NATIONAL RENEWABLE ENERGY LABORATORY

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1977 - 2017

Competitiveness Improvement Project Informational Workshop

December 6, 2017

NREL/PR-5000-70890

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

Karin Sinclair

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

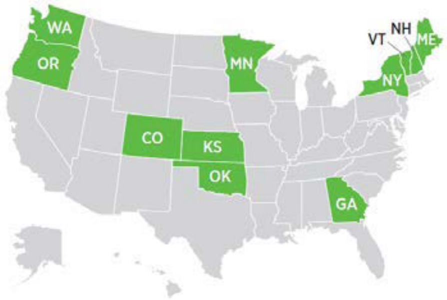
To expand U. S. leadership in the domestic and international distributed wind turbine sector by:

- 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).

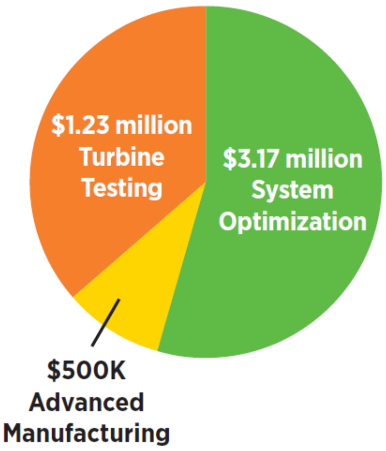
History of the CIP

The history of the CIP includes the following:

- CIP initiated in 2012
- Five annual solicitations have been released (Fiscal Year 2013–2017)
- Twenty-two awards have been issued to 12 manufacturers in 11 states
- Not all projects ultimately completed as originally scoped due to range of issues (five to date)
- Total original U.S. Department of Energy (DOE)/National Renewable Energy Laboratory (NREL) funding was $5.6 million; due to rescoping DOE/NREL investment reduced to $4.9 million
- NREL manages the projects through the subcontract period of performance, providing oversight and technical assistance as needed.



CIP manufacturer distribution



CIP budget breakdown, after decoping

CIP Technical Approach

The CIP technical approach includes the following:

- Competitively selected with cost-share requirements
- Short, normally 18–21 month contracts, to make sure that the projects are manageable and can be completed in a timely manner
- 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, through five cycles of solicitations, included:

- Component improvements
- Overall system optimization
- Manufacturing process upgrades
- Prototype testing
- Certification testing (<200-m^2 RSA)
- Type certification (>200-m^2 and $<1{,}000$-m^2 RSA).

Note: not all topics are offered each cycle. Topics are selected based on available funds and specific areas of concern determined through industry discussions as well as other factors.

Examples of Past Projects Within Scope

Previous CIP projects within scope included:

- Improvement of components, such as inverters, blade designs, and towers to reduce costs
- Overall system optimization
- Manufacturing process upgrades, such as injection molding blades to reduce costs
- Turbines < 1,000-m^2 RSA, such as:
    - 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).

Examples of Past Projects Outside of Scope

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

- Preprototype development
- Lacking technical merit, such as:
  - Violation of Betz limit
  - Insufficient preliminary work to assess probability of success
  - Lack of details in proposal
- Only information is a website or marketing brochure
- Stand-alone component not partnered with turbine manufacturer
- Turbines > 1,000-m^2 RSA
- Not U.S. manufacturer if required in request for proposals (RFP)
- More than one topic area included in proposal (component improvements/prototype testing/certification testing)
- Does not match specific topic being solicited (certification testing/prototype testing)
- Incomplete proposal (see session 2 on merit criteria).

Addressing Changes in Project Scope

The CIP has been designed to allow for some changes in scope, but not ones that substantially change the focus of the work (i.e., shifting work between topic areas, such as shifting from a turbine certification to prototype testing)

Potential modifications considered can include:

- Addressing changes in scope
- Shifting between specific subtier vendors
- Project schedule to plan for staffing and other unexpected challenges.

Questions?

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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 this is shown through 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 testing to technical standards, there should be a 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 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).

Questions?

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Session 3: NREL's Technical Support Opportunities

Scott Dana

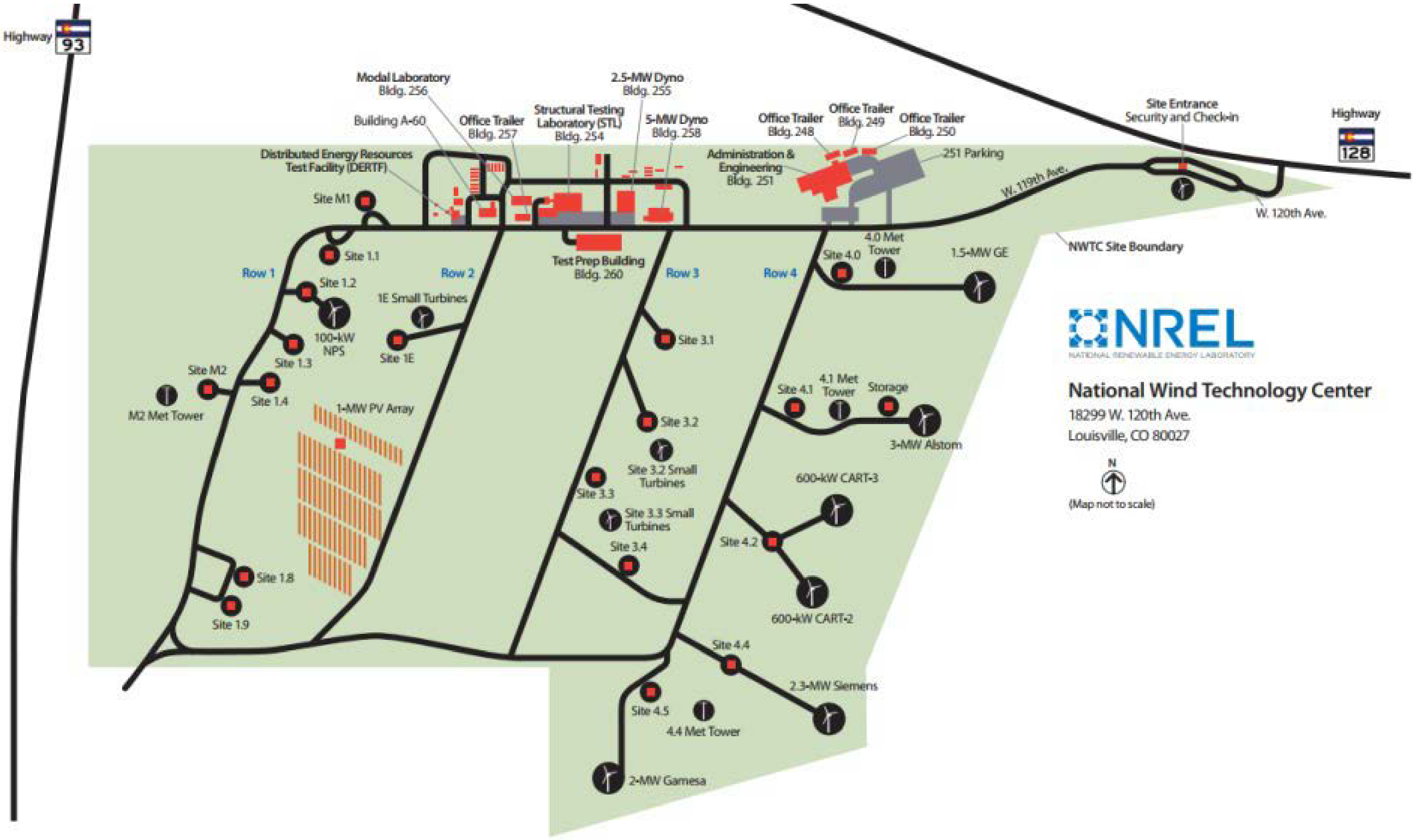
NWTC Facilities

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

Photo by Scott Dana, NREL

Photo by Dennis Schroeder, NREL 36245

NWTC Site 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

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?

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Session 4: Certification Body Requirements

Anant Jain

Contents

- Introduction
- Large Wind Turbine Compliance Requirements – International Electrotechnical Commission (IEC)
- Small Wind Turbine Compliance Requirements – IEC and American Wind Energy Association (AWEA)
- Summary

Introduction – Main Standards and Scopes – Large Wind Turbines

- IEC 61400-22: Conformity Testing and Certification

  This is an overarching standard for wind turbine certification process. This standard provides the main definitions of important terminology used in the wind turbine certification process. It further provides the conformity evaluation and surveillance requirements, and procedures for wind turbine certification. Design and test documentation requirements for certification are also included in this standard. Moreover, operational guidelines for organizations performing third-party assessment/testing such as certification bodies, inspection bodies, and testing laboratories are also provided. [Source: IEC 61400-22]

- IEC 61400-1: Design Requirements

  This standard provides the technical guidelines for mainly the design assessment of wind turbines. These requirements are essential to ensure that the structural, mechanical, electrical, and control systems of the turbine under review are capable of handling the external conditions the turbine would typically experience during its lifetime. This standard also provides guidance on transportation, assembly, installation, operation, maintenance, and personnel safety aspects of wind turbines. [Source: IEC 61400-1]

Figure 1. Large wind turbine (Source: www.wikipedia.com)

Introduction – Main Standards and Their Scope – Small Wind Turbines

- AWEA SWT-1: This standard is used for certifying small wind turbines intended to be installed in the United States. The standard provides technical guidelines related to quality and performance of small wind turbines. These guidelines were created to ensure that small wind turbines can sustain the loads the turbine is designed for, and also meet performance requirements such as power performance. This standard is harmonized with IEC standards. It refers to certain sections of IEC's small wind turbine design standard, i.e., IEC 61400-2, and some performance testing standards published by IEC. [Source: AWEA SWT-1]

- IEC 61400-2: This is an internationally recognized standard and is more elaborate regarding the technical requirements related to wind turbine quality, mechanical systems, structural components, and electrical systems, and also provides technical guidance for engineering assessments of quality and performance characteristics of a small wind turbine. This standard is applicable to wind turbines with a rotor diameter smaller than or equal to 200 m^2. Additional requirements related to turbine design validation through testing are also prescribed in this standard. [Source: IEC 61400-2]

Figure 2. Small wind turbine (Source: www.cleantechnica.com)

IEC: Wind Turbine Certification Options

Certification Options

Type Certification: *Wind turbine design (including testing and inspection) and manufacturing assessment (valid for 5 years max.)*

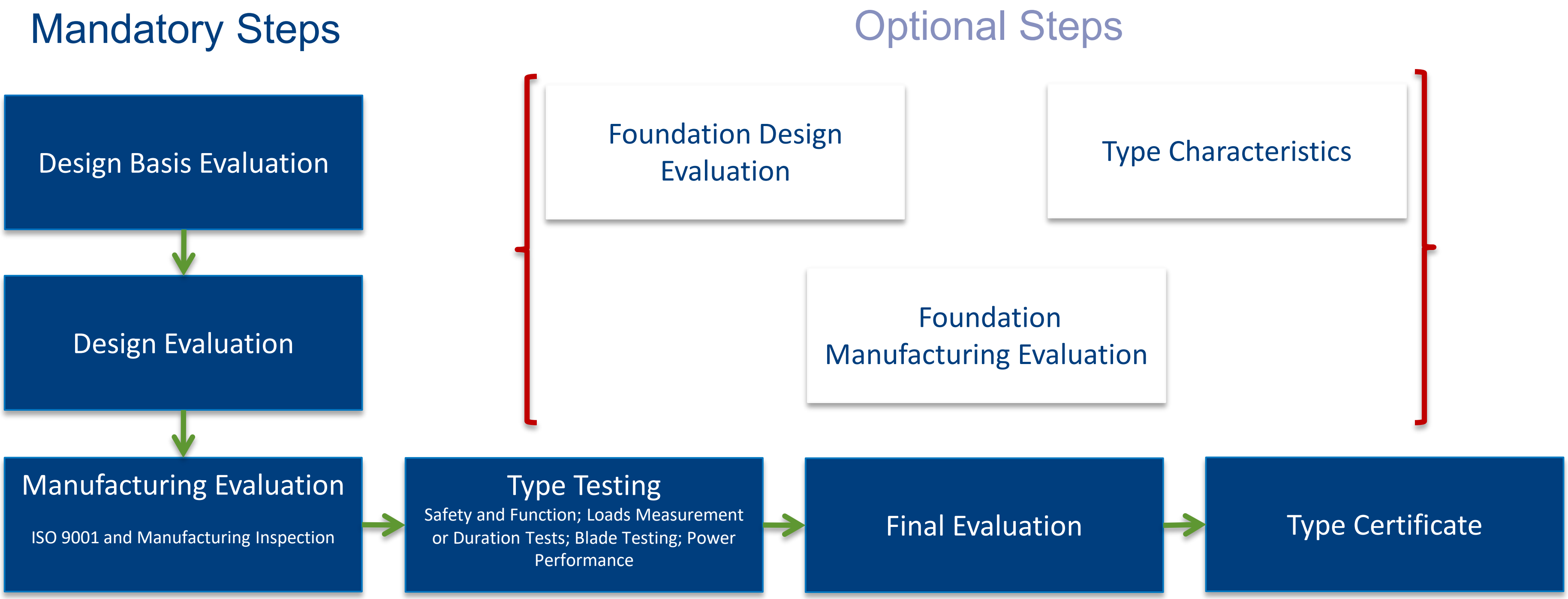
Project Certification: *Collective wind turbines assessment based on the site (validity period not specified).*

Prototype Certification: *Evaluation of a developing wind turbine design (valid for 3 years max.)*

Component Certification: *Evaluation of main electrical/mechanical/ structural components (valid for 5 years max.)*

[Source: IEC 61400-22]

Type Certification



Note: Component certification includes the same steps as type certification

[Source: IEC 61400-22]

Prototype Certification

Prototype certification is applicable to turbines that are in a limited production phase and need to be tested before the serial production model is released. This allows the original equipment manufacturer (OEM) to make corrections to the design based on the findings of limited design evaluation and testing.

Prototype design basis evaluation and design evaluation are both mandatory but with limited scope. Generally, control and protection system design verification, loads and load cases assessment, analysis of rotor blades and critical structural components, assessment of electrical components, and verification of personnel safety measures are deemed sufficient for prototype certification design basis and design evaluation.

Main requirements for prototype certification:

- Design basis and design evaluation (based on IEC 61400-1 or -2)
- Test plan evaluation (based on IEC 61400-12-1, -23, -11, etc.)
- Safety and function testing (based on IEC 61400-22).

Note: This certification is not mandatory to install a prototype.

[Source: IEC 61400-22]

Requirements in IEC 61400-1

- Terminology
- Turbine categorization
- Normal and extreme wind and environmental conditions
- Type of loads and guidance on calculations
- Load cases for the design
- Control and protection system functionalities (testing required)
- Hydraulic systems, such as pitch and/or yaw systems
- Drivetrain components (bearings, low-speed shaft, main gearbox, brakes, high-speed shaft, couplings, etc.)
- Electrical system and components (generator, motors, safety devices, cables, grounding, etc.)
- Lightning and surge protection
- Wind turbine assessment based on site conditions
- Wind turbine installation guidelines
- Wind turbine commissioning guidelines
- Operation and maintenance (O&M) guidelines.

[Source: IEC 61400-1]

Requirements in IEC 61400-2

- Terminology (addresses vertical-axis wind turbines)
- Normal and extreme wind and environmental conditions
- Loads measurement/calculations
  - Simplified load equations (static analysis)
  - Aeroelastic analysis
  - On-site loads measurements
- System/component stress/strain analysis
- Safety factors for loads, materials, etc.
- Static and dynamic characterization–strength and deflection assessment
- Turbine protection system–operational safety
- Electrical system compliance requirements
- Foundation/tower structure
- Wind turbine labels/markings
- Safety and performance testing
- Assembly/installation guidelines
- O&M guidelines
- Regular inspection requirements.

[Source: IEC 61400-2]

Modules Assessed by Certification Bodies (IEC 61400-22)

- Control and protection system (testing required)
- Loads and load cases (testing required)
  - System dynamics analysis
  - Modeling validation
  - Loading results and statistics
- Machine and structural components
  - Rotor blades (testing required)
  - Pitch system
  - Hub
  - Main or low-speed shaft
  - Gearbox (if applicable)
  - High-speed shaft
  - Frame
  - Yaw system
  - Tower (all applicable designs)
- Housings (nacelle, spinner, etc.)
- Electrical system (entire turbine)
- Component tests
- Foundation–*optional*

Modules subject to on-site witnessing and inspection

- Manufacturing
- Transportation (limited witnessing)
- Installation
- Maintenance
- Personnel safety (applicable to all of the above).

[Source: IEC 61400-22]

Requirements Given in AWEA SWT-1

- Includes additional guidance on areas that are different from the IEC standards
- Applicable to wind turbines with a rotor swept area of 200 m^2 or less
- Guidance on towers and foundations are not included, but tower loads, interactions with other components, and overall dynamics shall be defined
- Power performance testing–includes additional requirements
- Acoustic testing–includes additional requirements
- Safety and functions testing–includes additional requirements
- Duration testing–includes additional requirements
- Design assessment and other testing requirements
  - Sections 5.2, 7.7, 7.8, and 7.9 of IEC 61400-2 ed.3 are required to be used to show compliance with this standard
  - Rotor (blades, hub, and bolted connections), drivetrain (main shaft), yaw system, nacelle to tower connection, and main frame shall be analyzed
  - Static blade test per Section 13.5.2 of IEC 61400-2 ed. 3.

[Source: AWEA SWT-1]

Summary

- IEC system of standards for large wind turbines–IEC 61400-22 and IEC 61400-1
- IEC system of standards for small wind turbines–IEC 61400-22 and IEC 61400-2
- AWEA certification for small wind turbines–AWEA SWT-1, IEC 61400-2, IEC 61400-12-1, and IEC 61400-11
- Unconventional wind turbines can also be certified
- Design documentation shall be provided to the certification body depending on the certification system (IEC or AWEA)
- Involving the certification body at the design development stage is important
- When using consultants for analysis and documentation, ensure that detailed documentation (including calculations) is available for certification body for verification purposes.

References

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Intertek acknowledges IEC and AWEA standard committees for the development of standards discussed in this presentation

Session 5: Standards Applicable to Distributed Wind Generators

Robert Preus/Anant Jain

Standards That Apply to Distributed Wind

- IEC 61400-2 or -1 or AWEA SWT1
  - -2 or SWT1 for swept area < 200 m^2
  - -1 for swept area > 200 m^2
  - 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
- 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)
- UL6142 is a safety standard for a wind generator 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 that use
  - 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

National Electric Code

- 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 allow exceptions).

Why a Special Section for Wind?

- Some resistance from industry to making small wind subject to the code (they already were)
- With no guidance specific for wind Authority Having Jurisdiction(s), were using :
  - General section rules
  - PV special rules
  - Sometimes did not work and left installers uncertain what would be required.

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.

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.

Questions?

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Large and Small Wind Turbines Electrical System Compliance–UL 6141 and UL 6142

Contents

- Introduction
- Wind Turbine Electrical System Compliance Process, Standards, and Background
- Large Wind Turbine Compliance Requirements–UL 6141
- Small Wind Turbine Compliance Requirements–UL 6142
- Summary

Introduction–Electrical System Compliance

- Wind turbine electrical system compliance is a requirement of Article 694 of NFPA 70, which is stated in Section 694.7(B).
- 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). The turbines included in the scope can operate with or without a grid connection.
- 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.

Figure 1. Small wind turbine (Source: www.cleantechnica.com)

Figure 2. Large wind turbine (Source: www.wikipedia.com)

Sources: UL 6141, UL 6142, and NFPA 70

Electrical Compliance Evaluation Process

- The four major subassemblies (hub, nacelle, tower sections, and down tower) are assessed and certified under a normal product certification process involving full assessment in accordance with the applicable standard(s), as well as surveillance at the appropriate point of manufacture.
- Installation instructions and the overall integration process is also evaluated. A full assessment of a completed wind turbine installation, including documentation, is undertaken on a per-model basis, which results in the certification of a batch of wind turbines.

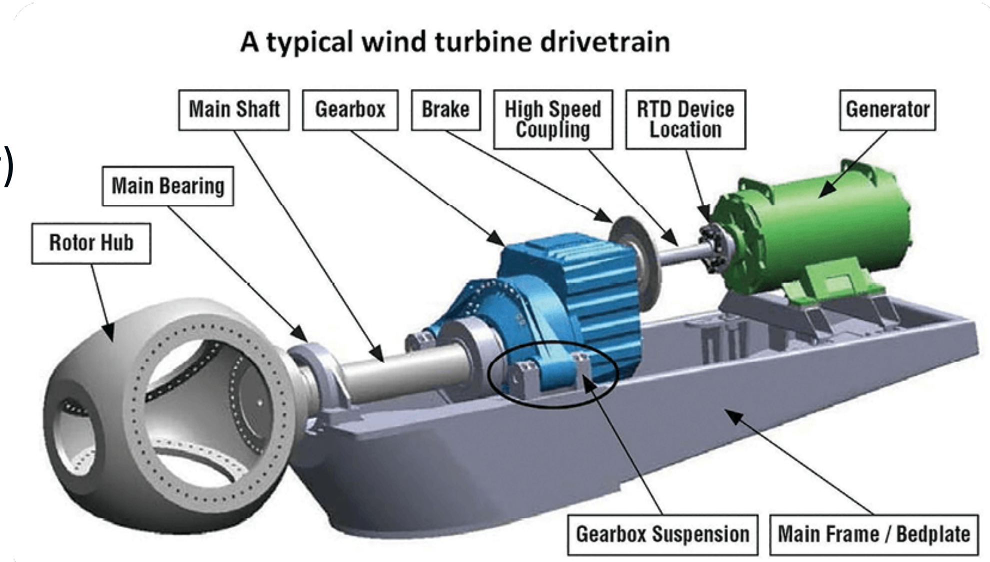
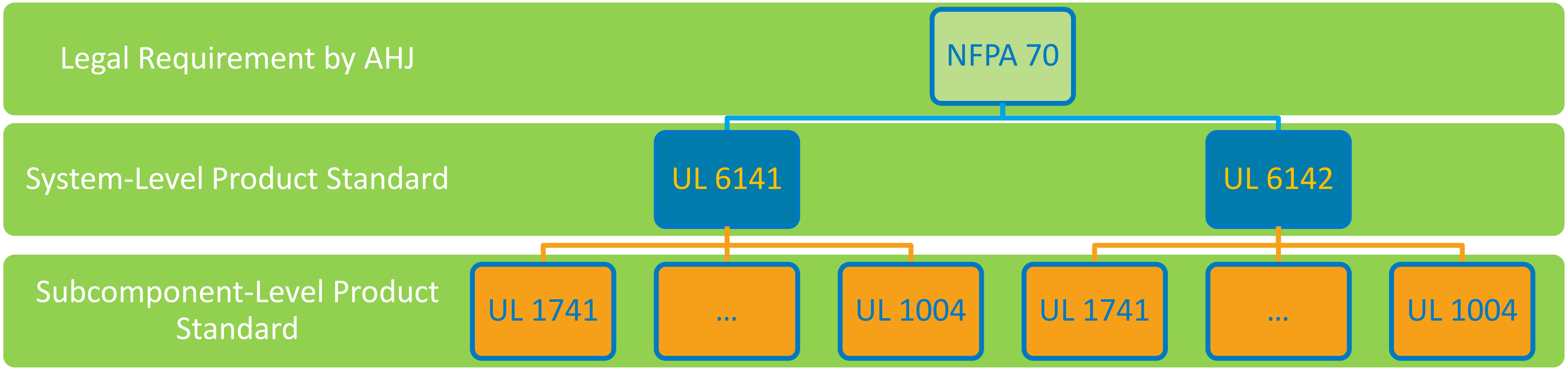


Figure 3. (Top) Wind turbine drivetrain (Source: www.windpowerengineering.com); (Bottom left) Wind turbine tower top (Source: www.energyclassroom.com) (Bottom right) Wind turbine tower base (Source: www.minzhutek.com)

Field Labeling Evaluation

- Field labeling is a process to evaluate the electrical system of those wind turbines that are already installed or are in the final stages of manufacturing
- This is a reduced-scope alternative to a full-scope listing or certification, only if permitted by the AHJ
- Field evaluation inspectors generally evaluate the major wind turbine components at the manufacturing facility and the installed turbine at the wind site
- The main aim of field labeling inspection/evaluation is to prove <u>essential compliance</u> with the same standards that are used for full-scope listing or certification.
- On-site testing, such as continuity tests, and insulation tests, are generally required for proving essential compliance
- The field evaluation inspector applies a label on the wind turbine (with a unique tracking number) upon successful completion of the evaluation.

Electrical System Standards Hierarchy/Background



- Electrical safety concerns in North America in wind turbines began in Canada in the 1980s with the publication of CAN/CSA-F416-87 Wind Energy Conversion Systems.
- F416 was withdrawn in 2014 as it did not reflect the current technology and was replaced by CSA C22.2 No 272 – Wind Turbine Electrical Systems.
- CSA C22.2 No. 272 aligns with European and U.S. electrical safety rules while adhering to the Canadian Electrical Code (C22.1).
- In the United States, UL published an Outline of Investigation for Wind Turbine Generating Systems (Subject 6140) in 2009.
- Standards Technical Panels were formed for large and small wind turbines. The small wind standard ANSI/UL 6142 was completed in 2012. Larger wind turbines are now covered by ANSI/UL 6141 Wind Turbines Permitting Entry of Personnel, which was published in 2016.
- The National Electrical Code (NFPA No. 70) added a small wind turbine section in the 2011 edition, requiring all wind electric systems to be listed or otherwise approved in 2014, and added field labeling as a path to approval in 2017.

What Are Certification Bodies Assessing?

- **Electrical**: The primary hazards are electric shock, fire, and malfunction.
  - *Mitigation - Proper selection and rating of components, implementation of environmental-type ratings for enclosures that are appropriate for the application, adequate working space, and lockout/tagout.*
- **Mechanical**: Rotating parts and risk of hydraulic component-related hazards.
  - *Mitigation - Guarding, signage, and the proper selection of pressure vessels and pressure-relief devices.*
- **Thermal**: Thermal hazards can result from contact with heating devices, brake discs, overloading of rotating electrical machinery, and lack of ventilation.
  - *Mitigation - Guarding, over-temperature sensors and protective devices, signage, and proper selection and application of components.*
- **Fire**: Sources of ignition include high-speed braking apparatus, improperly rated protective devices, malfunction of components, such as slip rings and cable splices, and mechanical failures.
  - *Mitigation - Isolation of sources of ignition from potentially combustible materials and the use of fire-resistant materials. The use of listed or approved components will also mitigate the risk of fire.*
- **Failure of Control Systems**: These failures can result in minor malfunction to catastrophic failure.
  - *Mitigation - Use of proven fail-safe strategies, including functional safety, need to be considered.*

UL 6141 – Main Requirements

- Generally applicable to wind turbine with nameplate rating of more than 100 kilowatts (kW)
- Converter/Inverter: UL 1741
- Lightning protection systems: IEC 61400-24
- Slip rings: UL 508, or IEC 60204-1
- Electrical system assembly of a gearbox: UL 508
- Hoists and winches: UL 1340
- Design documentation and functionality of Estop and control and protection system:
  - IEC 61400-1 Section 8
  - NFPA 79 Section 9.2.5.4.

Source: UL 6141

UL 6141 – Main Requirements

- Cable trays: Article 392 of NFPA 70
- Wireways: Article 376 or Article 378 of NFPA 70
- Hydraulic electromechanical components: no standard specified for compliance; generally, the components are evaluated to ensure no possibility of fire and shock
- Alternators, generators, and motors: UL 1004-1, UL 1004-4, and UL 1004-9 (new standard)
- Motor drives: UL 508C
- Energy storage units: UL 1989 or UL 810A
- Disconnect devices: require lockable disconnecting means
- Heating and cooling equipment: UL 1995
- Transformers: UL 1561 for dry type, IEC 60076 for oil-filled.

Source: UL 6141

UL 6142 – Small Wind Turbine Compliance Requirements

- Applicable to wind turbines rated below or at 100 kW
- Does not include requirements for heating and cooling equipment, wind turbine elevators, medium-voltage disconnect, and motor drives; the structure of the standard is similar to UL 6141
- Control and protection system: IEC 61400-2
- A few testing requirements are different in UL 6142, example stated below:
  - Testing requires various simulated faults that lead the wind turbine system to a fail-safe condition These tests mainly include:
    - Malfunction of power circuit, such as conductor failure in circuitry
    - Tests for power loss in the control system
    - Voltage fluctuation scenarios (above and below rated)
  - End of manufacturing line tests are also required for basic functionality verification.

Source: UL 6142

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.

Summary

- NEC (NFPA 70) is the main code/standard adopted by AHJ
- NEC 2011, 2014, and 2017 are the three widely adopted versions of NEC by AHJ
- UL 6141 and UL 6142 are the product standards used for listing or labeling
- Involving the certification body at the design development stage is important
- A comprehensive and customized certification roadmap shall be outlined at the beginning of certification process
- Field labeling can be used as an alternative approach to fulfill the requirements set by the AHJ
- Applicability of field labeling shall be discussed with the AHJ.

Sources: UL 6141, UL 6142, and NFPA 70

References

UL 6141. *Standard for wind turbines permitting entry of personnel* (Edition 1). (2016). United States: Underwriters Laboratories.

UL 6142. *Small wind turbine systems* (Edition 1). (2012). United States: Underwriters Laboratories.

NFPA 70. *National Electrical Code* (2014). United States: National Fire Protection Association.

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Questions?

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intertek

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Intertek acknowledges NEC and ANSI/UL standard committees for the development of standards discussed in this presentation

Session 6: Certification Testing Requirements

Jeroen Van Dam

First Step

- This part focused on turbine system testing (not electrical or component)
- What is being certified to what standard(s), which determines:
  - What tests will be needed (e.g., mechanical loads test, duration test)
  - Test requirements (e.g., turbine class impacting duration test)

In cases where several variations of a turbine system are available, a full design evaluation shall be performed on a representative configuration. Other variations need only be evaluated or tested in the ways in which they are different from the representative configuration. The decision as to whether to perform a design evaluation of the variants, or type testing, or limited testing, or no testing, or some combination will depend on the details of the deviation(s) from the representative configuration. In making this decision it is essential to have a good understanding of the design and knowledge of the weaknesses of the design.

- Keep target markets in mind when picking standards to certify to and thus test to.

Tests

- Tests:
  - Design data testing
  - Power performance
  - Safety and function
  - Acoustic noise
  - Duration
  - Mechanical loads
- Results in public reports can be found at:
  - http://www.intertek.com/wind/small/RTC/
  - https://smallwindcertification.org/certified-small-turbines/
  - http://windwardengineering.com/our-work/projects/nrel-rtc/
  - https://www.nrel.gov/research/publications.html (keywords: wind independent testing)
- Keep in mind that standards get revised and reports may use older versions of standards
-

Design Data Testing

- Objective:
  - Obtain realistic inputs to design loads (simple design equations or simulation model)
- Keep it simple and quick; objective is to confirm it a 10-kW vs. 13-kW turbine, instead of 10- vs 10.1-kW turbine; or max rpm being ~300 rpm and not 400 rpm
- Initial thought was that a prototype turbine could be used for this test
- Measurement of power, rpm, and wind speed
- From this P_{design}, n_{design}, Q_{design}, and n_{max} are derived (V_{design} is defined as $1.4V_{ave}$)
- Maximum yaw rate is <u>not</u> based on a measured value for free yaw systems.

Power Performance

Objective:

- Assess power performance so comparable reliable predictions can be made for reference power and expected annual energy production (assuming the wind resources are known).

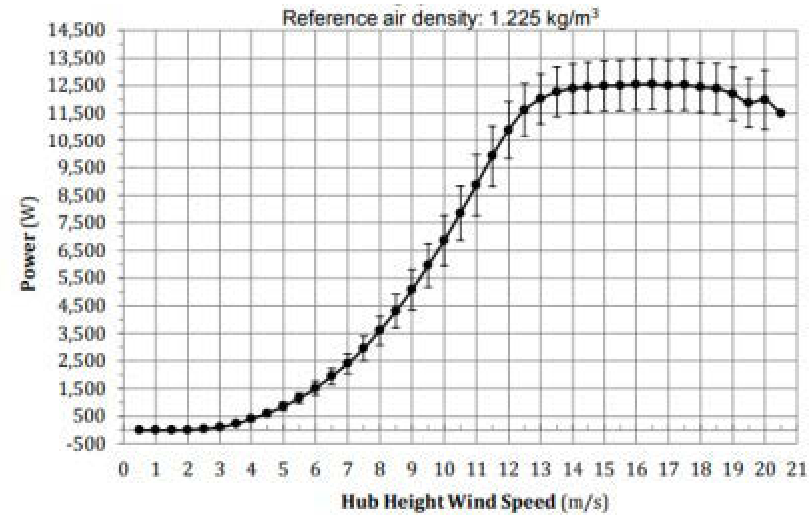
Met Tower		Turbine
Wind speed		Power (currents and voltages)
Wind direction		Turbine status (available, online)
Temperature		
Air pressure		
Precipitation		

Photo by Joe Smith, NREL

Power Performance

Keep in mind (will come back under test site topic):

- Needs accurate wind speed, representative of wind speed at turbine; thus unobstructed inflow, very specific instrument mounting and perhaps site calibration that needs to be done first (planning)
- For AWEA SWT-1: need 5 meters per second (m/s) beyond 95% peak power (up to cut out).



(source: smallwindcertification.org)

Corrected to a sea level air density of 1.225 kg/m^3

Hub Height Annual Average Wind Speed (m/s)	AEP Measured (kWh)	Standard Uncertainty in AEP (kWh)	Standard Uncertainty in AEP (%)	AEP Extrapolated (kWh)
4	7,135	503	7.05	7,135
5	13,842	884	6.39	13,842
6	22,300	1,281	5.74	22,300
7	31,342	1,604	5.12	31,342
8	39,755	1,824	4.59	39,755
9	46,652	1,944	4.17	46,652
10	51,626	1,982	3.84	51,626
11	54,685	1,961	3.59	54,685

(source: smallwindcertification.org)

Applicant	Turbine	SWCC Certification Type[1]	AWEA Rated Annual Energy[2]	AWEA Rated Sound Level[3]	AWEA Rated Power[4] @ 11 m/s	Peak Power[5]	C
Bergey Windpower Co.	Excel 10	AWEA 9.1-2009	13,800 kWh	42.9 dB(A)	8.9 kW	12.6 kW @ 16.5 m/s	
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	AWEA 9.1-2009	3,930 kWh	55.6 dB(A)	2.5 kW	3.0 kW @ 19.5 m/s	
Kingspan Environmental	KW6	AWEA 9.1-2009	8,950 kWh	43.1 dB(A)	5.2 kW	6.1 kW @ 17.0 m/s	
Lely Aircon B.V.	LA10	AWEA 9.1-2009	17,500 kWh	41.1 dB(A)	9.6 kW	11.3 kW @ 21.5 m/s	
Lely Aircon B.V.	LA30	AWEA 9.1-2009	48,800 kWh	49.8 dB(A)	27.2 kW	34.2 kW @ 16 m/s	

(source: smallwindcertification.org)

Safety and Function

Objective:

To verify that the turbine under test displays the behavior predicted in the design and that provisions relating to personnel safety are properly implemented

- Results link back to design evaluation
- Most instrumentation likely already in place for other tests, like wind speed, power, rpm, and status
- Test includes things like:
    - Rpm control
    - Power control
    - Yaw control
    - Start ups and shut downs (including e-stops, high wind cut out)
    - Grid loss
    - Testing of critical sensor failure (vibration, over temperature, rpm, anemometer).

Safety and Function (continued)

- Personnel safety items through observation:
  - Climbing facilities, tie-off points
  - Access ways and passages,
  - Lock-out/tag-out
  - O&M procedures
- Testing relatively quickly
- Testing is very turbine-specific
- Could overlap with loads measurements for transients or faulted conditions
- If turbine fails certain tests, it might not be able to obtain certification; therefore, doing some of the testing early in test campaign is recommended.

Photo by Jeroen van Dam, NREL

Acoustic Sound

Objective:

Obtain reliable acoustic properties to allow for turbine comparison and proper setback.

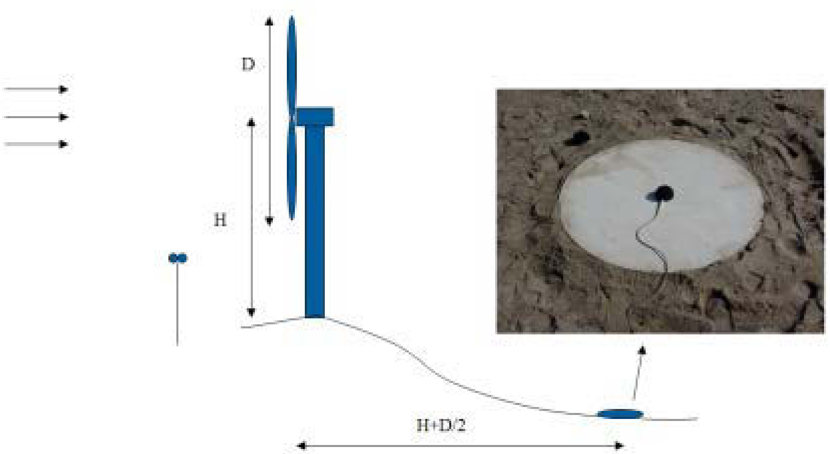
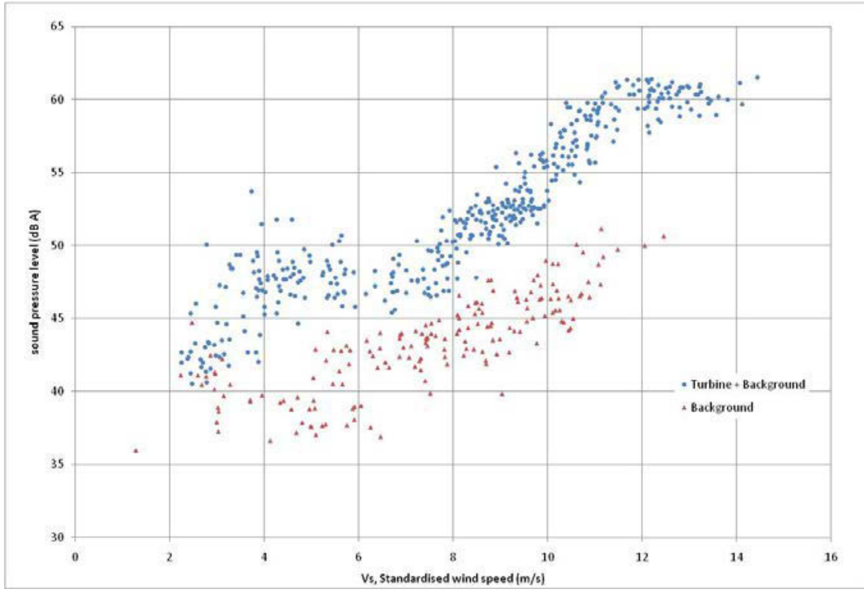


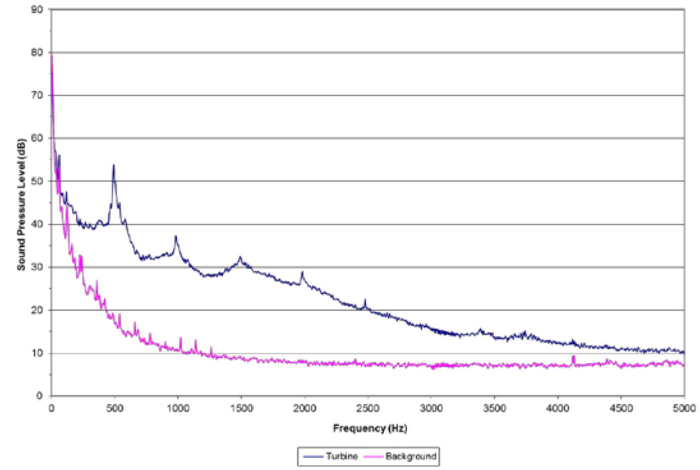
Photo by Jeroen van Dam, ECN



Source: NREL /TP-5000-49179

Acoustic Results

- AWEA: no tonality analysis needs to be done but presence of tones needs to be reported
- Apparent sound power level at the source
- AWEA-rated sound level at 9.8 m/s at 60 meters (m)



(source: NREL AOC1550-C-A-99182-1000

Wind Speed at 10m Height	Apparent Sound Power Level	Combined Uncertainty
m/s	dB(A)	dB(A)
6	94.8	1.0
7	96.6	2.0
8	98.3	1.7
9	99.9	2.0
10	102.9	1.0

- Keep in mind: need quiet site!

Applicant	Turbine	SWCC Certification Type[1]	AWEA Rated Annual Energy[2]	AWEA Rated Sound Level[3]	AWEA Rated Power[4] @ 11 m/s	Peak Power[5]	C
Bergey Windpower Co.	Excel 10	AWEA 9.1-2009	13,800 kWh	42.9 dB(A)	8.9 kW	12.6 kW @ 16.5 m/s	
Eveready Diversified Products (Pty) Ltd.	Kestrel e400nb	AWEA 9.1-2009	3,930 kWh	55.6 dB(A)	2.5 kW	3.0 kW @ 19.5 m/s	
Kingspan Environmental	KW6	AWEA 9.1-2009	8,950 kWh	43.1 dB(A)	5.2 kW	6.1 kW @ 17.0 m/s	
Lely Aircon B.V.	LA10	AWEA 9.1-2009	17,500 kWh	41.1 dB(A)	9.6 kW	11.3 kW @ 21.5 m/s	
Lely Aircon B.V.	LA30	AWEA 9.1-2009	48,800 kWh	49.8 dB(A)	27.2 kW	34.2 kW @ 16 m/s	

(source: smallwindcertification.org)

Duration Testing

- The purpose of the duration test is to investigate:
  - Structural integrity and material degradation (corrosion, cracks, deformations)
  - Quality of environmental protection of the wind turbine
  - The dynamic behavior of the turbine
- Initially came on the scene to replace the blade fatigue test
- Signals (at a minimum): wind speed, power, turbine status
- Observations for dynamic behavior and wear.

Duration Testing

- Passing criteria:
  - Reliable operation during the test period
  - At least 6 months of operation
  - At least 2,500 hours of power production in winds of any velocity
  - At least 250 hours of power production in winds of 1,2 *V*ave and above (Class I)
  - At least 25 hours of power production in winds of 1,8 *V*ave and above, and Class I: 18m/s; Class II: 15.3 m/s
  - At least 10 minutes in winds of 2,2 *V*ave and above but not less than 15,0 m/s, during which the turbine will be in normal operation (Class I: 22 m/s; Class II: 18.7 m/s)
- For AWEA SWT-1 also need 25 hours >15 m/s regardless of turbine class
- Reliable operation:
  - Operational time fraction of at least 90%
  - No major failure of the turbine or components in the turbine system
  - No significant wear, corrosion, or damage to turbine components
  - No significant degradation of produced power at comparable wind speeds
- Wind from any direction
- Duration test will take longest, major failure will reset test: thus trade-off between starting quickly and shaking out infant mortality.

Mechanical Loads

- Only needed if validated load model does not exist (e.g., VAWT, ducted), or rotor swept area > 200 m^2.
- Objective: obtain loads to validate simulation model or obtain design loads directly
- Current standard focuses on validating simulation model
- Standard specifies:
  - Minimum signals
  - Minimum load cases
  - Minimum amount of data.

Load Quantities

Load quantities	Level of importance
Blade root flatwise bending moment (M_{bf})	1 blade mandatory additional blade recommended
Blade root edgewise bending moment (M_{be})	1 blade mandatory additional blade recommended
Rotor tilt moment (M_{tilt})	Mandatory
Rotor yaw moment (M_{yaw})	Mandatory
Rotor torque (M_x)	Mandatory
Tower base normal (M_{tn})	Mandatory
Tower base lateral moment (M_{tl})	Mandatory

Photo by Jerry Hur, NREL

Photo by Mark Meadors, NREL

External Conditions and Turbine Operation Quantities

Quantity	Level of importance
Wind speed at hub height	Mandatory
Vertical wind shear (below hub height)	Mandatory
Vertical wind shear (above hub height)	Recommended
Vertical wind veer	Recommended
Upflow angle / flow inclination angle near hub height	Recommended
Turbulence intensity (horizontal) at hub height	Mandatory
Wind direction at hub height	Mandatory
Air density	Mandatory
Turbulence intensity (3D) at hub height	Recommended
Icing potential	Recommended
Atmospheric stability	Recommended

Quantity	Level of importance
Electrical power	Mandatory
Rotor speed or generator speed	Mandatory
Yaw misalignment	Mandatory
Rotor azimuth angle	Mandatory
Pitch position of all instrumented blades turbine controller output	Mandatory for all instrumented blades Recommended for all blades
Pitch speed	Mandatory
Brake status	Mandatory
Brake moment (if not possible, brake pressure) [a]	Recommended
Wind turbine status	Mandatory
NOTE Pitch speed can be derived from pitch position	
[a] If the mechanical braking device is part of the primary braking system (e.g. at stall controlled turbines), the measurement of the brake moment is mandatory.	

Photo by Jerry Hur, NREL

Photo by Simon Thao, NREL

Measurement Load Cases

MLC number	MLC	DLC number (IEC 61400-1)	Remarks
1.1	Power production	1.2	In this mode of operation, the wind turbine is running and connected to the grid
1.2	Parked	6.4	When the wind turbine is parked, the rotor may be either at a standstill or idling

MLC number	MLC	DLC	Target conditions
2.1	Start-up	3.1	v_{in} and $> v_r + 2$ m/s
2.2	Normal shutdown	4.1	v_{in}, v_r and $> v_r + 2$ m/s
2.3	Emergency shutdown (by pushbutton)	5.1	P_r
2.4	Grid failure	2.4	P_r

Normal start-up and shutdown events				
Event	Wind speed [a,b]	(v_{in} to $v_r - 2$)	($v_r - 2$ to $v_r + 2$)	$> v_r + 2$
Start-up	Minimum required repetitions	3	–	3
Normal shut- down	Minimum required repetitions	3	3	3

[a] The wind speed is the wind speed when the transient event gets triggered.

[b] For the wind speed ranges the upper limit is inclusive (e.g. $v_{in} < v \leq v_r - 2$).

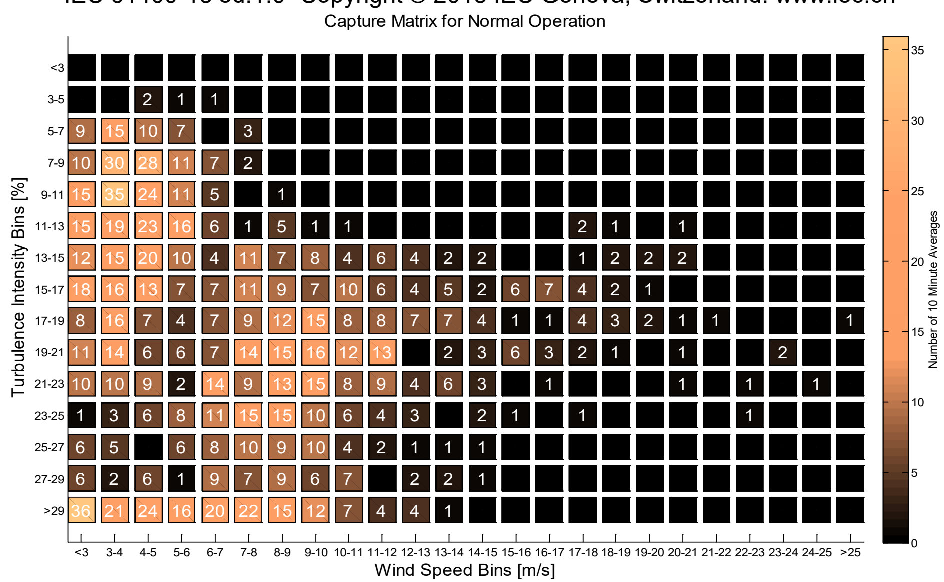
Other transient events		
Event	Target conditions	Minimum required repetitions
Emergency shutdown	P_r	3
Grid failure	P_r	3

Nonstall Controlled Turbines

	Normal power production Wind speed bin size: 1 m/s Turbulence bin size: 2 %									
Time series length	10 min									
WS range[b]	$\lceil v_{in} \rceil$ to $\lceil v_r \rceil - 2$				$\lceil v_r \rceil - 2$ to $\lceil v_r \rceil + 2$			$\lceil v_r \rceil + 2$ to $\lceil v_r \rceil + 4$		
Wind[b] (m/s)⇒ TI[b] %)⇓	$\lceil v_{in} \rceil$ -	...	4-5	...	...		...		...	...
>29										
27-29										
...										
...										
7-9										
5-7										
<5										
Minimum data requirement	20 time series for each 1 m/s bin OR one TI bin with 6 time series for each 1 m/s bin [a]				20 time series for each 1 m/s bin			10 time series for each 1 m/s bin		

[a] Time series that count towards both criteria above shall have TI > 5 %.

[b] For all wind speed and turbulence intensity bins in this table the upper limit of the bin is inclusive (e.g. 4-5 includes $4 < v \leq 5$ m/s).



Source: NREL TP-5000-67562

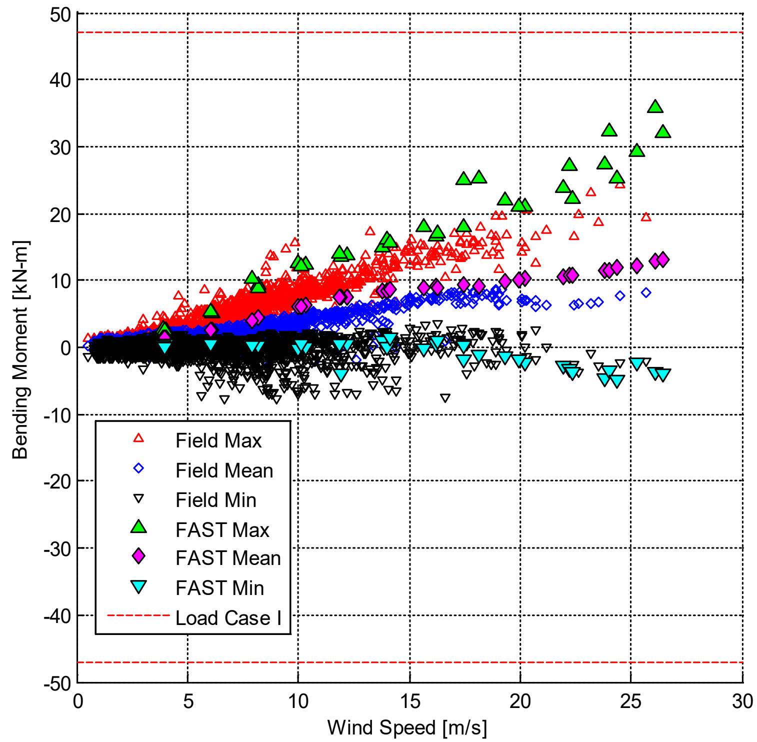
Stall-Controlled Turbines

	Normal power production Wind speed bin size: 1 m/s Turbulence bin size: 2 %												
Time series length	10 min												
WS range[b] m/s	v_{in} to 12					12 to 16				16 to 20			20 to v_{out}
Wind[b] (m/s) ⇒ TI[b] (%) ⇓	$\lceil v_{in} \rceil$	…	4-5	…	11-12	12-13	13-14	14-15	15-16	16-17	…	19-20	20-$\lceil v_{out} \rceil$[c]
>29													8 time series (In total, not for each 1 m/s bin)
27-29													
…													
5-7													
<5…													
Minimum data requirement	20 time series for each 1 m/s bin[a] OR one TI bin with 6 time series for each 1 m/s bin[a]					20 time series for each 1 m/s bin OR one TI bin with 6 time series for each 1 m/s bin				8 time series for each 1 m/s bin			

[a] Time series that count towards both criteria above shall have TI > 5 %.

[b] For all wind speed and turbulence intensity bins in this table the upper limit of the bin is inclusive (e.g. 4-5 includes $4 < v \leq 5$ m/s).

[c] If v_{out} is less than or equal to 20 m/s, only measurements up to v_{out} are required.



Source: NREL TP-5000-67562

New: Specific Guidance for VAWT in Annex

- Coordinate systems
- Required load quantities.

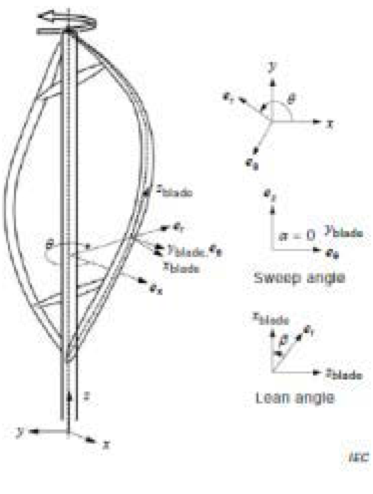


Figure J.1 – Darrieus style VAWT

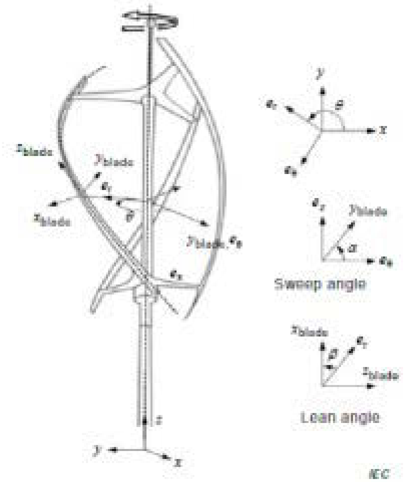


Figure J.2 – Helical Darrieus style VAWT

Load quantities
Blade connecting point tangential bending moment (M_{bct}) on one blade
Blade connecting point vertical bending moment (M_{bcv}) on one blade
Blade midspan tangential bending moment (M_{bmt}) on one blade
Blade midspan vertical bending moment (M_{bmv}) on one blade
Connecting strut tangential bending moment (M_{st}) on one strut
Connecting strut vertical bending moment (M_{sv}) on one strut
Connecting strut axial force (F_{sa}) on one strut
Rotor torque (M_z)
Tower base normal moment (M_{tn})
Tower torque (T_z)

Measuring Design Loads

- Measurement load cases (MLCs) in current IEC 61400-13 are insufficient
- Need to match the design load case (DLCs) of the design standard (-1 or -2)
- Would recommend looking at MLCs from TS 61400-13 (2001)
- TS 61400-13 as guidance on extrapolation of fatigue loads for turbulence intensity.

MLC is TS 61400-13 (2001)

MLC Number	Measurement Load Case	DLC number (IEC 61400-1)	Wind Condition at DLC	Remarks
1.1	Power production	1.2	Vin < Vhub < Vout*	In this mode of operation, the wind turbine is running and connected to the grid
1.2	Power production plus occurrence of fault	2.3	Vin < Vhub < Vout*	Any fault in the control or protection system, which does not cause an immediate shutdown of the turbine
1.3	Parked, idling	6.2	Vin < Vhub < 0.75 Ve1*	When the wind turbine is parked, the rotor may either be stopped or idling
* Has to be divided further into wind speed bins and turbulence bins.				

MLC	Measurement Load Case	DLC	Target Wind Speed
2.1	Startup	3.1	Vin and > Vr + 2 m/s
2.2.	Normal shutdown	4.1	Vin, Vr and > Vr + 2 m/s
2.3	Emergency shutdown	5.1	Vin and > Vr + 2 m/s
2.4	Grid failure	1.5	Vr and > Vr + 2 m/s
2.5	Overspeed activation of the protection system	5.1	> Vr + 2 m/s
Ideally, the measurements should be taken at Vout. As this is impractical, the measurements are taken at wind speeds higher than Vr + 2 m/s.			

TS 61400-13 Capture Matrix; Power Production

Normal power production Wind speed bin size: 1 m/s Turbulence bin size: 2 %														
Time series length	10 min										At least 2 min			
Wind (m/s) ⇒ I (%) ⇓	v_{in} -	...	4,5 5,5	...	...	v_r	...		...	...	v_m	...	...	v_{out}
<3														
3-5														
5-7														
7-9														
...														
...														
27-29														
>29														
Minimum number of turbulence bins with at least three time series	4	4	4	4	4	4	4	4	–	–	–	–	–	–
Minimum recommended number of time series for empirical load determination	30	30	30	30	30	30	30	8	8	8	3	3	3	1
Minimum recommended measurement hours for model validation	v_{in} to $v_r - 2$ 3 h				$v_r - 2$ to $v_r + 2$ 3 h			$v_r + 2$ to $\frac{(v_r+2)+v_{out}}{2}$ 3 h			$\frac{(v_r+2)+v_{out}}{2}$ to v_{out} 1 h			
NOTE The recommended number of time series at each wind speed bin is given in the last but one row. The actual number of measurements can be updated in the white cells.														

Load Measurements–SWT-Specific Issues

- Small spaces and instrumentation can alter behavior (mass, inertia) thus: small equipment
- Instrumentation exposed to elements (e.g., tower loads, blade loads)
- Free yaw (adds second rotating frame to get data from)
- Cost of SWT loads test similar to large turbine >$100,000.

Key Takeaways

- Link test planning and site wind resources (seasonal variability and available resources at test site[s])
- Do not postpone safety and function test to last moment
- Changes made along the way as experience is gained with system can impact validity of completed tests
- Look at changes (variants) and determine what needs to be redone: different any time (text from IEC 61400-2)
- Tests can be done on different turbines to speed things up but similarity between turbines will need to be assessed (no low-noise version and one high-performance version)
- Typical timelines:
  - Power performance: 3-6 months
  - Acoustic: weeks
  - Safety and function: weeks-months
  - Mechanical loads: months to a year
  - Duration testing: 6-12 months.

QUESTIONS?

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Session 7: Test Site Requirements

Robert Preus/Scott Dana

Existing Test Sites

- Windward Engineering, Spanish Fork, Utah
- Intertek, Cortland, New York
- Underwriters Laboratories, Canyon, Texas
- Appalachian State University, Beech Mountain, North Carolina
- Renew Test, Pampa, Texas
- National Wind Technology Center, Superior, Colorado.

Test Sites

Windward Engineering,
Spanish Fork, Utah

Photo by Joe Smith, NREL 19541

Intertek,

Cortland, New York

Photo from Intertek Group, NREL 28800

Test Sites

Appalachian State University,

Beech Mountain, North Carolina

Photo by Micah Shristi, Appalachian State University, NREL 15306

UL test site

Canyon, Texas

Photo from West Texas A&M University, NREL 49512

Testing at a Specific Site

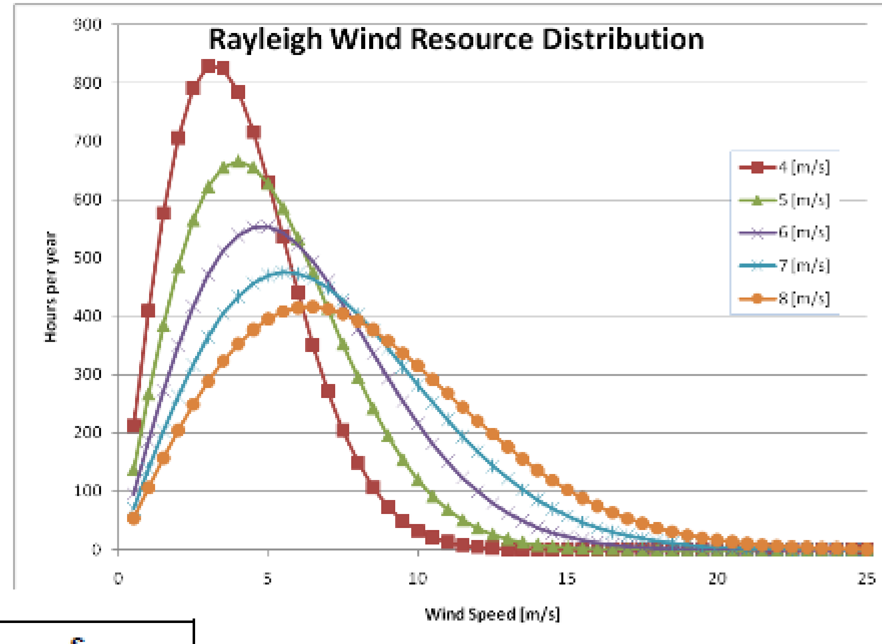
Site Selection

Things to consider:

- Size
- Location
- Terrain
- Wind resources (turbulence)
- Legal
- Construction
- Data collection
- Acoustic testing.

Test Site Wind Resources

- Match the turbine <u>and</u> test to the site
  - Save time
  - Save $$.



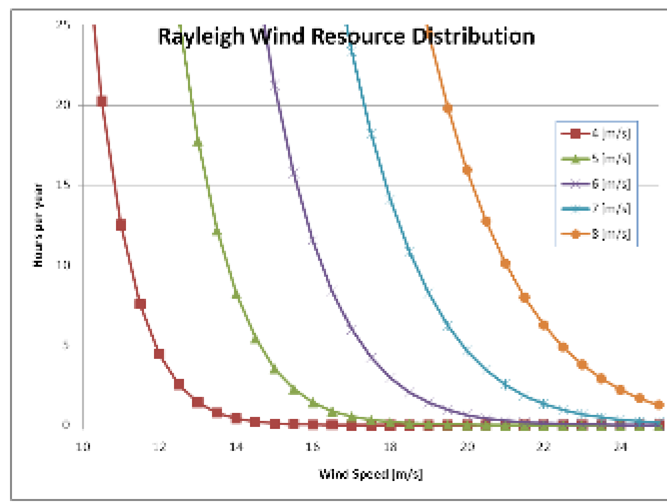
SWT class		I	II	III	IV	S
V_{ref}	(m/s)	50	42,5	37,5	30	Values to be specified by the designer
V_{ave}	(m/s)	10	8,5	7,5	6	
I_{15} (Note 2)	(-)	0,18	0,18	0,18	0,18	
a	(-)	2	2	2	2	

NOTE

1) the values apply at hub height, and;

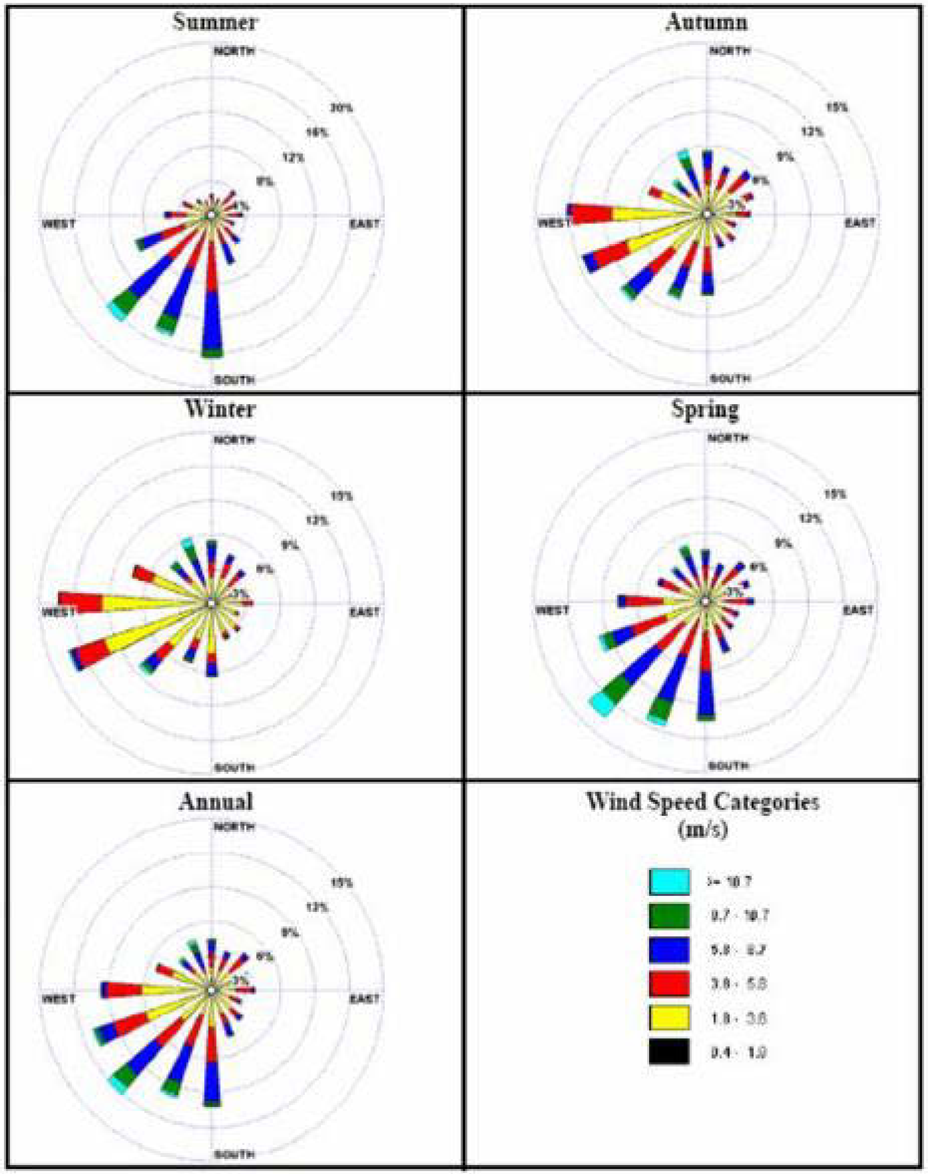
2) I_{15} is the dimensionless characteristic value of the turbulence intensity at 15 m/s, where 0,18 is the minimum value that shall be used, and noting that Annex M discusses observations regarding turbulence intensity;

3) a is the dimensionless slope parameter to be used in Equation (7).



Wind Resources (continued)

- Seasonal wind rose
- Direction and speed can vary by month
- Plan accordingly.



https://www.fhwa.dot.gov/environMent/air_quality/air_toxics/research_and_analysis/near_road_study/protocol/protocol11.cfm

Terrain

- Generally clear of obstructions; especially upwind
- Space for meteorological tower 2.5 D_{rotor} upwind
- Mostly Flat: < 5% slope out to 10 D_{rotor}
- Avoid a site calibration if possible
  - Time-consuming and potentially costly.

Terrain (continued)

- IEC61400-12-1 sectors and requirements

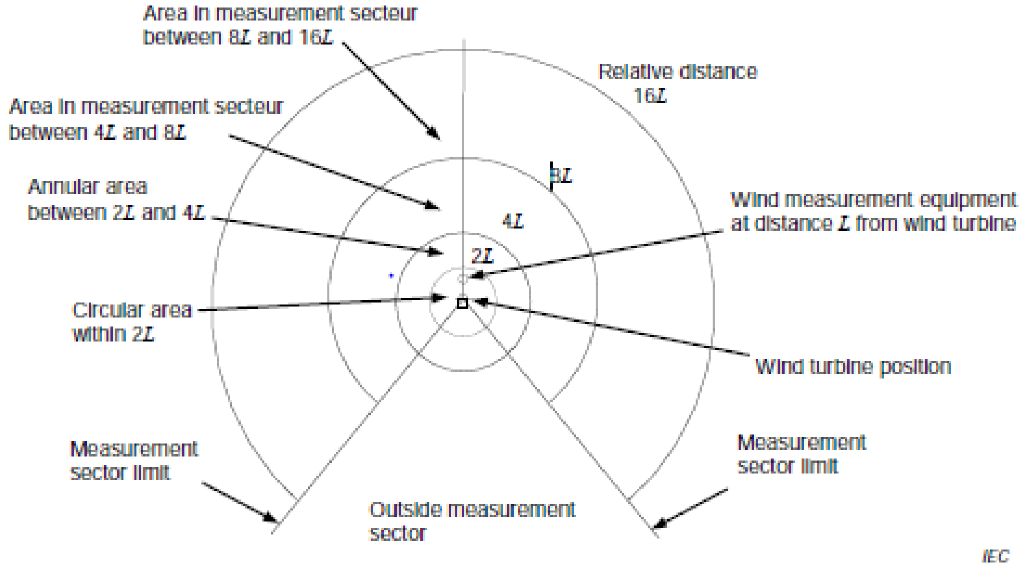


Figure B.1 – Illustration of area to be assessed, top view

Table B.1 – Test site requirements: topographical variations

Distance	Sector[a]	Maximum slope %	Maximum terrain variation from plane
<2L	360°	<3[b]	<1/3 (H – 0,5 D)
≥2L and < 4L	Measurement sector	<5[b]	<2/3 (H – 0,5 D)
≥2L and <4L	Outside measurement sector	<10[c]	Not applicable
≥4L and <8L	Measurement sector	<10[b]	< (H – 0,5 D)
≥8L and <16L	Measurement sector	<10[c]	Not applicable

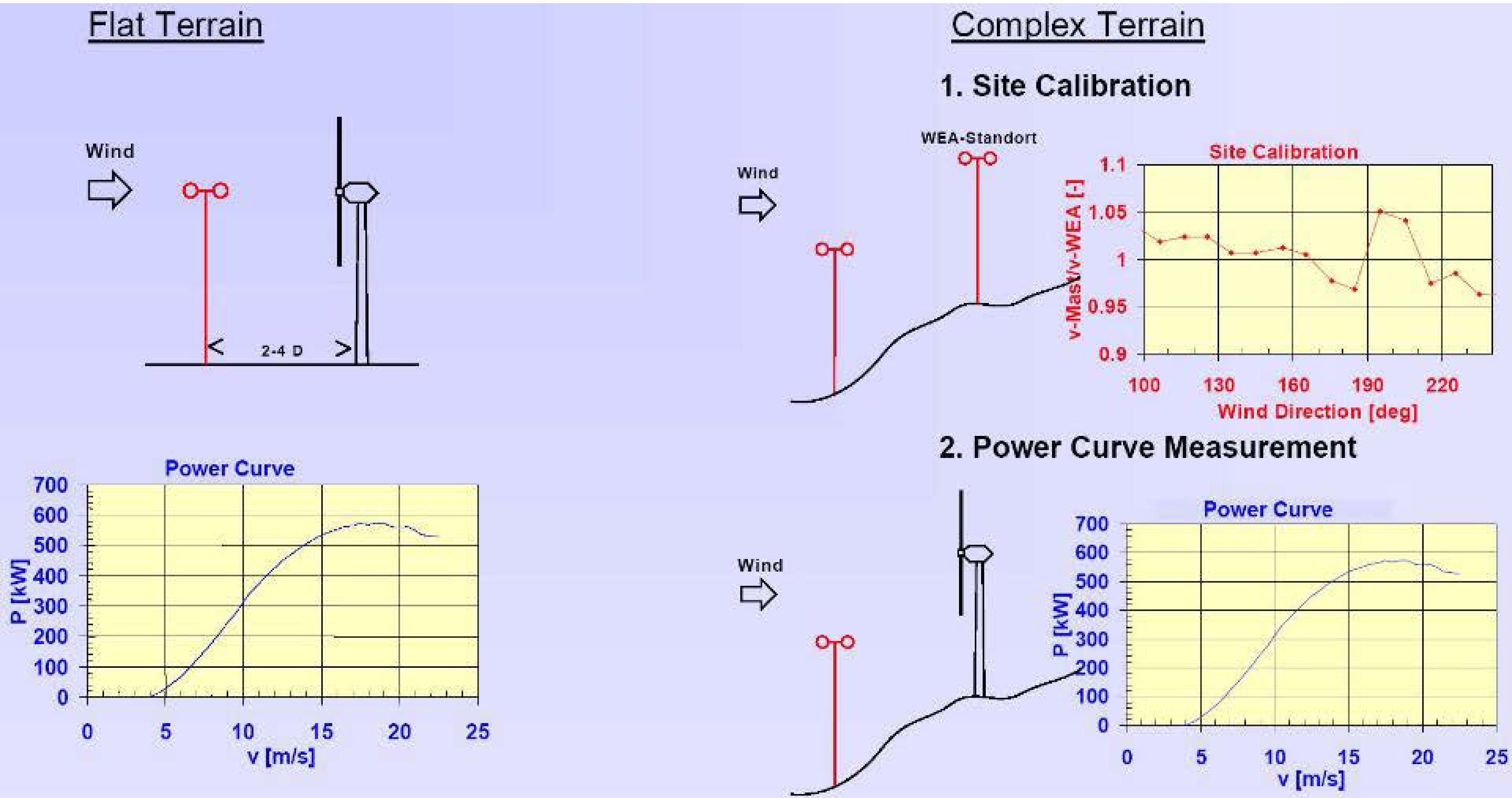
[a] Measurement sector is understood here by default as the remaining valid sector after execution of the procedure defined in Annex A, whereas it is also allowed to use a smaller measurement sector[24].

[b] The maximum slope of the plane, which provides the best fit to the terrain in the sector being considered and passes through the tower base. See Figure B.2 for an example.

[c] The line of steepest slope that connects the tower base to individual terrain points on the surface of the terrain within the sector. See Figure B.3 for an example.

Site Calibration

- Try to avoid–not trivial!
- IEC 61400-12-1 Annex C.



Source DEWI: http://www.exportinitiative.de/media/article005913/dewi_klug_kanada_englisch_28032006.pdf

Acoustic Testing

- Minimal extraneous noise sources (e.g., highways, vegetation, birds, insects, people, and other turbines)
- Reflective sources; avoid structures near the microphone or downwind of turbine
- Need access for microphone downwind of turbine
- Avoid ridges/water in downwind position
- If a drag design, a very quiet site is needed.

Additional Things to Consider

- Construction
  - Time and money
- Legal
  - Interconnect agreement
  - Land ownership/lease
  - Zoning
  - National Environmental Policy Act (NEPA)
- Data
  - Data acquisition system
  - Ability to check regularly
- Match testing needs with site
- Timing–different times for different tests
  - Plan accordingly.

National Environmental Policy Act

NEPA

- Criteria to trigger a NEPA review
  - Federally funded project (any CIP contract qualifies)
  - Involves any construction or other outdoor activity
- Installation of a wind generator requires a review
  - Even if using existing site and infrastructure
  - Requires review of any potential impact to endangered or threatened species
  - Requires review of impact of cultural artifacts
  - Requires review of radar system impact.

Information Needed

- What is being done
- Any sites where work will be done other than work done inside an existing building
- Nature of the site (e.g., industrial, commercial, agricultural)
- Land ownership or administration
- Types of activity at each location
- Scale of activity
- Neighboring land type and use
- Safety and environmental risks of the project
- Potential environmental impact, and so on.

Questions?

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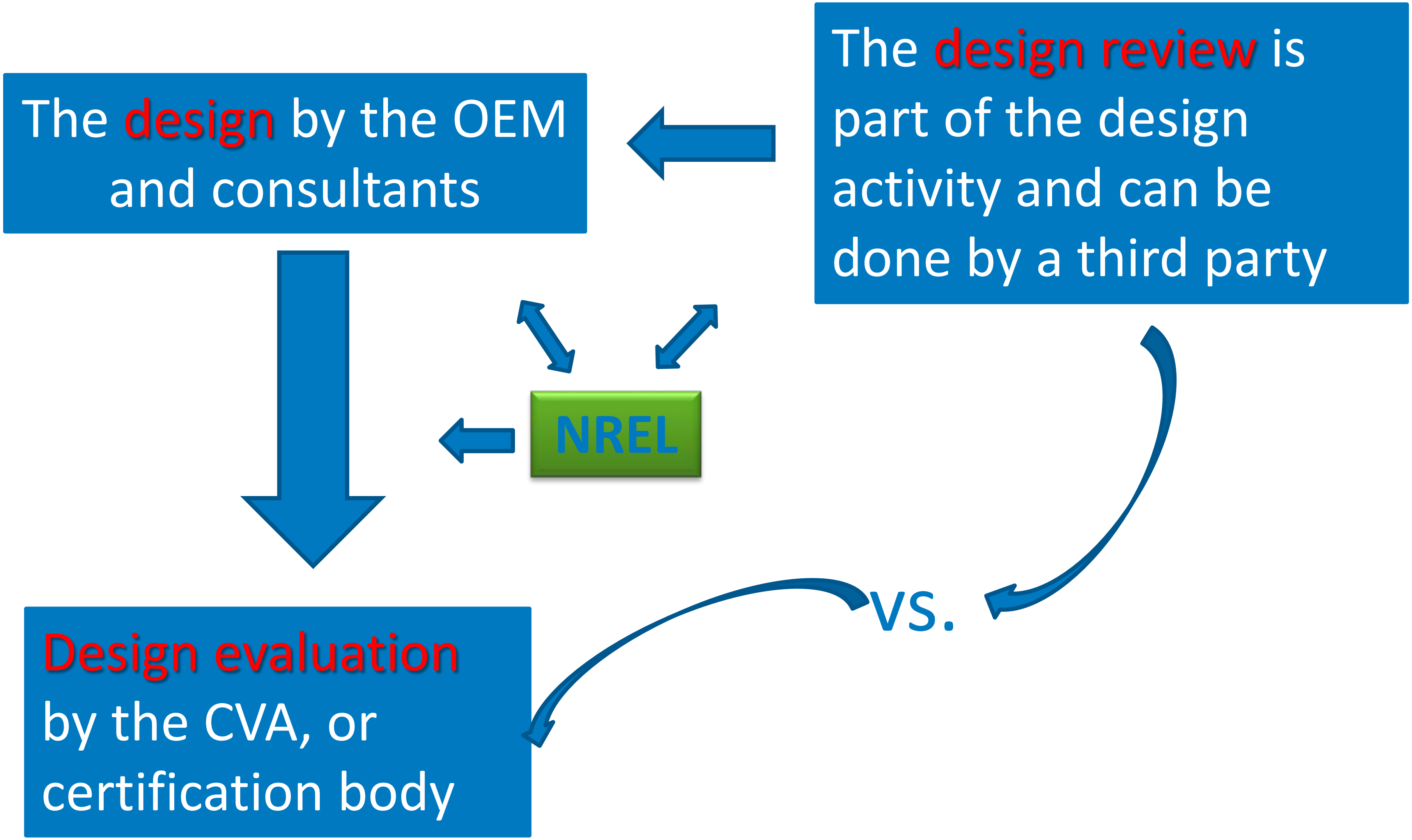
NATIONAL RENEWABLE ENERGY LABORATORY

Session 8: Design Review

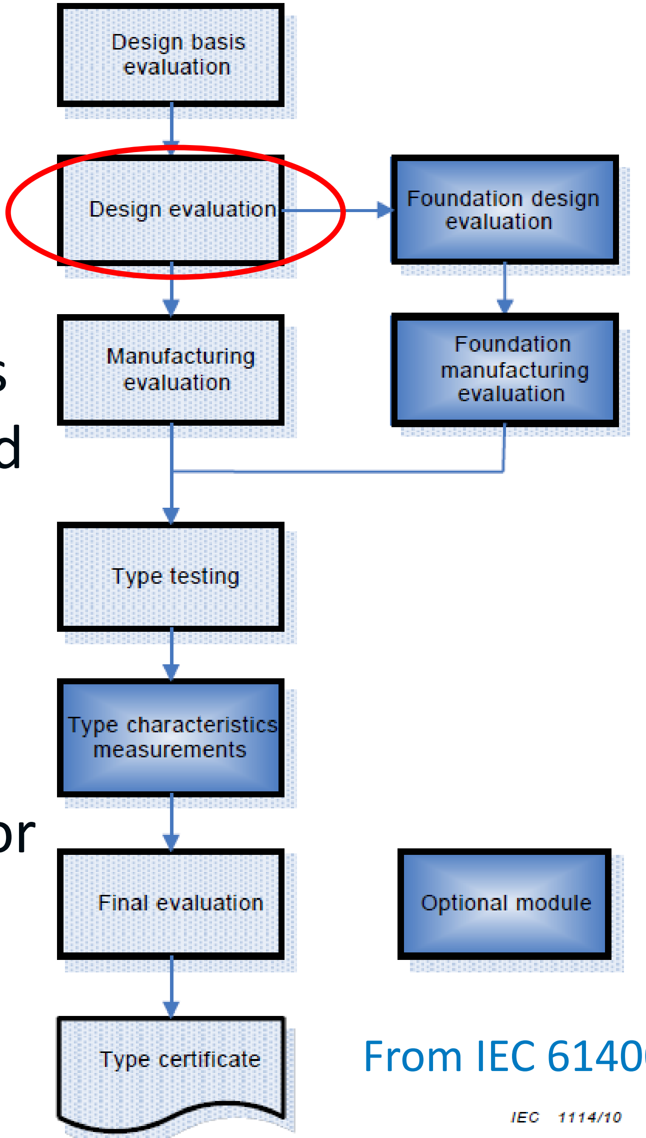
Rick Damiani

Design Evaluation vs. Design Activities and Review



Design Evaluation: Why?

- Mandatory to comply with standards (AWEA, IEC, MCS, …)
- Helps demonstrate that the wind turbine system is **designed** and **documented** in conformity with design assumptions and standards and technically proficient (safe and sound)
- “Keeps it real”
  - If done well, it helps speed up testing (including structural) and the issuing of certificate (or it <u>can send you back to the drawing board</u>).



From IEC 61400-22

Turbine Design: Aspects to Consider

Key Disciplines

- Aerodynamics
- Structural dynamics
- Material mechanics
- Control systems
- Aeroacoustics
- Electrical engineering
- Geotechnical engineering
- System engineering.

Key Components

- Blades
- Hub
- Shaft
- Gearbox
- Generator
- Bedplate
- Yaw system
- Tower
- Foundation.

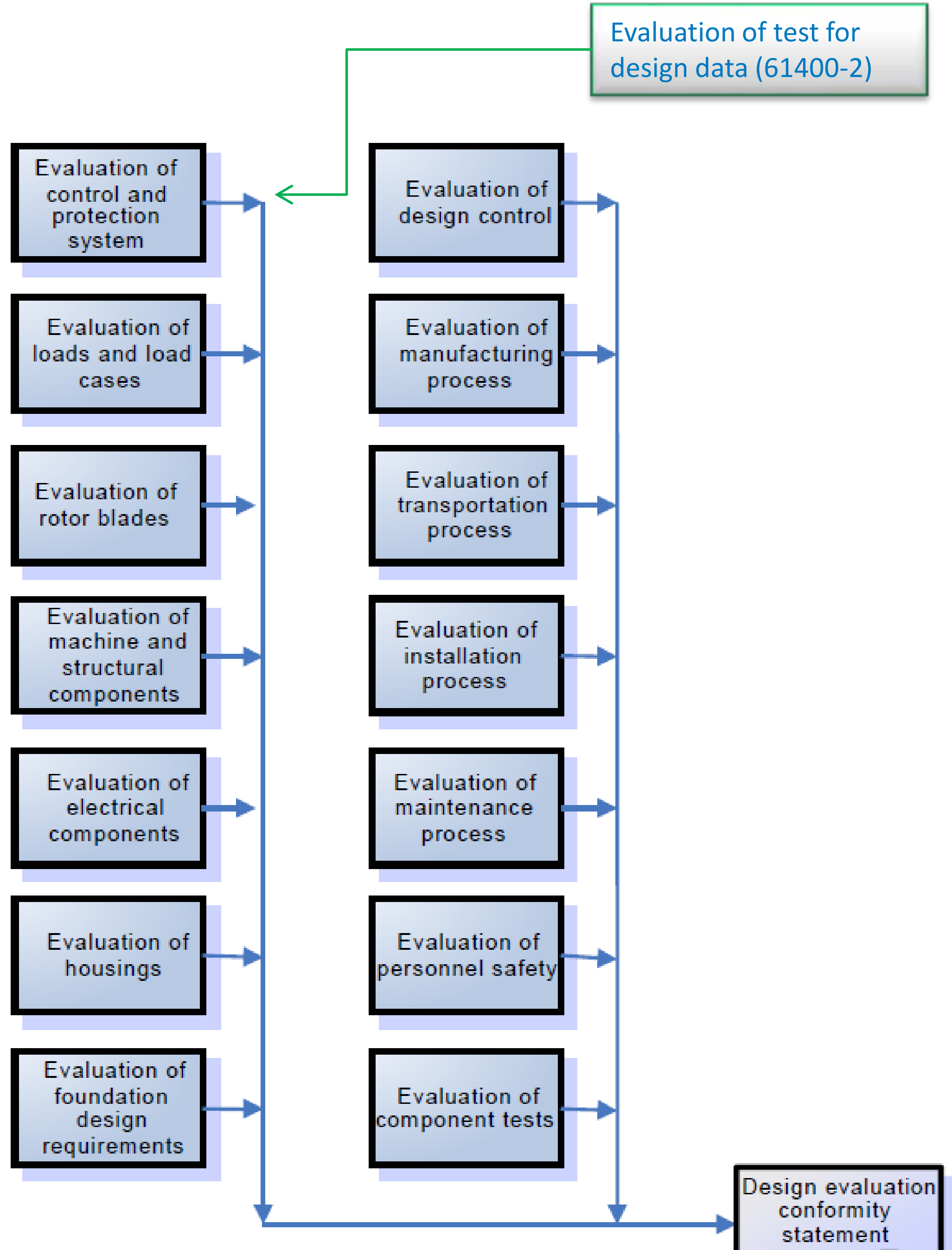
What to Include in the Design Report (At a Minimum)

What to Include in the Design Report

- Follow the standard of relevance
  - To demonstrate
- Safety
- Durability
- Performance

- Requires:
  - Extensive documentation and effort
  - Document and design control (cf. ISO9001)
    - Figure, table numbering
    - Symbols list, etc.
    - Version/revision control for tables, drawings, data, documents, etc.

- Things to consider:
  - Quality control processes
  - List of documents from -22
  - *SI units* strongly encouraged.



What to Include

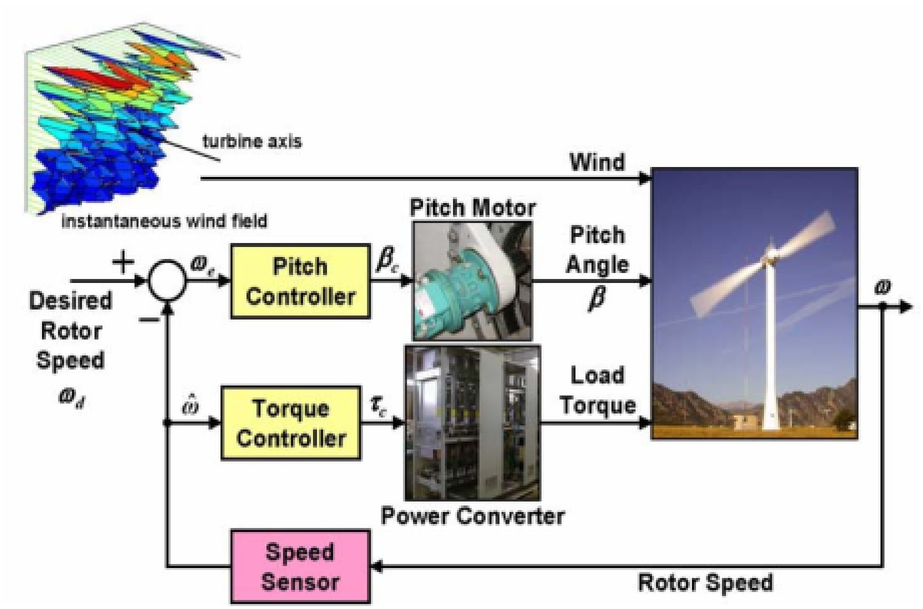
- System description and turbine specifications
  - Turbine class (e.g., IEC Class IIA)
  - Mechanical configuration (e.g., two-bladed downwind HAWT, direct drive)
  - Dimensions (e.g., rotor diameter, masses)
  - Rated power, rpm, wind speed
  - Control and protection system
  - Interconnection requirements (e.g., inverter, output voltage)

  - For AWEA certification:
    - AWEA rated power at 11 m/s
    - Annual energy production at 5 m/s
    - Sound level.

Class: IA (IEC 61400-1/2)
Type: three blades upwind, pitch-controlled
Rotor Diameter: 15 m (swept area 176.7 m^2)
Cut-in Wind Speed: 3 m/s
Cut-Out Wind Speed: 25 m/s
Rated Wind Speed: 12 m/s
Rated/Range rpm: 43 (0-43)
Rated Power: 75 kw
Rotor Nacelle Assembly mass: 10 tons
Overspeed Protection: pitch and high-speed-shaft brake
Power Control: variable speed, torque, and pitch
Yaw System: 1 DC motor with gearbox four-point ball bearing
Gearbox: two-stage planetary 40:1
Tower/Tower Height: tubular steel, 30 m
Generator: permanent-magnet alternator
Output Form: three-phase AC, variable frequency (400 VAC nominal), max current at terminals 50 A
Temperature Range: -40 to +60 Deg. C
Design Life: 25 years.
AWEA Rated Sound Level: 42.9 dB(A)
AWEA Rated Annual Energy: 13,800 kWh at 5 m/s

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

- DLCs
  - 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).

Design Load Cases

- Operational with normal external conditions
- Operational with extreme external conditions
- Fault with “appropriate” external conditions
- Transportation, maintenance, installation

+ checks on

- Flutter
- Vibration
- Rotor speed
- Cable twist.

61400-2 Ed3

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

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 got 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).

Notes on Simplified Loads Approach: Load Components

- e.g., DLC B: Yawing

$$M_{yB.B} = m_B \omega_{yaw,\max}^2 L_{rt} R_{COG} + 2\omega_{yaw,\max} I_B \omega_{n,design} + \frac{R}{9} \Delta F_{xshaft}$$

Strictly IEC-specified

But also, assuming design conditions:

$$F_{zB.B} = m_B \omega_{n,design}^2 R_{COG}$$

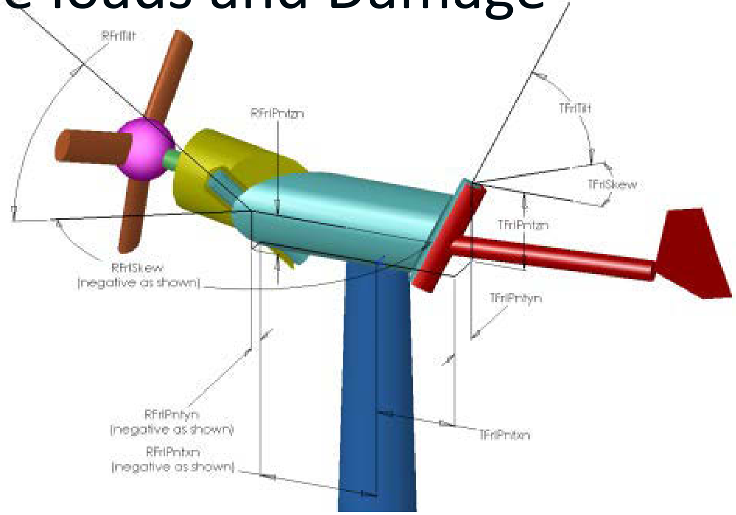
$$M_{xB.B} = m_B g R_{COG} + \frac{Q_{design}}{B}$$

- Consider **all applicable loads for finite element analysis (FEA)**
- Investigate beyond the SL equations
- Determine best strategy to apply loads to model and its sensitivities.

Aeroelastic Modeling

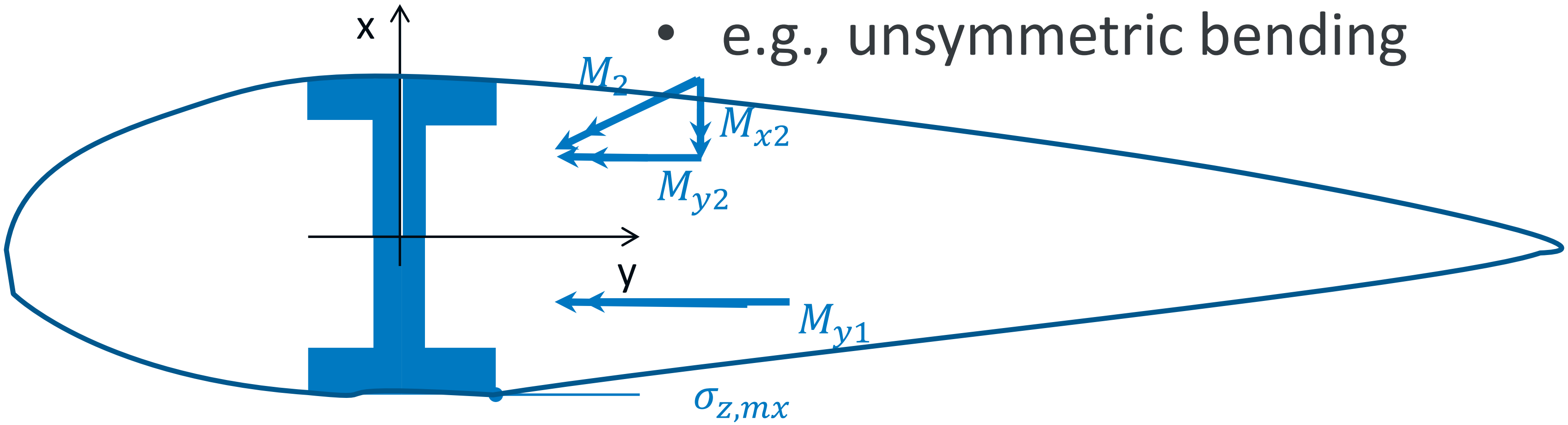
- Three-dimensional effects on blade aerodynamics, stall, and tip losses
- Unsteady aerodynamics and aeroelastic effects
- Structural dynamics and vibration mode coupling issues
- Control system effects
- Realistic load distribution on components
- Can explore other features (independent pitch, hinged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

URL:Github.com/OpenFast



Notes on Load Components

- e.g., unsymmetric bending



$$|M_2| << |M_{y1}|$$

$$S_{yy} \approx 10 S_{xx}$$ Bending Moduli

$$|\sigma_{z,mx1}| = \frac{|M_{y1}|}{S_{yy}} < |\sigma_{z,mx2}| = \frac{|M_{y2}|}{S_{yy}} + \frac{|M_{x2}|}{S_{xx}}$$

- Because Jxx≠Jyy, → consider load rose, multiple sectors
- Consider **all load components**
- Determine best strategy to apply loads to model and its sensitivities.

What to Include

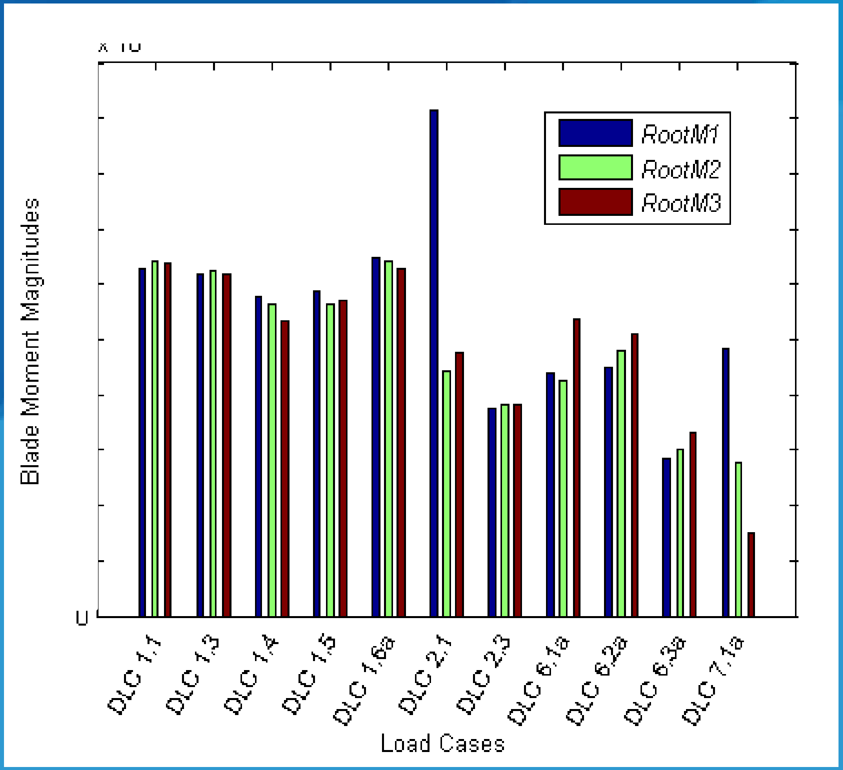
- DLCs loads analysis results
  - Simultaneous load component tables for all system parts of relevance Ultimate Limit States (ULS) loads/ deflections/strains, and Fatigue Limit States (FLS) DELs
  - Partial Safety Factors applied.

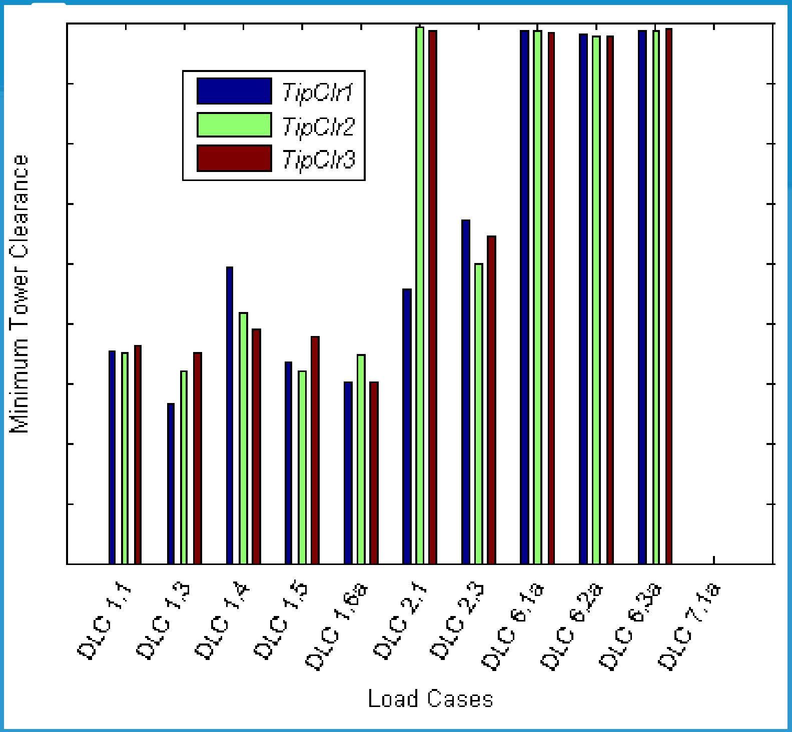
TOWER BASE ULS LOADS	TwrBsFxt	TwrBsFyt	TwrBsF	TwrBsFzt	TwrBsMxt	TwrBsMyt	TwrBsM	TwrBsMzt	Time	HorWindV	NacYaw Err	RotThrust
File Name/DLC	kN	kN	(kN)	kN	kN·m	kN·m	(kNm)	kN·m	s	(m/s)	(deg)	kN
DLC1.6\DLC16_61_24.0V0_S01.outb	- 6.32E+02	3.54E+02	7.25E+02	- 1.01E+04	- 1.81E+04	- 6.31E+04	6.57E+04	- 1.02E+04	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

- DLCs loads analysis results
  - Simultaneous load component tables for all system parts of relevance ULS loads/deflections/strains and FLS DELs
  - PSF applied.

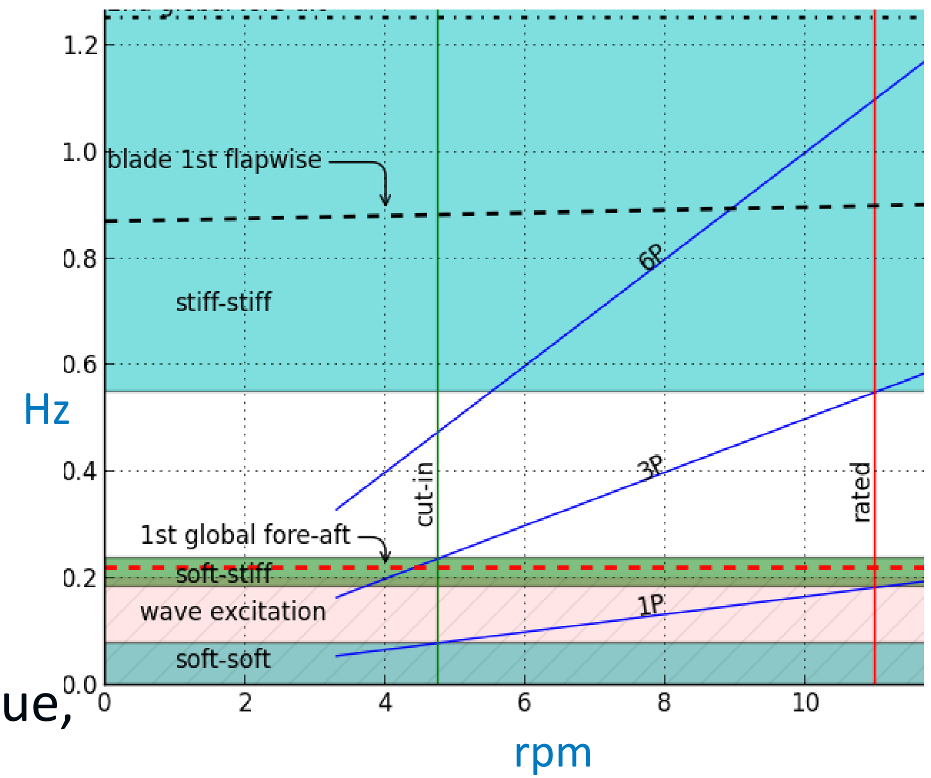




Component Verification: What to Include

"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
    - ULS, FLS, SLS (Ultimate, Fatigue, and Service Limit States).

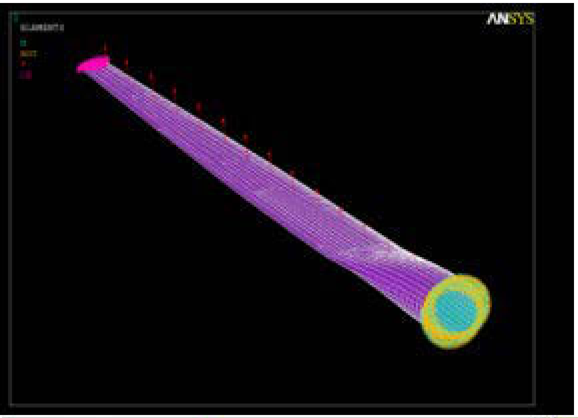


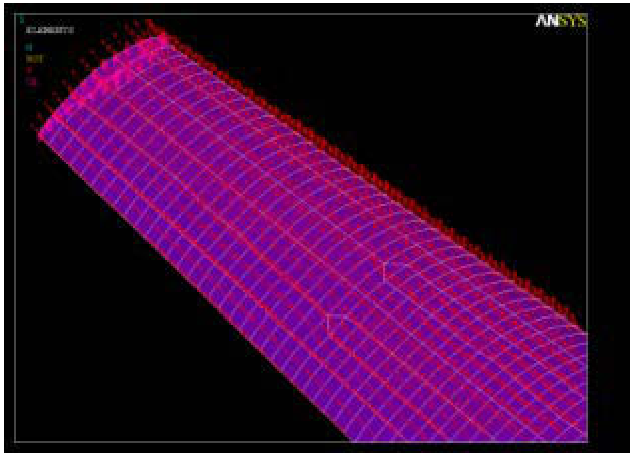
Component Verification

For all components of relevance include:

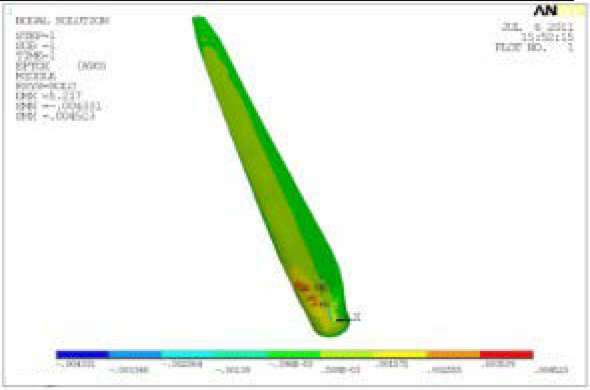
- Eigenanalysis
- FEA; at a minimum equivalent static loading
- Explanation of adopted boundary conditions
- Load distributions (including thermal effects as applicable, e.g., brakes, gear lubrication)
- Material properties (subcomponent and coupon test data)
- PSFs (loads and materials)
- Manufacturing 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.**

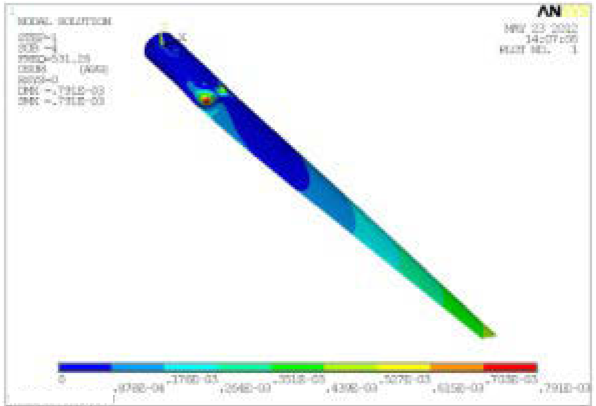
Component Verification (e.g., BLADE; Limit State Analysis; FEA)





- Sensitivity to mesh
- Boundary conditions
- Load distribution
- Failure criteria (e.g., Tsai-Wu)
- Buckling (linear vs. nonlinear).





Courtesy of NREL

Component Verification: PSF, Refer to Standards

Table 7 – Partial safety factors for loads

Load determination method (see 5.2)	Fatigue loads, γ_f	Ultimate loads, γ_f
1. Simplified equations	1,0	3,0
2. Simulation model	1,0	1,35
3. Full scale load measurement	1,0	3,0

$$\sigma_d \leq \frac{f_k}{\gamma_m \gamma_f}$$

- ULS (also check blade deflection and tower strike)

Table 6 – Partial safety factors for materials

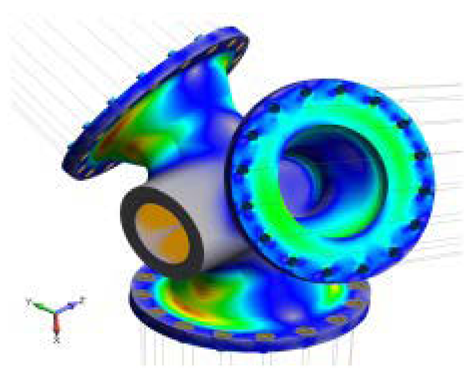
Material characterisation	Fatigue strength, γ_m	Ultimate strength, γ_m
Full characterisation	1,25[a]	1,1
Minimal characterisation	10,0[b]	3,0

a Factor is applied to the measured fatigue strength of the material.

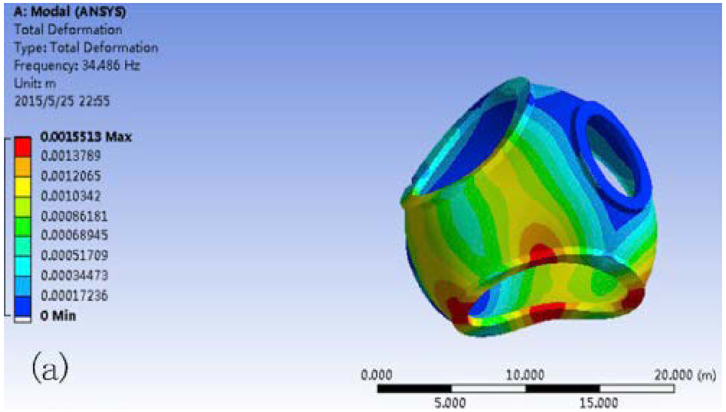
b Factor is applied to the measured ultimate strength of the material.

Component Verification: Examples of Other Components

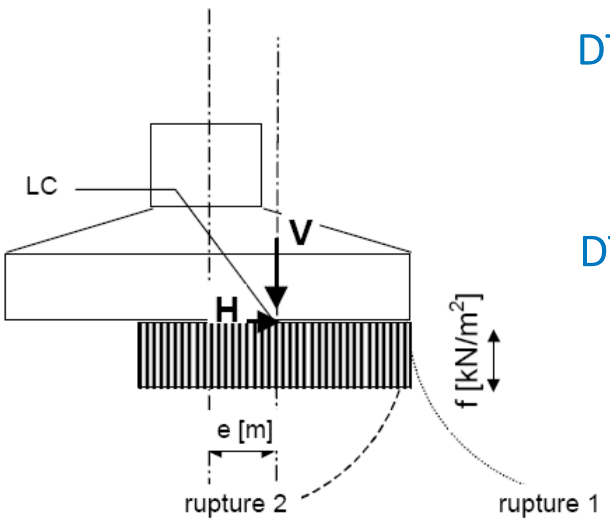
Hub FEA, Source: Romax

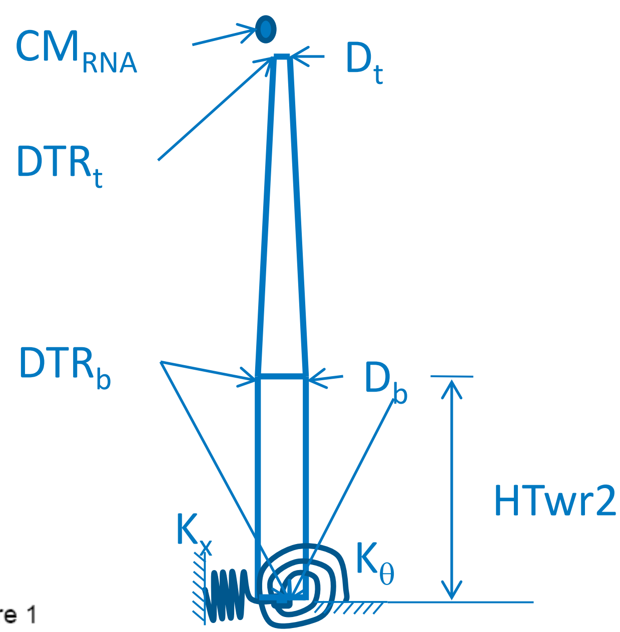


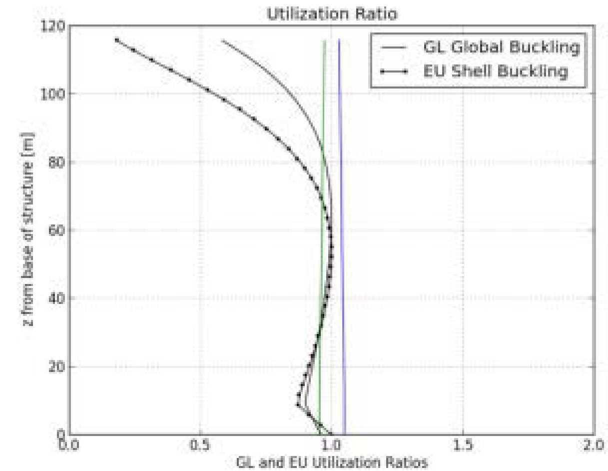
Hub FEA, Source: Predictive Engineering



Hub FEA, Source: W. Liu (2016). Design and kinetic analysis of wind turbine blade-hub-tower coupled system, Renewable Energy, 94, 547-557

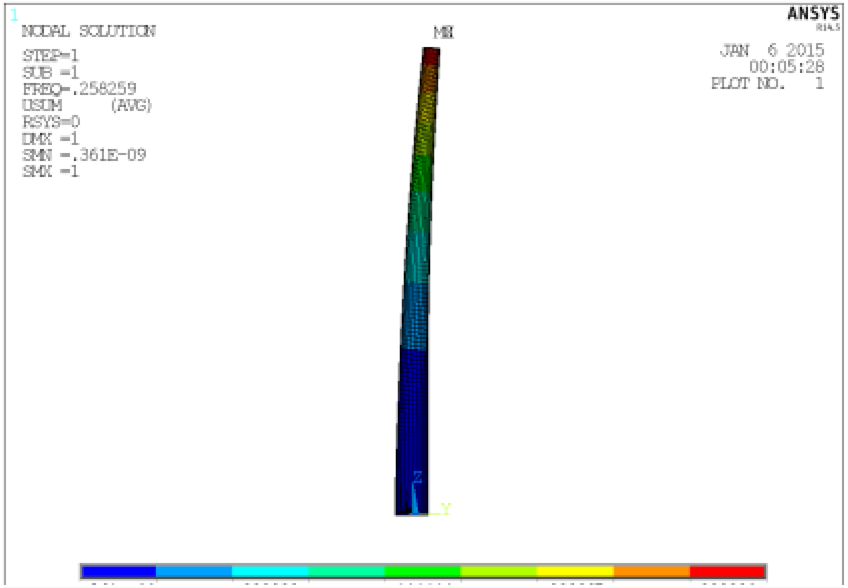


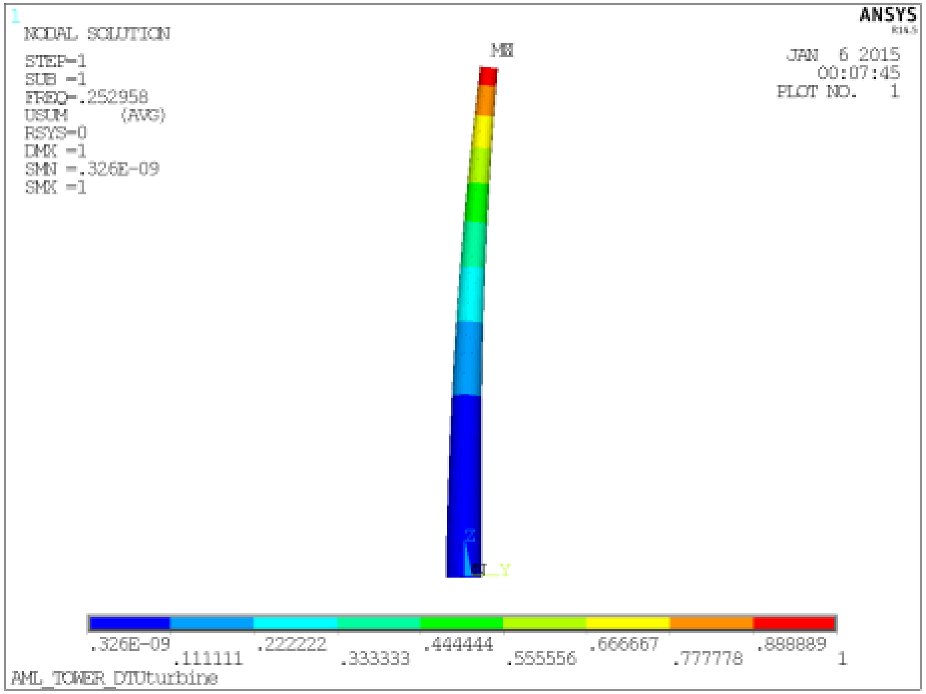


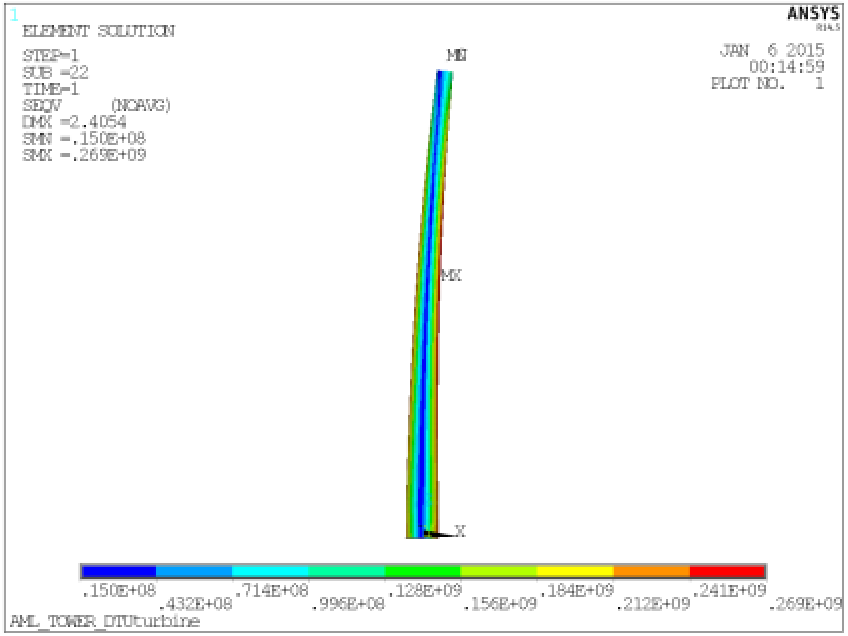


Component Verification: Examples of Other Components

- ULS verification
- Predicted buckling load (on top of self-weight): 170 MN
- Local buckling at ~4 x load.







Component Verification: Material Properties

Free body diagrams, force vector diagrams

ID	Material	ρ [kg/m^3]	VF [%]	E_L [Pa]	E_T [Pa]	G_{LT} [Pa]	ν_{LT} [-]	σ_{ut} [Pa]	ε_{ut} [%]	σ_{uc} [Pa]	ε_{uc} [%]	Notes
1	Gelcoat	1235		3.44e9			0.3					isotropic
8	Balsa	155		5e7			0.3					Isotropic
2	Resin (EP3)	1100		3.5e9			0.3					isotropic
4	ELT5500/EP3 (Uni)	1920	54	4.18e10	1.4e10	2.63e9	0.28	972e6	2.44	-702e6	-1.53	orthotropic
5	Saertex/EP3 (DB) $[\pm 45]_4$	1780	44	1.36e10	1.33e10	1.18e10	0.51	144e6	2.16	-213e6	-1.8	orthotropic
6	SNL Triax $[\pm 45]_2[0]_2$	1850		2.77e10	1.365e10	7.2e9	0.39					Orthotropic (avg. properties between Saertex and E-LT-5000)

Material	ASTM A311-A1144 steel	ASTM A36 steel
Ultimate Strength, σ_U [MPa]	620	400
Yield Strength, σ_Y [MPa]	550	250
Factored σ_Y [MPa]	500	227
Allowable stress in fatigue, σ_A @ 1.0E+06 cycles [MPa]	212	166*
Factored σ_A [MPa]	193	151
ΔL-N curve slope 1, m_1	9.5	3
ΔL-N curve slope 2, m_2	18	5
Reference number of fatigue cycles, N_A	2.0E+06	2.0E+06
Knee point of ΔL-N curve, N_D	5.0E+06	5.0E+06

** base metal, clean surfaces, without weld at 2.0E+06 cycles, stress range*

Component Verification: Electrical

- Generator
- Transformer
- Inverter
- Drives
- Electrical protection
- Switch gear
- Cables
- …

http://www.ntpwind.com/grid_tie_inverter_specs.php

Check UL 6141, NEC, and so on

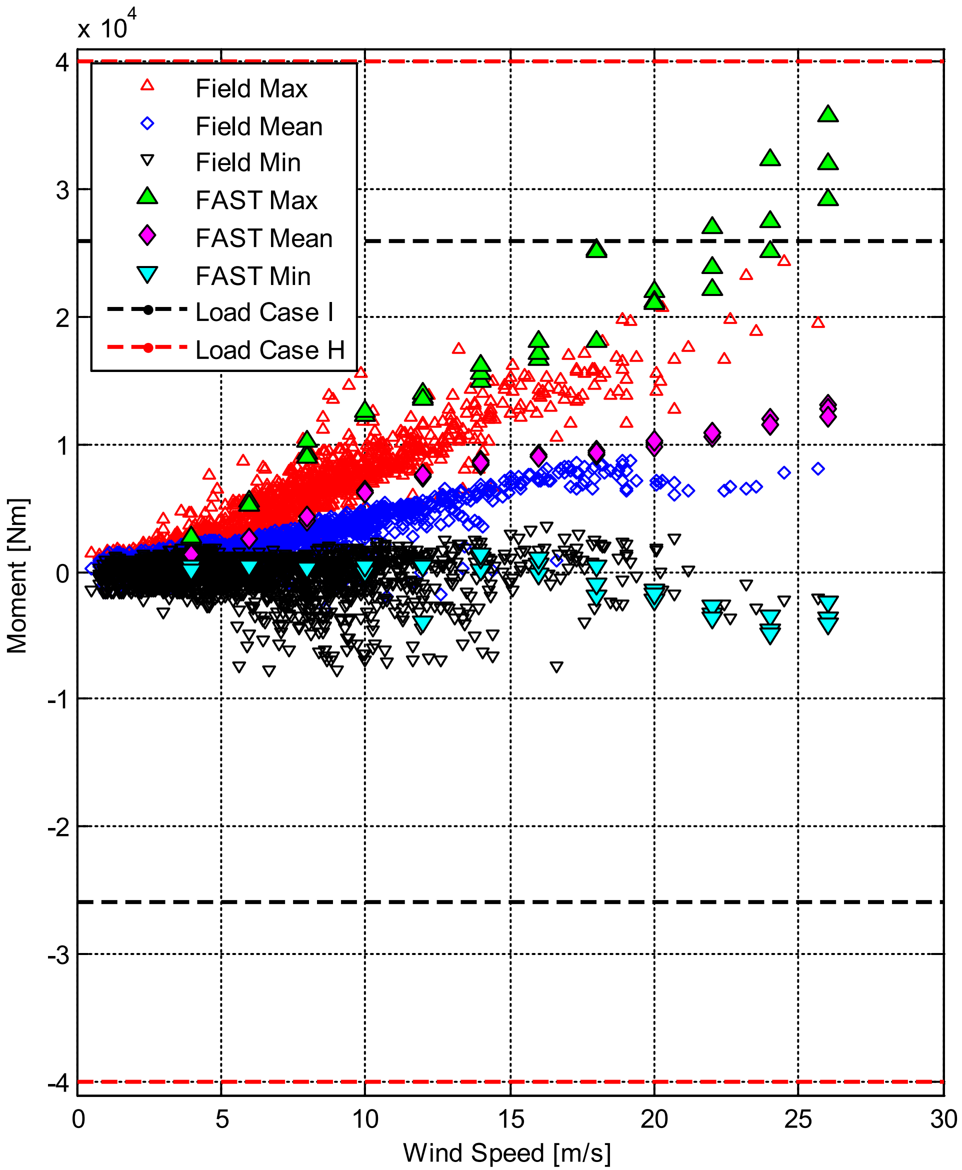
http://easywindenergy.blogspot.com/2013/02/how-to-build-homemade-wind-generator.html

Alternative Approach: Full-Scale Load Measurements

- Load measurements should be taken under conditions as close as possible to the aeroelastic model DLCs [61400-2]

- 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.

Full-Scale Load Measurements vs. Aeroelastic Predictions



Design Report Outline

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. DLCs (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.

Takeaways

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

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

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?

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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
- 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 the 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 LCEO 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				

- 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
- These are 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?

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Session 10: Procurement/Contracting

Kyndall Jackson

Proposal Submittal

- Request for proposals (RFP)
  - Posted on FedBizOps
  - Special notice provides RFP documents from previous rounds
    - www.fbo.gov (Keyword/Solicitation #: RGZ-8-101217)
  - Instructions for submittal (contact info, requirements, due date, and so on) 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 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)
- Forms
  - Price cost proposal
  - Organizational conflict of interest forms (representation OR disclosure)
  - New vendors (W-9, ACH banking information)
  - Representations and certifications
    - SAM.gov registration (system for award management)
    - Specifying proprietary/intellectual property.

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?

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Session 11:
Project Management/Deliverables

Karin Sinclair

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 9)
  - 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

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.

Questions?

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Session 12: Outreach Materials

Karin Sinclair

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 end of Q1 2018)
- 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 distributing to the public.

Questions?

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Session 13: Feedback

Ian Baring-Gould

Questions?

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