIP, please email your contact information to CIP's Procurement Office Subcontract Administrator Kyndall Jackson (Kyndall.Jackson@nrel.gov).
- Please reference NREL's CIP website for information and links: https://www.nrel.gov/wind/competitiveness-improvement-project.html

Questions?

Ian Baring-Gould

Session 1: Overview of the Competitiveness Improvement Project

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 as a result of 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 Competitive Improvement Process (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

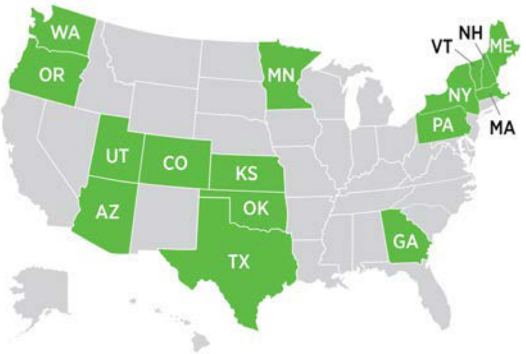
To expand U.S. leadership in the domestic and international distributed wind turbine sector by:

- 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).

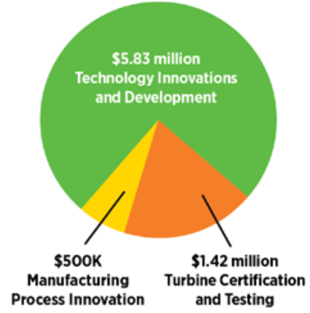
History of the CIP

The history of the CIP includes the following:

- CIP was initiated in 2012
- Eight annual solicitations have been implemented
- Thirty-nine awards have been issued to 21 manufacturers in 16 states
- Not all projects ultimately completed as originally scoped due to range of issues (eight to date)
- Through 2019 total U.S. Department of Energy investment of $7.75 million, leveraging $3.79 million in additional cost share
- NREL manages the projects through a defined period of performance subcontract, providing oversight and technical assistance.



CIP continues to support companies from across the nation



Funding continues to focus primarily on technology innovation and development

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 the projects are manageable and can be completed in a timely manner, typically 24 months
- Focused generally on higher technology readiness level efforts
- Technology-, configuration-, component-, and application-neutral
- A sustained solicitation process that allows technologies to move from initial innovative concepts to a certified turbine and innovative applications
- NREL works with awardees to end contracts if it is determined that the original scope is not achievable
- Technical assistance (see Session 8) provided by NREL or other laboratories 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, and new topics are added based on feedback of the distributed wind community.

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 at 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, vertical-axis wind turbines, unconventional designs or configurations
- Nonturbine components or systems (foundations and/or applications) are acceptable
- Turbine testing, including:
  - Prototype testing, with plan toward 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, video, 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 that are in essence conflicting.

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 include:

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

Scoring Criteria

- Scoring criteria are provided in the request for proposal (RFP) document for each topic; respond to every element, even if it is to acknowledge it as a weakness in your design.

Component Innovation

- Demonstrates evidence that the proposed innovation(s) are technically feasible, commercially attainable, and consistent with certification of the turbine
- Demonstrates evidence that investment in innovation will contribute to a reduction in the levelized cost of energy (25%)
- Submit outline of a product development plan that will lead to successful market introduction and certification, or maintain existing certification, of the turbine for the U.S. market (20%)
- Team/personnel/expertise (30%)

Certification Testing

- Demonstrates that the turbine system is likely to comprise a significant share of the distributed wind turbine market and the company can provide the associated installation and long-term maintenance support (25%)
- Extent to which the turbine system will impact the U.S. market (20%)
- Demonstrates evidence that the wind generator is ready for certification and that the company has a sound plan that will lead to certification of the turbine for the U.S. market (30%)
- Team/personnel/expertise (25%)

- CIP is very competitive; if you don't address a criterion, you will get fewer points and are not likely to be successful.

Proposal Considerations/Recommendations

- 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. If a consultant still needs to be identified for a skill set, just identify the skills that will be sought.
- You don't need to be a wind turbine manufacturer to apply for a component improvement award, but you need to identify a specific turbine for which the product will be deployed and have a documented consultation with that manufacturer about the use of the new component. If you feel your product is applicable to multiple vendors, articulate this, but that does not release you from the requirement to be partnering with a defined vendor.
- Most CIP efforts have internal go/no-go decisions; consider those carefully. For example, a *Pre-Prototype Development* award only grants funding through the design review.
- A documented path to certification is critical.
- Make sure you understand the appropriate standard, are very confident in your design, and have talked to one of the certification bodies.
- Other than some specific requirements, if you need to do something that seems to counter an element of the RFP, explain why you feel you need to do something different.

Questions?

Ian Baring-Gould

Competitiveness Improvement Project Topic Areas for 2020 RFP

- Pre-Prototype Development: with a maximum award value of approximately $200,000 and a minimum cost share (price participation) of 20%
- Prototype Testing: ~$250,000; 20% minimum cost share
- Component Innovations: ~$400,000; 20% minimum cost share
- System Optimization: ~$400,000; 20% minimum cost share
- Certification Testing (<200-m^2 rotor-swept area): ~$170,000; 20% minimum cost share
- Type Certification (>200-m^2 rotor-swept area): ~$800,000; 20% minimum cost share
- Manufacturing Process Innovation: ~$500,000; **50% minimum cost share**

Session 2: Standards for Grid Connected Equipment

Robert Preus

Standards That Apply to Distributed Wind

- IEC 61400-2 or -1 or AWEA SWT1 (Sessions 3 & 4)
  - -2 for swept area <200 m^2
  - -1 for swept area >200 m^2
  - SWT-1 for rated power $\leq$150 kW (draft)
  - These reference a whole family of standards for different tests
- Underwriters Laboratories (UL) 6141 & 6142
  - References UL1004, UL1741, etc.
- Institute of Electrical and Electronics Engineers (IEEE) 1547
- National Fire Protection Association 70 National Electric Code (NEC)

Why So Many? Are They Really Necessary?

- Each standard is for a specific area of interest, and they are cross-referenced and form a complete structure (consider Authority Having Jurisdiction [AHJ] perspective)
- IEEE 1547 establishes a set of rules for how a generator of any kind must be able to operate connected to the grid
- IEC61400-2 is a design, performance, and structural standard (references IEC testing standards)
  - This is covered in Session 4
- UL6142 and UL6141 are safety (mostly electrical) standards for wind generators specifically as a system
- NEC covers how that system is installed and connected

How Standards Weave Together for an Inverter

- Designed and tested to meet UL1741 requirements for inverters
  - UL1741 refers to the performance requirements of IEEE1547 for power quality and protection and testing requirements (IEE1547.1 for testing)
- Installed consistent with NEC and listed for the application (type of use and environment)
  - An inverter used in a wind system must be listed for use in a wind system or for any DC source
  - A listed wind system will be listed with specific inverter(s)
  - An inverter that is listed for indoor installation cannot be installed outdoors

National Electric Code NFPA 70

NEC

- The NEC applies to anything electrical unless exempted, such as utility equipment and boats
- It requires most things to be listed for the application (i.e., ties back 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 (in other words, they contain exceptions)
  - For example, the installation of turbines for testing at a supervised site is permitted without all components being listed

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 Microgrids

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 is officially adopted
- IEEE 1547.1 2020 for testing requirements is adopted

IEEE 1547 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
- Communication is required (IEEE 2030.5 or DNP3 or SunSpec)
- Anti-island protection is still required
- Several categories of capability are allowed
  - 1547 does not specify what category is required
  - Grid operator determines required category
  - Allowed category may vary by feeder or even location on the feeder

Exponential increase in testing effort to verify conformity

Large and Small Wind Turbines Electrical System Compliance

Listing of Wind Generators

- Wind turbine electrical system compliance (listing or field evaluation) is a requirement of Article 694 of NEC
- UL 6142—Applicable to 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—Applicable to large wind turbines where entry of personnel in the tower or nacelle is allowed (mainly because of the size of the turbine) to perform various activities related to 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
  - Inverter conformity cannot be covered with field labeling

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:

- Outline drawings, assembly drawings of electrical components and connections, and detailed 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, including component manufacturers, manufacturers' component part numbers, component ratings and U.S. certification information, and manufacturers' technical data sheets for components
- Material flammability, temperature, and electrical ratings information for all nonmetallic materials and insulations
- Drawings of all caution, warning, ratings, and terminal markings, including adhesive label marking system information (manufacturers, manufacturers' part numbers, ratings, and markings locations drawing)
- Component photos of each side, and inside views of enclosures, etc.
- Installation/operation manual, and, if available, type test plan and other test data

Slide provided by Anant Jain of Intertek

Why a Special Section for Wind?

- With no guidance specific for wind, AHJ(s) 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

Questions?

Robert Preus

Session 3: Review of the AWEA SWT-1

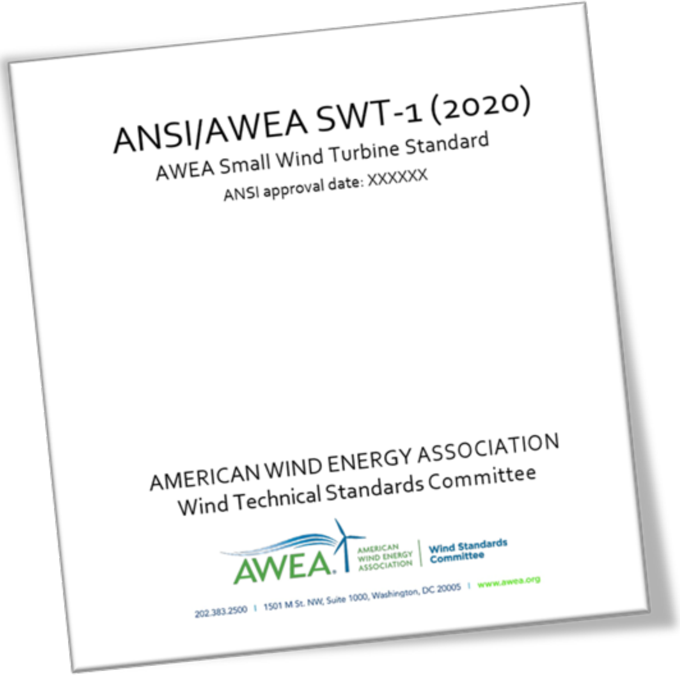
Brent Summerville

AWEA SWT-1 Update

Brent Summerville

NREL

- 08 December 2020
- *Competitiveness Improvement Project Virtual Informational Workshop*



ANSI/AWEA SWT-1 (2020)

AWEA Small Wind Turbine Standard

ANSI approval date: XXXXXX

AMERICAN WIND ENERGY ASSOCIATION

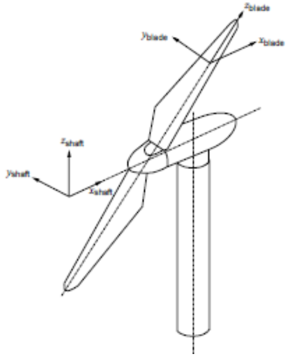
Wind Technical Standards Committee

AWEA AMERICAN WIND ENERGY ASSOCIATION | Wind Standards Committee

202.383.2500 | 1501 M St. NW, Suite 1000, Washington, DC 20005 | www.awea.org

Problems and Solutions

- Testing and certification identified as a barrier to market entry
  - NREL CIP funding has helped the financial barriers
  - Need to **optimize** the standard(s) for time and $$
- AWEA SWT-1 was remanded summer 2019
  - **Opportunity** to revise our national Small Wind Turbine (SWT) Standard
  - Use SWT-1 draft from 2016 as a starting point
  - A decade of lessons learned from AWEA 9.1-2009



Meeting 1: Denver, CO
13 February 2020

Meeting 2: Arlington, VA
28 February 2020
Following DWEA 2020

A draft standard was finalized in several virtual meetings

AWEA SWT-1 Overview

IEC 61400-12-1 ed. 2

IEC 61400-11 ed. 3

IEC 61400-2 ed. 3

IEC 61400-2 ed. 3

IEC 61400-2 ed. 3

IEC 61400-2 ed. 3

Sound Levels for Various Conditions

Conformity Assessment

Scope Increase

- Raise and redefine the scope to **150 kW** at Peak Power
  - (instead of 200-m^2 rotor swept area)

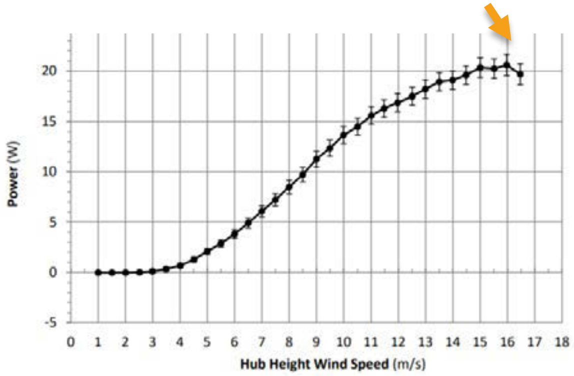
Specific power decreasing with small wind, driving swept area up

Peak power better defines maximum loads and electrical/thermal issues

Addresses gap between small and megawatt-scale (e.g., NW100, Pecos 85 kW, Endurance E3120 50-kW turbines)

- Set different requirements for different sizes based on peak power

Peak Power = top of power curve



Definitions

- Change **Reference Annual Energy** from 5 m/s to 6 m/s

Using a conservative 5 m/s annual average wind speed to estimate the Refence Annual Energy production for marketing material gives an immediate disadvantage to distributed wind technology (DWT) compared to the marketing ratings PV uses, in some cases leading to DWT directly being dismissed before a true comparison of both systems can be performed.

This can help level the playing field.

- **Micro Wind Turbine**: Peak power up to 1 kW

Power Performance Testing

- Adopt IEC wire run length and database criteria

Wire: AWEA 9.1 is at least 8 rotor diameters; IEC is base of tower to 3x tower height (-12-1 annex H.e)

Database: AWEA 9.1 requires 10 minutes per bin to 5 m/s beyond wind speed bin for which 95% of maximum power is reached. IEC requires 10 minutes per bin from 1 m/s below cut-in to 14 m/s, total of 60 hours (-12-1 annex H.n).

- Move peak power database requirement to S&F testing

- Site calibration is not required

Flow correction factors due to terrain have historically been quite high; met tower and turbine was relatively close for small wind

Acoustic Sound Testing

- Now incorporates the latest **IEC 61400-11, ed. 3** (Annex F for small wind applies to turbines with a *maximum power output less than* *100 kW)*

  We are proposing SWT-1 be expanded to turbines with peak power up to 150 kW

- Change **uncertainty calculation** to “should”

- Not required for micro wind turbines

Strength and Safety

- Based on work conducted in IEA and measurements conducted at typical installation sites, the I15 was raised from **18%** to **20%**
- Simplified load model (SLM) limited to 30 kW, not recommended for turbines with peak power greater than 10 kW
- IEC class limited to **Class II or S**
  - Class II provides turbines that are suitable for installation in most locations
  - S used for high or low wind regimes
- Design analysis not required for micro wind turbines

Duration Test Reports Collected

Viking VS25

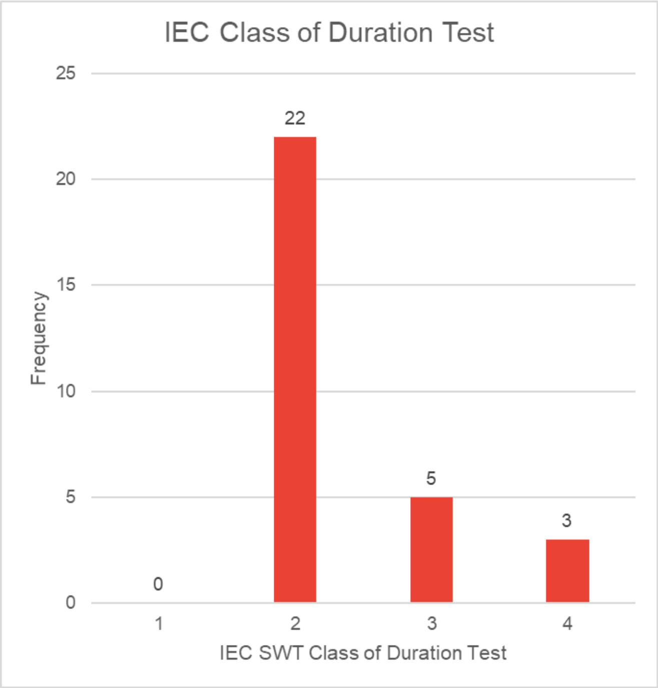
- 30 duration test reports collected
  - 24 passed
  - 6 did not
- From Jan 2007 to May 2018 (11.3 years)
- Per
  - IEC 61400-2 ed. 2 (2006)
  - AWEA 9.1 (2009)
  - BWEA (2008)
  - IEC 61400-2 ed. 3 (2013)
- From test sites
  - AEI/WTAMU RTC, Canyon, TX
  - Dr. Frey, Ihrhove, Germany
  - High Plains RTC, Colby, KS
  - Intertek RTC, Otisco, NY
  - NAREC, West Yorkshire, UK
  - NREL NWTC, Arvada, CO
  - Site in Shetland, UK
  - TUV-NEL, Myres Hill, UK
  - UL/WTAMU, Canyon, TX
  - USDA, Bushland, TX
  - WEICan, PEI
  - Windward RTC, Spanish Fork, UT
  - DTU Wind Energy, Denmark

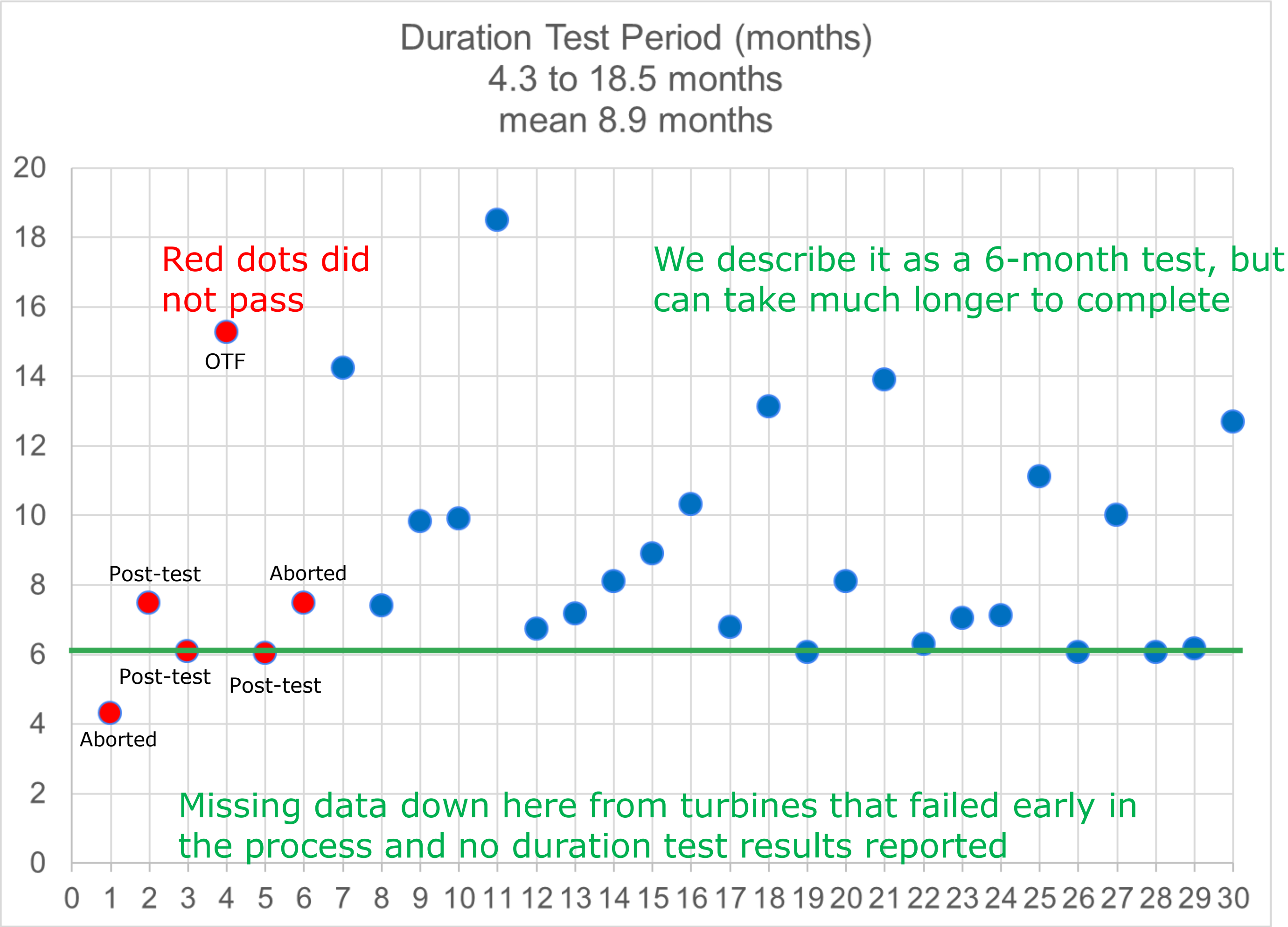
Three *attempts* at class I test, passed class II instead

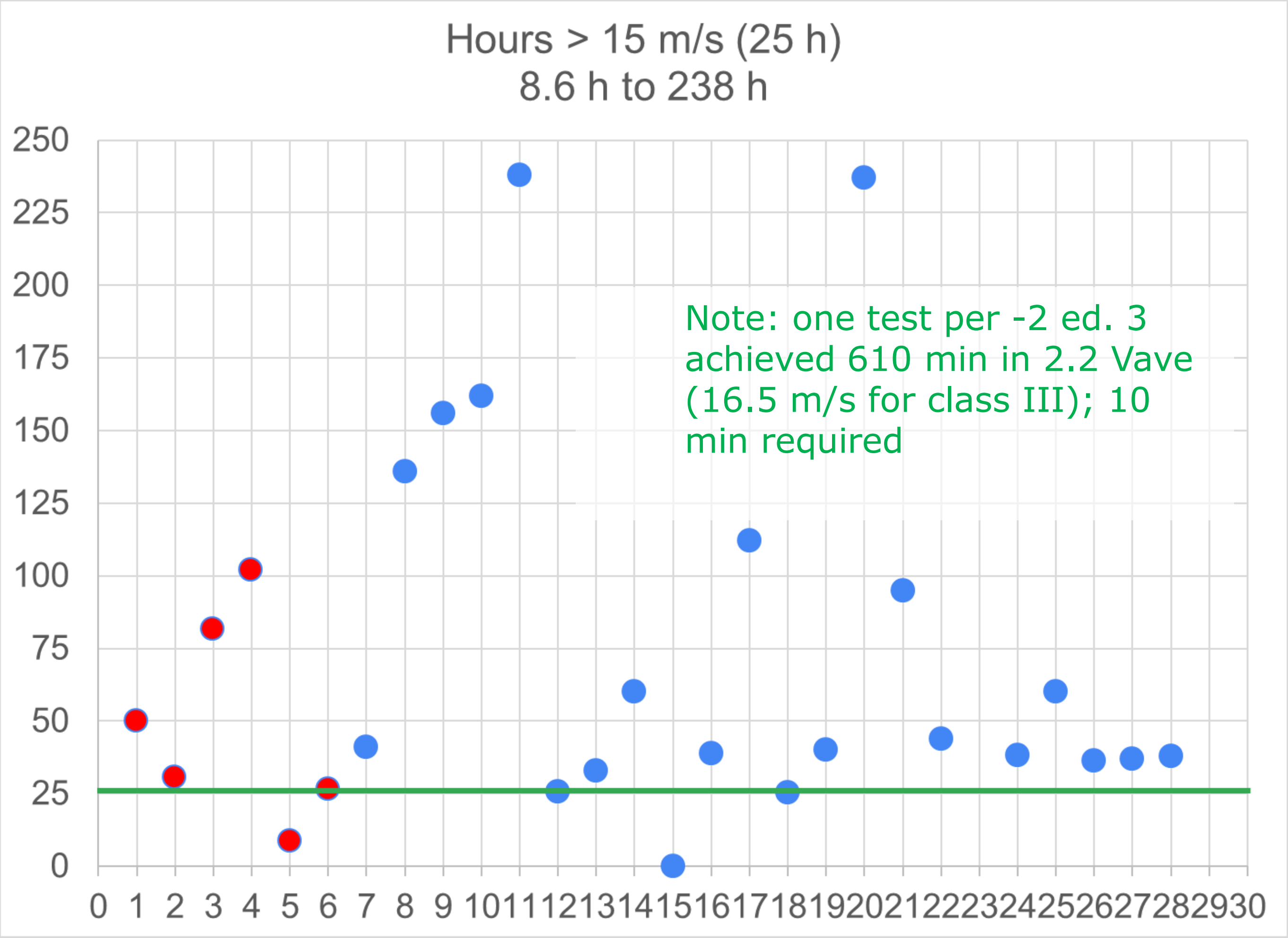
1.8 Vave was 23.7h/25h in one case

One attempt at class III test, passed class IV

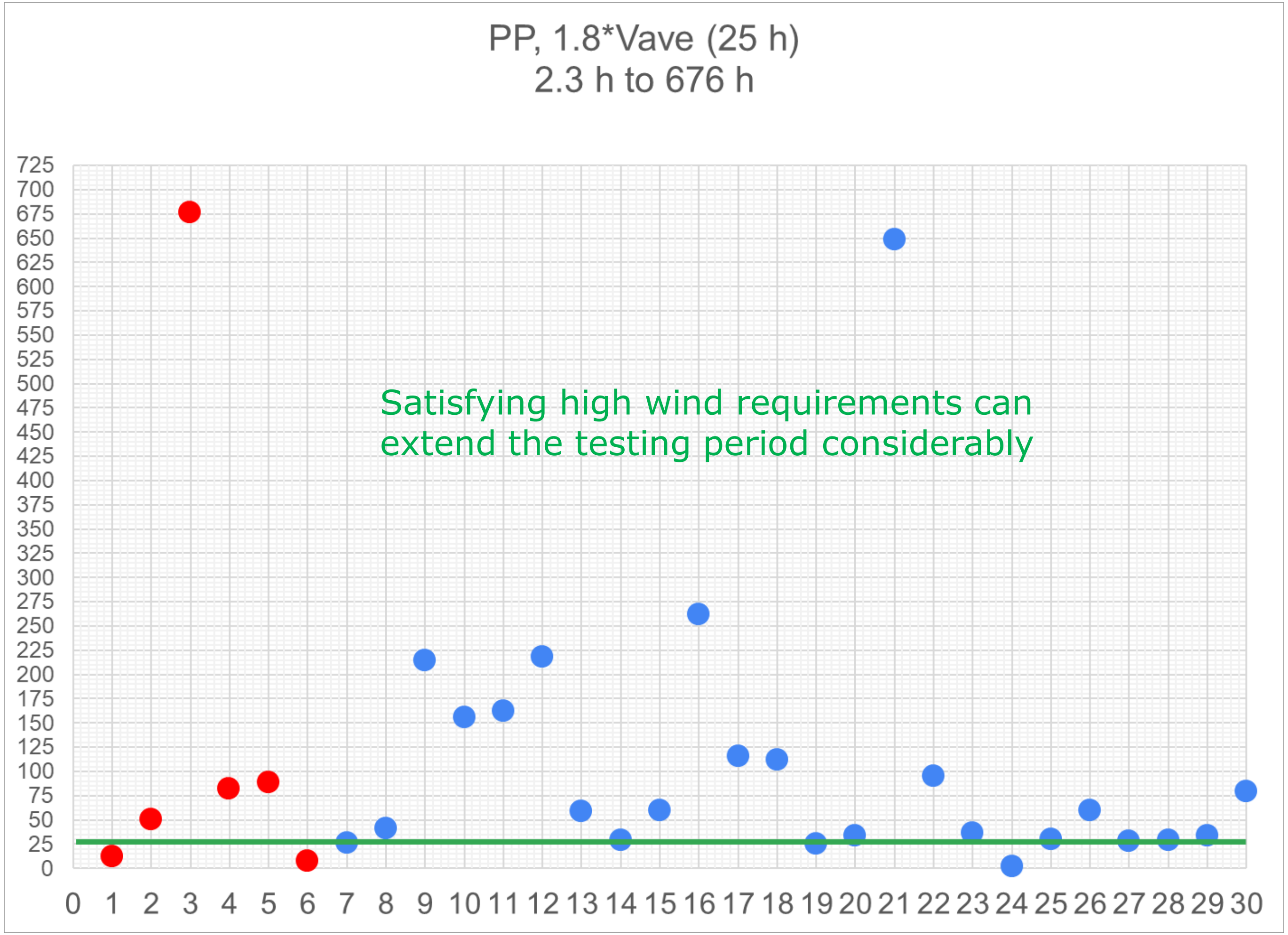
Vast majority of duration tests were per Class II requirements

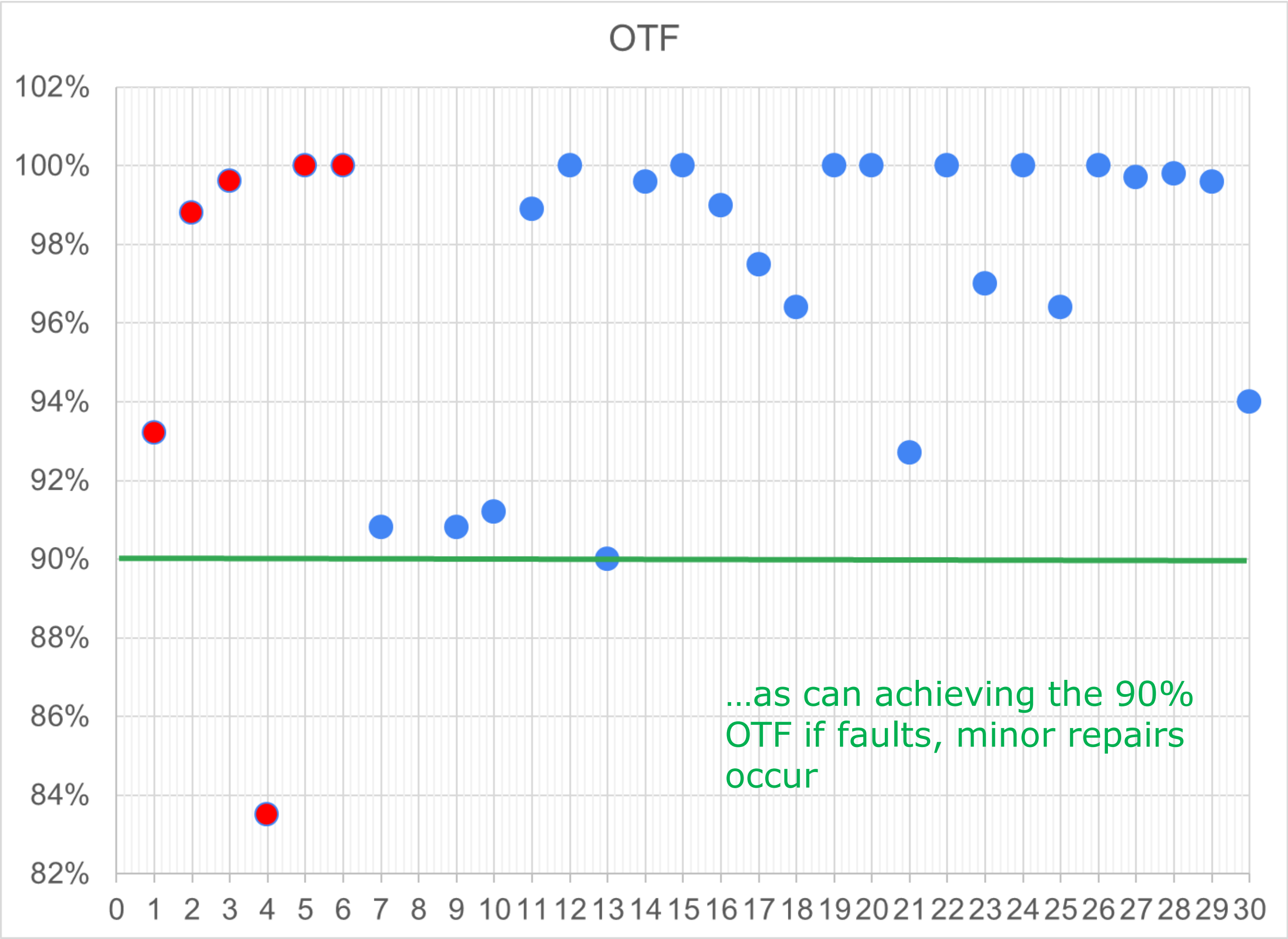



Duration Test Period (months)
4.3 to 18.5 months
mean 8.9 months
Red dots did not pass
We describe it as a 6-month test, but can take much longer to complete
OTF
Post-test
Aborted
Post-test
Post-test
Aborted
Missing data down here from turbines that failed early in the process and no duration test results reported
20
18
16
14
12
10
8
6
4
2
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

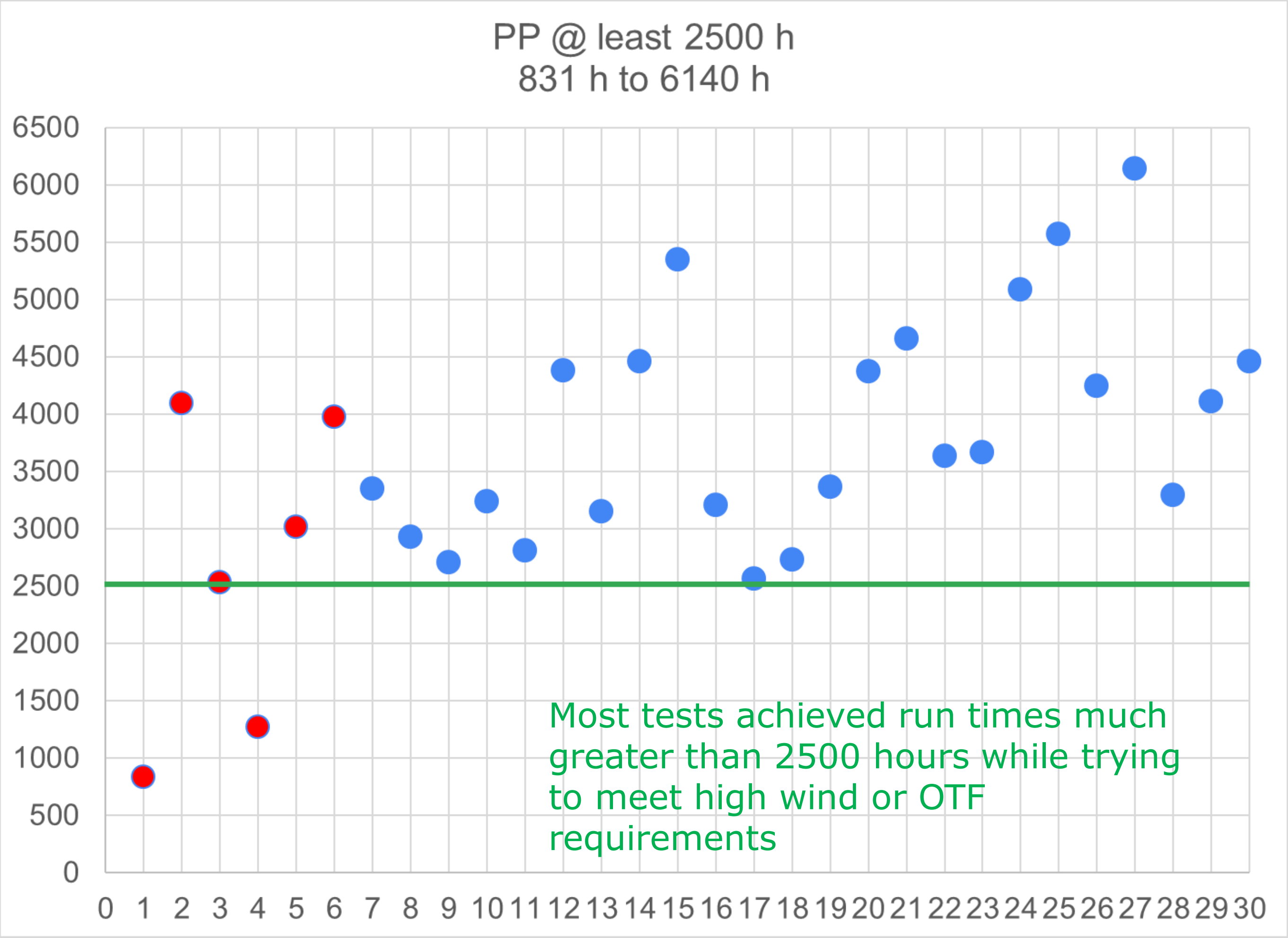


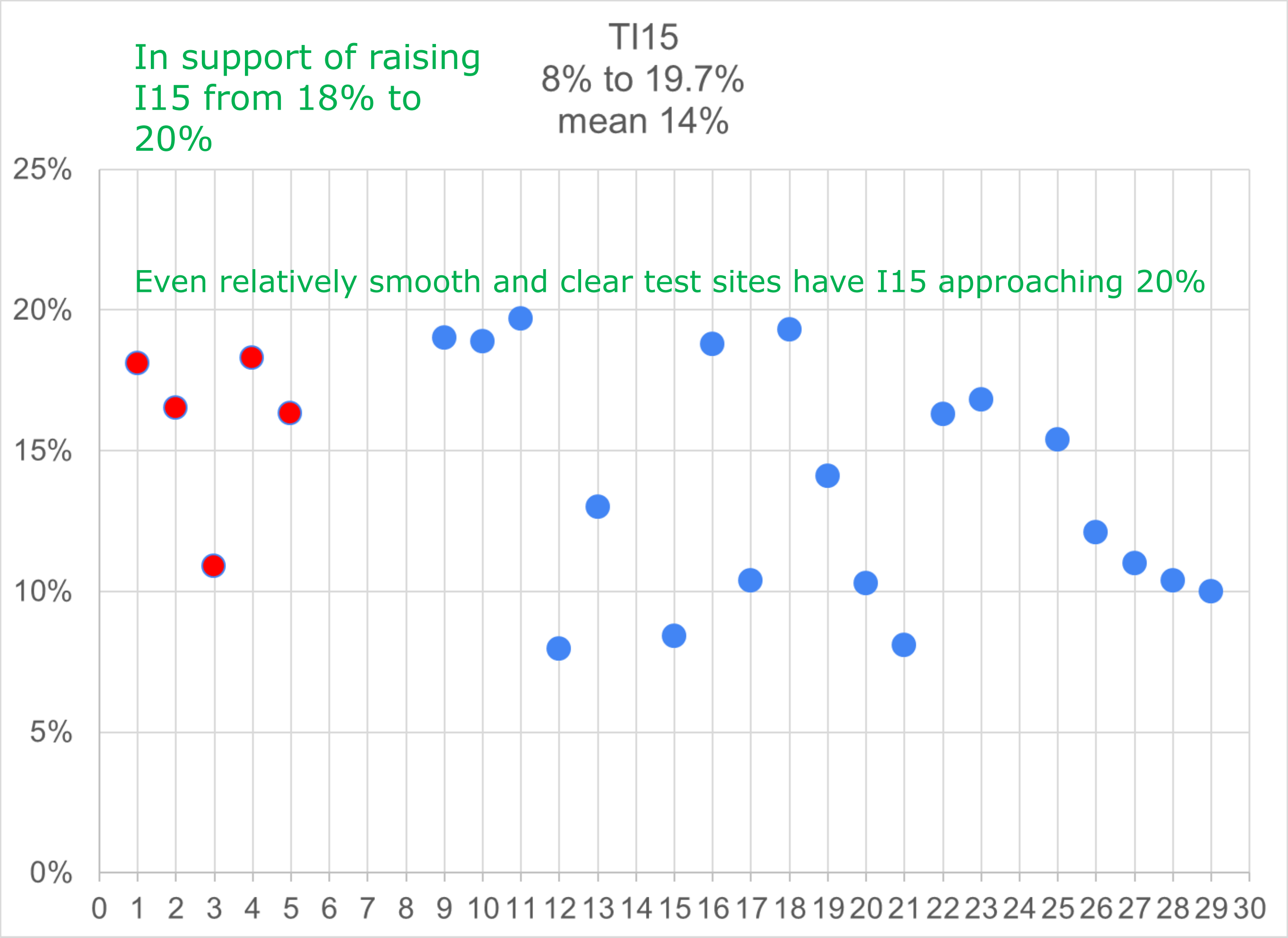
Hours > 15 m/s (25 h)
8.6 h to 238 h
Note: one test per -2 ed. 3 achieved 610 min in 2.2 Vave (16.5 m/s for class III); 10 min required
250
225
200
175
150
125
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30


PP, 1.8*Vave (25 h)
2.3 h to 676 h
Satisfying high wind requirements can
extend the testing period considerably
725
700
675
650
625
600
575
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30



OTF
102%
100%
98%
96%
94%
92%
90%
88%
86%
84%
82%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
...as can achieving the 90% OTF if faults, minor repairs occur


PP @ least 2500 h
831 h to 6140 h
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
Most tests achieved run times much greater than 2500 hours while trying to meet high wind or OTF requirements


In support of raising I15 from 18% to 20%
TI15
8% to 19.7%
mean 14%
Even relatively smooth and clear test sites have I15 approaching 20%
25%
20%
15%
10%
5%
0%
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

What major issues did the test catch/not catch?

- **Inverter** board components failing in sustained high winds; test aborted
- Excessive rotor friction, preventing the rotor from turning; discovered in post-test
- **Inverter** failure ended test; broken **welds**, broken washer, loose nuts found post-test
- Tail damage (from extreme tail action in gusty wind conditions), **blade damage/stress cracking,** corrosion/degradation in yaw mechanism; caught in post-test
- Failed anemometer, failed power supply, failed compressor and faults
  > OTF failure
- **Blade failure** (severe cracking close to root, loss of integrity, other blades showing signs of distress); caught in post-test

Duration Test

- Upon review, requirements greatly reduced to:
  - **10 hours in wind speeds of 15 m/s (33.6 mph) and above**

    (now based on **1-minute** averaged periods)

    and;
  - **1,000 hours of power production**

Micro Wind Turbine Requirements

- Power Performance
- Safety & Function
- Duration
- No Acoustics
- No Design Analysis
- No Blade Test

Cost of the turbine is relatively low, allows taking some additional risk without significant financial consequences

Validation will be through the testing and the follow-on field inspections

Surveillance More Robust

To maintain validity of a small wind turbine certification:

a. An initial **factory inspection** followed by an inspection every two (2) years

b. Field inspections of a sample of certified turbines per the Routine Inspection requirements of IEC 61400-2 ed. 3 section 11.2.5.3 with the following additional requirements:

   i. Sample size shall be **five (5) turbines** at different sites; turbines chosen by OEM and CB.

   ii. Inspections shall be performed **annually** by a party chosen by the OEM and CB (e.g., the installer or service provider).

   iii. The duration of the annual field inspections period shall be **three (3) years.** After the third consecutive field inspection is complete, per turbine, the inspection requirement is satisfied and the certification will be maintained through annual reporting, as listed in 2.a, 2.c and 2.d.

   iv. Inspection reports shall include photos of major components, as identified by the OEM and CB, and any signs of cracking, degradation, or significant wear.

   v. Report annual energy production and estimated annual average hub wind speed. Provide the source of wind speed estimate, e.g., NREL Wind Prospector or turbine-mounted anemometer.

c. Annual reporting of all design changes, field failures, complaints, and sales

d. Significant design changes and safety-related field failures shall be reported to the CB without delay

	Micro wind turbines up to 1 kW Peak Power	1-30 kW Peak Power	30-65 kW Peak Power	65-150 kW Peak Power
STRUCTURAL DESIGN				
SLM	Not required	Not recommended for turbines with Peak Power greater than 10 kW	Not allowed	Not allowed
Aeroelastic model	Not required	Allowed with validation through power, rotor speed. Validate weight of major components.	Allowed with validation through power, rotor speed, blade first flapwise (static) natural frequency*. Validate weight of major components.	Allowed with validation through power, rotor speed, blade first flapwise (static) natural frequency, tower loads*. Validate weight of major components.
Structural Analysis	Not required	Required	Required	Required
TYPE TESTING				
Duration Testing	Required	Required	Required	Required
Power Performance	Required	Required	Required	Required
Loads Testing	Not required	Not required	Not required	Required
Acoustics Testing	Not required	Required	Required	Required
Safety and Function Testing	Required	Required	Required	Required
Blade Testing	Not required	Static test required	Static test required	Static test required; accelerated fatigue testing according to IEC 61400-23 is not required but is encouraged
Labeling	Required	Required	Required	Required

* for passive-yaw machines, yaw behavior should be validated

Next Steps

- AWEA Wind Technical Standards Committee moving SWT-1 through ANSI process
  - Committee and public comment period closed in Oct 2020
  - Subcommittee drafted comment resolutions
  - Resolution of comments is under way
- Effort led by:
  - Brent Summerville, ICC-SWCC
  - Jeroen van Dam, NREL
  - Mike Bergey, Bergey Windpower
- Goal is to have an improved U.S. national standard in place by end of 2020
- Hope to have it considered in other countries
- Hope it will influence IEC 61400-2 update in 2022

Questions?

Brent Summerville

Session 4: Certification Testing

Windward Engineering

Background

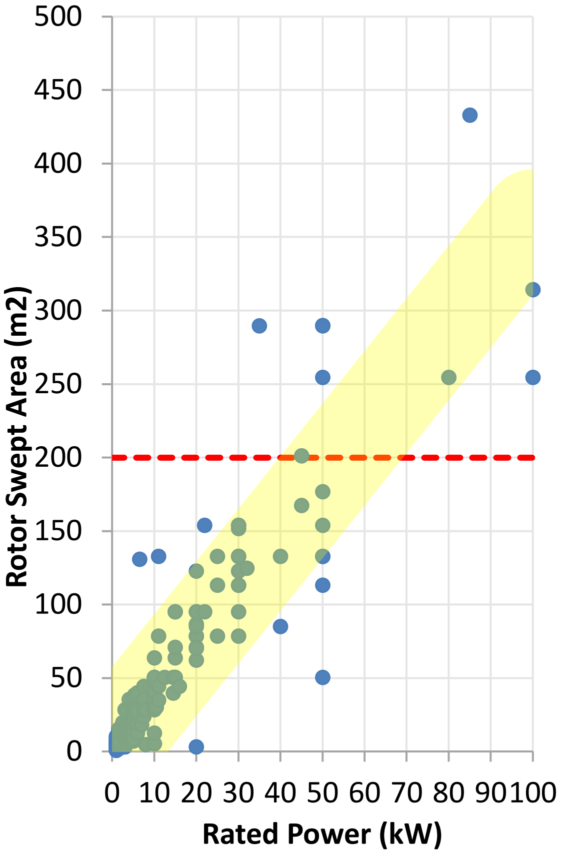
CIP Categories

- Pre-Prototype Development
- Prototype Testing
- Component Innovations
- System Optimization
- Certification Testing (<200 m^2 Rotor Swept Area [RSA])
- Type Certification (>200 m^2 RSA)
- Manufacturing Process Innovation

CIP and Testing

- Prototype Testing (PT)
- Certification Testing (CT)
  - <200 m^2 RSA
- Type Certification (TC)
  - 200 m^2 <(RSA) <1,000 m^2

Test	NREL (2020)	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

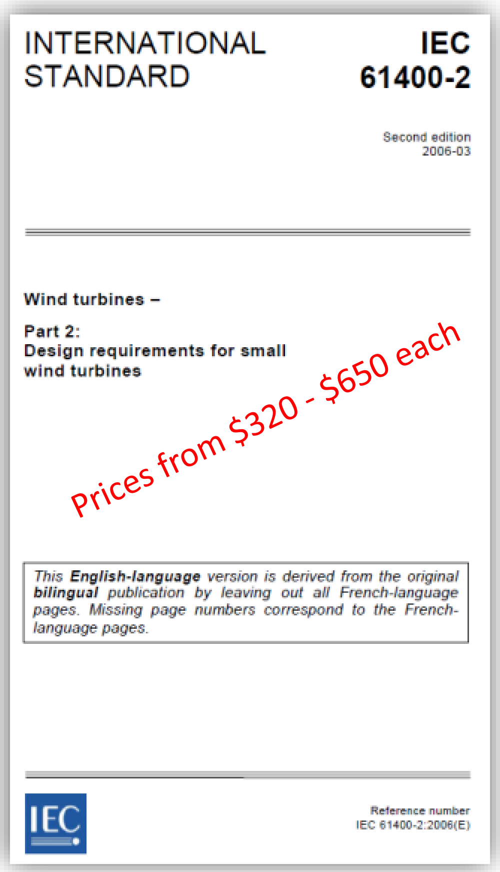
- Design evaluation
- Required field tests
  - Power performance
  - Acoustic
  - Safety and function
  - Duration

Type Certification

- 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**

Prices from $320 - $650 each

*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.*

IEC

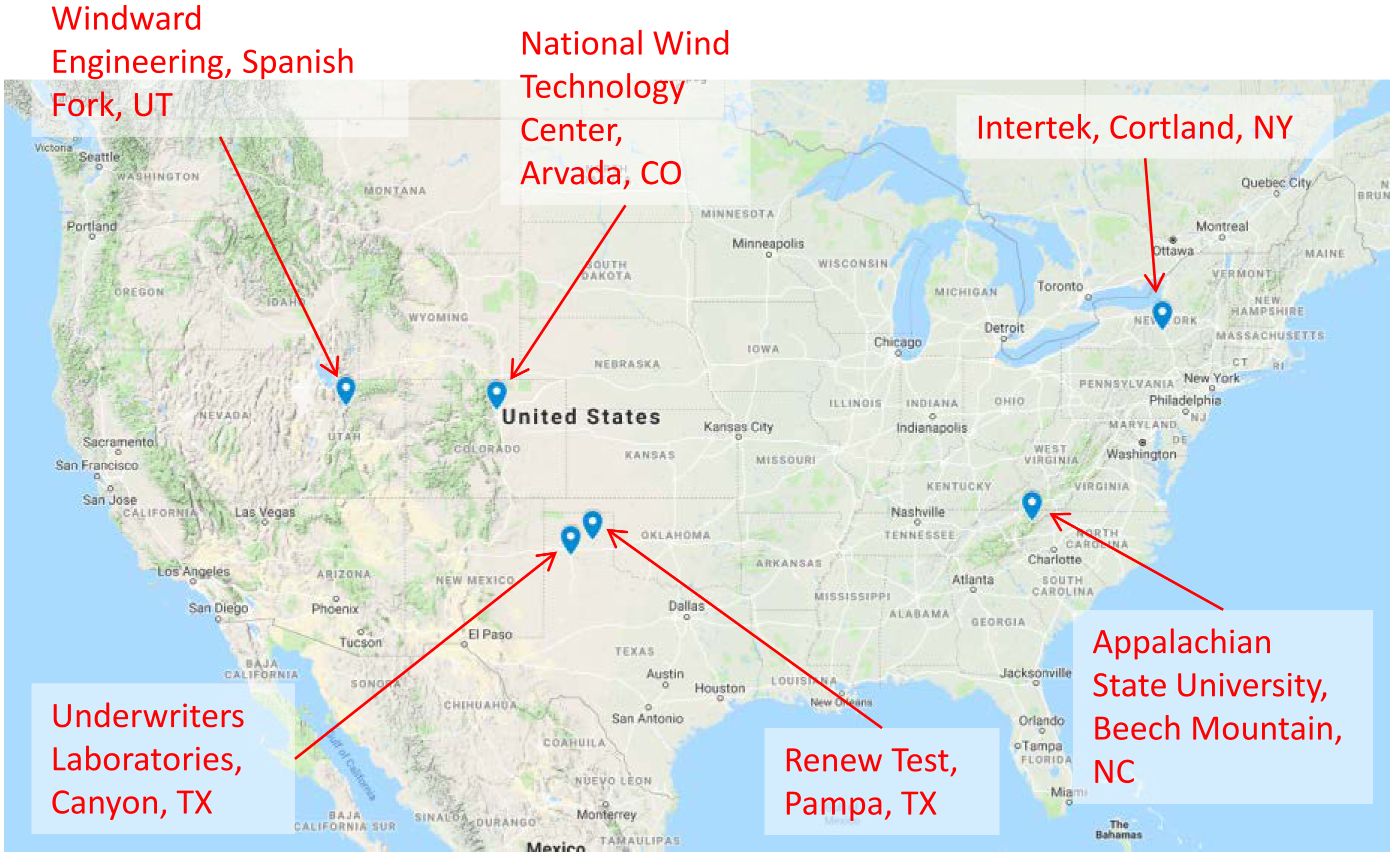
Reference number
IEC 61400-2:2006(E)

Certification Bodies

- Intertek
- ICC-SWCC
- UL (Underwriters Laboratories)
- 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

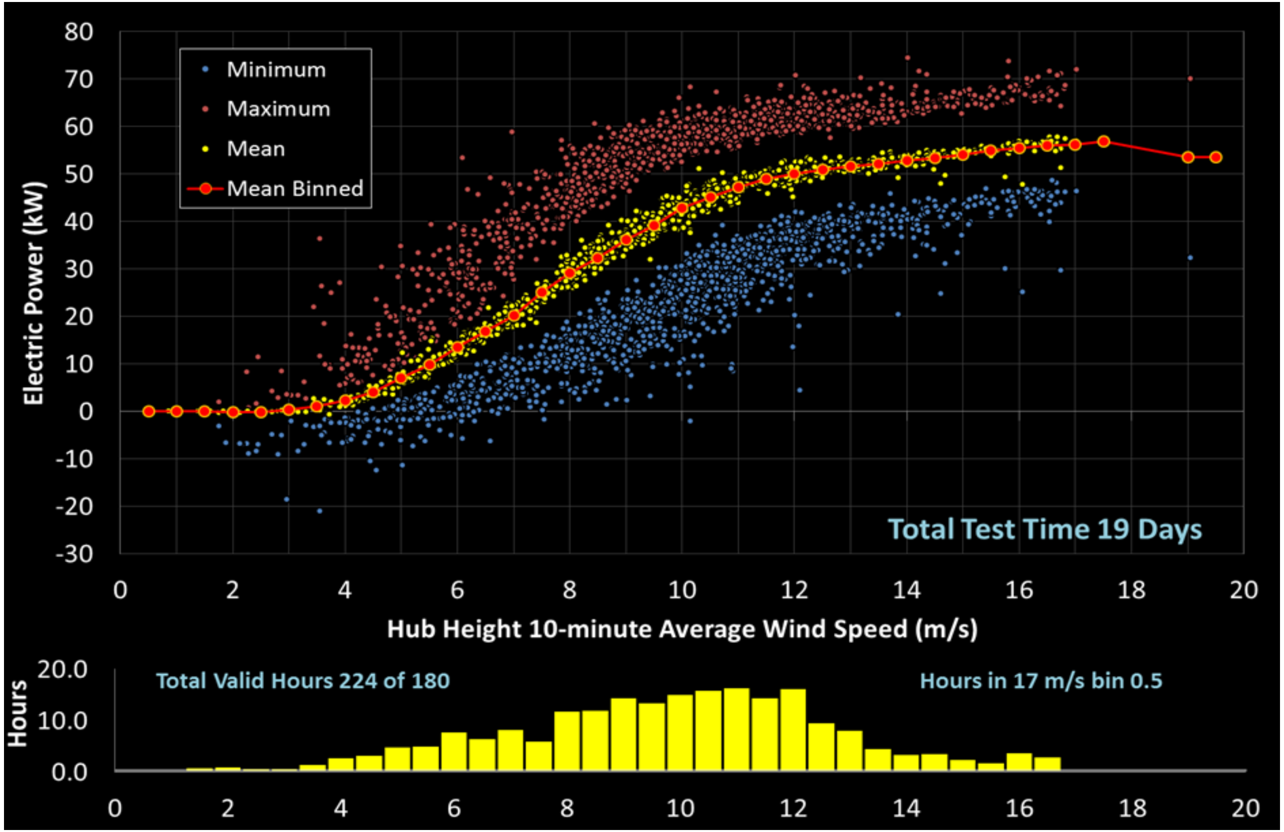
Ideal Test Site Attributes

- All field tests
  - Regular & nonseasonal winds
  - Favorable zoning and permitting laws
  - Nearby resources (heavy equipment, hardware store, etc.)
- Power performance
  - Unobstructed space
  - 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
- Duration test
  - Lots of power-producing winds
  - Not extreme winds
  - Some variability in ambient temperature
- Loads
  - Occasional high winds
  - Regular times of calm (for calibrations)
  - Variability in turbulence

Power Performance



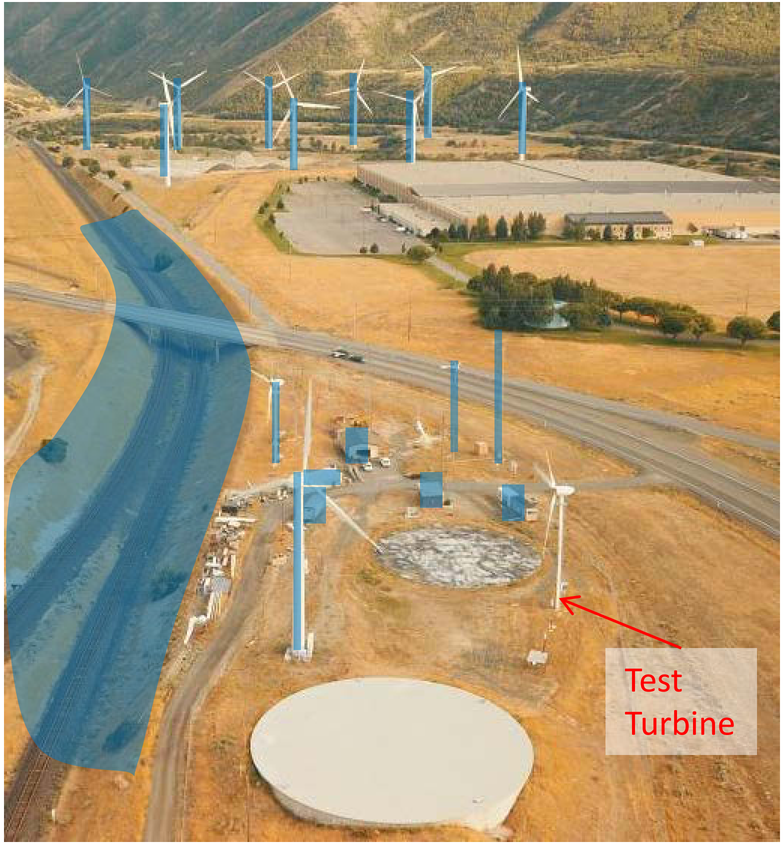
Power Performance (Test Site Evaluation)

- Some sites will pass all requirements easily

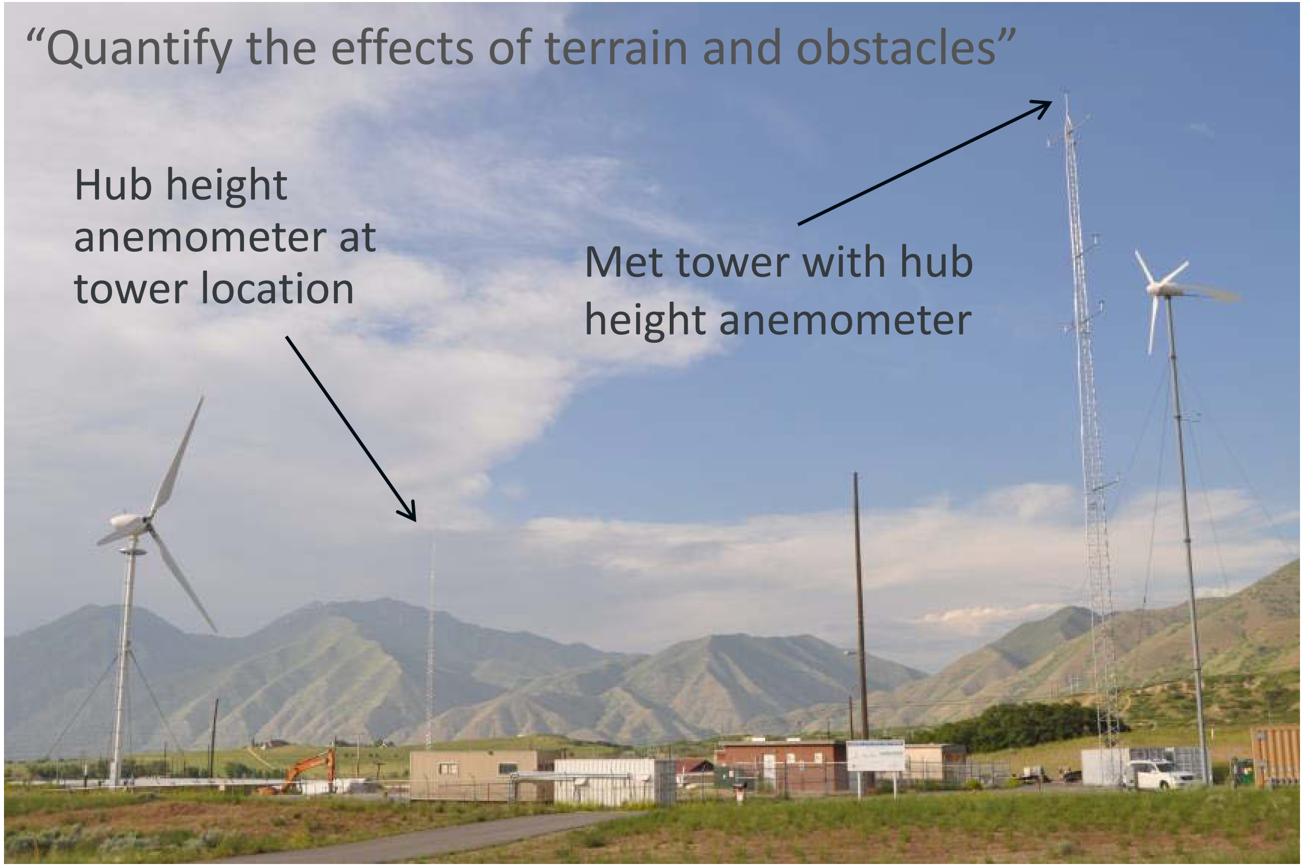
- Some will require a bit of analysis but will pass
- Others (like ours) will require a site calibration

Power Performance (Test Site Evaluation)

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



Power Performance (Site Calibration)

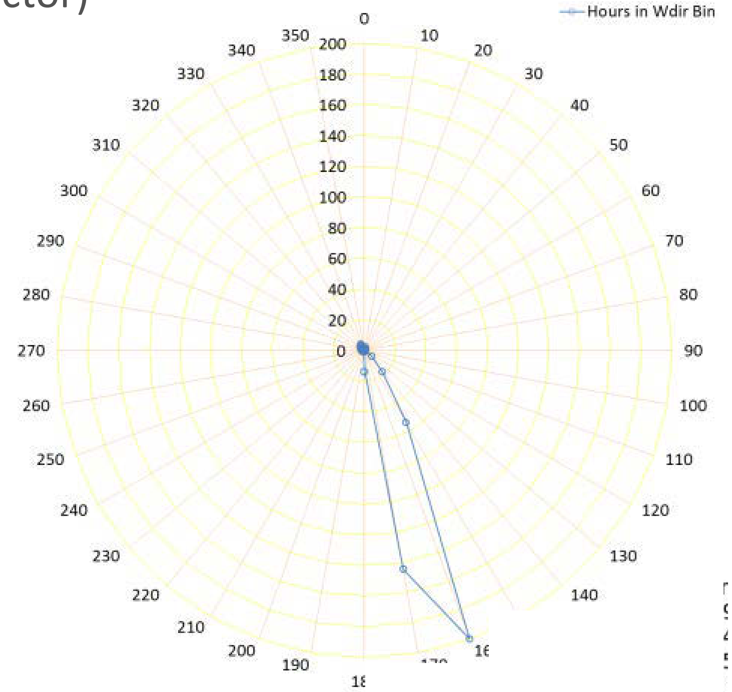


Power Performance (Site Calibration)

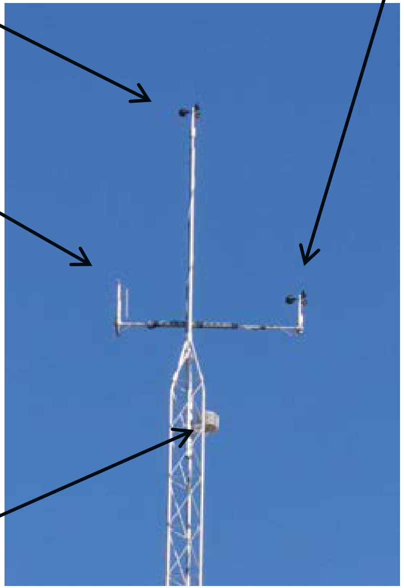
- Performed prior to installation or after removal of turbine
- Data requirements (for each 10° wind direction sector)
  - 24 hours (between 4 and 16 m/s)
  - At least 6 hours above 8 m/s
  - At least 6 hours below 8 m/s
  - Data must converge

- Not too difficult if unidirectional site (like ours)
  - In our last site calibration:
    - 4 days to calibrate 1 sector
    - 6 days to calibrate 2 sectors
    - 11 days to calibrate 3 sectors

Much harder and longer for a site like this

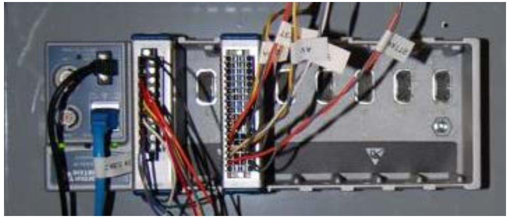


Power Performance (Met Tower Instrumentation)



Power Performance (Down Tower Instrumentation)

Power, VA, volts transducer (external CTs)

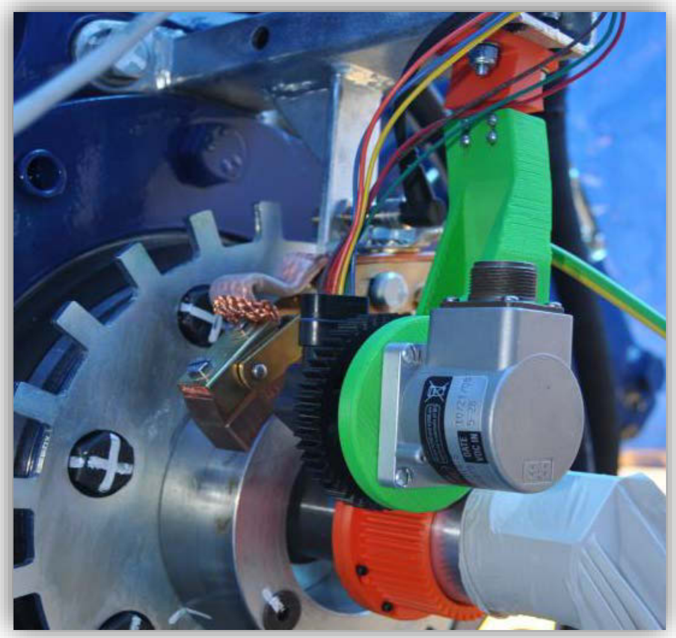


Data acquisition (chassis and modules)

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

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: $v\,[m/s] = 0.04632 \cdot f\,[Hz] + 0.22843$

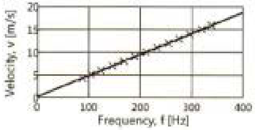
Standard uncertainty, slope: 0.00160 **Standard uncertainty, offset:** 0.07316

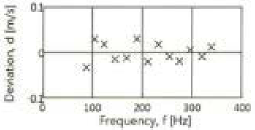
Covariance: -0.0000012 $(m/s)^2/Hz$ **Coefficient of correlation:** $\rho = 0.999986$

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





ANAB ACCREDITED CALIBRATION LABORATORY

AC-1746

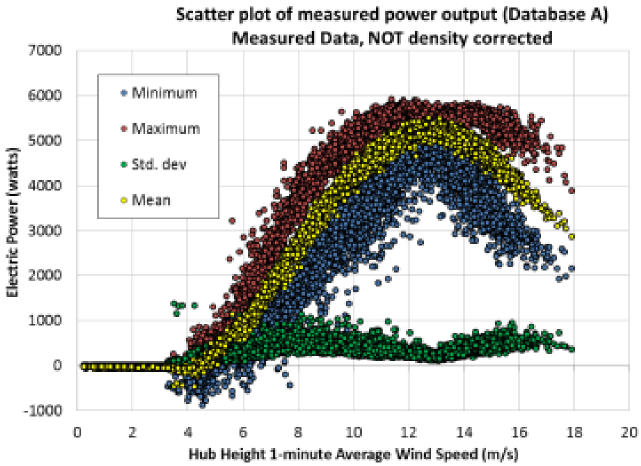
ilac-MRA

Page 1 of 2

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

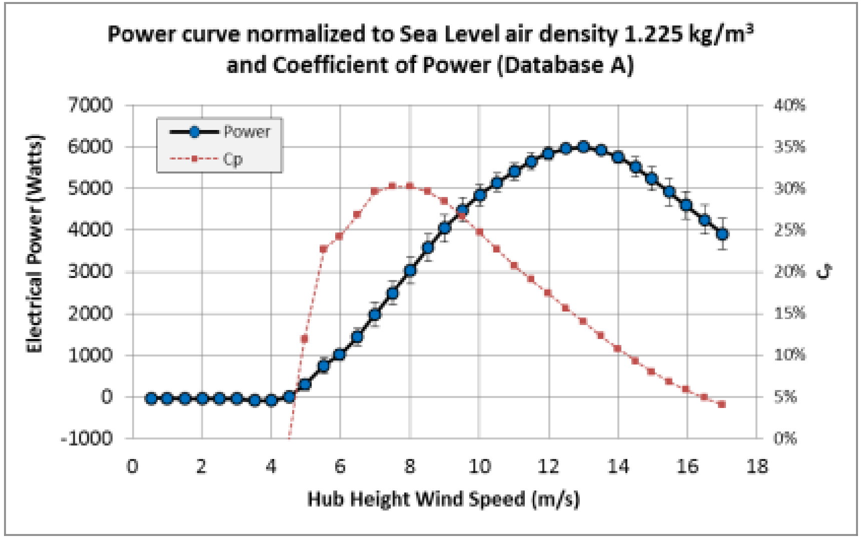
Rated = 5 kW
85%*5 = 4.25 kW
4.25 kW @ ~10 m/s
1.5*10 m/s = **15 m/s**



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 that 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 power performance 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 seconds 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 it’s 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 and 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 and 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 (vertical axis, 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
  - Slip rings or telemetry for rotating measurements
  - Anti-aliasing modules required
  - Others (such as rotor azimuth, yaw angle, etc.)

Slip ring 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
  - Startup, etc.
- Normal operating load conditions
  - Number of data sets 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

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

Time and costs could vary significantly

Type Certification

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

Dean Davis
ddavis@windwardengineering.com

Session 5: Breakout on Potential Topical Areas

Breakouts

Select one breakout session discussion based on your interest

- Pre-Prototype Development, Robert Preus (NREL)
- Component Innovation & System Optimization, Ian Baring-Gould (NREL)
- Prototype Testing, Certification Testing & Type Certification, Scott Dana (NREL) and Jeroen van Dam (NREL)
- Manufacturing Process Innovation, Dave Snowberg (NREL)

Session 6: Procurement/Contracting

Kyndall Jackson

Subcontract Administrator

Proposal Submittal

- Request for proposal (RFP)
  - Posted on beta.sam.gov (formerly FBO.gov)
  - Instructions for submittal (contact info, requirements, due date, etc.) will be identified in RFP
  - Timeline (past rounds): RFP released in late February
    - Submission due by late March
    - Awardees selected in summer with goal to complete negotiations by fall
- Technical questions
  - Date for submitting questions will be specified in RFP
  - Amendment(s) will be posted to beta.sam.gov
- Proposal review
  - Best value selection (qualitative merit and price)
  - Evaluated on merit criteria (weighted)
  - Evaluation process
    - Initial evaluation for acceptability (clarifications)
    - Proposal evaluation against statement of work 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/restricted data
- Provide acceptance of the statement of work, NREL's terms and conditions (general and intellectual property) or request exceptions
- Forms
  - Price cost proposal
  - Organizational conflict of interest (OCI) forms (representation <u>OR</u> disclosure)
  - New vendors (W-9, automated clearing house banking information)
  - Representations and certifications
    - SAM.gov registration (system for award management)

Payment Schedule & Invoicing

- Sample payment schedule (firm fixed price w/ participation)

Deliverable Description	NREL Portion	Subcontractor Portion	Total
6.1	$*.**		
6.2			
6.3			
6.4			
6.5			
6.6			
Total Price			

- Invoicing (post-award)
  - Based on pre-negotiated values in payment schedule
  - Invoices will be paid upon submission of approved deliverables
  - Submitted to accounts payable (instructions are detailed in subcontract award)

Questions?

Kyndall.Jackson@nrel.gov

Session 7: Design Evaluation

Robert Preus

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 are 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 (<200 m^2) Loads Approaches

- Three options
- Simplified loads equations (for <200 m^2 IEC 61400-2 or <30 kW SWT-1)
  - Horizontal axis wind turbine with two or more blades and fixed hub
  - Needs some measured data input
- Aeroelastic modeling (all sizes)
  - Needs to be validated
  - Few models for vertical axis wind turbines
- Full-scale load measurement (all sizes)
  - Most difficult, expensive, and time-consuming

Notes on Simplified Loads Approach

- Valid only for: horizontal axis, 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

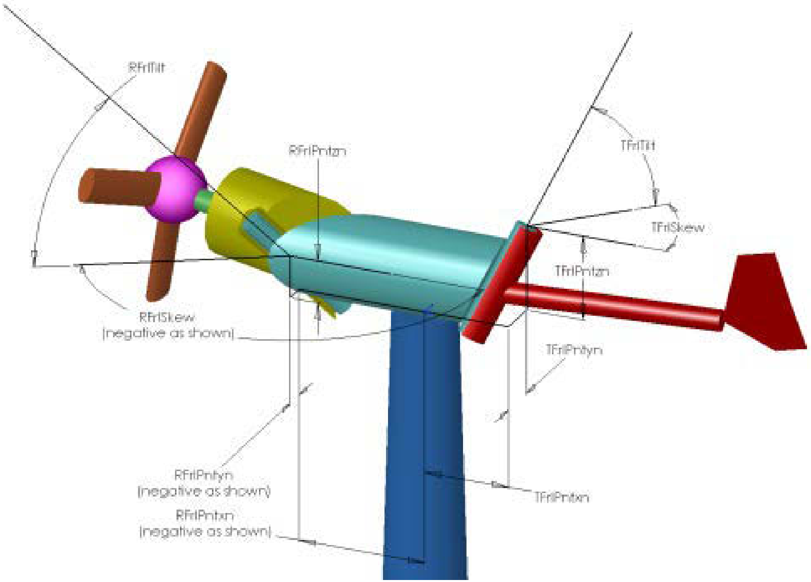
- Design shaft torque: Q_{design} -From test
  - Drivetrain efficiency, η (use IEC or test)

- 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 fatigue loads and damage equivalent loads
- Comprehensive view of loads and dynamic behavior of turbine—easy to postprocess and automate
- Remove unnecessary conservatism



Source: Github.com/OpenFast

Alternative Approach: Full-Scale Load Measurements

- Load measurements should be taken under conditions as close as possible to the aeroelastic model design load cases (DLCs) [61400-2]; this is difficult at most sites
- Load measurements <u>for large turbines almost exclusively used for model validation;</u> 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, set points, 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

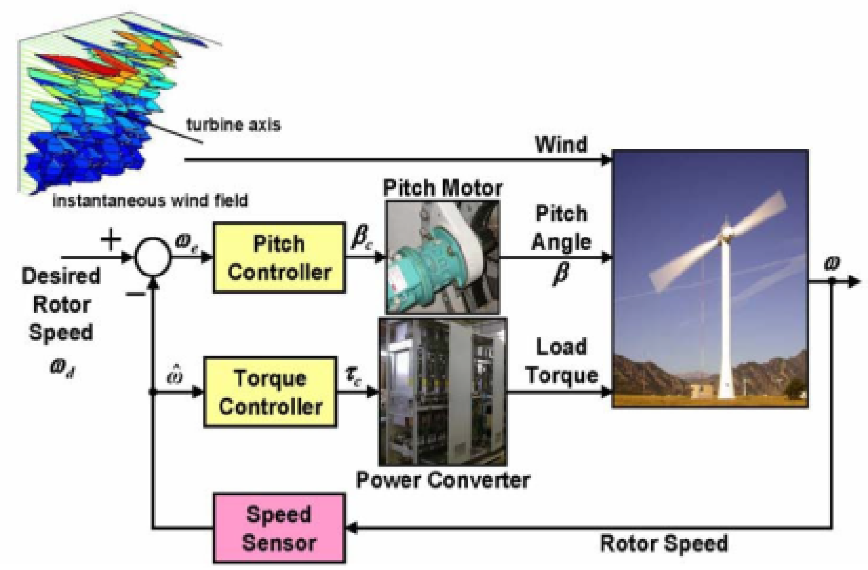
    13.2 Interconnection electrical requirements
13. Manufacturing process (quality assurance/quality control)
14. Safety and functioning and emergency procedures
15. Conclusions (summary tables, safety margins, utilization)

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: St. Louis, Missouri.

What To Include

- Design load cases
  - Take the time to understand all 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

- DLCs
  - 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

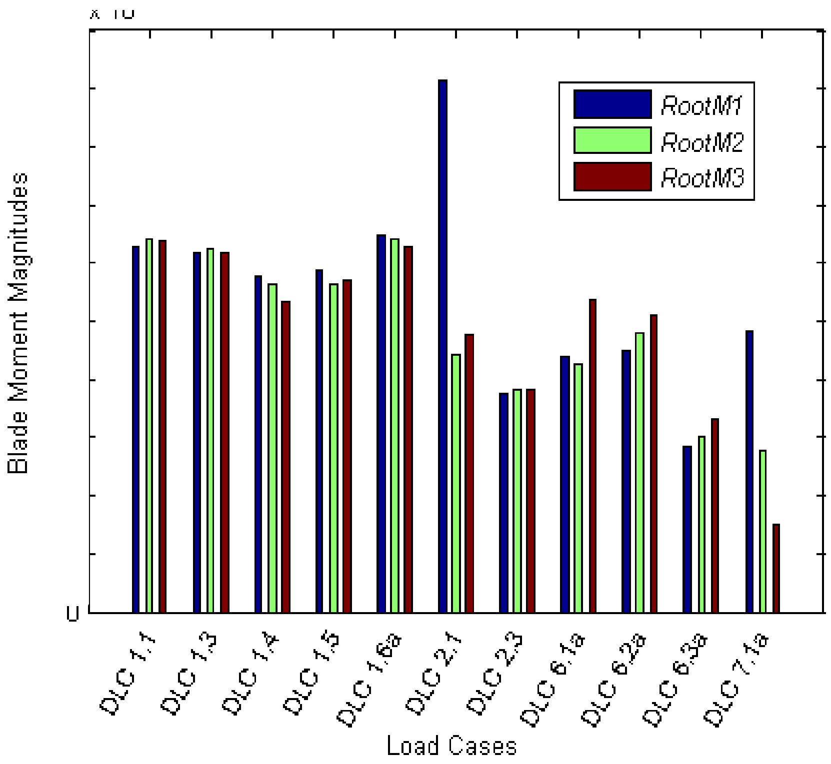
e.g., IEC 61400-2

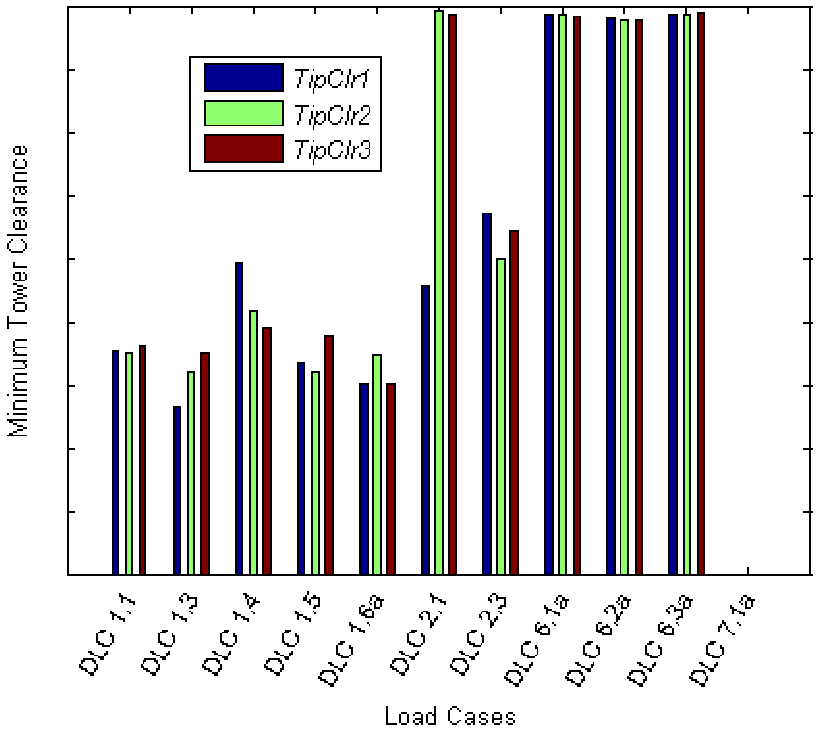
What To Include

TOWER BASE ULS LOADS	TwrBsFxt	TwrBsFyt	TwrBsF	TwrBsFzt	TwrBsMxt	TwrBsMyt	TwrBsM	TwrBsMzt	Time	HorWindV	NacYawErr	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

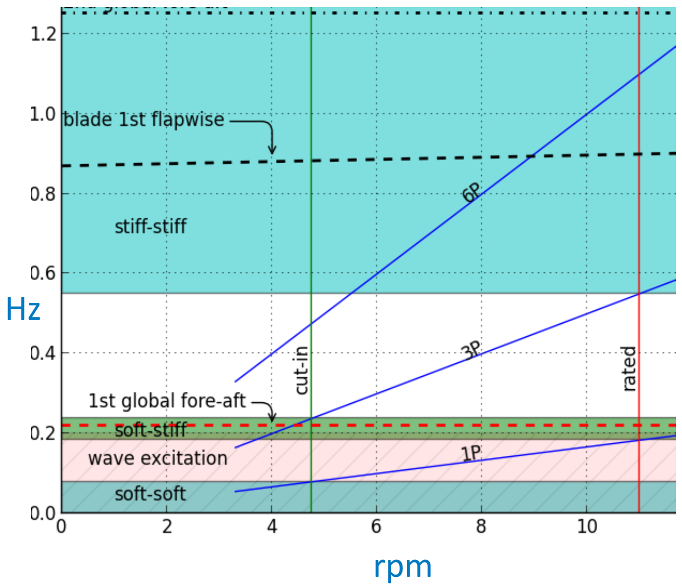
What To Include





Component Verification: What To Include

- 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



"It shall be verified that limit states are not exceeded"

➔(Finite element analysis or equivalent analysis to assess utilization)

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)
- **<u>Static load test required for blade</u>** (SWT-1 only >1 kW)

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 judgment

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

Session 8: NREL's Technical Support Opportunities

Scott Dana

Flatirons Campus Field Sites

- Numerous small and midsize field test sites
  - Adaptable sites
    - Meteorological towers
    - Data sheds
    - Customizable to meet test needs

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

Photo by Scott Dana, NREL

Photo by Dennis Schroeder, NREL 36245

Structural 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, NREL

Photo by Mike Jenks, NREL

Dynamometer 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

Grid Testing Facilities

- Microgrid testing
- Distributed wind focused controllable grid interface 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

Discussion of Opportunities for Technical Support

NREL Technical Support

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

QUESTIONS?

Scott Dana

Thank You

www.nrel.gov

NREL/PR-5000-78802

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