Distributed Wind Certification Best Practices Guideline

January 16, 2023 – January 15, 2026

Joseph Spossey

RE Innovations

NREL Technical Monitor: Brent Summerville

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Contract No. DE-AC36-08GO28308

Subcontract Report
NREL/SR-5000-88371
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Suggested Citation

Spossey, Joseph. 2024. *Distributed Wind Certification Best Practices Guideline: January 16, 2023 – January 15, 2026*. Golden, CO: National Renewable Energy Laboratory. NREL/SR-5000-88371. https://www.nrel.gov/docs/fy24osti/88371.pdf.

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Table of Contents

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This Distributed Wind (DW) Certification Best Practices Guideline describes the typical approach for certification of distributed wind turbines above and below 150 kilowatts (kW) in size based on the conformity assessment requirements in the United States. The purpose of the guideline is to clarify and consistently describe the complex path to certification for various systems and components. This is done via clarification of both the required turbine type certification elements, as well as third-party electrical safety listing of turbine system components and subassemblies.

In the United States specifically, there is no wind turbine certification scheme that governs or maintains a consistent set of conformity assessment requirements, and this can lead to wide-ranging interpretations of the standards and required elements for certifications. This guideline attempts to simplify the path by organizing the information and guiding the user to the applicable set of requirements. Any wind turbine manufacturer or designer of wind turbines used in distributed generation applications in the United States would find value in the conformity assessment guidance in this guideline. Users are expected to be involved in the technical development of the product and supporting documentation, as the details provided are geared toward electrical and mechanical engineering of the system and components.

For an overview of the process and hyperlinks to applicable parts of this guideline, please refer to Section 2 – User's Guide.

This guideline was initially released in early 2024, with the intention of additional revisions and updates over the next 2 years. For any comments, suggested edits, or additional topic areas, please do not hesitate to contact the author, and visit our website www.reinnovationsllc.com.

ACKNOWLEDGEMENTS

The author wishes to thank the U.S. Department of Energy and National Renewable Energy Laboratory and their teams associated with the funding and publication of this DW Certification Best Practices Guideline. Their leadership and vision related to distributed wind and distributed generation is unmatched and appreciated by all industry stakeholders. The author would specifically like to thank Brent Summerville and Ian Baring-Gould for their willingness to establish and work on a project scope dedicated solely to helping wind turbine manufacturers achieve certification in the United States.

The author wishes also to thank Matthew Oudt, RE Innovations, for his support in developing and editing this DW Certification Best Practices Guideline, contributions related to images, illustrations and figures, and the many hours of support related to publication. Also Drew Gertz, Northwind Engineering, for his contributions related to descriptions of suitable design methods and simulation modeling, design load cases, and related structural assessment guidance. And lastly, Ian Brownstein and the team at XFlow Energy for their peer reviews, comments, and contributions to the User's Guide and other parts of the Guideline.

Without these people, this document would not be publicly available and as useful to as wide an audience as it now is. Thank you!

1 EXECUTIVE SUMMARY

This Executive Summary is provided for the various parts of this guidance document, with brief descriptions of the topics covered related to the certification process for distributed wind turbines (DWTs). For a shortened summary of the certification process, see the User's Guide in Section 2.

Section 2 is a shortened User's Guide to guide both new and experienced designers in the use of this document for proper considerations for certification of a component or wind turbine system. Beginners can learn about the certification process and understand the basic requirements while experienced users may quickly select the component or section of interest via hyperlinked references in Table 1. Section 2.2 is an overview of the certification processes that make up a DWT certification, a Designers Quick Guide Table is given in Section 2.3, and Section 2.4 provides estimates on time and cost for the various certification elements.

Section 3 provides an overview of how certifications of DWTs and components or subassemblies are used in the United States, related to permitting or tax incentive or rebate programs. Section 3.1 gives a description of typical turbine types that this DW Certification Best Practices Guideline applies to. Section 3.2 gives an overview of compliance drivers for certification in the United States.

Section 4 provides general information and guidance related to the third-party certification process in North America. Section 4.1 provides an overview of product certifications and compliance with the National Electric Code. Section 4.2 gives general requirements related to DWTs, and Sections 4.3 and 4.4 give brief overviews of test and certification bodies and standards development organizations, respectively. In future releases, Sections 4.3 and 4.4 will be updated to include greater detail.

Section 5 covers detailed information related to electrical safety certification of DWT systems and components. An overview of the process and requirements is provided in Section 5.1, followed by more specific requirements for DWT system certifications in Underwriters Laboratories (UL) 6141 or UL 6142 in Section 5.2, including comparisons between the two. Section 5.3 discusses component requirements for common electrical components of DWT systems such as generators, control equipment, inverters, and others. Other common systems and protections and associated requirements are discussed in Section 5.4, including emergency stops, disconnect devices, and others. Section 5.5 outlines wiring methods, terminations, and connection requirements for acceptable wiring practices, cable twist loops, slip rings, bus bars, and others.

Section 6 covers detailed information related to type testing and certification of DWT systems according to American National Standards Institute/American Clean Power Association (ANSI/ACP) 101-1. An overview of the process and general requirements are provided in Section 6.1. A detailed description of the process and requirements for structural design compliance is given in Section 6.2. Section 6.3 provides an overview of the type testing requirements, including tests required for validation of design simulation models, along with the other common required type tests. Manufacturing conformity (Section 6.4) and certification surveillance (Section 6.5) are covered briefly in this initial version and will be updated in future releases of this DW Certification Best Practices Guideline. Section 6.6 Microturbines and Section 6.7 Test Site Requirements and Considerations will be covered in future releases.

Section 7 covers brief information related to type testing and certification of DWT systems according to International Electrotechnical Commission (IEC) 61400 methods that are similar to IEC type certification requirements. An overview of the process and general conformity assessment requirements are provided in Section 7.1. Descriptions of the design evaluation process and module requirements are given in Section 7.2. Section 7.3 provides an overview of the type testing requirements. Manufacturing conformity (Section 7.4), final evaluation (Section 7.5), and type certification (Section 7.6) are covered briefly in this initial version and will be updated in future releases of this DW Certification Best Practices Guideline.

In a future release of this DW Certification Best Practices Guideline, Section 8 will cover shrouded and diffuser wind turbines, rooftop and building integrated wind turbines, and other considerations related to novel archetypes.

Section 9 will cover international markets, certifications, and other considerations in a future release.

Section 10 is a checklist of common documentation types that are required for the various parts of the certification process for DW type certifications according to IEC and ANSI/ACP 101-1 processes.

Appendix A is a list of reference component and subcomponent standards that are applicable for use in developing products for electrical product safety requirements within UL standards 6141 and 6142.

2 USER'S GUIDE

Section 2 is a shortened User's Guide to guide both new and experienced designers in the use of this document for proper considerations for certification of a component or wind turbine system. Beginners can learn about the certification process and understand the basic requirements while experienced users may quickly select the component or section of interest via hyperlinked references in Table 1. Section 2.2 gives an overview of the certification processes that make up a DWT certification, Section 2.3 provides a Designers Quick Guide Table, and Section 2.4 provides estimates on time and cost for the various certification elements.

2.1 User's Guide Introduction

The User's Guide provides an abbreviated description of the overall DWT certification process for the United States. The process is broken down according to electrical product safety and wind turbine type certification requirements. This section provides only a brief overview of the process and requirements, but also guides the user via hyperlinks to the sections within this Distributed Wind Certification Best Practices Guideline covering all the detailed requirements. The User's Guide helps with locating parts of the guidance document related to specific components or topics and points designers of various components or subassemblies directly to applicable standards, typical tests, and requirements.

The User's Guide includes summary illustrations created by the author to help describe certification paths; they are for purposes of simplifying and providing overview. Please review the details of the DW Certification Best Practices Guideline for thorough assessment of the applicable process and requirements.

2.2 User's Guide Certification Overview

To certify a DWT in the U.S. market, it is necessary to understand what certification is, what classifies as a distributed wind turbine, and the various parts of the certification process. Certification in its simplest terms is confirmation that a product, service, or system complies with a set of requirements written in applicable industry codes or standards. Approvals are documented via written certificates, sometimes from an independent body, attesting that the product, service, or system conforms to the industry standards. Third-party certifications are required in North America, meaning the evaluation and testing is carried out by an independent body. Figure 1 gives an illustration that compares the applicable parts of certification for DWTs in the United States: electrical safety and type certification.

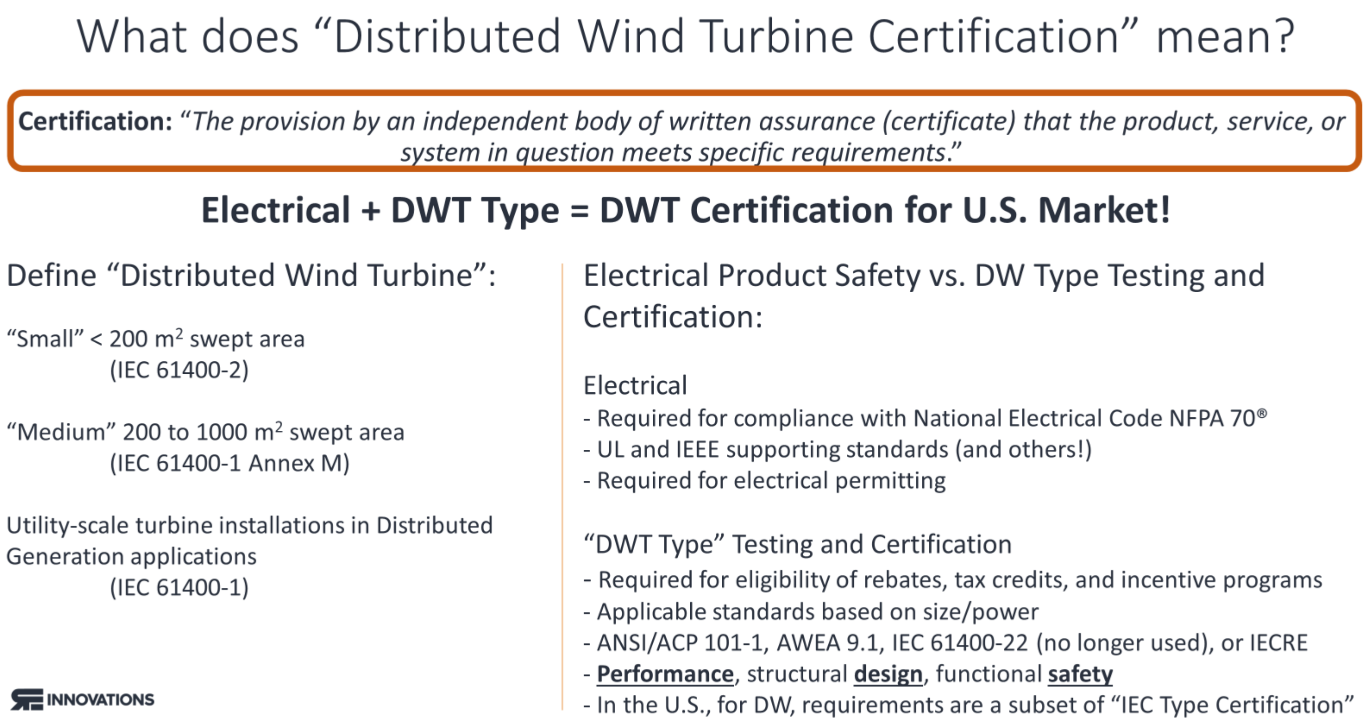


Figure 1 - DWT certification illustration

Figure 2 is extracted from the [Current status and grand challenges for small wind turbine technology](#) report, showing scaled comparisons of the various sizes of DWTs.

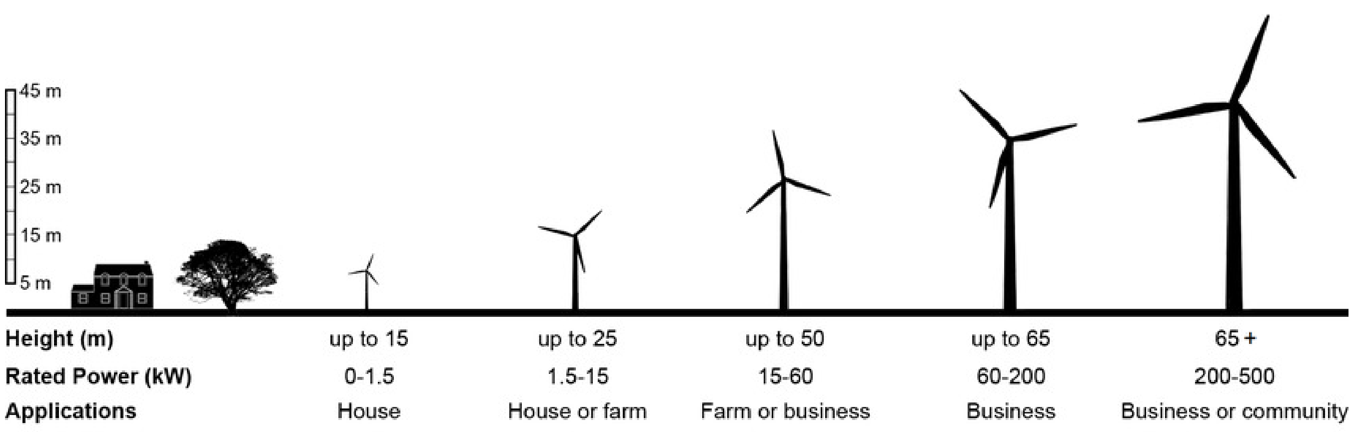


Figure 2 - DWT scaled comparison chart
Current status and grand challenges for small wind turbine technology

Section 3 gives additional description of the use and application of certified products as well as the various types of DWTs for which this Best Practices Guideline is applicable.

In North America it is mandatory for all electrical product safety certifications to be performed by accredited third-party test and certification laboratories. These labs and agencies must be accredited to all of the applicable standards for evaluation and testing and have them specifically identified on their scope of accreditation. The standards themselves are developed under various rules and procedures that are governed by standards development organizations who are responsible for the publishing and continual updating of the required codes and standards. A certification to a set of applicable codes and standards may be in the form of a "Listing" or "Certificate" or may be a similar or lesser degree of certification in the form of a "Recognition," "Classification," or "Conformity Statement." These are further described in Section 4.

For DWTs this translates into a set of requirements that are described in Section 5, which are applicable for any turbine shape and size that is used in a distributed generation application. In the United States, the following applicable wind turbine system standards are referenced for compliance with National Electric Code, National Fire Protection Agency (NFPA) 70:

- UL 6141 – Standard for Wind Turbines Permitting Entry of Personnel
- UL 6142 – Small Wind Turbine Systems.

With the only delineating factor being entry of personnel inside the tower or nacelle of the wind turbine, the requirements in both standards are mostly identical except for those requirements that apply above 1,000 V in UL 6141 that are not described in UL 6142. Figure 3 is an illustration that lists the similarities and differences between UL 6141 and UL 6142.

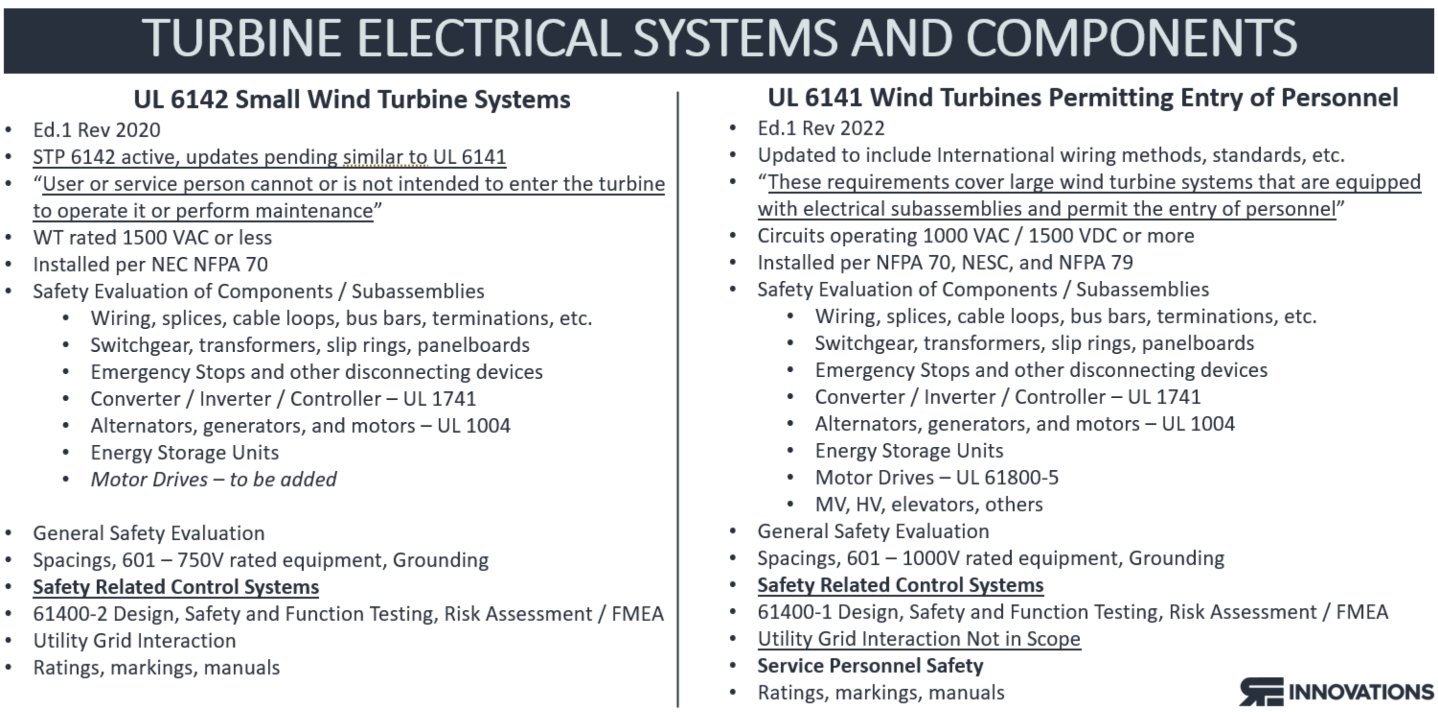


Figure 3 – UL 6141 and UL 6142 comparison

In summary, the major differences between the two are:

1. UL 6141 covers safety of service personnel where entry is permitted
2. UL 6141 covers higher voltage levels for larger utility-scale wind turbines and typical distribution voltages and requirements and thus also includes reference to other standards for higher voltage levels
3. UL 6141 was recently updated to include IEC-based wiring methods and accepted IEC, International Organization for Standards (ISO), and Institute of Electrical and Electronics Engineers (IEEE) product and component standards
4. UL 6142 provides additional requirements for wind turbines that are connected to the electrical network, whereas UL 6141 specifically does not include any electrical network requirements, as utility-scale machines are typically not governed by the National Electric Code (NEC) and are instead governed by the Federal Energy Regulatory Commission (FERC). The additional requirements are not discussed in this DW Certification Best

Practices Guideline, as they are not part of the certification process. A utility-scale machine used in a distributed generation applications must comply with the requirements outlined in this Guideline.

For these reasons, the electrical product safety information in this Guideline is outlined according to UL 6141;differences that exist for smaller machines not permitting entry will be specifically identified. Refer to Section 5 for all guidance related to DWT certification compliance related to electrical product safety.

For the other aspects of DWT certification requirements for the United States covering performance, structural safety, and functional safety requirements, refer to Sections 6 and 7. The requirements differ according to turbine size and are similar to or a subset of the IEC type certification process; these requirements are outlined for turbines below 150 kW according to ANSI/ACP 101-1 in Section 6 and turbines above 150 kW according to IEC type certification requirements and supporting standards in Section 7. Figure 4 is an illustration of the typical parts of the certification processes outlined in greater detail in Sections 6 and 7.

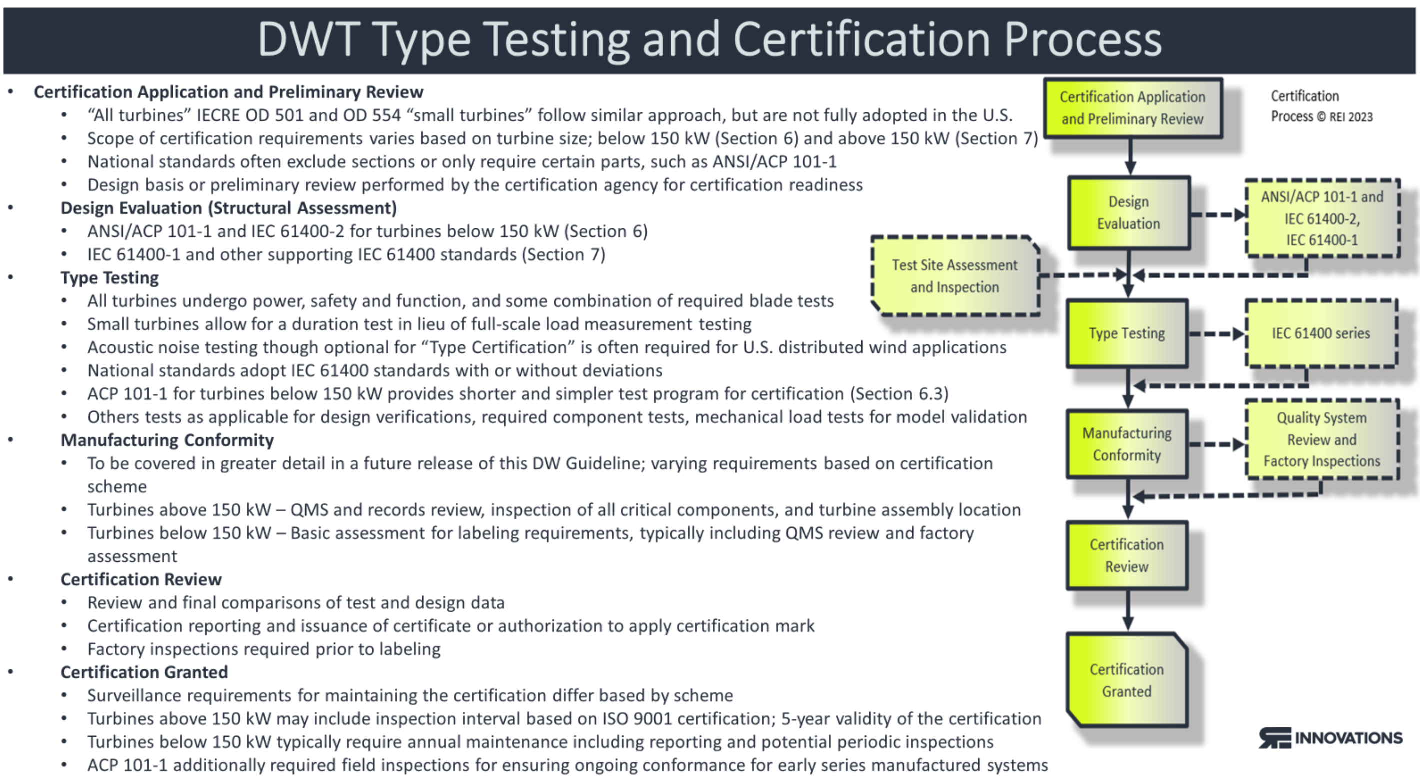


Figure 4 – DWT type certification process illustration

All DWT type testing and certification scopes will include preliminary documentation reviews, thorough design assessments, varying type testing requirements, varying manufacturing conformity requirements, and a final certification approval and authorization. This DW Certification Best Practices Guideline focuses on the detailed requirements for turbines below 150 kW, as turbines above 150 kW are typically evaluated or considered similar to utility-scale wind turbines, which have a well-established and documented path to certification via IECRE OD 501 (IECRE is the IEC System for Certification to Standards Relating to Equipment for Use in Renewable Energy Applications). For turbines under 150 kW, the mechanical and structural elements of certification are defined within ANSI/ACP 101-1-2021, which requires design compliance with the applicable portions of IEC 61400-2 and adapted testing in conformance with a variety of IEC 61400 standards.

The ANSI/ACP 101-1-2021 standard provides a method for certification of wind turbine systems in terms of mechanical and structural safety, reliability, power performance, and acoustic characteristics. It is applicable to electricity-producing wind turbines having a peak power up to 150 kW and is derived from the IEC 61400 wind turbine series of standards, offering a more simplified route for certification compared to the IEC type certification process. Specific differences exist in ANSI/ACP 101-1-2021 to streamline the DWT certification process and reduce barriers to United States market entry. A turbine system includes the wind turbine itself, the turbine controller, the inverter (if required), and all other components between the wind turbine and the point of connection with the electrical load. The standard does not consider towers and foundations as part of the turbine system because it is assumed that conformance of the support structure to the International Building Code, Uniform Building Code, or their local equivalent will be required for a building permit. Tower design requirements, however, must be provided by the turbine system original equipment manufacturer (OEM) to help specify the various tower types that may be used with the certified DWT system.

Section 7 provides specific guidance related to a subset of IEC type certification requirements that are commonly applicable to turbines above 150 kW used in distributed generation applications. For turbines above 150 kW peak power, the process of certification can widely vary in the United States, largely depending on the location or jurisdiction of the installation and the application and use of the turbine and exported power. The overall IEC type certification process is not generally required for wind turbines of any size in the United States, but typically many parts similar to the ANSI/ACP 101-1 process are required. A typical approach referencing the IEC 61400 series of standards is provided in this initial release of the DW Certification Best Practices Guideline. Further guidance will be provided in future releases as additional standards are adopted in the United States over the next couple of years. As such, designers and wind turbine manufactures of turbines above 150 kW should follow the primary set of guidance given in Section 6 while applying the additional considerations given in Section 7 of this initial release of the DW Certification Best Practices Guideline.

References:
Figure 2: Current status and grand challenges for small wind turbine technology

2.3 User's Guide – Table 1

Table 1 is the *DWT Designer Quick Guide*, which outlines typical DWT components or subassemblies and the associated applicable product standard, as well as the associated section of relevant guidance contained in this DW Certification Best Practices Guideline. Experienced users or designers may simply choose to skip to their associated set of requirements, and return users can use Table 1 for quick navigation throughout the sections and relevant components and subassemblies. The applicable standards are referenced from UL 6141 for "Electrical" elements and various IEC 61400 design standards, including IEC 61400-1, IEC 61400-2, and the certification scheme for "Structural" elements. The list may not include all types of components and subassemblies—if not in Table 1, refer to the Table of Contents for identifying the most appropriate section.

Table 1 - DWT designer quick guide

DWT Designer Quick Guide			
Turbine Component or Subassembly	**Applicable Standards**	**Electrical**	**Structural**
Rotating Hub	UL 6141, IEC 61400-1, IEC 61400-2	5.3.1	7.2
Wind Turbine Generators	UL 1004-1, UL 1004-4	5.3.2	n/a
Wind Turbine Motors	UL 1004 series, IEC 60034-1, and others	5.3.2	n/a
Control System and Equipment	UL 6141, UL 1741, IEC 60204-1	5.3.3	n/a
Motor Drives	UL 61800-5-1	5.3.4	n/a
Adjustable Speed Power Drives	UL 61800-5-1 and UL 1741 if conversion	5.3.4	n/a
Converters	UL 1741	5.3.5	n/a
Inverters	UL 1741, IEEE 1547, IEEE 1547.1	5.3.5	n/a
Gearboxes	UL 508, IEC 61400-4, IECRE OD-501-2	5.3.6	6.2, 7.2
Diversion Loads	UL 499	5.3.8	n/a
Emergency Stop	UL 6141, IEC 61400-1, IEC 61400-2, IEC 60204-1	5.4.1	n/a
Disconnect Devices	UL 6141, IEC 60204-1	5.4.3	n/a
Lightning Protection Systems	NFPA 780, IEC 61400-24, UL 1449	5.4.4	n/a
Rotor Blades	IEC 61400-1, IEC 61400-2, IEC 61400-5, IECRE OD-501-1	n/a	6.2, 7.2
Blade to Hub/Shaft Connectors	IEC 61400-1, IEC 61400-2, IEC 61400-8	n/a	6.2, 7.2
Towers	ANSI/ACP 61400-6-2021, IEC 61400-6, IECRE OD-501-3	n/a	6.2, 7.2
Connection to Tower	IEC 61400-1, IEC 61400-2, IEC 61400-8	n/a	6.2, 7.2
Main Shaft/Drivetrain	IEC 61400-2	n/a	6.2, 7.2
Structural for Components	IEC 61400-1, IEC 61400-2, IEC 61400-8, IEC TS 61400-30	n/a	6.2, 7.2
Casted, Forged, or Welded Structures	See "Structural for Components"	n/a	6.2, 7.2
Nacelle Frame	See "Structural for Components"	n/a	6.2, 7.2
Pitch and Yaw Systems	See "Structural for Components"	n/a	6.2, 7.2
Bearings and Bushings	See "Structural for Components"	n/a	6.2, 7.2
Brakes, Couplings, and Locking Devices	See "Structural for Components", UL 6141, IEC 60204-1	5.2	6.2, 7.2
Bolts and Connections	See "Structural for Components"	n/a	6.2, 7.2
Cooling and Heating Systems	See "Structural for Components", UL 6141	5.2	6.2, 7.2
Hydraulic Systems	See "Structural for Components"	n/a	6.2, 7.2
Housings (Spinners and Nacelle Covers)	See "Structural for Components"	n/a	6.2, 7.2
Teetering/Other Hub	See "Structural for Components"	n/a	6.2, 7.2
Control and Safety System Components	UL 6141, IEC 61400-1, IEC 61400-2, IECRE OD501-5, UL 61010-1	5.3.3	6.2, 7.2

2.4 User's Guide – Cost of Certification

The overall cost for certification of a DWT, component, or subassembly would of course include all of the design, research, and development costs to produce and continue to manufacture a compliant product. This would differ widely from one to the next and would be difficult to generalize, so it is not covered in this DW Certification Best Practices Guideline. Table 2 is included for the purpose of estimating the time and cost to certify turbines below 150 kW based on a scale ranging up to $200,000. The table is split between electrical product safety for typical components or systems complying with UL 6141 or UL 6142 on top, and ANSI/ACP 101-1 type testing and certification elements or components on the bottom. An estimate of the average time from initial review to completed certification is given in the table. In the table the cost scale is as follows:

- $ = $0–$25k
- $$ = $25k–$50k
- $$$ = $50k–$75k
- $$$$ = $75k–$100k
- $$$$$ = $100k–$200k

Table 2 - Estimated time and cost scale for certification

Electrical Product Safety Certification Time and Cost Scale (UL 6141/UL 6142)					
Product/System	Design Conformity	Type Testing	Other Costs	Total Cost	Average Time
-	USD $	USD $	USD $	USD $	Months
Turbine System	$	$		$	6
DWT Generator	$	$	$	$$	3
Control System	$	$$	$	$$	4
Control Equipment	$	$		$	2
Motor Drive	$	$		$$	2
Adjustable-Speed Drive	$	$$		$$$	5
Converter	$	$$$		$$$$	5
Inverter	$	$$$$		$$$$$	8
Gearbox	$	$$	$	$$$	4
Diversion Load	$	$		$	1
DWTs Below 150 kW Type Certification Time and Cost Scale (ACP 101-1)					
Certification Element	Design Conformity	Type Testing	Other Costs	Total Cost	Average Time
-	USD $	USD $	USD $	USD $	Months
Preliminary Review	$		$	$	1
Design Conformity	$$		$	$$	2
Type Testing – Power		$	$	$$	3
Type Testing – Noise		$	$	$	2
Type Testing – Duration		$		$	3
Type Testing – S&F		$		$	2
Type Testing – Design Data		$	$	$	1
Type Testing – Loads*		*	*	*	3
Manufacturing Conformity	$		$	$	1
Certification Surveillance			$	$	2
Overall System Time & Cost	$$	$$$	$	$$$$$	7
Turbine Components	Design Conformity	Type Testing	Other Costs	Total Cost	Average Time
Rotor Blade	$$	$$		$$$	8

Tower	$	$		$$	3
Gearbox	$	$$$		$$$	6
Pitch System	$	$$		$$	3
Yaw System	$	$		$$	3
Braking System	$	$		$$	6
Control/Safety System	$	$$		$$	4

*Test cost will vary depending on the turbine size, archetype, design model, and previous test and validation efforts

For electrical product safety, "Other Costs" may include travel or witnessing time, as type testing may typically be performed at a location other than the Nationally Recognized Testing Laboratory (NRTL), such as the component OEM facility or on an installed turbine in the field. Also note that the "Turbine System" cost is low compared to the components cost because the evaluation of the system itself is not complex and assumes all components are already listed, certified, or otherwise approved for use in the turbine system application.

For DW type certification according to ANSI/ACP 101-1, "Other Costs" may include equipment rental or installation costs, test site fees, and others. These cost estimates are purely the cost of certification, meaning they are a budgetary range for the cost estimate from the test or certification organization to perform the required tasks to complete a successful certification program. No indirect costs or internal costs are included in the table. Note also that "Overall System Time and Cost" is an average of the combination of common elements for certification, not including surveillance.

Loads testing is marked with an asterisk because the test cost will vary depending on the turbine size, archetype, design model, and previous test and validation efforts. The total cost range for loads validation testing can be anywhere between $25k and $125k, depending on many factors like the cost of all test equipment and data logging capabilities. It is suggested to work with an independent test organization early in the process to identify the requirements for loads validation testing to obtain accurate estimates from the certification body during application.

An overall cost and time estimate is given for the DW type certification elements, in the cost range of $100k to $200k with an average completion time estimate of 7 months. Where in that cost range the product ends up will depend on the loads validation testing requirement briefly discussed above. It is possible to achieve testing for a lesser cost, and even in a shorter time; this information is given for proper planning and budgeting for certification.

The data in Table 2 are illustrated in Figure 5 showing the percentage of overall cost and time of the electrical product safety certification elements, as well as the elements for DW type certification.

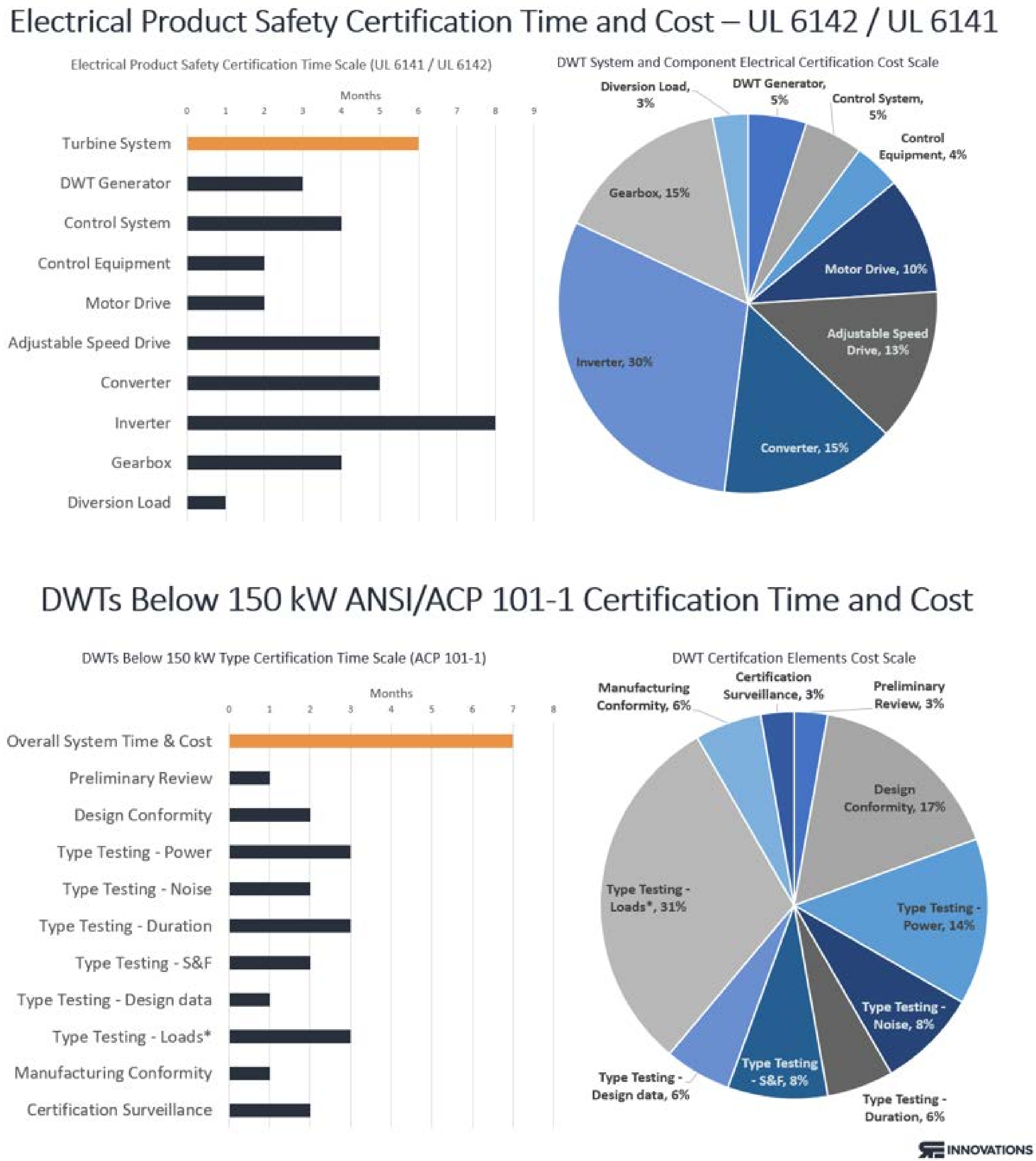


Figure 5 - Certification time and cost estimates for turbines below 150 kW

3 USE OF CERTIFIED DISTRIBUTED WIND PRODUCTS

Section 3 provides an overview of how certifications of DWTs and components or subassemblies are used in the Unites States, related to permitting or tax incentive or rebate programs. First a description is given of typical turbine types that are applicable for use of this DW Certification Best Practices Guideline in Section 3.1, followed in Section 3.2 by an overview of compliance drivers for certification in the United States.

3.1 Typical Distributed Wind Turbine Types

To certify a DWT in the U.S. market, it is necessary to understand what classifies as a DWT, considering the requirements are defined based on turbine size or output power. Several examples, figures, and images of complete wind turbine systems and installations are given, with information extracted from the internet. Figure 6 shows examples of typical horizontal-axis wind turbines (HAWTs) with or without gearboxes that could represent DWT applications even as small as 10 to 20 kW rated output power, or as large as a utility-scale wind turbine.

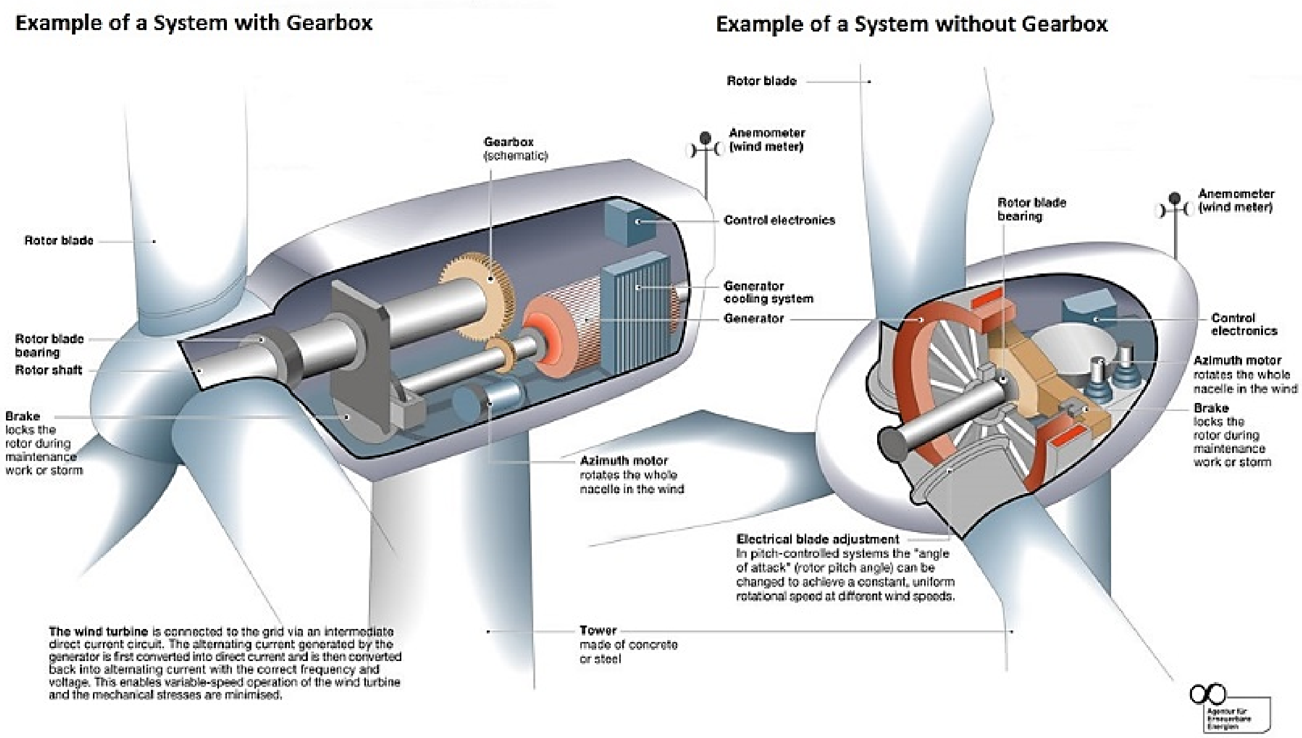


Figure 6 – Example HAWT turbine nacelle system cross sections
Lawrence Berkeley National Laboratory

For this DW Certification Best Practices Guideline, it is primarily assumed that the application is a grid-connected distributed generation application. Off-grid or battery charging systems do not necessarily have the same set of requirements, as the drivers related to compliance are not as impactful. An example single-line component diagram for a typical grid-connected distributed generation application of a DWT is given in Figure 7.

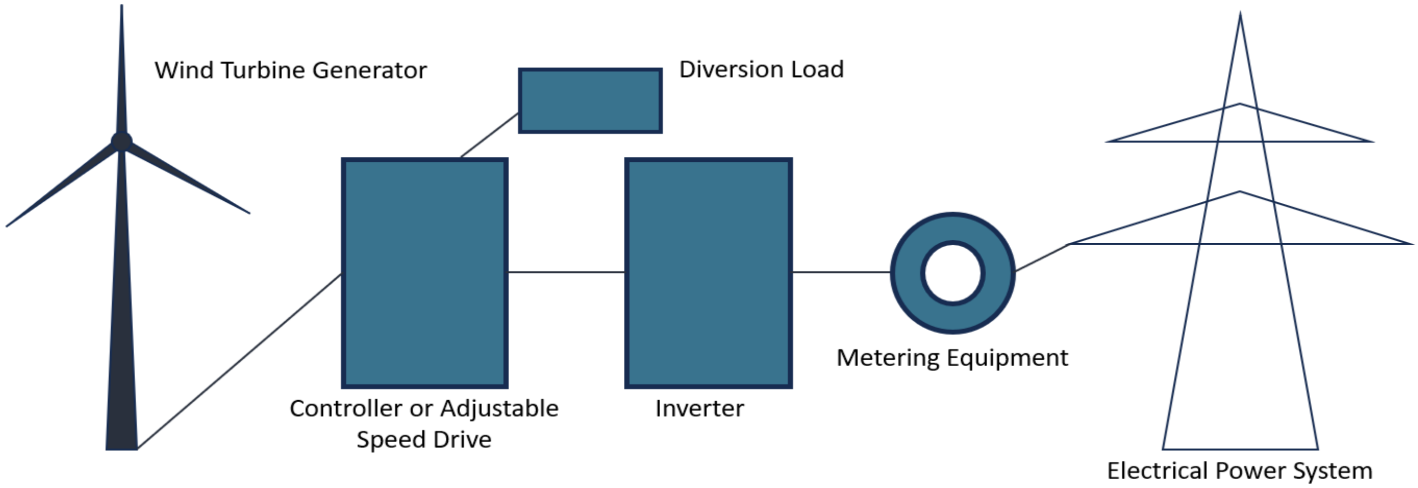


Figure 7 - Example DWT distributed generation application

Several images of common wind turbine configurations are shown in Figure 8 that represent typical HAWT, vertical-axis (VAWT), and shrouded or diffuser-augmented DWTs in distributed generation applications.

Figure 8- Various DWT configuration examples; horizontal axis (top), vertical axis (middle), shrouded or diffuser-augmented (bottom)

For further definition of common DWT sizes, note that the maintenance team MT2 for the upcoming fourth revision of IEC 61400-2 has been approved by the IEC Technical Committee 88 for Wind Turbines to increase the scope of the IEC 61400-2 standard to include "Medium Wind Turbines" ranging from 200 to 1,200 m^2 rotor-swept area. "Micro Wind Turbines" are those below 5 m^2 rotor-swept area, and "Small Wind Turbines" remain those between 5 and 200 m^2 rotor-swept area. Turbines in this size that range up to 1,200 m^2 rotor-swept area are commonly used in distributed generation applications, and can vary widely in configuration or archetype being upwind or downwind, two or more bladed, and with active or passive power and control mechanisms.

References

Figure 6: *Lawrence Berkeley National Laboratory*

MT2 update for Folkecenter Sept2023, Brent Summerville, NREL

3.2 U.S. Distributed Wind Turbine Certification Compliance Drivers

Product certifications are useful for many reasons related to ensuring quality and mitigating risks. For DWTs, the drivers for compliance in the United States are what guide the certification requirements. Figure 9 shows typical U.S. market compliance drivers related to DWTs in distributed generation applications.

Figure 9 - Certification compliance drivers

The compliance drivers can generally be split into two main areas: permitting and local regulations, and eligibility for rebate, incentive, or other funding programs. These two areas are discussed further in Sections 3.2.1 and 3.2.2, respectively. Certification is always useful for a baseline of product quality and mitigation of typical risks for the type of product and application. With use of established industry codes and standards, a minimum level of quality is established through the certification process and is also useful in early-concept or proof-of-concept design stages. Regardless of where "local" may be, each location will have differing requirements based on local laws and energy regulations. In the

United States, with more than 500 jurisdictions, the regulations can be based on certification requirements or similar engineering practices. In markets around the world there will generally always be a similar set of local electrical requirements coupled with structural and performance resulting from IEC 61400 related evaluations and tests.

3.2.1 Permitting, Zoning, and Local Regulations

For DWT installations, several types of permits are often required for compliance with local zoning regulations, county or state design codes, and the NEC. Electrical permitting is typically geared solely toward compliance with the NEC. Building permits are typical for permanent installations, but towers and specifically DWT installations often fall under separate requirements governed locally by special-use or conditional-use permits. All of these items are planned and reviewed by local planning authorities and boards prior to approval for construction and are monitored throughout the construction process until electrically completed and connected to the utility.

Electrical permitting in the United States is governed by adoption of versions of the NEC in the various states and jurisdictions. One of the simplest ways to visualize and understand the range of requirements from various markets within the United States is to focus on the utility interconnection requirements. IEEE maintains a map of states that have adopted the latest set of interconnection requirements from IEEE Standard 1547 – 2018 or later, and the map below is extracted from a late 2022 presentation given by Electric Power Research Institute (EPRI). Detailed information can be found at the website link that follows the map and is updated over time based on adoption at the local level.

The states that are color-coded have adopted or plan to adopt the latest set of requirements, which this DW Certification Best Practices Guideline is designed for. For electrical permitting, compliance with UL 6141 or UL 6142 will be required per the NEC (see Section 5).

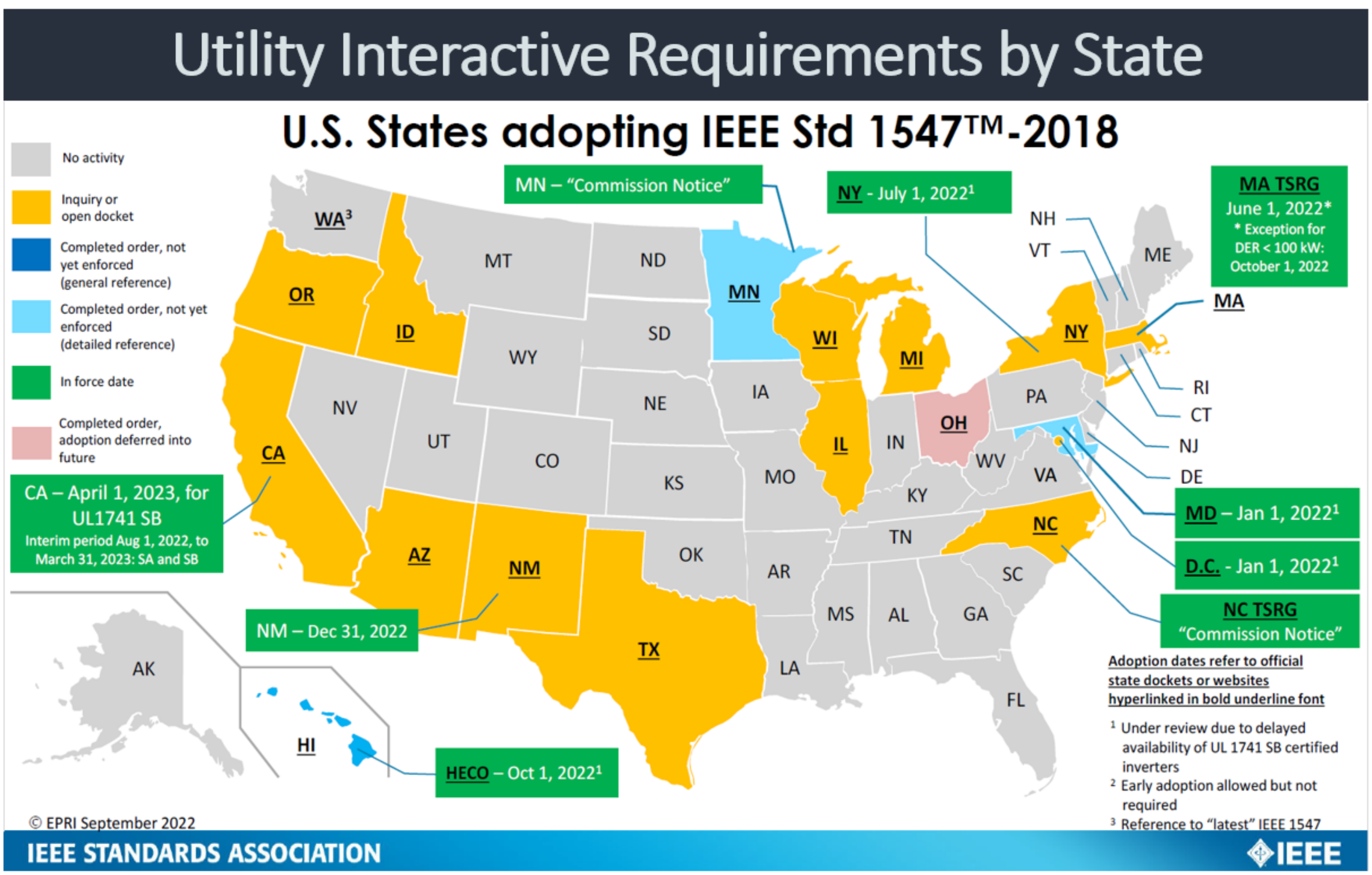


Figure 10 - Map of utility-interactive requirements in U.S. by state
IEE Standards Coordinating Committee 21 (SCC21)

Structural assessments would fall under the special-use, conditional-use, or building permit for construction of a permanent installation. These can vary from jurisdiction to jurisdiction, but they generally all cover project and site planning and consideration, the effects on local wildlife and people, and proper design of the tower and foundation. Towers and foundations, or support structures, and the requirements related to DWTs will be covered more specifically in a future release of this DW Certification Best Practices Guideline. Note that certification in accordance with the ANSI/ACP 101-1 standard requirements is not mandatory for installation or permitting approvals.

The Distributed Wind Energy Association has a "DWEA Permitting & Zoning Resource Center" that can be found at https://distributedwind.org/zoning-resource-center/, which includes a toolkit for local governments.

3.2.2 Tax Rebates, Incentives, and Other Programs

Certification in accordance with ACP 101-1 standard requirements is not necessarily mandatory for installation or permitting approval. The ANSI/ACP 101-1-2021 certification is, however, used for eligibility for U.S. tax incentives through the Investment Tax Credit (ITC) and is similarly required for other federal, state, and grant or incentive program eligibility. For additional information regarding ITC and other U.S. programs, please visit the federal and state policy pages on the DWEA Policy page.

4 NORTH AMERICAN THIRD-PARTY PRODUCT CERTIFICATION

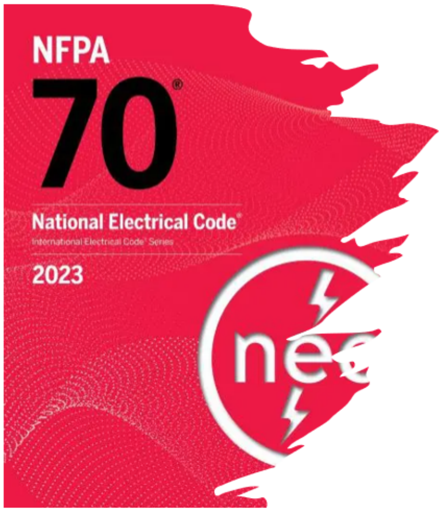
This section provides general information and guidance related to the third-party certification process in North America. An overview is provided Section 4.1 related to product certifications and compliance with the NEC. General requirements related to DWTs are discussed in Section 4.2. Brief overviews of test and certification bodies are in Section 4.3, and standards and standards development organizations are discussed in Section 4.4. In future releases, Sections 4.3 and 4.4 will be updated to include greater detail.

4.1 Product Certification Overview

Product certification is the process of certifying or attesting that a certain product or system meets specified design criteria and has also passed performance and safety/quality testing that complies with relevant codes and standards. In North America it is mandatory for all electrical product safety certifications to be performed by an approved and accredited third-party test and certification laboratory. These labs and agencies must be accredited to all of the applicable standards for evaluation and testing and have them specifically identified on their accreditation scopes for NRTL status from the Occupational Safety and Health Administration (OSHA). The testing laboratory must be accredited for ISO/IEC 17025 for test lab qualification and accreditations. Accreditations may be provided by various accreditation providers, as long as they are all approved under the International Laboratory Accreditation Cooperation. Each NRTL uses their own recognized certification marks. Upon completion of the certification process, the NRTL authorizes the product manufacturer to apply their registered certification mark on the product or system.

These requirements primarily apply in the case of electrical product safety certifications, outlined in Section 5 of this Guideline. For ACP 101-1 and IEC 61400 type certification, the requirements differ because they exist under different certification schemes, which are further discussed in Sections 6 and 7. Many NRTLs are qualified for various certification schemes internationally.

Electrical product safety regulations for the purposes of the information contained within this DW Certification Best Practices Guideline are based on the requirements outlined in the NEC, which is a NFPA code—NFPA 70. Without third-party proven compliance, an inspector or local Authority Having Jurisdiction (AHJ) can deny approval for the installation and connection to the electrical network. The NEC covers a wide range of products, but only those applicable to the product being considered would be required. Those requirements that are typical for DWT applications and installations are discussed further in this section.



- 2023 latest edition
- Applies to wide range of electrical products
- Article 694 Wind – all components listed and labeled (i.e. certified)
- UL 6141 and UL 6142 specifically referenced for wind systems
- General sections, special sections, special equipment (incl. wind), and others
- Field labeling still allowed – single label/application, same requirements
- Additional disconnects, protection relays, labeling, wiring practices, and grounding requirements
- Similar requirements to the prescribed standards in this DW Guideline
- Turbine shutdown requirements
- Interconnection equipment Article 705
- IEEE 1547 and IEEE 1547.1 testing specifically referenced

Figure 11 - NEC, NFPA 70 overview

Figure 11 makes reference to field labeling. Electrical product safety certifications can come in different forms, and a field label is a single turbine installation evaluation and is not equivalent to a classification listing of a DWT system. Other than a listing commonly referring to a "Public Listing" where the certification and product information are available on the NRTL website directories, a listing actually means that the NRTL has tested representative samples of a product and determined that the product meets all specific, defined requirements. Figure 12 further describes the various types of certifications that are applicable to DWT systems and components.

Electrical Product Safety Certification Types

Classification Listing of a Wind Turbine System

- "Listing" = public listing of the Certificate or other Certification documents.
- 3rd party accredited Nationally Recognized Testing Laboratories (NRTL)
  - OHSA's NRTL Program, Scopes identify allowable standards
- "Classification Listing" typically used for a grouping of components and subassemblies that on their own do not make up a complete system usable to the consumer
- UL 6141 or UL 6142 applicable listing standards

Recognition Listing of a Component or Subassembly

- Listing – full compliance with the product standard (e.g., inverter UL 1741)
- Recognition Listing – partial compliance or incomplete on its own, requires other system components for compliance with the product standard (e.g., generators UL 1004 and controllers UL 1741)
- Limited Evaluations in rarer cases where component is evaluated for use only in system
- Unlisted equipment, additional surveillance requirements

Field Label of single turbine system installation

- In lieu of the above listing, classification, and recognition
- NEC and UL 6141 or UL 6142 typically referenced by AHJ / Inspector
- Same component and subassembly requirements
- Same interconnection requirements
- Single label once approved
- Custom, one-off approach, some exceptions may be allowed by AHJ with additional protections employed

INNOVATIONS

Figure 12 - Electrical certification types and modules for DWTs and components

A recognition listing of a component is similar to a full listing; however, it is often not complete on its own and is part of a larger system classification listing. The recognized component cannot be directly sold and used on its own to generate electricity and connect to the electrical network. Recognitions will allow for some items of design or test requirements to be excluded or considered not applicable because there are other components in the overall system construction that address the requirement. These items are often identified as conditions of approval or acceptability (COA) of the recognized component and are documented in the certification reports for the component itself by the certification agency. Classification listings may also come with COA—for example, that the various parts must be used together in a system that replicates how it was tested in the field as part of the certification process.

4.2 General Requirements Relating to Distributed Wind Turbines

National Electric Code NFPA 70 Article 694 requires a wind turbine system and its components be listed and labeled for their intended use/application. NEC is an installation code, and a majority of states and jurisdictions in the United States are now following the 2017 version, which initially implemented the requirement for "listing and labeling" of all wind turbine components and systems. The current NEC 2023 version has not made significant changes in recent years; however, one "note" was added specifically referencing UL 6141 for turbines permitting entry and UL 6142 for small turbines where entry of personnel into the tower or nacelle are not permitted. For understanding which version of the NEC is required in various jurisdictions around the United States, NFPA maintains a map of code adoption on their website (https://www.nfpa.org/NEC/NEC-adoption-and-use/NEC-adoption-maps). For compliance with NEC, and for permitting approval, local inspectors will seek proof of compliance of the system and components. Regardless of adopted version, typical wind markets in the United States have adopted at least the 2017 version as noted above, and as such still require listed and labeled components and systems. This is best accomplished via certifications to UL 6141 or UL 6142.

UL 6141 covers wind turbine systems and electrical subassemblies where a user or service person can or is intended to enter the turbine to operate it or perform maintenance. The wind turbines can be intended for use in utility-interactive, grid-tied applications that operate in parallel with an electric power system to common or stand-alone loads. Small wind turbine (SWT) power, control, and protection systems are only evaluated to the extent that they function within the manufacturer's specified limits and response times. The users, operators, and service persons intended to enter this wind turbine system are expected to have necessary knowledge of its operation and reasonably foreseeable hazards. These individuals are expected to be equipped with necessary equipment for the application and hazard.

UL 6142 covers SWT systems and electrical subassemblies intended for use in stand-alone (not grid-connected) or utility-interactive applications. An SWT under UL 6142 is a turbine where a user or service person cannot or is not intended to enter the turbine to operate it or perform maintenance. SWT power, control, and protection systems are only evaluated to the extent that they function within the manufacturer's specified limits and response times. These functions are evaluated with respect to risk of electric shock and fire. It is intended that the evaluated electrical subassemblies that address power transfer control and protection functions are coordinated with the mechanical and structural limitations specified in AWEA 9.1 (also, ANSI/ACP 101-1-2021) or IEC 61400 series of documents.

The electrical product safety certification process will typically consist of the modules identified below. Please note that these modules may differ slightly from one NRTL to another, but the same approach will apply:

1. Documentation Desktop Review
2. Constructional Evaluation
3. Type Testing
4. Final Evaluation
5. Factory Inspection
6. Labeling and Certification

7. Follow-up Certification (Certification Maintenance).

These topics are discussed further below; however, items 4 through 7 above will often vary from one certification agency to another and are not covered in in this Guideline in detail. General guidance is briefly provided below.

Documentation desktop reviews are typically the first step in the process. This is often a dump of all electrical documentation on the certification agency, and a preliminary gap analysis is performed with the standard requirements. Typically, at this stage a review of only UL 6141 is performed, unless it is known that the DWT system contains other unlisted or unrecognized major components as identified in Clause 4 of the standard. In all cases, areas of the standard that are not applicable to the DWT system are identified as such by the certification agency. The desktop review typically concludes with a findings letter from the NRTL that will outline the gaps and issues in the design and identify additional information needed to perform the constructional evaluation.

The constructional evaluation is often a more detailed, clause-by-clause review of the standard simultaneously with a production version of the component. Often, provision of the component may be requested by the NRTL at various stages of assembly in the manufacturing process. For example, for the generator, typically a partially assembled sample (or multiple samples) is requested where the rotor and stator assemblies are separated such that the internal construction can be reviewed. For boxes or enclosures that are held together via hardware, the NRTL often can disassemble with minimal input from the turbine certification applicant. During the constructional evaluation, a test plan will be developed that will outline all the required tests as well as the detailed test setup and parameters for each test.

Once this evaluation is complete, multiple fully assembled and production test samples may be requested by the test laboratory for testing. Multiple samples are often requested because some tests can be destructive, and other samples will be needed to continue the testing and certification process. Safety-related control system testing as outlined in sections below can often be a combination of field testing of fully installed systems and lab testing on individual components.

After successful completion of the entire test plan, the NRTL will review the test results and perform a final update to the constructional evaluation for items that were pending the results of testing or respond to findings by the certification applicant that were identified in previous evaluations. At this stage, certification documentation and reports are drafted and communication begins regarding initial factory inspections and follow-up/annual certification requirements.

For any major components in the system that are purchased off-the-shelf and declared as certified by the manufacturer, such as the inverter, many supporting documents will still be requested by the NRTL to support the certification and to ensure that the latest and most applicable requirements have been applied, as some certifications may be to earlier or outdated versions of standards, or may not consider DWT applications. Typically, the certification reports including performed tests are required, as are any test data from the certification program of the previously approved component.

Each agency will also have differing requirements for their initial factory assessment/inspection requirements for labeling. A factory inspection is required at the applicant facility where the label is applied. Inspections will recur every 2 years. These inspections follow ISO 9001, but certification to ISO standards is not mandatory for electrical product safety certifications.

4.3 Nationally Recognized Testing Laboratories and Certification Bodies

This section provides a brief description of various NRTLs and certification bodies that may have accreditation scopes suited to provide various certification types related to DWTs and components. Future versions of this DW Certification

Best Practices Guideline will include additional information on typical test and certification bodies, their certification directories, and other information.

An NRTL is an independent organization that certifies products for the U.S. market. NRTLs are recognized by OSHA under Federal Code 29 CFR 1910.7 for products to be used in U.S. workplaces. OSHA maintains a list of qualified bodies, including the standards for which they are qualified, which can be found here: https://www.osha.gov/nationally-recognized-testing-laboratory-program/current-list-of-nrtls.

This list shows only a few NRTLs that can consider and certify according to the full UL 6141 or UL 6142 scope, including classification listing of the entire system. Several other NRTLs, though, are still qualified for listing, classification, or recognition of many of the DWT components discussed in this Best Practices Guideline.

For DW type testing and certification in North America, the list of certification bodies is based on size. For turbines below 150 kW, the Small Wind Certification Council is the primary offeror of wind turbine certification services according to ANSI/ACP 101-1. Their website provides their procedures and supporting application information as well as the certification directory.

For turbines above 150 kW, any Renewable Energy Certification Body (RECB) under the IECRE Wind Sector is qualified for the various parts described in this Best Practices Guideline. Several other certification bodies are qualified outside of the IECRE scheme for various markets or other certifications types. The list of IECRE RECBs can be found here: https://www.iecre.org/members/certification-bodies-recbs. Additional guidance related to turbines above 150 kW, international markets, and IECRE will be provided in future releases of this Best Practices Guideline.

4.4 Standards Development Organizations and Accreditation Bodies

In future releases of this DW Certification Best Practices Guideline, this section will summarize the standards development processes that relate to the various standards referenced herein. It will also describe how to get involved to enact change in the wind turbine standards.

Note that UL offers free digital versions of most of their published standards, with registration of a free account in their online standards store, here: https://www.shopulstandards.com/Catalog.aspx.

It is advised that those utilizing this DW Certification Best Practices Guideline visit the site and create an account for ease of viewing the standards and clauses referenced herein.

5 DWT ELECTRICAL PRODUCT SAFETY CERTIFICATION

Section 5 covers detailed information related to electrical safety certification of DWT systems and components. An overview of the process and requirements is provided in Section 5.1, followed by more specific requirements for DWT system certifications in UL 6141 or UL 6142 in Section 5.2, including comparisons between the two. Section 5.3 discusses component requirements for common electrical components of DWT systems such as generators, control equipment, inverters, and others. Other common systems and protections and associated requirements are discussed in Section 5.4, including emergency stops, disconnect devices, and others. Wiring methods, terminations and connection requirements are outlined in Section 5.5 for acceptable wiring practices, cable twist loops, slip rings, bus bars and others.

5.1 DWT Electrical Systems and Components

The specific requirements for compliance with UL 6141 for individual components or subassemblies are outlined below. These requirements are organized in a similar manner to the UL 6141 standard, Clause 4. The intention of the information below is to outline any standard requirements that are likely applicable to various parts of a typical wind turbine system. This information can be used to understand the basic requirements and any gaps existing in current design documentation.

Note that when evaluating for certification, NRTLs will typically assume all components of a wind turbine system are appropriately approved to the referenced standards. This is often not the case, as many components are often custom or not evaluated for the intended use. As such, in addition to the UL 6141 requirements outlined in Section 5.2, Section 5.3 further details the design, test, and certification requirements of several common wind turbine system components.

If a component is not listed in this DW Certification Best Practices Guideline or in UL 6141/UL 6142, then that component at a minimum must comply with all applicable sections of UL 508A, UL 61800-5-1, or UL 60947 along with any of the “Part 2” UL 60947 standards given in the Appendix. Where none of these adequately cover the construction of the assembly or component, NFPA 79 will be applied.

Likewise, if a component is not listed in this DW Certification Best Practices Guideline or in UL 6142, then that component at a minimum must comply with all applicable sections of UL 1741, UL 508, or NEC if neither of the previous adequately cover the construction of the assembly or component.

In UL 6141, “medium voltage” is defined as circuits operating above 1,000 VAC/1,500 VDC nominal. In all cases, components of the wind turbine system must be used in accordance with their ratings for the intended conditions of use, and as such must be rated for the electrical and environmental conditions expected during use. Enclosure ratings can be established following UL 50E, IEC 60529 (IP Code), or NEMA 250 (100 V max). For UL 50E/NEMA 250: types 3R, 3RS, 5, or 12 enclosure ratings are suitable depending on application. For IEC 60529 ratings of IP43, IP54, or IP65 address most internal enclosure requirements.

5.2 UL 6141/UL 6142 General Requirements

UL 6141/UL 6142 certifications are considered a system-level classification listing. Meaning the certification is an evaluation of a system of components, subsystems, or subassemblies (collectively referred to as “components” going forward), that are presumed to be listed, recognized, or otherwise approved. The various components of a DWT system are required to comply with the requirements for that specific component and are described in Section 4 of UL 6141/UL 6142. In the current edition of UL 6142, some standard references may be outdated but should be referred to additionally for Section 4 compliance. Please note that a component with a CE mark of conformity is not presumed to comply with UL product certification standards. CE marking is a European Union mark of conformity that has different requirements and is not applicable in North America.

UL 6141 provides electrical system general safety requirements regarding several other areas:

- Spacings (Clause 5)
- Components and circuits rated or operating between 601 and 1,000 V (Clause 6)
- Grounding (Clause 7)
- Safety Related Controls Systems (SRCS, Clause 8)
- Manual Shutdown (Clause 9)
- Self-Excitation (Clause 10)
- Ratings (Clause 11)
- Working Space (Clause 12)
- Markings – System and Subassembly Components (Clause 13)
- Markings – Cautionary Markings (Clause 14)
- General Installation, System, and Subassembly Instructions (Clause 15)
- Appendix A – Reference Standards for Components
- Appendix B – IEC Standards for Components
- Appendix C – IEEE Standards for Components

Though not a part of UL 6141, Clause 9 of UL 6142 covers utility grid interaction and requires that the utility-interactive device is compliant with UL 1741, IEEE 1547, and IEEE 1547.1. If connected to an electrical power network or system, the system must also be evaluated and demonstrated to operate safely in zero-voltage, low-voltage, and high-voltage ride through situations, or similarly defined limits of operation. Tests are verified by operating the wind turbine at several points, including the minimum and maximum voltage, frequency, and duration limits of the specified range of operation. IEC 61400-21 may also be referenced or required, especially for turbines above 150 kW or pursuing IEC type certification (Section 7). These items are discussed further below.

Many of the items in Clause 4 will additionally apply as mandatory and are further described in Section 5.3 of this Certification Best Practices Guideline.

Clause 5 for spacings is applicable; however is often achieved by using listed/recognized components and implementing installation practices that are in compliance with NEC. Spacings requirements given in 5.2–5.5 of Clause 5 are applicable for components and equipment within the system. UL 508 or UL 61800-5-1 is required in UL 6141 for electrical spacings of components and equipment rated 1,500 V or less. UL 840 and IEC 61800-5-2 are also referenced as an approach for determining spacings requirements and are application-specific or for use in exceptions to the requirements. A Pollution Degree 3 is applied to determine creepage spacings in general locations within a wind turbine, and Pollution Degree 4 is applied where conductive pollution may be present, such as brake dust or brush dust. Steps can be taken to reduce to a Pollution Degree 2, with noted exceptions. Overvoltage Category IV is also applied in general locations within a wind turbine, unless Category IV compliant surge suppression devices listed to UL 1449 are installed in close proximity to the equipment being protected. Surge protective device failures must be indicated in the control system. Most DWTs are not expected to have any circuits operating above 1,500 V and are not included in this DW Certification Best Practices Guideline. Additional requirements may exist above 1,500 V.

Clause 6 is applicable for components and circuits rated or operating between 601 and 1,000 V. The requirements in Clause 6.2–6.4 are applied when there is an absence of a component standard for greater than 600 V use, and the requirements relate to spacings at the higher voltages. Components or systems operating between this range must meet the spacings requirements in Table 6.1 or Clause 6 unless the component standard spacings are greater. UL 6142 Clause 6 covers components and circuits rated or operating between 601 and 750 V.

Clause 7 for grounding will certainly be required as well; however, it will again largely rely on the component certifications within the system, as well as installation practices that are in compliance with NEC. NEC will carry specific grounding and bonding requirements, but typically these are also found in component certification standards, or adopted in such a way as to lead to compliance with NEC. Turbine components and subassemblies must be provided with a grounding means that is compliant with both NEC and UL 1741. Typically, for a wind turbine system there is a mixture of grounding methods in combining the system of components, but ultimately the path to ground must be documented. Grounding and bonding are discussed throughout this DW Certification Best Practices Guideline for various components.

Clause 8 is SRCS. There is direct overlap between SRCS and safety and function and design requirements for wind turbines as outlined for the control and protection system in IEC 61400 standards. UL 6141 has been updated more recently than UL 6142 for small (non-entry) turbines and includes the most up-to-date evaluation procedure that would be followed for a DWT. UL 6142 is expected to be revised soon, and this information will be updated in future revisions of this DW Certification Best Practices Guideline. More information regarding SRCS, and other items pertaining to the controller and control system compliance are given in Section 5.3.3.

Clause 9 contains specific requirements regarding manual shutdown of the turbine. The shutdown must result in a controlled rapid transition from rotation and power production to parked rotor and yaw motion, and also de-energize or interrupt the turbine output power circuit. For UL 6142 machines, yaw motion does not have to be parked, as long as service manuals and procedures provide clear instruction on safe conditions for service of the machine. The turbine must also be provided with a manual shutdown button/switch and a shutdown procedure. Turbines under 40 m^2 swept area are not required to provide a manual shutdown button or switch, as long as a procedure exists for manual shutdown. In expected future updates to UL 6142, manual shutdown (Clause 10) will be revised to alternatively allow for manual shutdown compliance if designed according to ACP 101-1 or IEC 61400. Emergency stops have different requirements and are described in Clause 4.16 of UL 6141/UL 6142 and covered within Section 5.3 below.

As referenced previously, Clause 9 of UL 6142 covers utility grid interconnection and interactions**.** The system must operate safely over the specified range of grid interconnection operation parameters such as voltage and frequency ride through or other defined operational limits. This is typically verified via test. For connections to the electric utility at distribution levels, the utility-interactive device or DWT system must comply with:

- UL 1741, The Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
- IEEE 1547, Interconnecting Distributed Resources with Electric Power Systems
- IEEE 1547.1, Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.

Exceptions to this exist for DWT manufacturers that may not provide or produce a specific inverter or device with their system. In this case, the inverters are to be additionally marked as not having been evaluated for utility interconnection protective functions, and as such must be provided with a utility relay protection device in accordance with local codes and regulations. The marking is placed on the label, as well as in the product instruction manuals. The standards referenced above would still apply to a utility relay protection device, but the AHJ may accept other UL standards such as 508, as long as the required functionality of the protection device is suitable for grid code compliance. UL 1741 also allows for special-purpose utility-interactive applications with manufacturer-defined grid interconnection requirements; also see inverters in Section 5.3.5 in future releases of this Guideline.

Clause 10 is applicable with respect to protection against unintentional self-excitation during all foreseeable loading and unloading conditions, including loss of grid connection. Verifications are required for both normal and single-fault conditions. These verification tests should be included as part of SRCS testing. This is covered in Clause 11 of UL 6142.

Clause 11 outlines the ratings that must be defined for the wind turbine system at a minimum and that must be validated via compliant testing with IEC 61400-12-1 power performance testing. This is another area where a direct link between electrical compliance and IEC/ACP compliance is presumed necessary. This is covered in Clause 12 of UL 6142.

Clause 12 covers service personnel safety and specifically “Working Space” requirements. NFPA 79 is again referenced here in UL 6141, and even though NFPA 79 is only applicable up to 600 V, it is used within UL 6141 here for establishing compliance for wind turbines rated up to 1,000 V nominal. Article 11.5 of NFPA 79 is required for any electrical enclosure, compartment, or specific area within the wind turbine (including any part of the tower or support structure) that is likely to require a service person to enter to wire, examine, adjust, or perform maintenance or other service. Lockout-tag-out procedures should be defined, and any area of a wind turbine that requires lockout for worker safety must be provided with disconnecting means for the turbine that is at the point of connection of electric power to the wind turbine (or affected circuit), be readily accessible, and be capable of being locked in the open position.

Clauses 13 and 14 identify the markings and cautionary warnings that are mandatory to be placed on the label, and Clause 15 includes general required information to be included in the various product manuals, outside of those already specified in IEC 61400 standards.

Appendix A of this DW Certification Best Practices Guideline provides a list of standards for components and subcomponents relating to electrical product conformity. The list is provided for reference during the development of the system and for use to ensure certification of subcomponents to appropriate UL standards when building components and subassemblies. UL 6141 provides IEC and IEEE reference standards for components in addition to UL references, and they are also included in the table.

5.3 DWT Common Electrical Component Requirements

For compliance with component and system certification requirements for UL 6141 and UL 6142, it is always suggested to utilize off-the-shelf appropriately certified and rated equipment where possible. When not possible, or when using a custom-designed component, additional guidance is given in the subsections below to aid in developing common DWT system components. In some cases, direct reference is made to external standards where they exist, and in other cases the requirements are specified in UL 6141, UL 6142, or UL 1741.

5.3.1 Rotating Hub

All turbines have rotating parts that are subject to forces of rotation, acceleration, and deceleration. They must be verified as constructed of sufficient mechanical strength to withstand the mechanical forces defined within IEC 61400 design load cases and situations, including emergency shutdown. All electrical components within the hub—for example, the generator, control equipment, and others—are required to be housed within suitably rated enclosures for the application. It is expected that the entire assembly must also comply with rain and, if desired, sprinkler testing. Often, it is desirable that common tests like rain testing for classification listing of the electrical components within the hub be performed simultaneously once on a fully assembled hub.

5.3.2 Wind Turbine Generators and Motors

This section provides more detail on the typical design and test requirements for a wind turbine generator. This is due to the fact that a majority of wind turbine generators are not certified appropriately off the shelf or are custom designed for the specific wind turbine application. According to UL 6141, rotating electrical machines must comply with the applicable parts of UL 1004. Those parts are as follows:

- Standard for Rotating Electrical Machines – General Requirements, UL 1004-1
- Standard for Impedance Protected Motors, UL 1004-2
- Standard for Thermally Protected Motors, UL 1004-3
- Standard for Electric Generators, UL 1004-4

- Standard for Servo and Stepper Motors, UL 1004-6
- Standard for Electronically Protected Motors, UL 1004-7
- Standard for Inverter Duty Motors, UL 1004-8.

For the generator, the applicable parts are limited to UL 1004-1 and UL 1004-4, and the certification is a recognition listing. The other UL parts are applied to motors used for motor drive assemblies, for example. Note that even if connected to an inverter, the generator is not inverter duty. Also, there is not commonly an enclosure for the generator, and as such it is susceptible to required environmental tests. The rain test and others are often combined with other up-tower assemblies and electrical components to accomplish testing for multiple components at one time. For this reason, it is recommended that the recognition listing of the generator to UL 1004-4 be performed simultaneously with the UL 6141/UL 6142 classification listing to aid in justifying the conditions of acceptability for a variety of applicable tests.

The IEC 60034 series is also acceptable assuming all 60034-1 safety and all applicable 60034-2 subparts have been considered. Refer to the list of standards for a full list.

5.3.2.1 Motors

All motors must meet applicable parts of UL 1004 for impedance protected motors, thermally protected motors, servo and stepper motors, electronically protected motors, and inverter duty motors. The IEC 60034 series is also acceptable, assuming all 60034-1 safety and all applicable 60034-2 subparts have been considered. Refer to the list of standards for a full list.

5.3.2.2 Wind Turbine Generator Requirements – UL 1004-1

The Standard for Safety: UL 1004-1 Rotating Electrical Machines – General Requirements covers rotating electrical machines and linear motors up to 1,000 V, AC or DC.

Often, the largest area of consideration is the insulation system and classification of components. The UL database also maintains a detailed list of UL 1446 approved insulation systems. The entire system of components must have been tested and certified as a system previously to be classified as an insulation class greater than Class A.

Class A insulation systems, however, do afford several additional exceptions throughout the evaluation and testing process, and if winding temperatures never exceed 100°C during temperature testing, a Class A system can be declared. Use of appropriately rated and approved film-coated magnet wire also affords many exclusions within the standard.

For some requirements, the terms “motor” or “machine” can be used interchangeably with “generator”; however, Table 3 outlines typical construction design and test requirements for wind turbine generator applications. Some off-the-shelf options may exist that are UL 1004 approved or claim compliance. In all cases, the supplier should be able to provide evidence from a third party or provide online database references for listed or otherwise certified products. Often, UL 1004-4 is not considered, and additional testing based on application may be required. See 5.3.2.3 below.

Table 3 - Applicability of UL 1004-1 subclauses for DWT generators

Applicability of UL 1004-1 Subclauses for DWT Generators			
Subclause	**Title**	**Required**	**Comment**
1 - 5	Various - General	Yes	As applicable
6	Current and Horsepower Relation	Yes	
7	Motors Provided with Controls	**NO**	Motor requirements
8	Mechanical Assembly	Yes	
9	Frame and Enclosure	Yes	
10	Grounding	Yes	
11	Grounding Identification	Yes	
12	Ventilation Openings	Yes	If ventilated
13	Accessibility of Uninsulated Live Parts, Film-Coated Wire and Moving Parts	Yes	
14	Protection Against Corrosion	Yes	
15	Cord-Connected Motors	**NO**	Motor requirements
16	Input and Output Connections	Yes	
17	Factory Wiring Terminals and Leads	Yes	As applicable
18	Spacings	Yes	
19	Current-Carrying Parts	Yes	
20	Internal Wiring	Yes	
21	Bonding for Grounding	Yes	
22	Electrical Insulation	Yes	See exceptions for film-coated magnet wire
23	Insulation Systems	Yes	
24	Windings	Yes	
25	Brush Holders	Yes	As applicable
26	Capacitors	Yes	As applicable
27	Switches	Yes	As applicable
28	Nonmetallic Functional Parts	Yes	Class A insulation exceptions
29	Traction Motors	**NO**	Motor requirements
Performance (Testing)			
30	General	Yes	
31	Ratings Tests	Yes	Generator output
32	Temperature Test	Yes	
33	Mechanical Tests	Yes	Depending on materials, some tests not required; rain test always required

Applicability of UL 1004-1 Subclauses for DWT Generators			
Subclause	**Title**	**Required**	**Comment**
34	Strain Relief Test	**NO**	Typically, only for motors
35	Push-Back Relief Test	**NO**	Typically, only for motors
36	Resilient Elastomer Mounting Tests	**NO**	Typically, only for motors
37	Dielectric Voltage Withstand Test	**Yes**	
38	Limited Short-Circuit Test	**Yes**	Depends on construction, may not be required
39	Grounding Test	**Yes**	Combine with other turbine components
40	Oil Compatibility Test	**Yes**	As applicable
41	Electrolytic Capacitor Overvoltage Test	**Yes**	As applicable
42	Locked Rotor Test for Nonmetallic Functional Parts	**NO**	Typically, only for motors
Manufacturing and Production Tests			
43	Production-Line Dielectric Voltage Withstand Test	**Yes**	100% tested
Markings			
44	General	**Yes**	
45	Legibility and Permanence	**Yes**	
46	Environmental Related Markings	**Yes**	
Instructions			
47	General	**Yes**	

5.3.2.3 UL1004-4 for Electric Generators in DWT Applications

The Standard for Safety: UL 1004-4 Electric Generators additionally covers electrical generators or alternators rated up to 34,000 V.

Table 4 - Applicability of UL 1004-4 subclauses for DWT generators

Applicability of UL 1004-4 Subclauses for DWT Generators			
Subclause	**Title**	**Required**	**Comment**
1 - 4	Various - General	Yes	Requires compliance with UL 1004-1, per the above section
Performance (Testing)			
5	Overspeed Test	Yes	Always required
6	Short-Circuit Test	Yes	If provided with output overcurrent protective device
7	Output Waveform Distortion	Yes	Only required for directly connected machines and machines where full power conversion and grid interconnection is NOT provided by a UL 1741/IEEE 1547 approved device
8	Surge Tests	Yes	May be required after short-circuit testing for induction or directly connected machines
9	Temperature Test for Standby Generators	**NO**	Only required for standby generator applications
Marking			
10	General	Yes	
Instructions			
11	General	Yes	

5.3.3 Control System and Equipment

UL 6141 (and similar photovoltaics [PV] or microgrid standards) require controllers and charge controllers to comply with UL 1741. It is advisable to utilize off-the-shelf certified components and systems where available; however, even in the case where certified components are used, much of the control system evaluation and testing described below will still be required by the certification agency for verification of protection functionality and software control. In the case where multiple controllers are employed within the system, each controller will only have to apply with applicable parts below.

There are several ways these components could be evaluated as part of a UL 6141 or UL 6142 certification. If individual certifications are desired for each controller type, a recognition listing would be suggested for the controllers. If the controllers are sourced externally, the requirements outlined below are what a supplier must comply with. If these are custom and made in-house by the OEM, a limited evaluation (which is not a certification) may also be appropriate. A limited evaluation is typically a full constructional evaluation of the component by the NRTL as part of the UL 6141 or 6142 system certification and includes all applicable design and test requirements; however, the follow-up certification and other requirements will vary, as they are considered “unlisted components” of a certified electrical system. The component itself will not be considered certified. Thus, it will not be labeled, it will only be evaluated as part of the turbine system, and it can only be used in that configuration to be considered part of the UL 6141 or 6142 classification listing. Unlisted components require annual or more frequent testing (quarterly) to maintain the certifications. Each certification type comes with pros and cons, which can be considered when the time is appropriate.

The information provided in the section below will apply regardless of which certification path is taken. For UL 1741 evaluation, parts of the standard that apply only to the controller construction and functionality would only be applied to the controller. Section 5.3.3.1 gives design and test requirements from UL 1741, and 5.3.3.2 outlines additional tests and considerations for safety-related control systems, UL 6141, and UL 6142 Clause 8.

5.3.3.1 Control System and Equipment Requirements – UL 1741

UL 1741 covers inverters and utility-interactive equipment but also provides general electrical safety requirements that can be commonly applied across a wide range of electrical components, including controllers. A bulk of the general safety requirements are applicable, whereas the inverter and utility-interactive portions of UL 1741 are excluded based on the assumption that a UL 1741 listed inverter, converter, or other device is used in the system and manages the connection with the utility.

Table 5 shows applicable clauses with reference to UL 1741 Supplement B (SB) for controller certification for compliance with UL 6141 and UL 6142 requirements under Clause 4 components. For additional test requirements related to SRCS, see 5.3.3.2.

Table 5 - Applicability of UL 1741 SB subclauses for controls and controls equipment

Applicability of UL 1741 SB Subclauses for Controls and Controls Equipment			
Subclause	**Title**	**Required**	**Comment**
1 - 6	Various - General	**Yes**	As applicable
7	Frame and Enclosure	**Yes**	
8	Protection Against Corrosion	**Yes**	
9	Mechanical Assembly	**Yes**	
10	Mounting	**Yes**	
11	Protection of Users - Accessibility of Uninsulated Live Parts	Yes	For units intended for user interaction
12	Protection of Service Personnel	**Yes**	
13	Electric Shock	**Yes**	For determining risk level of system voltages
14	Switches and Controls	**Yes**	
15	Disconnect Devices	Yes	If employed
16	AC Output Connections	NO	Assuming UL 1741 inverter manages AC connections
17	Receptacles for Low-Voltage Output Circuits	Yes	If employed
18	Supply Connections	**Yes**	
19	Wire-Bending Space for Low-Voltage Field Conductors	**Yes**	
20	Equipment Grounding	**Yes**	
21	AC Output Circuit Grounded Conductor	NO	Assuming UL 1741 inverter manages AC connections
22	Internal Bonding for Grounding	**Yes**	

Applicability of UL 1741 SB Subclauses for Controls and Controls Equipment			
Subclause	Title	Required	Comment
23	Internal Wiring	Yes	
24	Live Parts	Yes	
25	Separation of Circuits	Yes	
26	Spacings	Yes	
27	Alternate Spacings	NO	Unless alternate spacings are required/pursued
28	Insulating Materials	Yes	
29	Capacitors	Yes	If employed
30	Isolated Accessible Signal Circuits	Yes	If employed
31	Control Circuits	Yes	
32	Low-Voltage Overcurrent Protection	Yes	
33	Panelboard Features	Yes	
34	DC Ground Fault Detector/Interrupter	NO	Not typical for controller construction
35	Printed Wiring Boards	Yes	
36	External Transformers	Yes	If employed
Protection Against Risks of Injury to Persons			
37	General	Yes	
38	Enclosures and Guards	Yes	
39	Moving Parts	NO	Not typical
40	Switches and Controls	Yes	
41	Mounting	Yes	
Output Power Characteristics and Interactive Compatibility			
42	General	NO	UL 1741/IEEE 1547 Inverter connected required
43	Interactive Equipment	NO	UL 1741/IEEE 1547 Inverter connected required
Performance (Testing)			
44	General	Yes	
45	Maximum Voltage Measurements	Yes	
46	Temperature	Yes	
47	Dielectric Voltage Withstand Test on Low-Voltage Circuits	Yes	
48	Output Power Characteristics	Yes	
49	Utility Compatibility	NO	Not used for utility connection
50	Abnormal Tests	Yes	Only: Short circuit, input miswiring, ventilation openings (if employed), component short- and open-circuit

Applicability of UL 1741 SB Subclauses for Controls and Controls Equipment			
Subclause	**Title**	**Required**	**Comment**
UL 6142 cl 8.3	Additional Abnormal Tests	Yes	Complete loss of control power, loss of conductor in polyphase circuit, and control power under- and overvoltage
51	Grounding Impedance Test	Yes	
52	Overcurrent Protection Calibration Test	Yes	If employed
53	Strain Relief Test	Yes	For field wiring connections
54	Reduced Spacings Tests for Low-Voltage Printed Wiring Boards	NO	Unless design exception is desired
55	Bonding Conductor Test	NO	Unless design exception is desired
56	Voltage Surge Test	NO	
57	Calibration Test	NO	
58	Overvoltage Test	NO	
59	Current Withstand Test	NO	
60	Capacitor Voltage Determination Test	Yes	If employed, for capacitor stored energy determination
61	Stability	NO	Expected to be fastened to fixed or supporting structures
62	Static load	Yes	As applicable, depending on materials
63	Compression Test	NO	Unless design exception is desired
64	Rain and Sprinkler Tests	Yes	For outdoor mounted equipment. Rain often combined with other equipment such as generator if control equipment is located in nacelle. Sprinkler only required for outdoor ground mounted equipment
Rating			
65	Details	Yes	
Markings			
66	Details	Yes	
67	Cautionary Markings	Yes	
68	Equipment Information and Instructions	Yes	
69	Important Safety Instructions	Yes	
Manufacturing and Production Tests			
70	Dielectric Voltage Withstand Test – Low-Voltage Circuits	Yes	
71	Production Tests for Interactive Equipment	NO	Not interactive equipment
Charge Controllers - Introduction			
72	General	Yes	

Applicability of UL 1741 SB Subclauses for Controls and Controls Equipment			
Subclause	Title	Required	Comment
Charge Controllers - Construction			
73	General	Yes	
Charge Controllers - Performance			
74	General	Yes	As applicable
75	Sources and Loads	Yes	Yes, for battery systems controlled by control equipment, when testing using simulated sources/loads
76	Normal Operation	Yes	Similar to voltage determination, often combined
77	Temperature	Yes	Similar to above, often combined
78	Temperature Compensation	Yes	If integral temperature compensation is employed
79	Connection Sequence	Yes	
80	Abnormal Tests	Yes	Modifications to the above abnormal tests, and additional
Charge Controllers - Markings			
81	Cautionary Markings	Yes	
82	Details	Yes	
83	Important Safety Instructions	Yes	
Remaining Subclauses are NA:			
84 - 91	AC Modules and PV Modules with Integrated Electronics	NO	
92 - 102	Rapid Shutdown Equipment and Systems	NO	
SA1 - SA18	Supplement SA	NO	
SB1 - SB7	Supplement SB	NO	

Appendix A of this DW Certification Best Practices Guideline provides a list of reference standards for components and subcomponents relating to electrical product conformity. For certification, all subcomponents must be listed, certified, or otherwise approved and used within their ratings. Any component that is not listed, recognized, or otherwise proven evaluated by a third party to the standard identified must either be evaluated by the certification body or be considered an unlisted component that will undergo additional surveillance and evaluation requirements to comply with certification requirements.

5.3.3.2 Control System – UL 6141/UL 6142 Safety Related Control System Tests

Clause 8.1 requires the SRCS to be designed to comply with IEC 61400-2 or IEC 61400-1, depending on turbine size or entry type. The IEC 61400 design standards define several critical controls and protection functions that are required to be evaluated to maintain the turbine within its mechanical and structural limitations. The information below describes an evaluation means and test for the control and protection functions. From a simplified electrical controls and protection point of view, the electrical control and protection systems will monitor the turbine speed. They may do so by measuring a frequency or corresponding voltage related to the turbine speed. At some predefined speed limit, or trip limit, the turbine electrical controls and protection systems will perform some function or functions within a predefined amount of time to prevent an overspeed condition. The trip limits, responses, and response times are set by the turbine manufacturer based on mechanical structural evaluation. The mechanical structural evaluation of a wind turbine is outside the scope of UL 6141, but the evaluation of the controls and protection are critical to the safe operation of a wind turbine and must be done properly to prevent catastrophic failures.

For SRCS, the controls functions identified in IEC 61400-2 or IEC 61400-1 are evaluated to safety critical parameters identified through risk assessment or failure mode and effects analysis (FMEA) to maintain the turbine within structural and mechanical limits as required. All potential fault cases must be identified in the FMEA for analysis of loads and control system testing. For any occurrence resulting in overspeed, overpower, catastrophic failure, or a similar situation where hazardous conditions may result, the mechanisms for protection must be evaluated and tested, and a secondary protection method provided. Power and safety controls should be segregated to simplify review and testing. A control or protection system response is required to occur when the operating parameters reach a specific limit or activation level. The operational limits are programmed into the SRCS, and the operational parameters are specified in the manufacturer's documented ratings for the equipment. The risk analysis, FMEA, etc. must include consideration of the following at minimum: complete loss of control power, loss of one power conductor of a polyphase control power circuit, control power undervoltage and overvoltage, component single faults, vibration amplitude and frequency, and failure of critical wiring insulation, isolation, and/or continuity. If any of these considerations occur, a safe and controlled shutdown of the turbine must be initiated and all power output must stop.

Compliance with this and other requirements for SRCS are demonstrated by compliance with either a redundant system (complying with clauses 8.2.4–8.2.7) or one of the following:

1. IEC 62061, Safety of machinery – Functional safety of safety-related electrical, electronic and programmable electronic control systems
2. IEC 61508, Functional safety of electrical/electronic/programmable electronic safety related systems – Part 1: general requirements
3. ISO 13849, Safety of machinery – Safety-related parts of control systems – Part 1: general principles for design.

Redundant systems are not considered part of this DW Certification Best Practices Guideline.

As required by UL 6141, IEC 61400-2, and IEC 61400-1, these electrical control and protection functions need to be evaluated for proper operation during normal and abnormal failure conditions. Evaluating the electrical controls and protection limits and response times are a critical part of wind turbine electrical safety. The UL 6142 standard for turbines not permitting entry suggests that IEEE 1547 includes an accurate and well-documented test method to evaluate trip limits and response times that can easily be applied to evaluate turbine protection and control systems. It is often relied upon by NRTLs for trip limit testing.

Safety and function testing is very similar to IEEE trip limit methods if applied appropriately; therefore, careful planning is necessary to organize the tests in the field during safety and function testing for verifications to comply with UL 6141 and UL 6142 SRCS requirements simultaneously.

SRCS testing is required for UL 6141 compliance of the control system. This is not to be confused with the UL 1741 design and test requirements above, which are separately used for the compliance of the control system equipment with Clause 4 requirements of UL 6141. An initial sample test list is given in Table 6 based on the standard requirements. This is a single list of complete tests; some tests may not be applicable to a given set of control equipment or may need to be repeated for different equipment that perform the same functions. Each applicable test will be applied to each controller during the certification process.

Table 6 - UL 6141 safety related control system testing requirements

UL 6141 Safety Related Control System Testing Requirements	
1	**Safety and Function Testing Performed in field, with set point testing methods incorporated**
1.1	Primary/critical control functions:
1.1.1	Power and speed control (including peak power determination)
1.1.2	Yaw system control (wind alignment)
1.1.3	Loss of load
1.1.4	Overspeed protection above design wind speed
1.1.5	Start-up and shutdown above design wind speed
1.1.6	Emergency stop, normal and extreme conditions
1.2	Secondary protection functions:
1.2.1	All single faults in the primary control method
1.2.2	Loss of grid
1.2.3	Emergency stop
1.3	Other items, as employed:
1.3.1	Excessive vibration protection
1.3.2	Battery overvoltage and undervoltage protection
1.3.3	Cable twist
2	Additional SRCS Tests and Design Validations
2.1	All set point verification testing - any control or protection system set point or limit and monitoring
2.2	All other protective stop, shutdown, or fault conditions
2.3	All operational modes and service modes
2.4	All design input validations as required (power/MPPT, rpm, etc.)
2.5	Other system verifications as required (e.g., pitch position/control)
2.6	Loss of power supplies or backup battery
3	Additional Abnormal Considerations
3.1	Complete loss of control power
3.2	Loss of one power conductor of polyphase control power circuit
3.3	Control power undervoltage and overvoltage
3.4	Component single faults
3.5	Failure of critical wiring insulation or continuity testing

5.3.4 Motor Drives and Adjustable-Speed Power Drives

Clause 4.20 covers motor drives, variable frequency drives, and other adjustable-speed power drives that supply power to control a motor (or motors, or generator) operating at a frequency or voltage different than that of the input supply. These types of drives must have electrical and environmental ratings for the intended application and comply with UL 61800-5-1 for adjustable-speed electrical power drives or IEC 62477-1 for power electronic converter systems and equipment. Note that referencing both will additionally require compliance with UL 1741 where there are safety and performance requirement gaps in the 61800-5 or 62477 standards, specifically when the drive converts power from AC to DC and/or DC to AC. Safety-related functions must be verified and tested per SRCS requirements and safety and function tests and are typically part of the verification of set points and control functionality.

Regarding IEC compliance for the Variable Frequency Drive (VFD), there is an IEC 61800-5-1 standard that is largely harmonized but not identical with the UL standard, based on many of the international deviations and considerations outlined within this plan. The component may be able to be purchased with a dual certification to both standards. The UL 61800-5-1 version incorporates many national deviations, including specific reference to UL 1741 for power conversion requirements. Similar to the control equipment discussed above, the full set of "inverter" requirements are not applied for a "converter" that is not connected to the electrical utility but is always connected to a UL 1741 listed device that manages that connection. In the UL 61800-5-1 recognition listing of the drive, this would be listed as a condition of acceptability.

For the purposes of the information and guidance related to drives, Figure 13 is replicated from the UL 61800-5-1 standard to define the type of drive system being considered, which relates to the applicable requirements of the standard. DWT applications where a drive is used to control the generator are Complete Drive Module (CDM) or Basic Drive Module (BDM) systems. The requirements are generally the same between CDM and BDM, so a CDM is suggested to ensure proper system design.

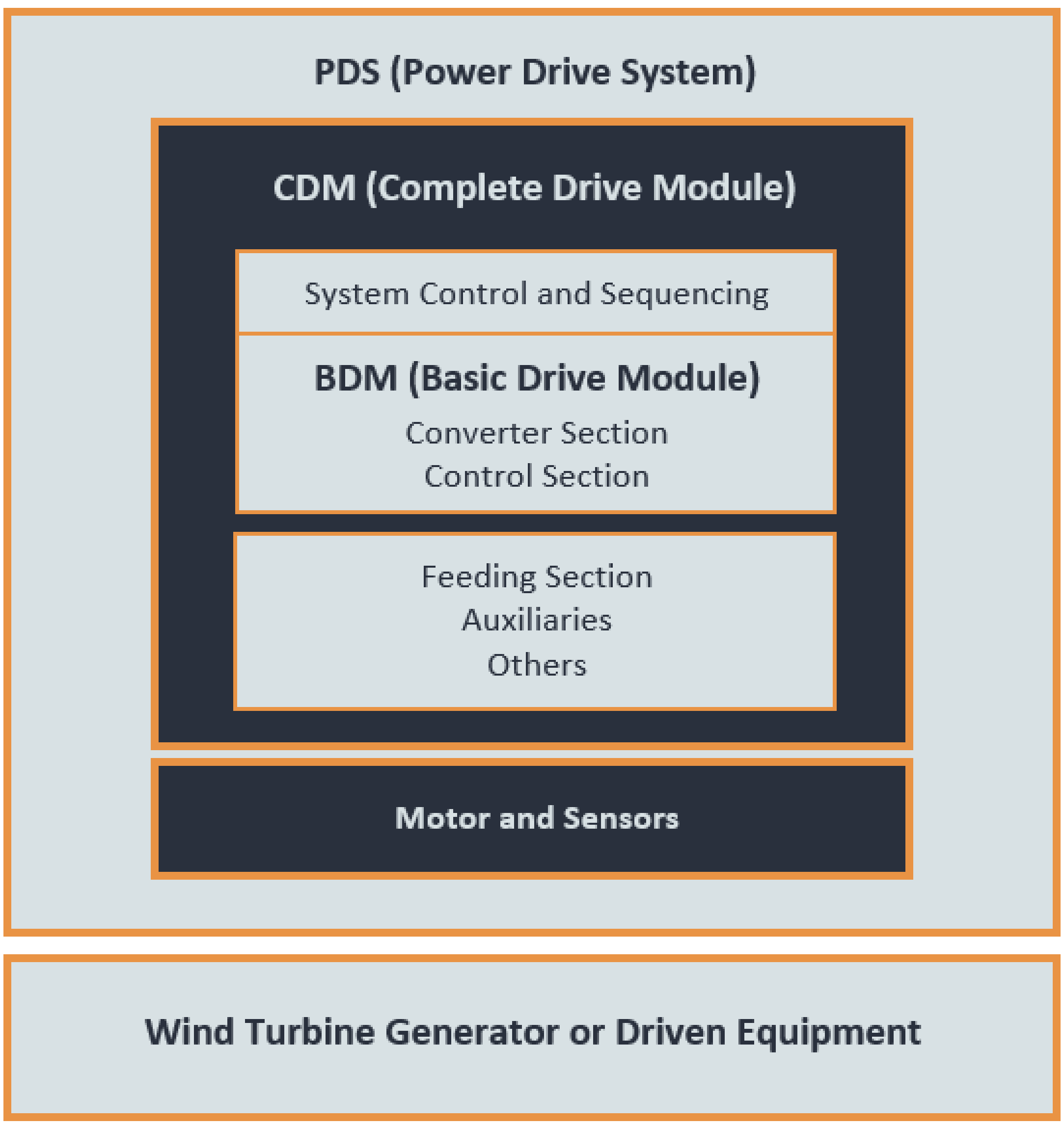


Figure 13 - Types of drive systems

A power drive system (PDS) would apply for off-the-shelf motor drives for yaw systems, pitch systems, or other parts of the wind turbine construction where a motor and sensors are included to drive the system. A drive used for control and protection of the wind turbine generator does not have a motor in the system driving the generator ("driven equipment"), and thus is not a PDS.

5.3.4.1 Motor and Adjustable-Speed Power Drives Constructional Requirements – UL 1741/UL 61800-5-1

Table 7 is reproduced from UL 61800-5-1 with additional information related to the requirements. In the table:

- A = Required
- C = Required, unless CDM or BDM is incorporated into an assembly that provides the required protection
- S = U.S.-specific additional requirement from national deviations.

Applicable clauses of UL 1741 are also in the table. This is provided primarily for use with "C" items in the table to verify proper protections exist in the system.

Table 7 - Applicability of design requirements of UL 61800-5-1: Table 2 with UL 1741 related subclauses

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	Title	PDS	CDM/BDM	Comment	
4.2	Fault Conditions	A	A		n/a
4.3.1	DECISIVE VOLTAGE CLASSIFICATION	A	A		n/a
4.3.2	PROTECTIVE SEPARATION	A	A		n/a
4.3.3	Protection Against Direct Contact	A	C	4.3.3.2 or 4.3.3.3 must be used for protective methods, either insulation of live parts or enclosures	9 Mechanical Assembly 11 Protection of Users 12 Protection of Service Personnel 37 - 41 Protection Against Risks of Injury to Persons
4.3.4	Protection In Case of Direct Contact	A	C	Generally applicable unless housed in the same enclosure as the inverter, or UL 1741 approved device. Several exceptions and options exist	n/a
4.3.5.1	Protection Against Indirect Contact	A	A		n/a
4.3.5.2	Insulation Between LIVE PARTS and Accessible Conductive Parts	A	C	Basic insulation and clearances	26 Spacings 27 Clearances and Creepage Distances

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	Title	PDS	CDM/BDM	Comment	
4.3.5.3	4.1.1.1 Protective Bonding Circuit	A	C	Generally applicable unless housed in the same enclosure as the inverter, or UL 1741 approved device. Several exceptions and options exist	20 Equipment Grounding 21 AC Output Circuit Grounding Conductor 22 Internal Bonding for Grounding 23 Internal Wiring
4.3.5.4	PROTECTIVE EARTHING CONDUCTOR	A	A		20 Equipment Grounding 21 AC Output Circuit Grounding Conductor 22 Internal Bonding for Grounding 23 Internal Wiring
4.3.5.5	Means of Connection for the PROTECTIVE EARTHING CONDUCTOR	A	A		20 Equipment Grounding 21 AC Output Circuit Grounding Conductor 22 Internal Bonding for Grounding 23 Internal Wiring
4.3.5.6	Special Features in Equipment for PROTECTIVE CLASS II	A	C	Not expected for non-entry turbines; this is for equipment that employs double or reinforced insulation between live parts and wishes to be designated as protection class II. Not required unless desired	n/a
4.3.6	Insulation Between LIVE PARTS and Accessible Conductive Parts	A	A		24 Live Parts 28 Insulating Materials
4.3.7	Enclosures	A	C	Annex DVD is used for U.S. compliance. Applicable unless housed in same enclosure as inverter or UL 1741 device	7 Frame and Enclosures 8 Protection Against Corrosion

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	Title	PDS	CDM/BDM	Comment	
					9 Mechanical Assembly
4.3.8	Wiring and Connections	A	A		16 AC Output Connections 18 Supply Connections 19 Wire-Bending Space 23 Internal Wiring 25 Separation of Circuits Spacings, Clearances, etc.
4.3.9	Output Short-Circuit Requirements	A	A		50 Abnormal Tests
4.3.10	Residual Current-Operated Protective or Monitoring Device Compatibility	A	C		n/a
4.3.11	Capacitor Discharge	A	A		13.2 Stored Energy
4.3.12	Access Conditions for HIGH-VOLTAGE PDS	A	C		n/a
4.3.13DV	Control Circuit Transformer Grounding		S	Applicable for control circuit transformers who's secondary is intended to supply an external control circuit, it must be grounded appropriately	31 Control Circuits 20 Equipment Grounding 22 Internal Bonding for Grounding
4.3.14DV	Transformers Protection		S	If applicable according to above, then various protection methods are allowable	25 Separation of Circuits 26 Spacings 27 Alternate Spacings 30 Isolated Signal Circuits 31 Control Circuits 32 Overcurrent Protection 36 external transformers
4.3.15DV	Blower Motors		S	If employed, applicable	

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	**Title**	**PDS**	**CDM/BDM**	**Comment**	
4.3.16DV	Fuseholders		S	Power conversion equipment incorporating a disconnect switch and fuseholder must be constructed such that when the switch is open the fuse may be replaced without touching any energized part. Not applicable for control circuits when fuse and load are in the same enclosure. Not applicable to fuses not accessible and not for renewal	9 Mechanical Assembly 15 Disconnect Devices 26 Spacings 32 Overcurrent Protection
4.4	Protection Against Thermal Hazards	A	A	4.4.2 also applicable, but in general 4.4.2.2DV replaces 4.4.2 for U.S. compliance	26 Spacings 28 Insulating Materials 35 PWBs Others in General, Various
4.4.3	Flammability of Enclosure Materials	A	C	Covered in DVD	7 Frame and Enclosures
4.4.4	Temperature Limits		S	40 C ambient in U.S. Table 15DV for max measured temperatures allowed during testing for various materials and components	23 Internal wiring 26 Spacings 46 Temperature
4.4.5	Special Requirements for Liquid Cooled PDS	A	A		n/a
4.5	Protection Against Energy Hazards	A	A	See 4.5.2	39 Moving Parts
4.5.2	Mechanical Energy Hazards	A	C	Not applicable if the motor/generator is not a part of system.	39 Moving Parts
4.6	Protection Against Environmental Stresses	A	A	Not applicable for U.S. requirements according to 4.6DV	7 Frame and Enclosure 8 Protection Against Corrosion
NOTE that 4.7DV through 4.16DV are additions to the standard for U.S. compliance. Only those that are potentially applicable for this application are included in the table below					

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	Title	PDS	CDM/BDM	Comment	
4.8DV	Position of Operating Handles		S	Handles, switches, and pushbuttons	7 Frame and Enclosure 14 Switches and Controls 15 Disconnect Devices 22 Internal Bonding for Grounding 32 Overcurrent Protection 38 Enclosures and Guards 40 switches and controls
4.11DV	Securement of Live Parts		S	Terminals and other securement means	13 Electric Shock 18 Supply Connections 19 Wire Bending Space 20 Equipment Grounding 23 Internal Wiring 25 Field Wiring 26 spacings 27 alternate spacings 32 overcurrent protection
4.12DV	Provisions for Mounting		S	Generic	10 Mounting
4.13DV	Phase Reversal Protection		S	If employed, applicable.	n/a
4.14DV	Capacitors		S	Capacitor requirements	13 Electric Shock 22 Internal Bonding for Grounding 26 Spacings 29 Capacitors 30 Isolated Accessible Signal Circuits
4.15DV	Isolation Devices		S	Applicable for any isolated circuits via use of isolation	30 Isolated Accessible Signal Circuits

Applicability of Design Requirements of UL 61800-5-1: Table 2					UL 1741 Related Subclause
Subclause	Title	PDS	CDM/BDM	Comment	
				devices, insulating materials, and barriers	
4.16DV	BDM/CDM/PDS Supplied by PV Modules		S	BDM/CDM/PDS Supplied by Distributed Energy Resource (DER) must be supplied by approved DER. If BDM/CDM/PDS includes power conversion it shall additionally be approved to UL 1741	UL 1741 applicable parts for conversion

It is this last clause, 4.16DV, where reference to UL 1741 is made for any drive system that includes conversion. Depending on preference, it may also be possible to simply use UL 1741 for all design and constructional safety aspects. In this case, the required CDM/BDM testing from UL 61800-5-1, in addition to full UL 1741 safety and performance testing (similar to controllers above, plus conversion related tests) and UL 6142 SRCS test program of all control functionality, would be required. This may provide an alternate path for drives with power conversion functionality.

5.3.4.2 Motor or Adjustable-Speed Power Drive Test Requirements – UL 1741/UL 61800-5

Similar to above, the required tests for drives are included in Table 8. In the table:

- X = assumed to be required according to standard requirements (may be addressed via certified components or exceptions in some cases)
- ? = may be required if employed in the final component design, or exceptions exist that are likely applicable
- [blank] = assumed not required
- "Type" = required tests for certification of a motor drive or PDS system
- "Routine" and "Sample" = testing as part of production or certification maintenance.

Abnormal testing for loss of phase is typically applicable to a PDS, but in a multiphase system it may be applied in principle to a BDM or CDM. Many of the "?" items would typically not be part of the construction, but if included must be part of the test program. All of the DVC.2.x tests are applicable to *isolated* secondary control circuits and are applicable where they exist.

Table 8 - Applicability of test requirements of UL 61800-5-1: Tables 15/15DV with UL 1741 related subclauses

Applicability of Test Requirements of UL 61800-5-1: Tables 15 and 15DV								UL 1741 Related Subclause
Test	Type	Routine	Sample	Related Subclause	Test Subclause	CDM or BDM w/conversion		
Visual Inspection	X	X	X		5.2.1	X		n/a
Mechanical Tests					**5.2.2**			
Clearance and Creepage Distances	X			4.3.6.1, 4.3.6.4, 4.3.6.5	5.2.2.1	X		n/a, UL 840
PWB Short-Circuit	X			4.3.6.7	5.2.2.2	X		Clause 54
Non-Accessibility	X			4.3.3.3	5.2.2.3	X		n/a, UL 50
Enclosure Integrity	X			4.3.7.1	5.2.2.4	X		Clauses 62, 63, 64 and UL 50
Deformation Tests				**4.3.6.4.3**	**5.2.2.5**	**SEE ANNEX DVD**		
Deflection	X			4.3.7.1	5.2.2.5.2	X		n/a, UL 50
Impact	X			4.3.7.1	5.2.2.5.3	X		Clause 62, and UL 50
Electrical Tests				**4.3.4.1, 4.3.6.8.2**	**5.2.3**			
Impulse Voltage	X		X	4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.1	X		Clause 56
AC or DC Voltage	X			4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.4.2	5.2.3.2	X		Clauses 45 and 47
Partial Discharge	X		X	4.3.6.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.3			n/a
Protective Impedance	X	X		4.3.4.3	5.2.3.4	X		n/a
Touch Current Measurement	X			4.3.5.5.2	5.2.3.5	X		n/a

Applicability of Test Requirements of UL 61800-5-1: Tables 15 and 15DV							UL 1741 Related Subclause
Test	Type	Routin e	Sample	Related Subclause	Test Subclause	CDM or BDM w/conversion	
Short-Circuit Tests				4.3.9	5.2.3.6.3	X	Clause 50.3 and 50.6
Breakdown of Components	X			4.2	5.2.3.6.4	X	n/a
Capacitor Discharge	X			4.3.11	5.2.3.7	X	Clause 60, and UL 810
Temperature Rise	X			4.3.8.8.2, 4.4.2.1	5.2.3.8	X	Clause 46
Protective Bonding	X	X		4.3.5.3	5.2.3.9	X	Clauses 51 and 55
Abnormal Operation Tests				**4.2**	**5.2.4**		
Loss of Phase	X			4.2	5.2.4.4	X	n/a, UL 6142
Inoperative Blower	X			4.2	5.2.4.5.2	?	n/a, UL 50
Clogged Filter	X			4.2	5.2.4.5.3	?	n/a, UL 50
Loss of Coolant	X			4.4.5.2.5	5.2.4.5.4	?	n/a
Material Tests					**5.2.5**		
High Current Arcing Ignition	X			4.4.2.2	5.2.5.1	?	n/a
Glow-Wire	X			4.4.2.2	5.2.5.2	?	n/a
Hot Wire Ignition	X			4.4.2.2	5.2.5.3	?	n/a
Flammability	X			4.4.3	5.2.5.4	?	n/a, UL 94
Environmental Test				**4.6**	**5.2.6**		
Dry Heat	X			4.6	5.2.6.3.1		n/a
Damp Heat	X			4.6	5.2.6.3.2		n/a
Vibration Test	X			4.6	5.2.6.4		n/a
Hydrostatic Pressure	X	X		4.4.5.2.2	5.2.7		n/a
Contactor Overload	X			4.4DV.2	5.2.4.5.5DV	?	n/a
Current Limiting Control	X			4.2DV.3	5.2.4.5.6DV	?	n/a
Solid-State Motor Overload Protection Test	X			4.4.6DV.1	5.2.8DV.1	?	n/a
Thermal Memory	X			4.4.6DV.2	5.2.8DV.2	?	n/a

Applicability of Test Requirements of UL 61800-5-1: Tables 15 and 15DV								UL 1741 Related Subclause
Test	Type	Routin e	Sample	Related Subclause	Test Subclause	CDM or BDM w/conversion		
Retention (Shutdown)								
Thermal Memory Retention (Loss of Power)	X			4.4.6DV.2	5.2.8DV.3	?		n/a
Speed Sensitivity (Loss of Power)	X			4.4.6DV.2	5.2.8DV.4	?		n/a
Circuit Functionality Evaluation Test		X		4.4.6DV	5.2.9DV.1	?		n/a
Clamped Joint Test	X			C.1DV	5.2.13DV	?		n/a
Secondary Circuits Test				DVC.1.1.2	DVC.2	?		n/a
Limited Voltage/Current Secondary Test				DVC.1.5	DVC.2.2	?		n/a
Limited Energy Secondary Test				DVC.1.6	DVC.2.3	?		n/a
Limited Impedance Test				DVC.1.7	DVC.2.4	?		n/a
Limited Voltage Secondary Test				DVC.1.8	DVC.2.5	?		n/a
Isolated Power Supply Capacity Test				DVC.1.9	DVC.2.6	?		n/a

5.3.5 Converters and Inverters

More thorough consideration of inverters and converters is planned for future releases of this DW Certification Best Practices Guideline. Simply stated, DW systems intended for gird-connected operation must employ a UL 1741 listed inverter, additionally certified to IEEE 1547 and IEEE 1547.1 for interconnecting distributed resources. Multiple options exist for grid interconnection compliance. These and other grid interconnection considerations will be covered in a future release of this guideline.

Converters are evaluated in the same fashion as an inverter, except grid functionality testing is not required, presuming that grid connection is managed via UL 1741 and IEEE 1547.1 listed inverter or device. Variable frequency drives or other power converters providing drive and control functionality must additionally comply with UL 61800-5-1. Inverters above 1,000 V are not included in this DW Certification Best Practices Guideline.

5.3.6 Gearboxes – Electrical Features

The primary function of a wind turbine gearbox is not electrical, but gearboxes often employ features or connections that are electrical. Any such electrical features of a gearbox assembly must comply with UL 508, including but not limited to heaters, coolant pumps, fans, sensors, and their interconnection. Wiring must comply with either UL 508 or the UL 6141 internal wiring requirements of Clause 4.2.

Additionally, it is suggested that the gearbox follow the design and test requirements of IEC 61400-4 Ed.2. Several supporting technical specifications or technical reports exist or are in development also including 61400-4-1 for reliability of drivetrain components, 61400-4-2 for lubrication, and 61400-4-3, which is a report including explanatory notes on the use and application of IEC 61400-4 Ed. 2. Additional information on gearboxes may also be found in the type certification sections below.

5.3.7 Energy Storage Systems and Devices

Energy storage units, systems, and devices have varying requirements based on the types of batteries and equipment utilized. Batteries must be approved to the appropriate type product standard, and other considerations for mounting and enclosures are given.

Standby batteries must comply with UL 1989 or UL 1973. Energy storage capacitors must comply with the applicable requirements of UL 810A, electromechanical capacitors. Lithium batteries must comply with UL 2054 applicable requirements. Energy storage devices intended to provide power for protective functions or braking systems must comply with the capacity test in UL 1989 and demonstrate sufficient capacity to perform the protective function or braking action. Uninterruptible power supply functions shall comply with the applicable requirements of UL 1778, UL 62109-1, IEC 62040-1, or UL 9540. The system is evaluated for all environmental conditions in which it is intended to be used in the end application, including special or extreme conditions.

Batteries must be located and mounted to prevent the terminals from contacting adjacent battery terminals or other metal parts as a result of the batteries shifting. A bracket or strap or similar means, if used, must not cause undue compression of the walls of the battery, and a few examples are given for compliant methods (others are allowed).

A metal case or container of a battery, such as an alkaline battery, must be insulated or spaced away from contact with uninsulated live parts of the assembly. An enclosure or compartment housing batteries employing metal containers or similar must be constructed so the batteries are insulated or spaced from each other, or otherwise arranged to prevent short-circuiting of part or all of the battery supply after installation.

Battery charge controllers are required to comply with UL 1012, UL 1741, or UL 1973 if employed.

5.3.8 Diversion Loads

More thorough consideration of diversion and dump loads is planned for future releases of this DW Certification Best Practices Guideline.

Diversion loads are not currently specifically mentioned UL 6141 or UL 6142, but any resistive loads that may be used in the system will be required to comply with the applicable requirements in UL 499. It is suggested to procure a resistive load that is already UL approved, otherwise a subsequent evaluation to UL 499 may be necessary for UL 6141 compliance. Depending on the location and use of the device, additional testing under SRCS may be required, or additional environmental testing if not contained within an appropriately rated enclosure for the application.

5.4 Common Systems and Protections Requirements for DWT

5.4.1 Emergency Stop

Emergency stops are critical to the protection of the wind turbine system and components. They are often employed or already provided in the form of a pushbutton on a UL approved grid-connected inverter, but depending on the machine size and electrical system design, multiple emergency stop devices may be employed. Emergency stop functionality is tested in safety and function or SRCS testing.

Emergency stop devices must comply with manual shutdown requirements given in Section 8 of IEC 61400-2 and Section 9.2.5.4 "Emergency Operations" in NFPA 79. Activation must initiate the shutdown procedure to bring the turbine to a parked condition per IEC 61400-2 requirements. Suitable means must be provided via a switching function that can be operated to isolate the wind turbine from the electrical network, and may be initiated by personnel or the turbine protection system, but must not rely on the control system. The stop must override all other functions and operations in all modes, and power/energy to moving parts must be removed as quickly as possible without creating other hazards. Resetting must not restart the machinery or initiate any hazardous conditions but only permit restarting. All commands or stop functions must be manually reset prior to restarting the wind turbine.

The stop actuator itself must comply with UL 508 and IEC 60947-5-5 and be Category 0 or a 1-stop function as defined in NFPA 79, and rated for a minimum of 10,000 operations. It must have the same red color with immediate background colored yellow.

IEC 61400-2 Clause 8.4 goes on to require that a safe method for shutdown be provided for inspections, service, and/or maintenance, including specification of the maximum wind and other conditions under which the procedure can be carried out (V_{maint}), which must not be less than 1.4 V_{ave} (V_{maint} = 11.9 m/s for Class II). Rotation must be brought to a parked condition for maintenance or service below this value, and the means and procedures for shutdown must be provided within the maintenance manual.

5.4.2 Hydraulic Electromechanical Systems

Hydraulic and pneumatic electromechanical components must be appropriately rated and approved for the intended use and application. Often, they are employed for hydraulic actuation of the main braking system or other protections. Many of these components fall under an applicable product certification standard, and as such should be ensured in the product specifications for the procured components of the wind turbine system.

There must not be risk of fire, electric shock, or injury to personnel resulting from the operation of a pressure relief means. Pressure relief and system drains must be located to prevent released liquid to fall, spray, leak or drip on electrical components or systems, unless those components or systems are appropriately rated for hydraulic exposure for the foreseeable range of release pressure conditions.

5.4.3 Disconnect Devices

Where disconnecting devices are used for branch or other protections, they must be appropriately designed and approved for the expected range or operating conditions. Each supply source or mains input must be provided with a lockable disconnect that positively prevents the start-up and operation of the circuit. Service and maintenance manuals are typically reviewed in this process for acceptance of the procedure for disconnection for service. A rotor lock is suitable for lockout of the generator as a supply circuit, if required.

Any system that requires repair or maintenance with the main supplies remaining energized are required to have a lockable disconnect. When a disconnect device is provided, it must open all ungrounded conductors and consist of either a manually operated switch or motor-operated switch with provisions for manual operation. It additionally must require provisions for locking in the open position. The devices must be marked to identify the disconnect device, switch, or breaker for the specific power circuit.

5.4.4 Lightning Protection Systems

Lightning protection systems and hardware are not typically mandatory for smaller turbines (e.g., under UL 6142), but UL 6141 outlines requirements for those systems that employ a "lightning protection system." These are again not required to be employed, but if employed, they must comply with the prescribed requirements.

Any lightning protection system installed in a wind turbine system must comply with NFPA 780 or IEC 61400-24. Components of the system must comply with UL 96, and any surge suppression components must comply with UL 1449 (this includes surge protection/suppression devices used throughout the entire electrical system). Components for these systems are available off-the-shelf as certified. This is not to be confused with proper grounding and bonding continuity, which is discussed elsewhere in this Guideline.

5.4.5 Other Systems

A few other less common systems and components are briefly described below.

5.4.5.1 Hoists, Winches, and Other Lifting Devices

Hoists, winches, or other devices that are mounted to the structure aren't common for DWTs, but if one is employed it must comply with UL 1340.

5.4.5.2 Fire Protection

If employed, a fire protection system and alarm must comply with UL 864. NFPA 850 is a recommended practice that provides guidance for wind turbine fire protection systems.

5.4.5.3 Heating and Cooling

Any heating or cooling equipment employed must comply with UL 1995.

5.4.5.4 Medium-Voltage Disconnect Devices

Although not common for DWT applications, any circuits operating greater than 1,000 VAC and 1,500 VDC are considered medium voltage (MV). When entry is permitted, any MV supply must be provided with provisions for disconnecting. Similarly, if MV equipment is in the nacelle or hub, it must be provided with an electrical actuator, lockout device, or similar equipment to open and to prevent closing of the MV disconnecting device. This is for providing means to disconnect within the hub or providing means for a disconnect not within the nacelle. NFPA 70E is also referenced for additional guidance related to worker safety and MV equipment.

5.5 DWT Wiring Methods, Terminations, and Connection Requirements

5.5.1 Wiring

Internal wiring of components and subassemblies that are not covered by an appropriate product standard must then comply with UL 508, IEC 60204-1 (Clauses 12 and 13), or NFPA 79 (Clauses 12 and 13), in addition to the general wiring requirements outlined within UL 6141. All wiring within a wind turbine system that is accessible to users or service personnel, or run vertically up the tower, must either be installed in a raceway or be rated for tray cable usage. Tray cables must be installed in accordance with NEC Article 300. Any wiring subject to UV exposure during operation must be rated for exposure to sunlight, and similarly all wire and cable must be appropriately rated for the application and intended use.

Several UL standards are referenced for various wire types and applications. For NEC-based compliance, wiring within the wind turbine must additionally be compliant with applicable articles from NEC NFPA 70, as referenced. Additionally, IEC-based wiring methods are also prescribed. Test methods exist for verifying suitability of wiring and cables if ampacity verification methods cannot be established, in which temperature evaluation and tests are additionally performed to demonstrate no risk of fire or adverse effect on the materials employed in the equipment/component and that rated temperature limits are not exceeded. There are various suitable methods for separation of wiring circuits for when more than one circuit is operating at the same or different voltages in the same cable run, and each should be investigated for overall cost for a compliant system design.

All conductors are to be identified at each termination by a letter or number coding system corresponding to either the North American or international color scheme. A number/letter coding system could be used both in North America and internationally, thus preventing the need for two different wiring systems if designed carefully.

For routing of cables down the tower, and where multiple cables may be grouped and/or tied together, the cable having the largest outer diameter must be rated or evaluated for the additional weight-carrying capacity of all the cables that are attached, unless a fixture is provided where the load is not transferred from one cable to another. Where multiple cables are grouped and tied together, the cable having the largest outer diameter shall be rated or evaluated for the additional weight-carrying capability of all the cables that are attached.

5.5.2 Splices

Any splices in a power circuit cable must be provided with insulation suitable for the voltage and the thermal and mechanical stresses expected, and be rated for the size, type and number of conductors. Strain relief must be provided within 24 inches of the spliced connection. Below 1,000 V, splices must follow use and instructions from the manufacturer, including use of appropriately calibrated tools. Above 1,000 V, the finished assembly must additionally comply with testing requirements of UL 486A and 486B. Between 600 V and 1,000 V the finished assembly must additionally be exposed to the insulation puncture tests at a test voltage of 2,000 V plus 2.25 times circuit operation voltage. Flashover tests are conducted in accordance with insulation puncture and flashover test voltages. Additional requirements exist above 1,000 V in Clauses 4.3.6 and 4.3.7 of UL 6141.

5.5.3 Cable Twist Loop

A cable twist loop is often utilized where operation of the wind turbine results in the potential twisting of cables, and a slip ring is not used for transferring connection between rotating parts and parts fixed to the structure. No expected operational conditions are permitted to cause damage to the conductors and their insulation. Cables must be rated and used appropriately for the rotation and temperature. If the cable provider cannot prove acceptability, then testing is often required. Controls preventing damage to conductors and insulation are verified and tested as part of SRCS and safety and function testing. Where multiple cables are grouped together, their individual load ratings must not be exceeded. The cables also must be protected against contact with other surfaces that would cause damage or compromise the integrity of the insulation. Strain relief is often provided to properly support the cable or cable assembly and reduce strain and torque being transferred to the electrical terminations.

5.5.4 Bus Bars

Any bus bars must comply with one of the following standards at a minimum: UL 857, Standard for Busway, for Bus rated 600 V or less; IEEE C37.23 Standard for Metal-Enclosed Bus, for Bus rated more than 600 V; and IEC 61439-1 and -6 for bus rated 1,000 V or less.

5.5.5 Slip Rings

Slip rings used for transmission of power, control, or signal circuits within rotating elements of the wind turbine must be evaluated to UL 508 or IEC 60204-1. Slip rings rated above 1,500 V have additional requirements and are not covered in this Guideline. Temperature tests are conducted with the unit rotating as intended in its end-use installation as well as in a fixed position. The circuits and ground paths must have short-circuit ratings greater than or equal to the overcurrent protection in the end-use installation, or must withstand fault current levels according to UL 508, IEC 60204-1, or IEC 60204-11 above 1,000 VAC or 1,500 VDC.

Slip rings must additionally be subjected to overload testing. They are mounted and enclosed to represent the end application and tested at rated voltage ±15%. There must be no evidence of ignition, sealant leakage, cracking, breakage, or similar physical damage. For a slip ring with overcurrent protection, the "overload" rating of the device defines the overload current of the system. The test current is applied for a duration equal to the max clearing time permitted for overcurrent protection used. Any integral overcurrent protection is shunted out of the circuit for this test. Typical U.S. overcurrent devices have 135% overload rating, and max clearing time permitted is commonly 1 or 2 hours, depending on type, rating, and applicable standard. If no integral or external overcurrent protection is provided, the test is conducted using a current value that can be supplied to the unit continuously by the wind turbine source circuit, plus 10%, and is conducted until ultimate results occur but not more than 7 hours. After overload, the slip ring is subjected to (another) dielectric voltage withstand test as defined in UL 508, and there must be no breakdown between conductors or between conductors and dead metal parts.

5.5.6 Cable Trays

Cable trays and wireways are required to comply with Article 392 or 376 of NEC, as applicable. Metal cable tray and wireway assemblies must be investigated for bonding between sections and comply with the same mechanical tests for busbars identified above.

5.5.7 Switchgear

Switchgear, which covers various types of circuit breakers, contactors, control circuit devices/switches, terminal blocks, and others, are commonly used throughout the wind turbine electrical system. These types of equipment can be sourced as certified components. Various standards are referenced in the section of the standard based on type and application and also in Appendix A of this Guideline. The switchgear must be rated for the application and service conditions of the turbine system. Enclosures for switchgear must not have openings on the top surface, unless they are protected by a drip hood preventing entrance of falling water. Commonly, UL 60947 applicable parts are referenced for various types of switchgear.

5.5.8 Transformers

Transformers are commonly employed in various types, ratings, and applications in wind turbine electrical systems and components. These types of equipment can also be sourced as certified components, but sometimes they are custom or do not carry appropriate approvals. Power transformers less than 600 VAC are commonly approved to UL 506 or UL 1561, and the UL 5085 series for lower voltages. Any power transformers rated greater than 600 VAC must comply with UL 1562. Various transformer standards are referenced within this Guideline in Appendix A and in UL 6141, based on type and application. Additionally, many IEEE and IEC standards are referenced for instrument transformers in the IEEE C57.13 series and IEC 61869 series. UL 508 may sometimes be appropriate and acceptable based on application.

5.5.9 Panel Boards

Panelboards that are used within the turbine system, tower assembly, or customer interface must comply with UL 67, Standard for Panelboards.

6 DWT TYPE TESTING AND CERTIFICATION BELOW 150 kW

Section 6 covers detailed information related to test testing and certification of DWT systems according to ANSI/ACP 101-1. An overview of the process and general requirements are provided in Section 6.1. A detailed description of the process and requirements for structural design compliance is given in Section 6.2. Section 6.3 provides an overview of the type testing requirements, including tests required for validation of design simulation models, along with the other common required type tests. Manufacturing conformity (Section 6.4) and Certification Surveillance (Section 6.5) are covered briefly in this initial version and will be updated in future releases of this DW Certification Best Practices Guideline. Section 6.6 for Microturbines, and Section 6.7 for Test Site Requirements and Considerations will be covered in future releases of this Best Practices Guideline.

6.1 ANSI/ACP 101-1 General Requirements

The purpose of an ANSI/ACP 101-1-2021 certification is to confirm that the small turbine system is designed, documented and manufactured in conformity with design assumptions, specific standards, and other technical requirements. Demonstration that it is possible to install, operate and maintain the turbines in accordance with the design documentation is required. ANSI/ACP 101-1-2021 certification applies to a series of wind turbines of common design and manufacture. Where several variations of a turbine system are available, it is expected that a full evaluation would be performed on one of the more representative arrangements. Other variations, such as different power forms (single vs. three phase), need only be evaluated or tested in the ways in which they are different from the base certified configuration.

The technical requirements for conformity assessment are dependent on the wind turbine peak power rating as defined in the standard and measured during the safety and function test (See Section 6.3). Appendix B of ANSI/ACP 101-1 gives a table outlining the conformity assessment requirements for certification based on turbine power ranges. Table 9 is similar and is adapted for use within this DW Certification Best Practices Guideline.

Table 9 - ANSI/ACP conformity assessment tiered requirements

	"Micro" up to 1,000 W Peak Power	1 – 30 kW Peak Power	30 – 65 kW Peak Power	65 – 150 kW Peak Power
ACP STRUCTURAL DESIGN				
Simplified Loads Methodology	Not required	Recommended only for turbines < 10 kW	Not allowed	Not allowed
Simulation (Aeroelastic) Model	Not required	Allowed	Required	Required
Structural Analysis	Not required	Required	Required	Required
Minimum Code Validations	Not required	See Section 6.3.4	See Section 6.3.4	See Section 6.3.4
Safety Factors	Not required	Required	Required	Required
ACP TYPE TESTING				
Duration Testing	Required	Required	Required	Required
Power Performance	Required	Required	Required	Required
Loads Validation Testing	Not required	See Section 6.3.4	See Section 6.3.4	See Section 6.3.4
Acoustics Testing	Not required	Required	Required	Required
Safety and Function Testing	Required	Required	Required	Required
Blade Testing	Not required	Static test only	Static test only	Static test required; fatigue
Labeling	Required	Required	Required	Required

Note that for passive yaw machines, yaw behavior must additionally be validated, which would not be applicable to vertical-axis wind turbines (VAWTs). Structural design verification is not required for certification of microturbines according to ACP 101-1; additional guidance can be found in Section 6.6 in future releases of this Guideline.

The ANSI/ACP 101-1 standard provides the industry method for evaluation of wind turbine systems in terms of mechanical and structural safety, reliability, power performance, and acoustic characteristics. It is derived from existing international wind turbine standards in the IEC 61400 series, with deviations or "specific departures" for streamlining the certification process. A turbine system includes the turbine itself, the controller or controllers and associated equipment, inverter, and all components between the wind turbine and point of connection with the electrical load.

There are several definitions within Clause 1.4 of the ANSI/ACP 101-1 standard that are critical to use and for understanding the document:

- "Peak Power: Highest bin-averaged power output of all filled wind speed bins per the procedure defined in Section 4 Safety and Function expressed as [Peak Power] kW @ [Peak Power Wind Speed] m/s."
- "Reference Power: The wind turbine's power output, expressed as kW, at 11 m/s (24.6 mph), or the maximum output power of the wind turbine system at a lower wind speed if this is a higher power output, per the power curve from IEC 61400-12-1 Ed. 21, except as modified in Section 2 of this standard."
- "ACP Reference Sound Pressure Level: The sound pressure level, expressed as dB(A), that will not be exceeded 95% of the time, assuming an average wind speed of 5 m/s (11.2 mph), a Rayleigh wind speed distribution, and 100% availability. For these conditions, the wind speed of 9.8 m/s would not be exceeded 95% of the time. The

ACP Reference Sound Pressure Level is calculated from IEC 61400-11 Ed. 3 test results at an observer location 60 m (197 ft.) from the rotor center, except as modified in Section 3 of this standard."

Though uncommon, turbines that are above 200 m^2 rotor-swept area and less than 150 kW peak power may instead choose to comply with IEC 61400-1 and associated requirements for IEC type certification. The process outlined in this DW Certification Best Practices Guideline is focused on ANSI/ACP 101-1, which was developed to reduce the barriers to market entry in the United States. An IEC 61400-1 compliant design and type certification is always acceptable, as it has a more rigorous set of requirements than what is outlined here in Section 6. See Section 7 for additional information.

6.2 ACP 101-1 Structural Design Compliance

One of the major topic areas of consideration for certification according to the ANSI/ACP standard is the structural design, or strength and safety of the wind turbine system. The evaluation performed by the certification agency may be referred to also as a "design evaluation." The purpose of the design evaluation is to examine whether the turbine type is designed and documented in conformity with the design assumptions, specific standards, and other technical requirements. The certification agency will require the applicant to submit a package of documentation that sufficiently describes the turbine system and shows compliance with the standard requirements.

The structural design and type testing requirements are further discussed in the following subsections. The overall requirements are the same, with varying levels of validation based on peak power category. Differences between the tiers are identified in the sections below.

6.2.1 External Design Conditions

The external conditions considered in the design are dependent on the SWT Classes defined in IEC 61400-2 Clause 6.2. These set the basic wind speed and turbulence inflow conditions for the chosen design method (discussed in Section 6.2.2). Turbines under the ANSI/ACP 101-1 scope are required to be IEC SWT Class II or Class S, and the TI15 must be increased from 18% to 20%. The defining design conditions for a Class II SWT are given below:

- Reference wind speed, V_{ref} = 42.5 m/s
- Annual average wind speed, V_{ave} = 8.5 m/s
- Turbulence intensity at 15 m/s, I_{15} = 0.20
- a = 2 (slope parameter used in Normal Turbulence Model)
- 50-year extreme wind speed, V_{e50} = 59.5 m/s
- 1-year extreme wind speed, V_{e1} = 44.625 m/s.

If defining external conditions are desired other than those defined above for Class II, a Class S designation can be used for certification. This is only suggested if designing a system for a SPECIAL application or location, such as cold or hot weather extremes, high or low wind sites, or international certifications. Each set of external conditions would need to be considered independently as part of their own design conformity related to certification. Varying testing requirements could be expected for the varying alternate configurations to a Class II certified system. Class S systems have special documentation requirements in Annex B of IEC 61400-2.

DWTs are subjected to environmental and electrical conditions that may affect their loading, durability, and operation. To ensure the appropriate level of safety and reliability, various environmental, electrical, and soil parameters are accounted for in the design and recorded in the design documentation. Environmental conditions are divided into "wind conditions" and "other environmental conditions." Electrical conditions refer to electrical network and load conditions for batteries, hybrid systems, or local grid.

Wind conditions are the primary external consideration for structural integrity, and normal and extreme conditions are defined in Clause 6.3 of IEC 61400-2. These wind conditions form the basis of the applied wind conditions for the chosen design method. Other environmental conditions also affect design features such as control system functionality, durability, and resistance to corrosion, among others. Some external conditions are subdivided into normal and extreme conditions. Normal external conditions are typically long-term structural loading and operating conditions, and extreme external conditions are rare but critical external design conditions. The design load cases consist of a combination of these external conditions with wind turbine operational modes, faults, and conditions.

Clause 6.4 of IEC 61400-2 covers other environmental conditions that must be considered at a minimum, including:

- Temperature
- Humidity
- Air density
- Solar radiation
- Rain, hail, snow, and ice
- Chemically active substances
- Mechanically active particles (sand, dust, etc.)
- Lightning
- Earthquakes
- Corrosion.

Annex J of IEC 61400-2 gives additional info as well on extreme environmental conditions. Normal environmental conditions are typically an ambient temperature range of -10°C to +40°C, relative humidity up to 95%, solar radiation intensity of 1 kW/m^2, and air density of 1.225 kg/m^3. The only other extreme condition of consideration is an extreme temperature range of -20°C to +50°C for the standard wind turbine classes (including Class II). Lightning and earthquake are optional and dependent upon application, but if resistance to either is claimed, it must be proven in the design and verified via test as applicable. Consideration of ice buildup is not required, but if chosen to include in the estimation of loads, a minimum layer of 30 mm of ice with 900 kg/m^3 density on all exposed areas is recommended. Static ice load is combined with the drag loads on the parked/idling/motoring turbine system at 3 x V_{ave}.

Electrical loads with normal and extreme electrical conditions are defined in IEC 61400-2 Clause 6.6. Electrical network design load conditions can vary, but IEC 61400-2 provides some guidance for design occurrences, including number of outages (20 times per year) with at least one up to more than 24 hours as normal conditions. Voltage and frequency allowances are also provided; however, in the United States this is dictated by electrical product conformity and the inverter, converter, controller, or interconnected system equipment that is managing connection to the electrical network or load.

6.2.2 Initial Testing

Initial design data testing must be performed to verify and/or determine key design parameters such as design power, design rotational speed, blade first flapwise (static) natural frequency, and validated weights of major components. These design parameters must be obtained via field testing on a fully installed wind turbine system that is compatible with the design documentation considered for certification. Additional type testing guidance for loads validation tests are found in IEC 61400-13, and further guidance will be outlined for loads validation testing in a future release of this DW Certification Best Practices Guideline. All design features that are considered critical must be implemented and active during the measurements. This includes any unconventional features as well.

Guidance is given in Clause 13.2 of IEC 61400-2 and IEC 61400-13 for these tests and parameters, and others that may be helpful. See also Section 6.3.4 of this DW Certification Best Practices Guideline.

6.2.3 Structural Evaluation

The structural evaluation consists of the calculation of lifetime extreme and fatigue loads on the critical components, and follow-on stress analysis to verify the safety. Also required for certification is a resonance analysis, or Campbell diagram, for the main structural components of the system according to Annex I of IEC 61400-2.

The wind turbine design loads are obtained either via simplified load methodology (SLM) or simulation modeling. Details of these methods are provided in Sections 6.2.3.1 and 6.2.3.2. No matter the method, all vibration, inertial, and gravitational loads must be considered in addition to the operational and aerodynamic loads acting on the wind turbine and structure. External design conditions used in the loads calculations are specified in the standard and reproduced above in Section 6.2.1.

Section 5 of ANSI/ACP 101-1-2021 provides applicable loads calculation and validation methods as a function of the peak power of the turbine:

1. Simplified load methodology (1–10 kW suggested only, and not applicable to VAWTs)
2. Aeroelastic modeling with tests to verify design data and component weights (1–30 kW)
3. Aeroelastic modeling with limited validation testing and component weights (30–65 kW)
4. Aeroelastic modeling with validation testing and component weights (65–150 kW).

VAWTs and other novel designs may require additional validations where non-validated design codes are used, or where codes are used that do not accurately reflect the turbine archetype. IEC 61400-13 Annex J gives additional guidance for VAWT load model validation measurements that are not required but suggested for design validations. See Section 6.3.4 below for additional specification of validation testing requirements.

Note that determining the design loads via loads measurement testing is not an accepted design method. Loads measurements are only for the purpose of validation of load simulation models. Loads calculations are validated during testing via the “tests to verify design data,” which are discussed in Section 6.3 Type Testing Requirements.

Measured design data are not necessary prior to the development of a model but are used in the validation process to ensure accuracy of results. If design data testing yields inconsistent or different results, the loads calculations and structural analyses will need to be revised for the final certification of the turbine.

Loads are calculated over a range of wind speed conditions and operating situations, or design load cases (DLCs). A minimum set of DLCs are provided in Clause 7 of IEC 61400-2, for both the SLM and simulation modeling design methods. These tables are reproduced below in Section 6.2.3.1. Considerations should be made regarding unique turbine conditions or occurrences in a 20-year design life of each turbine design that might not be captured by the IEC table of DLCs. These tables provide the minimum that is required to comply, but a certification agency may require additional DLCs if other design situations exist that are not adequately considered in IEC 61400-2 or defined in the turbine system documentation. The manufacturer should perform a detailed FMEA to identify all scenarios that should be modeled to ensure design driving loads are captured. Ultimately, the DLC table is unique to the turbine and must reflect the archetype, features, control system, etc.

For certification and design verification, all relevant combinations of external conditions and design situations must be analyzed. The DLC table is a minimum set, and if unique conditions apply, additional DLCs may need to be considered. Additionally note that all DLCs are required to be considered in a single suite of simulations; none can be left off without written approval from the certifying agency.

6.2.3.1 Simplified Load Methodology

The SLM is a more conservative limited set of load cases. Due to higher uncertainty in the SLM methods, higher partial safety factors are required in the limit state analysis, referenced in Section 6.2.4. Clause 7.4 and Annex F of IEC 61400-2 describe the SLM. In the current Edition 3 of IEC 61400-2, the turbine must meet the following stipulations to use the SLM:

1. HAWT, upwind or downwind configuration
2. Two or more propeller-style, cantilevered rotor blades
3. Coordinated blade movement (fixed, or not independent and uncoordinated pitching, coning, etc.)
4. Rigid hub (not teetering or hinged).

Variable- or constant-speed machines are allowed, with or without furling. Fixed-pitch, or variable active/passive pitch mechanisms are allowed as long as they are coordinated in all blades simultaneously. The SLM utilizes input parameters that are determined via the "tests to verify design data" in Clause 13.2 of IEC 61400-2. For early stage designs, it is common to use assumed values from the turbine designer or manufacturer, but for certification these values must be validated in the type testing program. This is why it is suggested to run these tests early in prototype testing programs, or independently of a certification program for early design validations. For example, design power and rotational speed are extracted from design power performance test results at design wind speed (1.4 V_{ave}, or 11.9 m/s for a Class II design). If test values are greater than those used in initial design calculations, it would result in increased loads and decreased margins of safety in limit state analysis.

Table 2 from IEC 61400-2 is reproduced below in Table 10 for the minimum set of required DLCs for a wind turbine utilizing the SLM design method.

Table 10 - Minimum set of DLCs, Table 2 extracted from IEC 61400-2

Design Situation	Load Cases		Wind Inflow	Type of Analysis	Remarks
1) Power Production	**A**	Normal operation		F	
	B	Yawing	$V_{hub} < V_{design}$	U	
	C	Yaw error	$V_{hub} < V_{design}$	U	
	D	Maximum thrust	$V_{hub} = 2.5xV_{ave}$	U	Rotor spinning but could be furling or fluttering
2) Power Production Plus Occurrence of Fault	**E**	Maximum rotational speed		U	
	F	Short at load connection	$V_{hub} < V_{design}$	U	Maximum short-circuit generator torque
3) Shutdown	**G**	Shutdown (Braking)	$V_{hub} < V_{design}$	U	
4) Extreme Wind Loading	**H**	Extreme wind loading	$V_{hub} < V_{e50}$	U	The turbine may be parked (idling or standstill) or governing. No manual intervention has occurred.

Design Situation	Load Cases		Wind Inflow	Type of Analysis	Remarks
5) Parked and Fault Condition	I	Parked wind loading, maximum exposure	$V_{hub} < V_{ref}$	U	Turbine is loaded with most unfavorable exposure
6) Transport, Assembly, Maintenance and Repair	J	To be stated by manufacturer		U	
Key F = Analysis of Fatigue Loads U = Analysis of Ultimate Loads					

Following the DLC table in the standard are descriptions of each DLC. Equations are provided for the calculation of various ultimate and fatigue forces and moments. Many assumptions apply, and for detail on the SLM and background calculations, refer to Annex F of IEC 61400-2.

6.2.3.2 Simulation Modeling

According to IEC 61400-2, in the case that a simulation model is used to determine the loads, the model must be simulated "over a range of wind speeds, using the turbulence conditions and other extreme wind conditions defined in 6.3.3, and design situations defined in 7.5." Clause 7.5.9 also stipulates that "Where relevant, the following shall also be taken into account:

- wind field perturbations due to the wind turbine itself (wake-induced velocities, tower shadow, etc.)
- the influence of 3D flow on the blade aerodynamic characteristics (e.g. 3D stall and tip loss)
- unsteady aerodynamic effects
- structural dynamics and the coupling of vibration modes
- aeroelastic effects; and
- the behavior of the control and protection system of the wind turbine."

Some commonly used codes that meet the requirements above are:

- OpenFAST
- HAWC2
- Bladed
- QBlade
- ASHES.

These types of code include modules for aerodynamics, hydrodynamics for offshore structures, control and electrical system (servo) dynamics, and structural dynamics to enable coupled nonlinear aero-hydro-servo-elastic simulation in the time domain. Note that both HAWC2 and QBlade are capable of modeling HAWTs and VAWTs.

To build the model, the user must provide data relating to all of these disciplines. For a DWT, the key input parameters are:

- Blade model: cross-sectional stiffness, geometry, and mass distributions; mass and mass center location; first few natural frequencies; airfoil data (Cl, Cd, Cm vs. alpha)
- Tower model: cross-sectional stiffness, geometry, and mass distributions; first four natural frequencies

- Nacelle and hub: mass and mass center location, inertias
- Tail and furl system: geometry, mass and mass center location, fin airfoil data
- Controller: rotor speed range, rated power, pitch and torque rates and limits
- Protection system: description of operating states (for defining DLCs).

Many of the inputs to the model are generated using preprocessing tools. For example, to generate, correct, and extrapolate airfoil data and to calculate cross-sectional structural distributions.

Once the model input files are ready, the DLCs are simulated. The minimum set of required DLCs for a wind turbine utilizing simulation (aeroelastic) modeling tools for design is provided in Table 4 from IEC 61400-2 and reproduced below in Table 11. Considering this table and the differences between VAWTs and HAWTs, a proposal for the minimum set of DLCs for VAWTs has been provided in a second table including number of simulations per wind speed (sims/ws) (Table 12). A general description of the DLCs is provided below the tables.

For further guidance on how to define the DLCs refer to *Design Load Basis for onshore turbines* by Hansen et al.[1] Note that a complete design load basis, which is the collection of DLCs, will consist of 300–500 or more simulations for a DWT.

Table 11 - Minimum set of DLCs, Table 4 extracted from IEC 61400-2

Design Situation	DLC	Wind Condition		Other Conditions	Type of Analysis
1) Power Production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$ < or $3xV_{ave}$		F,U
	1.2	ECD	$V_{hub} < V_{design}$		U
	1.3	EOG_{50}	$V_{in} < V_{hub} < V_{out}$ < or $3xV_{ave}$		U
	1.4	EDC_{50}	$V_{in} < V_{hub} < V_{out}$ < or $3xV_{ave}$		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 $2.5xV_{ave}$	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 $2.5xV_{ave}$	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 Shutdown	4.1	NTM	To be stated by the manufacturer		U

[1] Hansen, M. H., Thomsen, K., Natarajan, A., & Barlas, A. (2015). Design Load Basis for onshore turbines - Revision 00. DTU Wind Energy. DTU Wind Energy E No. 0074(EN)

Design Situation	DLC	Wind Condition		Other Conditions	Type of Analysis
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
Key F = Analysis of Fatigue Loads U = Analysis of Ultimate Loads					

Table 12 - Minimum suggested set of IEC 61400-2 DLCs for VAWTs

Load Case	DLC #	Wind Conditions [m/s]			Other Conditions	Analysis Type	What Is Simulated
Power Production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$ or $3{*}V_{ave}$	Every 2 m/s 6 sims/ws		F/U	Normal operation sim len. 620 s
	1.3	EOG50	$V_{in} < V_{hub} < V_{out}$ or $3{*}V_{ave}$	Every 2 m/s 1 sim/ws		U	Normal operation sim len. 320 s
	1.5	ECG	$V_{hub} = V_{design}$	1 sim/ws		U	Normal operation sim len. 320 s
Power Production + Fault	2.1	NWP	$V_{hub} = V_{design}$ or V_{out} or $2.5{*}V_{ave}$	1 sim/ws	Control system fault	U	Grid off at T = 60 s, brake deployment after system delay sim len. 620 s
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$ or V_{e1}	Every 2 m/s 6 sims/ws	Control or protection system fault	F/U	Grid off at T = 60 s, turbine runaway avoided by protection system sim len. 620 s
	2.3	EOG1	$V_{in} < V_{hub} < V_{out}$ or $2.5{*}V_{ave}$	Every 2 m/s 1 sim/ws	Loss of electrical connection	U	Grid off at T = 65 s, brake deployment after system delay sim len. 320 s
	2.x				Additional cases as defined by FMEA		
Normal Shutdown	3.1	NTM	$V_{in} < V_{hub} < V_{out}$	Every 2 m/s 1 sim/ws		F/U	Brake deployment at 60.0 s, gen off based on system delay sim len. 120 s
	3.2	EOG1	$V_{hub} = V_{out}$ or $V_{max,shutdown}$	1 sim/ws		U	Brake deployment at 65.0 s, gen off based on system delay sim len. 320 s
Emergency or Manual Shutdown	4.1	NTM	$V_{in} < V_{hub} < V_{out}$	Every 2 m/s 6 sims/ws		U	Brake deployment at T = 60.0 s and instantaneous grid cutoff (T = 60.0 s) sim len. 320 s

Load Case	DLC #	Wind Conditions [m/s]			Other Conditions	Analysis Type	What Is Simulated
Parked	5.1	EWM	$V_{hub} = V_{e50}$	1 sim/ws	Possible loss of electrical power network	U	Parked turbine, no rotation; electrical network loss could impact the operation of the engaged brake. Sim len. 320 s
	5.2	NTM	0.5 m/s < V_{hub} < 0.7*V_{ref}	1 sim/ws		F/U	Parked turbine, no rotation. Sim len. 620 s
Parked + Fault	6.1	EWM	$V_{hub} = V_{e1}$	1 sim/ws	Brakes worn	U	Parked turbine, no rotation. Sim len. 620 s
	6.2	EWM	$V_{hub} = V_{e1}$	1 sim/ws	Brake fault	U	Parked turbine, no initial rotation. Sim len. 620 s
Transport, Assembly, Maintenance & Repair	7.1	To be stated by manufacturer				U	

DLC 1.x: This is the set of DLCs encompassing normal power production scenarios without system faults, start-ups, or shutdowns. The differences between the DLCs are in the inflow conditions. DLC 1.1 simulates power production from cut-in to cut-out under turbulent wind conditions. DLC 1.2 includes an extreme coherent gust with direction change, where the wind speed increases and the direction changes at the same time. DLC 1.3 covers the extreme operating gust for a 50-year return period, DLC 1.4 is the extreme direction change for a 50-year return period, and DLC 1.5 is an extreme coherent gust at the design wind speed. Simulation results should include the effects of any passive or active control features. In Table 12 for VAWTs, DLC 1.2 and DLC 1.4 are eliminated, as direction change has no effect on a VAWT and the gust situation from DLC 1.2 will be covered in DLC 1.3.

DLC 2.x: These DLCs cover normal production plus occurrence of a fault. Typically included are grid loss scenarios, where the first-layer safety system is deployed in DLC 2.1, and in DLC 2.2 the primary layer fails and the secondary layer is activated. DLC 2.3 is a 1-year extreme operating gust combined with a loss of electrical connection. Additional load cases may be required to consider other design-specific faults. These load cases are defined by the manufacturer after a detailed FMEA.

DLC 3.x: These are the normal shutdown DLCs. DLC 3.1 is with turbulent wind over the range of production wind speeds. DLC 3.2 is with a 1-year extreme operating gust. If the shutdown procedure for DLC 3.2 is the same as that for DLC 2.3, then it may be eliminated. The exact shutdown sequence for a grid drop vs. normal shutdown must be documented. Also, if the normal and emergency shutdown sequences are the same, it may be possible to eliminate DLC 3.1 because it will be covered by DLC 4.1.

DLC 4.1: This DLC covers emergency or manual shutdowns with turbulent wind over the range of production wind speeds. Emergency shutdown is defined by the manufacturer and must be fail-safe under grid loss conditions.

DLC 5.x: DLC 5.1 covers the 50-year return wind speed. DLC 5.2 is with turbulent inflow covering 0.5 m/s up to 70% of the reference wind speed. In both cases the rotor is parked, idling, motoring, or producing power, depending on the control strategy.

DLC 6.x: This DLC covers a parked plus fault condition. If there is a redundant brake, it is possible that this situation replicates DLC 5.1. In this case it may be possible to eliminate it, again with proper documentation of the control and protection system.

DLC 7.x: This is the transportation, assembly, maintenance, and repair DLC. The transportation and assembly cases are typically analytical calculations. The maintenance and repair scenarios may require aeroelastic simulations if those conditions are not covered by the other DLCs.

It is necessary to simulate the turbine and control responses under all the different conditions as specified in the IEC 61400-2 DLCs. A certifying agency would only allow elimination of those DLCs that end up being identical based on the planned control responses, or not applicable to the particular system.

The DLC simulations are postprocessed to determine the extreme and fatigue loads, from which a governing loads table is assembled that identifies the maximum governing loads in each load case. The calculated loads must also be validated. This process is defined in Sections 6.3.4 and 7 for turbines below and above 150 kW, respectively. OD-554-1 applies to small wind turbines, but also provides guidance related to use of non-validated code and the required steps for validation and verification. ASME Standard for Verification and Validation in Computational Solid Mechanics (V V 10) is also recommended. Neither are firmly required for certifications of DWTs below 150 kW but are suggested for better understanding of the verification and validation process.

6.2.3.3 Structural Verification

The integrity of the wind turbine structure is based on verification of the structural design of the turbine system and components. This is generally all based from IEC 61400-2 Clause 7, even for turbines above 200 m^2 in the rotor-swept area as long as they have less than 150 kW peak power. The structural integrity of all components in the critical load path from rotor blade to foundation are verified via ultimate and fatigue strength analysis.

Once the DLCs have been calculated and governing loads and load cases identified, those loads are translated to the critical load-carrying components in the structure (from rotor to foundation, as outlined above) for stress analysis. Typically, finite-element analysis or other tools are used for proper stress calculation, although analytical methods are possible. ANSI/ACP requires the strength be evaluated by the certification agency at a minimum for the following components: the blade, other aero/rotor blade features, blade-to-shaft connections, main shaft/drivetrain, gearbox, bearings, yaw system, pitch system, teetering/other hub, connection to tower, critical safety/protection systems and components, and nacelle frame, spinners, and covers. The foundation is not required to be verified; however it typically is part of local permitting for building or other permits. Any novel feature in the critical load path is subject to following the requirements outlined herein.

Stress analysis must consider combined loading situations. If using aeroelastic modeling,, contemporaneous loads may be extracted and applied simultaneously in the stress analysis, rather than the individual extremes of the components. For SLM the stresses calculated from the individual forces and moments within a load case must be combined to find equivalent stresses. The resulting equivalent stresses must be compared with design values for material stresses.

The stress analysis must include considerations for the following:

- Stress variations
- Stress concentrations
- Magnitude and direction of the resulting loads
- Component dimensions and material thickness values and properties
- Component surface roughness, surface treatments, and other surface protections
- Type of loading (bending, tensile, torsion, etc.)
- Welding, casting, machining, end grain construction, etc.

Table 5 from IEC 61400-2 provides guidance in determining appropriate equivalent stresses of the blade root and rotor/drive shaft, based on type of loading condition.

Coincident with the determination of equivalent stresses is the identification and use of appropriate safety factors, as described in Clause 7.8 and Annex E of IEC 61400-2. IEC 61400-2 provides partial safety factors (PSFs) for both loads and materials that are used in the subsequent phase of the structural analysis (limit state analysis). Load factors are given in Clause 7.8.2 of IEC 61400-2 and are typically straightforward, depending on the design method chosen (simple loads or simulation modeling) and the load type (ultimate or fatigue). Do not deviate from these values; PSF is 1.0 for simulation modeling fatigue loads and 1.35 for ultimate loads. For SLM, PSF is 1.0 for fatigue loads and 3.0 for ultimate loads. Refer to Table 7 of IEC 61400-2.

One of the largest areas of interpretation is the appropriate selection of PSF for materials of each component and geometry. Most often, this section is not well-understood by the certification applicant. Materials are discussed next in Section 6.2.4.

6.2.4 Material Partial Safety Factors

Much more complex than the loads PSF is the determination of PSF for materials, as described in Clause 7.8.1 and further supported in Annex E in IEC 61400-2. Higher material PSFs are required as compared to IEC 61400-1 for utility-scale turbines due to the simplified nature of the certification process of an IEC 61400-2 wind turbine compared to the more rigorous certification process for utility-scale wind turbines. This is also due to variability in archetypes of DWTs, whereas utility-scale turbines all utilize models for the same configuration.

Most often, the required characterization of materials and selection of material PSFs is not well-understood by the certification applicant, which can lead to gaps in design compliance. It is paramount to understand the material requirements of IEC 61400-2. Note that any wind turbine of any size and configuration can always choose IEC 61400-1 and utilize lower design factors but must also then meet the full set of type certification requirements for a utility-scale machine. Those requirements are not directly covered in this DW Certification Best Practices Guideline.

Clause 7.8.1 of IEC 61400-2 details several requirements that must ALL be adequately considered and documented in the certification design documentation for verification and requires statistically significant testing of full-scale samples and material test samples for use of lower PSFs. Determining material properties from published sources is not sufficient to classify a fully characterized material according to IEC 61400-2; additional guidance is outlined below on the additional factors that must be considered.

Table 13 reproduces Table 6 from IEC 61400-2, which lists the PSFs for materials that must be used for fatigue and ultimate strength analysis. When the five factors above have been adequately considered in the test samples and data, the minimum PSFs for materials may be used. This situation is termed “full characterization” and may include those cases where recognized material codes are available (e.g., ISO). If material properties are based solely upon coupon testing and do not consider the above factors, the maximum material factor shall be used. This situation is termed “minimal characterization.” Intermediate factors between minimal and full values are allowable with proper justification of consideration of the five factors above and are applied as reduction factors to the characteristic material strength.

Table 13 - Material PSFs, Table 6 extracted from IEC 61400-2

Material Characterization	Fatigue Strength, γ_m	Ultimate Strength, γ_m
Full characterization	1.25[a]	1.1
Minimal characterization	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.		

Material testing is the most effective way to consider these effects in the declaration of a characteristic value and use of full characterization values for PSF for materials. The best data would be derived from full-scale testing that includes all items as required from a) through e) below, where sufficient test samples were tested to yield results with 95% probability and 95% confidence. If the material database does not include ALL this supporting information and test data, including material certificates and composition from suppliers, then additional factors MUST be applied to the PSF for materials as described above. Separate factors can be estimated for each of the five effects. These factors are multiplicative for all conditions that apply and for arriving at a final material PSF for ultimate and fatigue. The characteristic value of the material is divided by the resulting factor.

Annex E of IEC 61400-2 gives additional guidance for consideration of appropriate additional factors to apply as material PSF for DWT designs. Reference E7 from Annex E (MACHINE DESIGN, Norton), or similar machine design texts, are often referred to and offer guidance and additional reference for effects on material properties. If none of the required considerations are made and only a material certificate is used from the supplier, "minimal characterization" values are typical. Often, though, the higher factors are difficult to comply with when applied in the limit state analysis, and as such lower or intermediate factors between full and minimal characterization are desired. When determining intermediate factors, it is important to remember that the worst case is always "minimal characterization," and the product of the combined material PSFs should never exceed that value. If able to comply with minimal characterization values, the design documentation only requires material certificates and compositions to be verified, and the use of an appropriate characteristic value agreed with the certification agency is chosen.

For proper determination of material PSFs, a characteristic value first must be determined for use in the limit state analysis, covered in Section 6.2.4. For the purposes of certification of DWTs to the referenced standards herein, characteristic values are mechanical properties of materials or elements that have a specified level of statistical probability and confidence associated with them. For design compliance, materials are required to be based on 95% probability that the material will exceed the characteristic value with 95% confidence limits. For other survival probabilities additional factors will be applied, using Table E.1 IEC 61400-2 as guidance. Refer to Annex E for further information.

Then, five major factors that influence the fatigue and ultimate strength of a material <u>must</u> be considered in the test data sampling and testing for establishing characteristic material strength. The factors are given as follows:

a) Materials and material configurations representative of the full-scale structure
b) Manufacturing method of the test samples that are typical of the full-scale structure
c) Static, fatigue, and spectrum loading testing (including rate effects)
d) Environmental effects (e.g., UV degradation, humidity, temperature, corrosion, etc.)
e) Geometry effects as they affect material properties (e.g., material orientation for injection molded blades, ply drops in composites and wood, material orientation from forging of metals, etc.).

For a) above, this requirement relates to the test sample materials and configuration as compared to the full-scale structure, both related material composition as well as the geometry, size, and shape of the component(s) for which the material is used. If full-scale component testing is not performed, a size or scaling factor must be added.

The requirement in b) above relates to the test sample manufacturing method and how that compares to the finished product of the component(s) for which the material is used. The material test samples do not go through the same identical manufacturing process as the end material in the full-scale structure. Surface preparations, plating, further machining, or other manufacturing processes in the end product that differ as compared to the test samples for which the material strengths are derived require additional factors to be added.

For c) above, this is often a partial factor of 1.0 of metals and common materials where published fatigue data and values are known, but for less common materials and fiber-reinforced plastics used in complex geometries or rotor blades, additional factors are common where fatigue testing data are not available. The strength reduction (both for ultimate and fatigue strength) of fiber-reinforced plastics due to material temperatures higher than controlled room temperature (see IEC 61400-2 Clause 6.5) are additionally considered by a PSF of 1.1 for item c. This factor can be set to 1.0 if the coupon tests are executed at the highest (extreme) temperature the wind turbine is designed for, i.e. 50°C, unless a higher figure is stated in the design conditions. Higher factors can be seen in addition to the temperature consideration above, ranging up to 1.6 is typical.

For d) above, the environmental effects on the load-carrying structure of fiber-reinforced plastic materials such as material degradation and aging of due to UV radiation, humidity effects, and others are required to add an additional material factor of 1.35 on static strength analysis only. This factor can be reduced if representative tests show lower degradation effects. Fiber-reinforced plastic materials include all fiber-reinforced plastic materials, such as glass or carbon and epoxy, polyester, or vinyl ester. For metallic materials the environmental effects of corrosion can be excluded with adequate means of protection over the lifetime of the wind turbine (20 years).

For e) above, guidance is given in E.5 of IEC 61400-2 related to geometry effects and discontinuities, which are common for fiber-reinforced plastics but must also be adequately considered for cast and forged materials.

Several examples are provided in Annex E of IEC 61400-2, and in some cases specific factors are provided for various materials or effects. E.4.2 covers composite materials and defines a PSF for materials γ_m of 7.4 for glass fiber and 3.7 for carbon fiber. These are total factors applied to static ultimate material strength to adequately account for fatigue, environmental, reliability, size effects, etc. from the five factors above (a through e). When using these factors, additional considerations are typically not required, but additional factors for geometry effects as they apply to local material properties may need to be investigated as discussed in E.5. These geometry effects may be determined empirically, or through analysis, with appropriate consideration of stress concentrations.

IEC 61400-2 E.4.3 covers metals, and various fatigue factors can be inferred from Figure E.5, which is very useful. Similar plots are available in similar published references.

Other environmental partial factors and effects for steel, aluminum, and titanium are stated as 1.3, 1.3, and 4.2, respectively. Considerations for wood material effects refer to E.4.4 IEC 61400-2. Geometry effects are covered in E.5, and again, a reference is provided for various geometric discontinuities and their associated additional factors. There are many similar figures, charts, and supporting information in Reference E7 from Annex E (MACHINE DESIGN, Norton), Ch. 6 with reference to the third edition from 2006.

6.2.5 Limit State Analysis

After PSFs are determined and adequately documented and the equivalent stresses have been determined, Clause 7.9 of IEC 61400-2 is used for ultimate and fatigue limit state analyses. For ultimate strength, the design requirement to be met is expressed by the equation:

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

Where:

- F_k is the characteristic material strength
- y_m is the partial safety factor for materials
- y_f is the partial safety factor for loads.

Yield strength can be used as the characteristic strength in some cases.

Fatigue failure is a calculation of damage from all load cases combined. Damage is estimated using appropriate fatigue damage calculations—for example Miner's rule—where the limit state is reached when the accumulated damage exceeds 1. The accumulated damage within the lifetime of the turbine must be less than or equal to 1:

$$\text{Damage} = \sum_i \frac{n_i}{N(\gamma_f \gamma_m \, s_i)} \leq 1.0$$

Where:

- n_i is the number of cycles in bin *i* of the characteristic load spectrum, including all relevant load cases
- s_i is the stress/strain level associated with the cycles in bin *i*, including effects of mean and cyclic range
- *N*(.) is the number of cycles to failure as a function of stress/strain indicated (i.e. the characteristic S-N curve)
- y_m is the partial safety factor for materials
- y_f is the partial safety factor for loads.

Where S-N data are not available for a given material or component, ultimate strength analysis must be substituted, with higher factors considered, as described in Clause 7.9.2 of IEC 61400-2 and the PSF for materials is set to 10.0.

A critical deflection analysis must also be performed as outlined in Clause 7.9.3. The critical deflection analysis is also used in appropriately defining the blade/tower clearance as required as part of the tower design criteria that must be specified by the turbine system OEM. The tip deflection analysis is based on the most severe bending moment distribution assumed for any of the design load cases typically, but for a VAWT, critical deflection may exist, for example, more in the supporting turbine frame or if the rotor blade overhangs the supporting tower. Any such occurrences must be properly evaluated.

To ensure the turbine is paired with an appropriate tower, the manufacturer shall submit design requirements for towers, including:

- Mechanical and electrical connections
- Minimum blade/tower clearance
- Maximum tower top loads
- Maximum allowable tower top deflection
- Fundamental frequencies to avoid as evidenced by a resonance diagram (e.g., Campbell diagram) per IEC 61400-2 Annex I.

Though not mandatory for certification, additional guidance for the design of wind turbine components can be found in many published standards and is recommended for consideration in early design stages. ACP 101-1 and the requirements in this DW Certification Best Practices Guideline can be used as overarching guidelines for certification requirements and determination of design loads required for certification. See Section 7 for additional references of component and structural design standards.

6.3 Type Testing Requirements

The testing process is very well-defined in ANSI/ACP 101-1. The tests are well-established published IEC standards, and ANSI/ACP 101-1 makes additions or revisions to the IEC 61400 test, which are required for compliance in the United States. The ACP 101-1 standard was developed with the intent of being a simpler test program to help reduce time and cost for certification. The tests that must be performed as part of the ACP 101-1 certification process are illustrated in Figure 14, and additional background and considerations are provided in this DW Certification Best Practices Guideline.

Referring back to the conformity assessment table in Appendix B of ACP 101-1, the various tests that are required or not are identified in the table. The testing program is the same for all turbines above 1,000 W peak power, with only variations in the required validation testing. Detailed test procedures and requirements are not outlined in this document, as a third party is required for the type testing program, and their expertise is necessary for successful completion of compliant testing. Communication between the test organization and certification body is paramount throughout the entire test program.

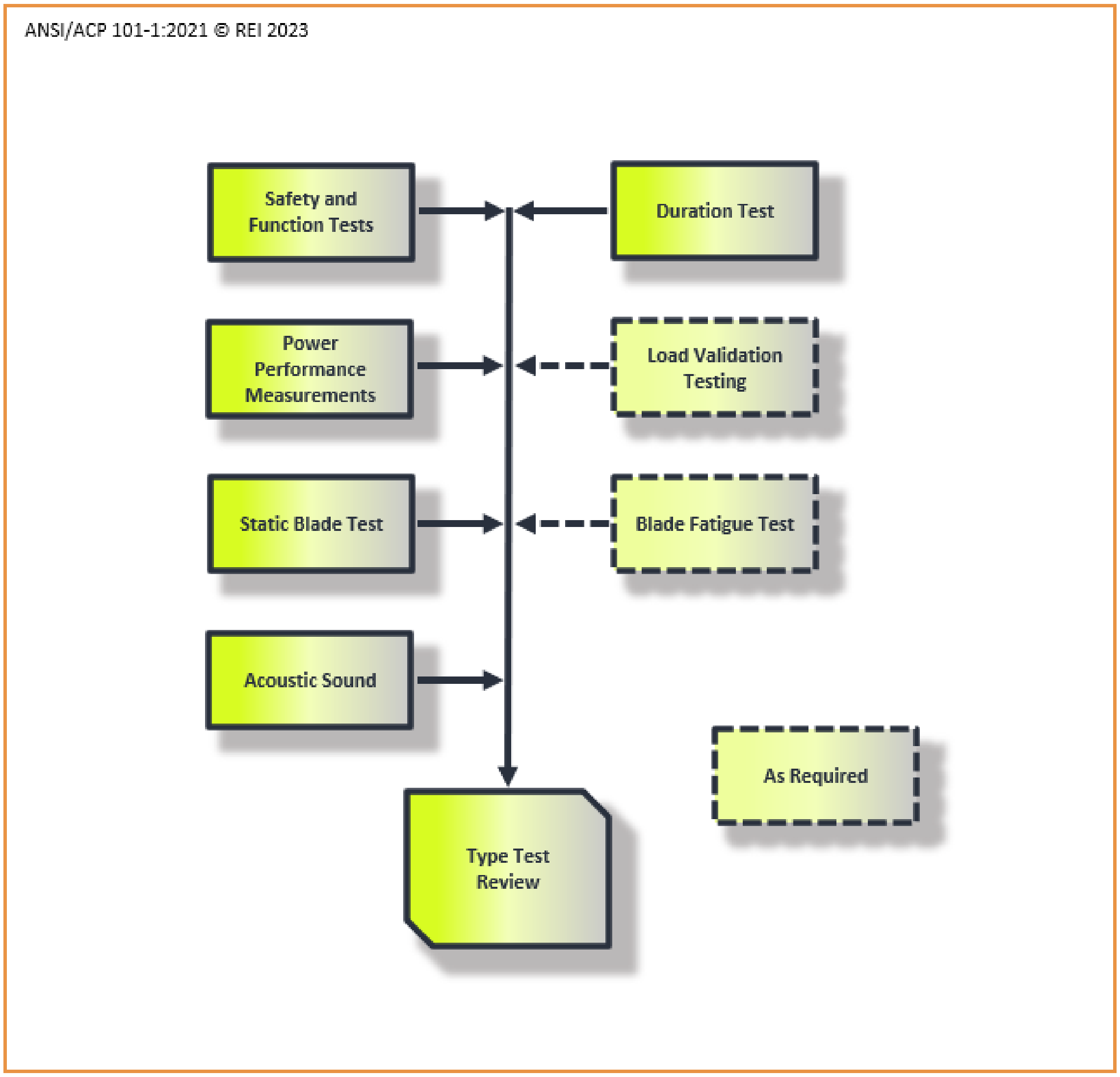


Figure 14 - ACP 101-1 certification process

These tests must either be performed by an ISO/IEC 17025 accredited test laboratory or witnessed by an ISO/IEC 17065 accredited certification body. Testing may be performed at a customer site and witnessed by the certification body, following their data acceptance program requirements. Certifications to ANSI/ACP 101-1-2021 shall be issued by a certification body accredited to ISO/IEC 17065 with ANSI/ACP 101-1-2021 listed in their scope of accreditation.

6.3.1 Power Performance Measurements

A power performance test is required to be performed for all ACP 101-1 turbine size categories in accordance with IEC 61400-12-1 Edition 2, Annex H. Power performance testing results are given in a measured power curve, which is determined by collecting simultaneous measurements of wind speed and power output at the test site for a period that is long enough to establish a statistically significant database over a range of wind speeds and under varying wind and atmospheric conditions. The estimated annual energy production of the wind turbine is calculated by applying the measured power curve to a reference wind speed frequency distribution, assuming 100% availability. Consumers can utilize the resulting performance characteristics for comparing wind turbine models. The measured power curve can be used to estimate site-specific annual energy production if estimations are properly adjusted for the local conditions, including wind resource and distribution, elevation, terrain, turbulence, obstacles, hub height, etc. The procedure for determining peak power is provided for safety and function testing in Section 6.3.3.

For ACP 101-1 compliance, some additional guidance is given for measurements of DC systems with battery banks. More importantly, a site calibration is not required, which also then excludes the need for IEC 61400-12-1 Annex B Terrain Assessment of the test site. This means only an obstacle assessment is required for assessing the valid sector for power performance testing. ACP 101-1 also introduces a few key terms and required results: Reference Power and Reference Annual Energy.

6.3.2 Acoustic Sound Testing

An acoustic sound test is required to be performed for all ACP 101-1 turbine size categories, except micro, in accordance with IEC 61400-11 Edition 3, Annex F. Acoustic sound testing involves the measurement and analysis of acoustical emissions by small wind turbines and enables the acoustic emissions to be characterized. The results of the testing can be used by the consumer to compare the acoustic characteristics of different turbine models. Consumers can use the provided appendix to calculate sound pressure levels for different observer locations and background sound levels.

For acoustic testing under the ACP 101-1 standard, a tonality analysis is not required, but the presence of prominent tones shall be observed and reported. Prominent tones are tones that are clearly audible over the broadband sound of the wind turbine. The tones can change in frequency our loudness with rpm or yawing. There are numerous ways this can be observed and reported, including as observation from test personnel or via comparison of adjacent frequency bands of 1/3 octave sound pressures at integer wind speeds. Uncertainty should be calculated and reported, but Equations 22–25 of IEC 61400-11 are not necessary, as uncertainty of the ACP Reference Sound Pressure Level is not required. The ACP Reference Sound Pressure Level is calculated via the guidance and equation given in Clause 3.1.3 of the ANSI/ACP 101-1 standard.

6.3.3 Safety and Function Testing

Safety and function testing is required to be performed for all ACP 101-1 turbine size categories in accordance with IEC 61400-2 Ed3, Clause 13.6, with some additional requirements as outlined in the ANSI/ACP standard. The purpose of safety and function testing is to verify that the turbine under test displays the behavior predicted in the design and that provisions relating to personnel safety are properly implemented. Critical functions of the control and protection system—such as power and speed control, wind alignment (yaw), overspeed protection, start-up and shutdown—are tested and verified. Any and all safety or control functions are going to be tested or verified in some way under both the ANSI/ACP and UL certifications. Additional tests may be suggested to be included in field safety and function testing to correlate with UL 6142 SRCS testing that must be performed in a variety of ways on the electrical system and/or individual components in the field or in a laboratory environment. SRCS testing is covered in Section 5 in this Guideline and should be considered along with safety and function test planning. A sample test list is provided, but each turbine system will employ different protections to be tested.

Most notably for compliance of safety and function with ANSI/ACP 101-1-2021 is demonstration of power limitation, rotor speed limitation, and determination of peak power. The demonstration of peak power is considered additional to the power performance test, as data are collected and analyzed in the same manner, although it is not a database requirement for the power test. For safety and function testing, the turbine must exhibit power control and show a peak power value where the curve is not still increasing. The database for safety and function testing must extend 5 m/s beyond the lowest wind speed at which power is within 95% peak power, or up to a wind speed where the turbine shuts down as a power regulation response.

For determining peak power, the following procedure is used. The anemometer is mounted at hub height, similar to that of the power performance test setup, but no direction sectors need to be excluded. The methods of normalization and binning of hub-height wind speed and power per IEC 61400-12-1 Annex H must be used. One-minute averaging must also be used for wind speed and power. Bins are filled (at least ten 1-minute data points in each 0.5 m/s bin) over at least the following wind speed range: FROM 5 m/s below the lowest wind speed at which power is within 95% peak power TO 5 m/s beyond the lowest wind speed at which power is within 95% of peak power, or up to the wind speed where the turbine shuts down as a power regulation response. The highest binned power of the filled wind speed bins covering the wind speed range above is defined as peak power.

6.3.4 Loads Validation Testing

As mentioned for strength evaluation above, loads validation testing is required for validation of certain quantities and input parameters for the design and simulation tools, only for the load components necessary for aeroelastic model validation. As outlined in Clause 13.3 of IEC 61400-2, the load measurement program must be based on and consist of measurement load cases that are as close as practically possible to the design load cases as defined in Clause 7.5. The measurement load cases must include all normal and critical operating and fault conditions, braking performance, and pitch and yaw behavior. Testing must be sufficient to characterize typical operational behavior throughout the design wind speed range. A statistically significant amount of data for relevant wind speeds allowing extrapolation must be collected.

VAWTs and other novel designs may require additional validations where non-validated design codes are used or do not accurately reflect the turbine archetype. VAWTs specifically also refer to IEC 61400-13 Ed. 1 Annex J; load quantity requirements may be adjusted based on VAWT design features. Tower top loads may additionally be required for some archetypes. See Figures 15 and 16.

For turbines where the SLM was utilized for obtaining design load cases, Figure 15 shows the minimum validation requirements.

Minimum Design Validation Requirements for SLM	
Micro <1 kW Peak Power	**1–10 kW Peak Power**
Not required	Tests to verify design data IEC 61400-2 cl 13.2
Additional notes:	
VAWTs and other novel designs may require additional validations where non-validated design codes are used or do not accurately reflect the turbine archetype. VAWTs specifically also refer to IEC 61400-13 Ed. 1 Annex J; load quantity requirements may be adjusted based on VAWT design features. Tower top loads may additionally be required for some archetypes.	

Figure 15 - SLM validation requirements

For turbines where a simulation model was used for aeroelastic simulations and determination of design load cases, Figure 16 below shows the minimum validation requirements.

Minimum Design Validation Requirements for Simulation Modeling		
10-30 kW Peak Power	**30-65 kW Peak Power**	**65-150 kW Peak Power**
1. Tests to verify design data IEC 61400-2 cl 13.2 2. Major component weights	1. IEC 61400-13 ed. 1 Cl 6.3.2.1 power production shall be completed. 6.3.5.2 is recommended for data collection guidance but is not required. Alternatively, IEC 61400-12-1 power testing will also suffice for power curve validation. 2. IEC 61400-13 ed. 1 Cl 6.4.2: - Table 9 Load Quantities: Blade root flatwise bending. Alternatively blade modal testing may be performed during static blade tests; see IEC 61400-23 for this. - Table 11 all "mandatory" items, excluding "vertical wind shear below hub height". Note a compliant 61400-12-1 measurement tower will suffice. - Table 12 rotor speed at minimum, but other "mandatory" items are suggested and any available status signals from the controller. Rotor speed may also be tested in the tests to verify design data or other IEC 61400 methods. 3. Major component weights	1. IEC 61400-13 ed. 1 Cl 6.3.2.1 power production shall be completed. 6.3.5.2 is recommended for data collection guidance but is not required. Alternatively, IEC 61400-12-1 power testing will also suffice for power curve validation. 2. IEC 61400-13 ed. 1 Cl 6.4.2: - Table 9 Load Quantities: Blade root flatwise bending, tower base normal, and tower base lateral. - Table 11 all "mandatory" items, excluding "vertical wind shear below hub height". Note a compliant 61400-12-1 measurement tower will suffice. - Table 12 rotor speed at minimum, but other "mandatory" items are suggested and any available status signals from the controller. Rotor speed may also be tested in the tests to verify design data or other IEC 61400 methods. 3. Major component weights
Additional notes:		
VAWTs and other novel designs may require additional validations where non-validated design codes are used or do not accurately reflect the turbine archetype. VAWTs specifically also refer to IEC 61400-13 ed.1 Annex J; load quantity requirements may be adjusted based on VAWT design features. Tower top loads may additionally be required for some archetypes.		

Figure 16 - Simulation modeling minimum design validation requirements

Measured loads testing data shall at least include loads, meteorological parameters, and wind turbine operational data. Loads at critical load path locations in the structure must be measured. These loads may include blade root bending moments, shaft loads, and loads acting on the support structure. Meteorological parameters must include hub-height wind speed and wind direction. Relevant wind turbine operational data including rotor speed, electrical power, yaw position, pitch, and turbine status must be measured. The data must be analyzed in such a way that valid comparison with calculated loads is possible. As a minimum, the mean, minimum and maximum values, and standard deviation of the appropriate load data must be evaluated and included over the recorded wind speed and turbulence ranges, and relevant data included in the test report.

For the *Tests to Verify Design Data*, IEC 61400-2 Clause 13.2 is referenced in the figures above. Clause 13.2.2 covers design power, design rotational speed, design wind speed, and design shaft torque. *Design wind speed* is simply 1.4 V_{ave}, and design power and rotational speed are the power and rpm at that design wind speed. Design torque is derived from design power and rotational speed. Maximum rotational speed and yaw rate determination methods are also described.

6.3.5 Duration Test

The duration test is required to be performed for all ACP 101-1 turbine size categories in accordance with IEC 61400-2 Ed. 3, Section 13.4 with various modifications to test requirements as outlined in the ANSI/ACP standard. A duration test is conducted to establish a minimum threshold of reliability. The test is designed to investigate structural integrity and material degradation (corrosion, cracks, deformations), and quality of environmental protection of the wind turbine.

For ACP 101-1, wind speed is averaged over a 1-minute period for the definition of wind speed in the duration test results for hourly assessment. The required database for ACP 101-1 is reduced as compared to IEC 61400-2, where a test is deemed completed once:

a) The turbine has achieved reliable operation throughout the test period

b) The test database includes greater than 10 hours of wind speeds of 15 m/s and above, where the wind turbine is operating normally
c) The test database includes at least 1,000 hours of power production.

Calculation of operational time fraction, analysis of power degradation, and dynamic behavior observation are not required for ACP 101-1 duration testing. "Reliable Operation" is defined for the purposes of ACP 101-1 testing, as no major failure of the turbine or components in the turbine system, and no significant wear, corrosion, or damage to turbine components as verified by pre- and post-test inspections.

6.3.6 Static Blade Test

For all turbine sizes, except micro, a static blade test in accordance with IEC 61400-2 Ed. 3, Section 13.5.2 is required. The loads that are derived from the DLCs are used with varying test and other load factors to apply a known load or load distribution for max/min flap and edge static testing. Testing is typically performed at the customer facility and witnessed by the certification body, as lab testing costs can be prohibitive to the certification process and may include sandbags or other verified weights distributed across the span of the rotor blade.

6.4 Manufacturing Quality and Evaluations

There is no specified manufacturing quality evaluation for ANSI/ACP 101-1 compliance. This is loosely due to the fact the certification program falls under a North American third-party product certification scheme. Each certifying agency has their own listing and labeling requirements, which typically require the certifying agency to perform an initial factory audit or assessment after the successful completion of all design and test requirements, and prior to completing the certification program and issuing labels to the factory for the compliant product. The factory assessments are typically similar to ISO 9001, but an ISO 9001 compliant facility is not mandatory. For ANSI/ACP 101-1, the Small Wind Certification Council (SWCC) publishes their procedures, which are available online here: https://smallwindcertification.org/resources/swcc-policies/.

The qualifying inspections typically include a review of policies, procedures, and verification of documentation and records covering factory and design control, customer complaints, suppliers and incoming goods inspections, training and qualifications of personnel, equipment and calibrations used in manufacturing and assembly, and inspection and assembly procedures. Incoming goods inspection procedures must minimally exist, including records of them being performed and identification and separation of non-conforming goods. It is recommended that procedures also cover typical root-cause analysis through engineering change notices and updates to the product and design. The inspection will occur during a time of assembly, so checks can be made on various stages of the production process.

6.5 Certification Surveillance

The certification agreement and process will vary from agency to agency, and again can refer specifically to SWCC and their procedures for turbines in this size category (less than 150 kW peak power).

Once the turbine has successfully completed and documented compliance with all design and test requirements, including those for qualifying initial inspection and authorization to apply the certification mark, an ACP consumer label is created. Specific label requirements are given in Clause 7 of the ANSI/ACP standard but are similar to the guidance given in Annex M of IEC 61400-2 Ed. 3. The ACP consumer label and test summary reports are to be made continuously and publicly available, in the English language as a minimum, on the manufacturer's website and/or the certification body's website. The test summary report covers primary results from all of the required tests and is a shorter summary of all tests.

Each agency will also have differing requirements for their initial factory assessment inspection requirements for labeling, as well as follow-up or surveillance inspections for maintaining the certification of the product. A factory inspection is aways required at the applicant facility where the label is applied, which was discussed in the prior section. Surveillance inspections will recur every 2 years unless a change or other issue from surveillance activity requires inspections to occur sooner.

After certification is completed and labels authorized each year to maintain the validity of certification, additional surveillance activities are required in the form of field inspections and annual reporting. The field inspections of a sample of certified turbines per the “routine inspection” requirements of IEC 61400-2 Ed. 3, Section 11.2.5.3 are required with some additional guidance per Appendix B of the ANSI/ACP standard, outlined in the paragraph below. For routine inspections, the turbine manufacturer must provide the typical inspection interval for maintenance of the turbine covering the tower, drivetrain, control system, and rotor. The turbine manufacturer must prepare maintenance and inspection checklists of components to be checked and items to verify and confirm, including any measurements to be performed to ensure proper operation of the system. The turbine manufacturer must state all values of normal operating ranges, which are critical to the safety of the DWT. Manufacturers must recommend that a logbook be maintained for each DWT installed with data such as date, time, personnel conducting inspection, any important events, and any corrective actions taken, or additional information recorded.

For field inspections, the sample size is five turbines at different sites chosen by the certification applicant and certification agency. The inspections are performed annually by a party chosen by the turbine manufacturer and certifying agency (e.g., the installer or service provider). The field inspections are performed annually for the first 3 years of certification surveillance. After the third consecutive year is complete, per turbine, the inspection requirement is satisfied and is no longer required for subsequent surveillance (i.e., only annual reporting will be required beyond this, discussed below). Inspection reports include photos of major components and signs of cracking, significant wear, and degradation. Annual energy production and estimated annual average hub wind speed are also reported, with the source of wind speed estimate (e.g., NREL Wind Prospector or turbine-mounted anemometer).

Annual reporting includes reporting to the certification agency various updated information pertaining to the certified product. All design changes, field failures, complaints, and sales are reported. Significant design changes and safety-related field failures must be reported to the certification agency without delay, instead of waiting until annual reporting.

6.6 Microturbines

Future release of this DW Certification Best Practices Guideline will include additional guidance for microturbines.

6.7 Test Site Requirements and Considerations

Future release of this DW Certification Best Practices Guideline will include guidance for the selection of appropriate test sites and general test planning considerations related to equipment, calibrations, and test setup.

7 DWT TYPE TESTING AND CERTIFICATION ABOVE 150 kW

Section 7 covers brief information related to testing and certification of DWT systems according to IEC 61400 methods that are similar to IEC type certification requirements. An overview of the process and general conformity assessment requirements are provided in Section 7.1. A description of the design evaluation process and module requirements is given in Section 7.2. Section 7.3 provides overview of the type testing requirements. Manufacturing conformity (Section 7.4), final evaluation (Section 7.5), and type certification (Section 7.6) are covered briefly in this initial version and will be updated in future releases of this DW Certification Best Practices Guideline.

7.1 IEC 61400 General Conformity Assessment Requirements

In the United States, the American Renewable Energy Standards and Certification Association (ARESCA) is in process of adopting various IEC 61400 standards, either with or without national deviations. Over the three future updates of this DW Certification Best Practices Guideline, this information will be updated to align with U.S. adopted standards.

The IEC process for certification of DWTs would typically follow either IEC 61400-22 (withdrawn) or IECRE OD501 for type, prototype, and component certifications. Below is a list of the various parts that are currently covered in this Best Practices Guideline:

- Full "Type Certification"
  - IEC 61400-22 withdrawn, OD501 for ALL turbines
  - OD554-1 for small turbines less than 200 m^2 rotor swept area
  - Briefly outlined in Section 7.1, updated in future release
  - Often not required for DWTs in U.S.
  - Design and type testing conformity often are suitable
- Design Evaluation
  - Briefly outlined in Section 7.2
  - Updates in future release
- Type Testing
  - U.S. compliance outlined initially in Section 7.3
  - Additional updates in future release
- Manufacturing – not yet covered
  - Covered in future release
  - Often applied for turbines above 150 kW
- Prototype Certification – not yet covered
  - Covered in future release
  - Limited requirements as compared to type certification
  - Prior to serial manufacturing of turbine
  - Can be useful to OEM and possibly suitable for U.S. market
- Component Certification – not yet covered
  - Covered in future release
  - Same as type certification, but for an individual component
  - Component OEMs who sell to turbine OEMs for use in certified systems
  - Same process, focusing solely on the component design, test, and manufacturing.

Note that OD554-1 is not discussed in this guideline because in the U.S. market, a turbine that falls under this scope also falls under ANSI/ACP 101-1, which is the more appropriate reference. DWTs above 200 m^2 rotor-swept area that are less than 150 kW fall under this category. Turbines above 150 kW are typically above 200 m^2 rotor-swept area and as such would fall under OD501 or IEC 61400-22, both with reference to IEC 61400-1. Currently, MT2, the Maintenance Team for the Revision of IEC 61400-2, is working on a major revision with approved increase in scope to include "medium wind turbines" between 200 and 1,200 m^2 rotor-swept area. This is not currently considered in this DW Certification Best Practices Guideline but will be updated in future releases as the document matures and reaches various stages of approval in the consensus standards approval process.

The IEC 61400-22 and OD501 are very similar. IEC 61400-22 was withdrawn with the creation of IEC's IECRE Scheme and the creation of many wind sector operational documents and other rules of procedure. IEC 61400-22 was used for the development of OD501, but some differences apply related to the IECRE program and scheme requirements.

IEC 61400-22 provides procedures for the type certification scheme related to specific standards and technical requirements for the safety, reliability, performance, testing, and interaction with electrical power networks. Type certification typically includes various modules as shown in Figure 17.

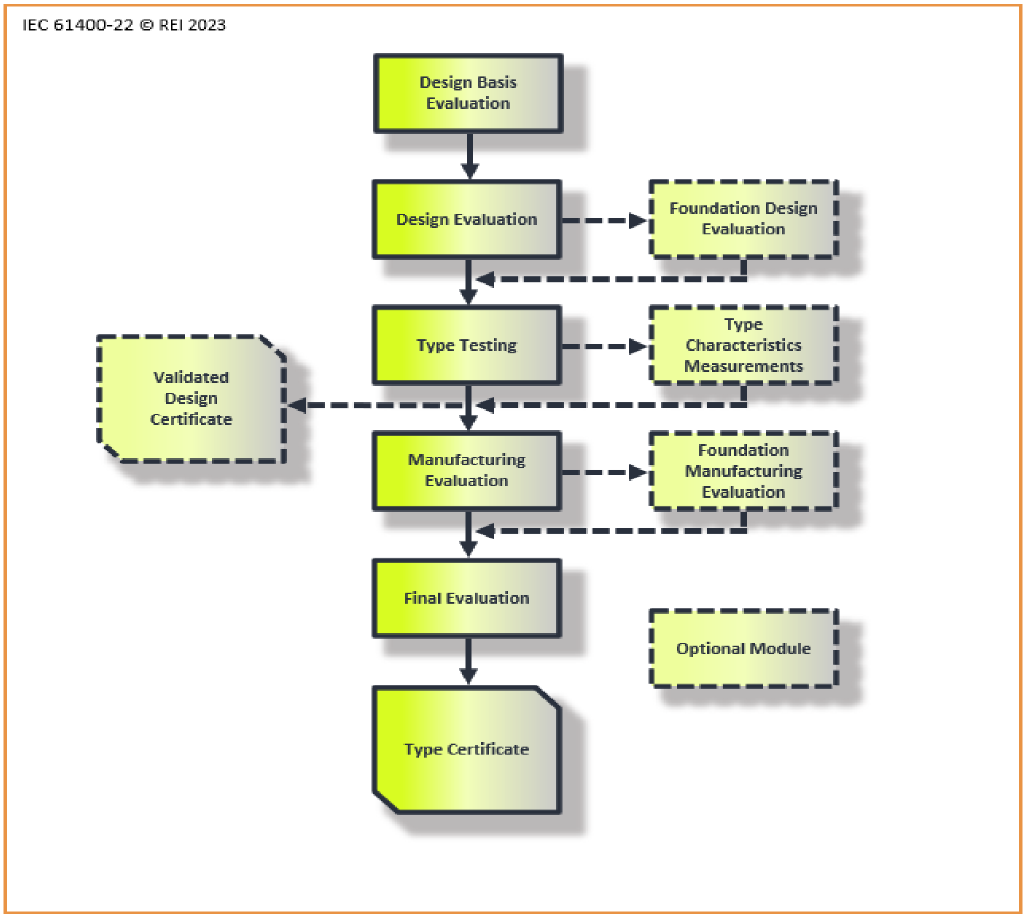


Figure 17 - IEC 61400-22 certification process

Type certification and reference to OD501 are not specifically discussed in this section or initial release of the DW Certification Best Practices Guideline but may be inferred. In the United States, the process for certification of a turbine above 150 kW used in a distributed generation application does not formally exist, other than to simply be treated as a utility-scale wind turbine or for specific compliance with tax rebate, incentive, or other funding program.

Design evaluation conformity and type testing conformity are covered in this initial release, as typically those subsets of a full type certification are suitable to comply with market access drivers where IEC-related certifications are required. Refer to Section 3 related to Use of Certified Distributed Wind Products.

7.2 Design Evaluation Conformity

The design evaluation typically first consists of an introductory documentation review called the design basis evaluation (DBE). A DBE is an examination of the design documentation to ensure the information is sufficiently documented for formal design evaluation review by the certification agency. The DBE also serves to form the requirements of the design evaluation, by identifying all requirements and assumptions, design methods, codes and standards, and others. Typically reference to various operational documents or other IEC 61400 standards are identified at this stage. Areas typically covered in a DBE are:

- External design parameters
- Design load cases
- Load factors and load reduction factors
- Partial safety factors for loads and materials
- Duration and number of simulations
- Methods for extreme and fatigue structural analysis
- Environmental conditions
- Inspection scope and frequency
- Target lifetime of components, systems and structures
- Requirements for condition monitoring systems.

Upon completion of the DBE a Conformity Statement may be issued by the certifying agency, if not included in the design evaluation module.

The design evaluation is a formal review of the design documentation for conformance with the identified required codes, standards, and other requirements outlined in the DBE. Many IEC 61400 or other IECRE ODs are required as normative references for the design evaluation. The design evaluation typically includes all of the modules shown in Figure 18.

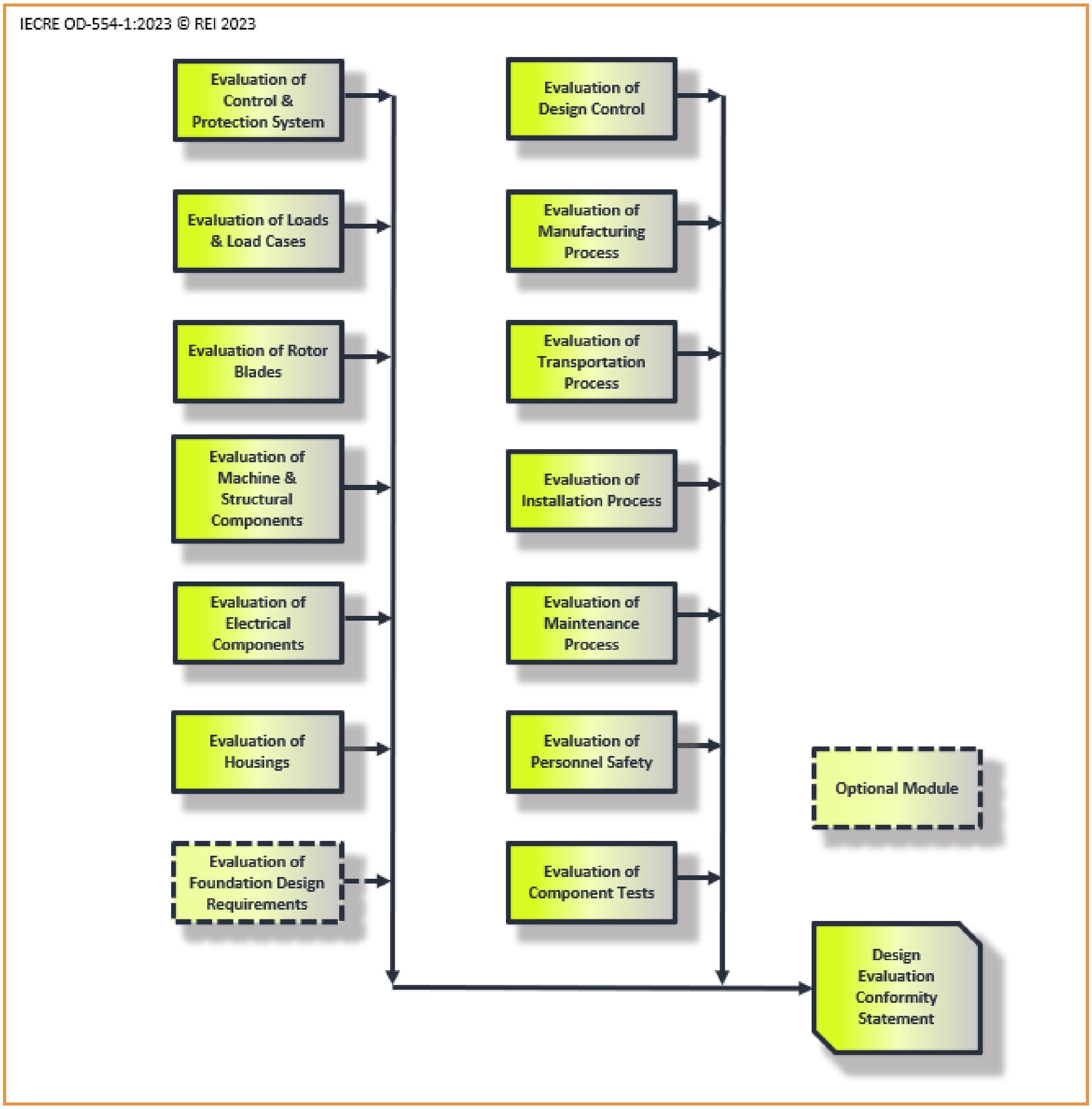


Figure 18 - Design evaluation

Each of the modules in Figure 18 entails a thorough investigation of documentation pertaining to the design of system components related to standard requirements. Comparatively, ANSI/ACP 101-1 only covers parts of the loads and load cases, control and protection, and machine and structural modules above.

Design control is a quality procedures review for any procedures related to control of the design process. Certification to ISO 9001 is not mandatory; however, for design conformity, applicable parts are required to be covered in the quality procedures. If ISO 9001 certified, the requirement for a design control module evaluation is satisfied.

Loads and load cases are similar to the process outlined in Section 6 for structural design requirements. The same process applies under IEC 61400-1 for the determination of governing loads and load cases, applying material and load factors, and performing limit state analysis of components in the load path. Compared to IEC 61400-2, IEC 61400-1 has different ultimate safety factors depending on whether the load case is considered normal or abnormal. Also, depending on the load case, the ultimate load may be taken as the absolute extreme or as an average of the extremes of a group of simulations. The DLC table is also different, as can be seen in Table 14.

Table 14 - Minimum set of DLCs, Table 2 extracted from IEC 61400-1

Design Situation	DLC	Wind Condition		Other Conditions	Type of Analysis	Partial Safety Factors
1) Power Production	1.1	NTM	$V_{in} < V_{hub} < V_{out}$	For extrapolation of extreme events	U	N
	1.2	NTM	$V_{in} < V_{hub} < V_{out}$		F	*
	1.3	ETM	$V_{in} < V_{hub} < V_{out}$		U	N
	1.4	ECD	$V_{hub} = V_r$ - 2 m/s, V_r, V_r + 2 m/s		U	N
	1.5	EWS	$V_{in} < V_{hub} < V_{out}$		U	N
2) Power Production plus Occurrence of Fault	2.1	NTM	$V_{in} < V_{hub} < V_{out}$	Normal control system fault of loss of electrical network or primary layer control function fault (see 7.4.3)	U	N
	2.2	NTM	$V_{in} < V_{hub} < V_{out}$	Abnormal control system fault or secondary layer protection function related fault (see 7.4.3)	U	A
	2.3	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM	$V_{in} < V_{hub} < V_{out}$	Control system fault, electrical fault or loss of electrical network	F	*
	2.5	NWP	$V_{in} < V_{hub} < V_{out}$	Low voltage ride through	U	N
3) Start-Up	3.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	3.2	EOG	$V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}		U	N
	3.3	EDC	$V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}		U	N
4) Normal Shutdown	4.1	NWP	$V_{in} < V_{hub} < V_{out}$		F	*
	4.2	EOG	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
5) Emergency Stop	5.1	NTM	$V_{hub} = V_r \pm 2$ m/s and V_{out}		U	N
6) Parked (Standing Still or Idling)	6.1	EWM	50-year return period		U	N
	6.2	EWM	50-year return period	Loss of electrical network connection	U	A

Design Situation	DLC	Wind Condition		Other Conditions	Type of Analysis	Partial Safety Factors
	6.3	EWM	1 year return period	Extreme yaw misalignment	U	N
	6.4	NTM	$V_{hub} < 0{,}7\ V_{ref}$		F	*
7) Parked and Fault Conditions	7.1	EWM	1 year return period		U	A
8) Transport, Assembly, Maintenance and Repair	8.1	NTM	V_{maint} to be stated by the manufacturer		U	N
	8.2	EWM	1 year return period	Control or protection system fault	U	A

Key
DLC = Design Load Case
ECD = Extreme Coherent Gust with Direction Change (See IEC 61400-1 cl 6.3.3.6)
EDC = Extreme Direction Change (See IEC 61400-1 cl 6.3.3.5)
EOG = Extreme Operating Gust (See IEC 61400-1 cl 6.3.3.3)
EWM = Extreme Wind Speed Model (See IEC 61400-1 cl 6.3.3.2)
EWS = Extreme Wind Shear (See IEC 61400-1 cl 6.3.3.7)
NTM = Normal Wind Profile Model (See IEC 61400-1 cl 6.3.3.2)
$V_r \pm 2$ m/s = Sensitivity to All Wind Speeds in the Range Shall Be Analyzed
F = Fatigue (See IEC 61400-1 cl 7.6.3)
U = Ultimate Strength (See IEC 61400-1 cl 7.6.2)
N = Normal
A = Abnormal
* = Partial Safety for Fatigue (See IEC 61400-1 cl 7.6.3)

The governing loads and DLCs are determined from an aeroelastic model, which must be validated by field measurements. OD501-4 is used within IECRE for assessment of the loads and could be additionally referred to for guidance on requirements for loads that are translated to the rest of the components. The main structural components, rotor blades, towers, and gearbox are all required to be designed in accordance with applicable codes and standards. Some of those are initially outlined below but may be updated in future release of this guideline as U.S. adopted standards are published.

- Rotor blades
  - IEC 61400-5 Ed. 1
  - OD501-1
- Gearboxes
  - IEC 61400-4 Ed. 1 – Design Requirements
  - OD501-2
- Towers
  - ANSI/ACP 61400-6-2021 or IEC 61400-6
  - OD501-3
- Structural for components
  - IEC 61400-8 Ed. 1 Design of wind turbine structural components

- IEC TS 61400-30 Ed. 1 Safety of wind turbines – General principles
- IEC 61400-1 Ed. 4 Design requirements.

The types of components to be considered will include all load-bearing components, such as:

- Casted, forged, or welded structures
- Nacelle frame
- Pitch and yaw systems
- Bearings and elastomer bushings
- Brakes, couplings, and locking devices
- Bolts for connecting these structures and components
- Cooling and heating systems
- Hydraulic systems
- Housings (spinners and nacelle covers).

The documentation is reviewed by the certifying agency to ensure compliance with the defined codes and standards related to design loads and external conditions, design loads, boundary conditions, influence on adjacent components and drivetrain dynamics, materials and stresses, and others.

Foundation design requirements can be included for a specific foundation design or type but are not always required based on local permitting requirements for distributed generation applications. Towers and support structures will be covered further in future releases of this DW Certification Best Practices Guideline.

A control and protection system evaluation is often performed at minimum to IEC 61400-1 Edition 4, but IECRE OD-501-5 may additionally be referred to. The control system documentation is evaluated along with descriptions of safety-related control circuits, system logic and software, control functionality and performance or safety levels, and locking and braking devices. A risk assessment, FMEA, or similar for critical complex systems is required. OD-501-5 also provides additional guidance related to safety and function testing requirements and defining applicable tests.

Transport, assembly, installation and erection, commissioning, operation, and maintenance processes are all typically evaluated via review of relevant manuals and procedures. The transportation process is typically outlined via technical specifications, limiting environmental conditions, transport arrangements, fixtures and any tooling for transport, and transport loads.

Assembly, installation, and erection process must be sufficiently described for certification body evaluation and must include relevant commissioning procedures and checklists. Procedures should cover resource and skill levels, civil and electrical construction, specialized tooling and lifting equipment, quality checks and inspections, and protections for the turbine and personnel.

Maintenance processes must also be similarly documented in manuals and procedures, including personnel safety guidance and requirements. Maintenance manuals may include:

- Scheduled maintenance actions, inspection intervals, routine maintenance actions
- Description and specification of the process for repair or exchange of critical components such as gearbox, generator, and blade without impacting the safety or structural integrity of the wind turbine
- Identification of all safety-related operational procedures or maintenance activities
- Description of planned environmental protection measures
- Identification of required specialized tooling and maintenance equipment
- Identification of human resource requirements and skills
- Description of personnel safety and planned protection measures

- Outline of planned operating instructions and maintenance manual
- Description of quality recording and recordkeeping processes.

Personnel safety aspects may include instructions, climbing facilities, access ways, standing places and platforms, ladder systems, handrails and fixing points, lighting, electrical and earthing systems, fire protection and resistance, emergency stop buttons, and provisions for alternative escape routes.

The electrical evaluation can typically be excluded for a design evaluation for U.S. distributed generation applications and compliance, as the requirements outlined in Section 5 would be required and evaluated separately. If included in the IEC design evaluation, it should follow the same guidance given in Section 5, and not follow IEC-prescribed methods.

Upon successful completion of all design evaluation modules a Design Evaluation Conformity Statement will be issued and include identification of the wind turbine type and system of components, certification applicant, applied codes and standards, external design conditions, and any reference reports or documentation.

7.3 Type Testing Requirements

For U.S. distributed generation applications, the requirements for type test conformity are very similar or in some cases identical to those already outlined in Section 6, including the need for third-party evaluation and type testing. The major difference is that both static and fatigue rotor blade tests are required, and full load measurement validation testing is also mandatory. Figure 19 outlines the various tests that may be applied for type testing conformity.

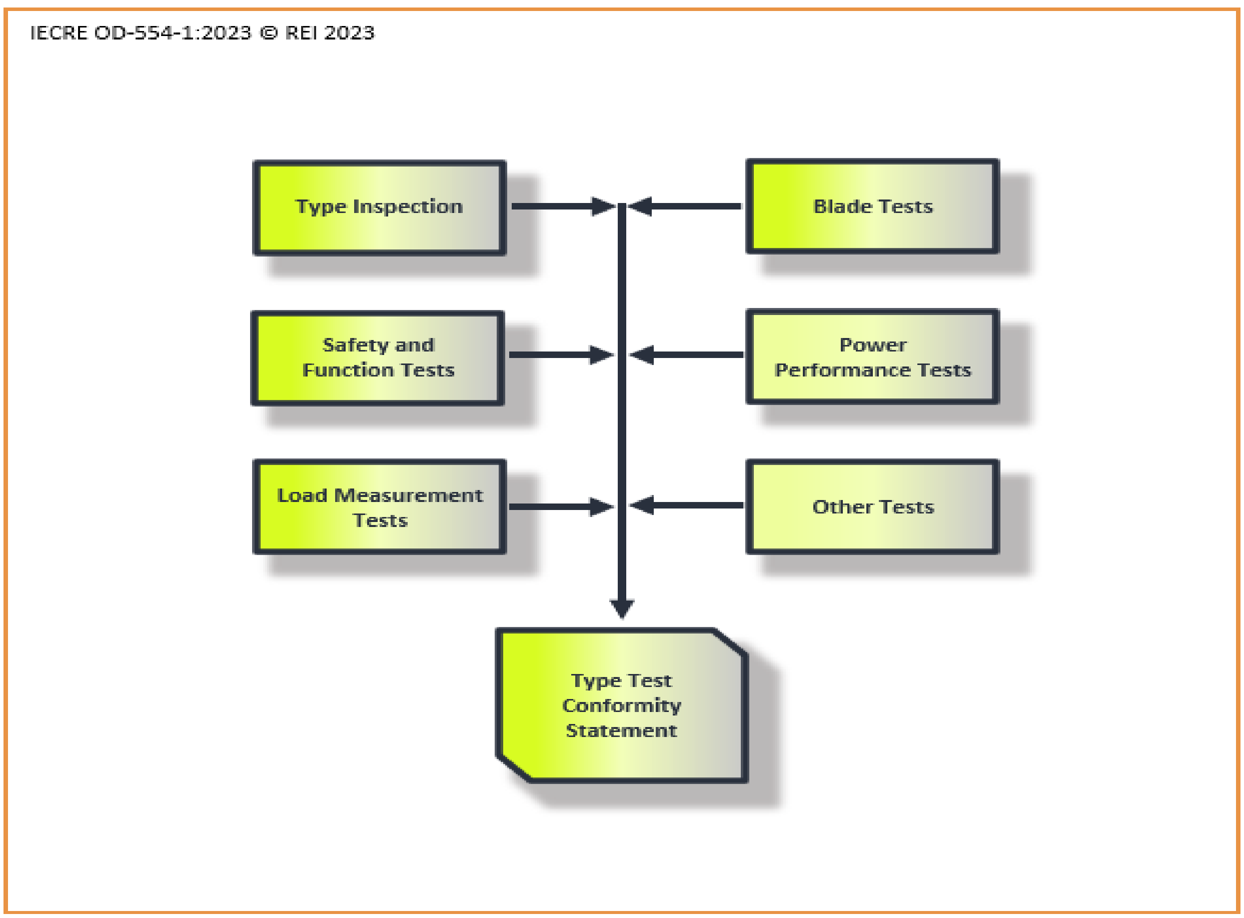


Figure 19 - Type testing conformity requirements

Considering a duration test only applies to turbines below 150 kW, a type inspection is typically performed and documented prior to the type testing program to confirm that the turbine under test aligns with the approved design documentation. Power performance and safety and function are the same as required in Section 6; however, as pointed out for design evaluation above, OD-501-5 may be specifically referred to for safety and function. Following the guidance and test lists suggested in this DW Certification Best Practices Guideline as given for SRCS in Section 5.3 incorporates any additional considerations related to OD-501-5.

Other tests as required for various components such as gearboxes or those seeking qualification under the design evaluation via direct testing and measurement can additionally be performed.

For type certification, typically modal, four-way static, and both flapwise and edgewise fatigue rotor blade tests are required to be performed. Depending on size and application in the above-150-kW range, fatigue testing may not be required, unless it is necessary for design evaluation conformity of the rotor blade and associated materials. All of these are described in detail in IEC 61400-23, and tests typically are performed at an established blade test facility.

Loads validation testing is more rigorous under a type testing program, or as required for design validations, where a full IEC 61400-13 loads measurement test is performed assuming the use of a validated aeroelastic simulation code. This covers all steady-state and transient operational events, or measurement load cases (MLCs), as well as the required load, environmental, and operational quantities, such as (at minimum):

- Steady-State MLCs
  - Power production DLC 1.2
  - Parked 6.4
- Transient MLCs
  - Start-up DLC 3.1
  - Normal shutdown DLC 4.1
  - Emergency shutdown DLC 5.1
  - Grid failure DLC 2.4
- Load Quantities
  - Blade root flapwise and edgewise bending moments – 1 blade required, recommended for 2
  - Rotor tilt and yaw moments
  - Rotor torque
  - Tower base normal and lateral moments
- Environmental Quantities
  - Hub-height wind speed and vertical wind shear below hub height
  - Turbulence intensity at hub height
  - Wind direction and air density at hub height
- Operational Quantities
  - Electrical power
  - Rotor or generator speed
  - Yaw misalignment
  - Rotor azimuth angle
  - Pitch position
  - Pitch speed
  - Brake status
  - Wind turbine status.

Several other MLCs and quantities are recommended or suggested to be considered during the test program but may not always apply or be required for certification. Only those required are included in this Guideline.

If a non-validated code is utilized for the simulation model, the certification agency would additionally typically require a code-to-code verification comparison performed independently by the certification agency. Additional information for VAWTs is given in Section 8.

Upon successful review and approval of all tests by the certifying agency, a Type Test Conformity Statement is issued, which documents the tests performed, applied standards, the wind turbine type, and the required test reports.

7.4 Manufacturing Quality and Evaluations

Manufacturing evaluations under type certification are typically not required for distributed generation applications of wind turbines above 150 kW. The manufacturing evaluation is a thorough review and inspection process of the quality system and all critical components and major equipment suppliers. Similar to design control under the design evaluation, an ISO 9001 certification would alleviate the need for any further quality system evaluation or inspection. That said, for a type certification, a manufacturing inspection process is typically carried out by the certifying agency for witnessing critical manufacturing processes of at least one representative production component. This is typically done directly at the manufacturing facility, or it can sometimes be covered at the wind turbine assembly facility as part of incoming goods inspection. This typically covers evaluation of facilities and workshops, instructions and procedures, fabrication methods and qualification of personnel, and random checks. The range of components subject to potential inspection includes rotor blades, hub, shaft, pitch/yaw mechanisms and drives, bearings and housings, locking devices and brakes, generator, main electrical components, mainframe, tower and tower connections, hub and nacelle assembly, and any bolted connections.

This topic may be discussed further related to type certification in future releases of this DW Certification Best Practices Guideline.

7.5 Final Evaluation

The final evaluation is a final check as part of the type certification process and is the culmination all the required modules. Final evaluation consists of a final evaluation report that is used to support the type certificate and is a summary of all information, including turbine type information, to define the system being certified. It typically would not be part of an approval process for a turbine above 150 kW in the U.S. market used in a distributed generation application. If pursuing full type certification, it will be mandatory, though some certification agencies may include parts of a final evaluation for those parts completed as part of the evaluation and test program.

7.6 Type Certificate

Type certificates are issued based on satisfactory completion of all elements as identified in Figure 19. They remain valid for 5 years, after which recertification is required. Surveillance and maintenance are required throughout the 5-year interval to maintain the certificate through its 5-year validity. This topic would be covered additionally in future releases of this guideline, as applicable for international market considerations.

8 ADDITIONAL GUIDANCE FOR NOVEL DWT ARCHETYPES

Shrouded and diffuser wind turbines, rooftop and building integrated wind turbines, and other considerations related to novel archetypes will be covered in a future release of this DW Certification Best Practices Guideline.

9 INTERNATIONAL MARKET CONSIDERATIONS

Section 9 will cover international markets, certifications, and other considerations in a future release of this DW Certification Best Practices Guideline.

10 DOCUMENTATION REQUIREMENTS FOR CERTIFICATION

At an early stage of development, it is critical to be aware of the certification requirements for the product when entering the U.S. market. Aside from the obvious mechanical and electrical theoretical design effort, the engineering effort associated with executing what was covered in this DW Certification Best Practices Guideline requires research into the materials and components and their thermal, electrical, and other ratings and certifications.

For electrical elements, a full bill of materials of the entire construction of the wind turbine generator (including hardware) identifying the following at minimum must be developed: component manufacturer, model/part number, thermal ratings, electrical ratings, flammability ratings, material properties and type, mechanical properties and dimensions, and marks of conformity or certifications. Other information may be required by the certification agency.

Additional generic documentation guidance is listed in Table 15 pertaining to DW type certification preparation of initial certification documentation packages. This list may be updated or revised in a future release and is given purely for example.

Table 15 - IEC and ANSI/ACP initial certification documentation requirements

IEC and ANSI/ACP Initial Certification Documentation Requirements	
1	**Pre-Assessment**
1.1	General Turbine Description
1.2	Datasheet and Rated Characteristics
1.2.1	Operational Limits and Environmental and External Wind Conditions (See IEC 61400-2)
1.2.2	External Design Parameters
1.2.3	Description of the Different Configurations – If Any
1.2.4	Target Lifetime of Components, Systems and Structures
1.3	General Basic Scheme of the Electrical System (Main Components and Interconnection With the Grid – W/O Auxiliary Systems or Control)
1.4	List of Codes and Standards Used During Design
1.5	Basic Geometrical Design and Dimensioning of the Wind Turbine
1.6	Design Control Procedure (According to ISO 9001)
2	**Structural Evaluation**
2.1	Load Cases Evaluation
2.1.1	Load Cases Definition Document: Different Inputs, Wind Conditions, Model, Description on How Every Load Case Will Be Applied. If Any Is Going To Be Neglected, It Should Be Properly Justified, etc.
2.1.1a	Load Factors and Load Reduction Factors
2.1.1b	Partial Safety Factors Applied on Loads and Materials
2.1.1c	Justification of Measurement of RPM
2.1.1d	Justification of Max Yaw Speed Calculation
2.1.2	Load Cases Calculations (Including Files: Spreadsheet) and Load Case Report, Summarizing the Results and Loads To Be Considered for the Design and the Safety Factor To Be Considered

IEC and ANSI/ACP Initial Certification Documentation Requirements	
2.1.2a	Duration of Simulation Coupled With Number of Simulations
2.1.2b	Methods for Extreme and Fatigue Design Loads/Response Analysis
2.1.3	Calculation Tools
2.2	Components
2.2.1	Drawings and Material Description per Component, Including Major Components Weights, Center of Gravity, Stiffness, Natural Frequencies, etc.
2.2.1a	Codes, Standards, and References
2.2.1b	Design Loads and Relevant External Conditions
2.2.1c	Influence of Adjacent Structures and Components
2.2.1d	Materials and Permissible Stresses
2.2.1e	Material and Subcomponent Test Program – If Applicable
2.2.1f	General Description of Manufacturing Processes
2.2.1g	Tolerances Influencing the Design
2.2.1h	Justification per Component of Life Span > 20 years
2.2.1i	Type/Data Sheets (for Mass-Produced Parts)
	Components To consider:
2.2.2	Blade: Geometry and Aerodynamics Inputs
2.2.2a	Full-Scale Blade Test Program – If Applicable
2.2.3	Hub
2.2.4	Nacelle or Corresponding Subitems: Water Protection
2.2.5	Shaft and Rotor
2.2.6	Main Frame
2.2.7	Bearings
2.2.8	Housings: Spinners and Covers
2.2.9	Yaw System Analysis: Connection, Bearings, Transmission of Loads, Corrosion
2.2.10	Tower Connections and Tower, Including Items as: Cable Twist
2.3	Strength Assessment per Component: Description, Materials (and Applied Safety Factors), Finite Element Analysis Description, Hot-Spots Identification (Correlation Between Most Stressed Points and Recurrent Stress Areas for Different Load Cases), Ultimate and Fatigue Analysis and Calculation of SFs
2.3.1	Blades
2.3.2	Tower
2.3.3	Foundation
2.3.4	Pitch Mechanism/Yaw Systems
2.3.5	Nacelle and Frame and Components (Main Bearing and Tail and Frame)
2.3.6	Generator
2.4	System Dynamic Model Description, per Component – When Needed, Otherwise It Should Be Justified
2.5	Braking System Description and Characterization
2.5.1	Torque Curves

IEC and ANSI/ACP Initial Certification Documentation Requirements	
2SD	*Supporting Documents:*
2SD.1	Materials Datasheets and Certificates
2SD.2	Functional Description of the Controller (*)
2SD.3	Generator Description and In-House Tests (IEC 60034-1), Including Short-Circuit Fault (*)
3	**Control Evaluation**
3.1	Functional Description of the Controller
3.1.1	Description of Wind Turbine Modes of Operation
3.1.2	Design and Functionality of All Elements
3.1.3	System Logic and Hardware Implementation
3.1.4	Authentication of Reliability of All Safety Critical Sensors – If Applicable
3.1.5	Condition Monitoring, If Applicable
3.2	FMEA of the Entire Machine
3.3	Control Cabinets Schematics
3SD	*Supporting Documents:*
3SD.1	Electrical Schematics and List of Components (*)
3SD.2	Braking System Description and Characterization (Torque Curve, etc.) (*) (Note: Should Include All Systems Related to Braking Behavior – e.g. Generator, Pitch, etc.)
4	**Electrical Evaluation**
4.1	Detailed Electrical Scheme of the Power System and Auxiliary Systems
4.2	List of Critical Components With: Ratings, Operational Temperatures and Certificates/Approvals (Including Sensors, Measuring Equipment, Disconnecting Devices and Power Converters)
4.2.1	Generators
4.2.2	Transformers
4.2.3	Inverters
4.2.4	Converters
4.2.5	Dump Loads
4.2.6	Medium- and High-Voltage Components
4.2.7	Electrical Drives
4.2.8	Charging Equipment and Storage Batteries
4.2.9	Switchgear and Protection Equipment
4.2.10	Cables/Bus Bars and Electrical Installation Equipment
4.2.11	Slip Ring

IEC and ANSI/ACP Initial Certification Documentation Requirements	
4.2.12	Lightning Protection
4.3	Wiring and Cables: Sizing and Ratings
4.4	Generator Description and In-House Tests (IEC 60034-1, UL 1004, etc.), Including Short-Circuit Fault – If Applicable
4.5	Electrical Protection Data: Overcurrent and Short-Circuit Faults, Over Voltages
4.6	Lighting Protection Description According to IEC 61400-24 – If Applicable
5	**Tests Evaluation**
5.1	Type Test Reports Issued by Accredited Laboratories:
5.1.1	Duration Test
5.1.2	Power Performance
5.1.3	Noise Measurement
5.1.4	Safety and Function Test
5.2	Possible Tests To Be Performed at Non-Accredited Laboratories or Manufacturer's Facilities (With Certification Body Preapproval and Supervision)
5.2.1	Blade Tests
5.2.2	Loads Tests/Model Validation
5.2.3	EMC Tests
6	**Factory Approval**
6.1	Flowchart and General Description of the Manufacturing and Assembling Process
6.2	Main Components External Suppliers and Quality Control (Bill of Material and Supplier Assessment)
6.3	Specific Work Instructions and Procedures for In-House Build Components
6.4	Purchase Specifications
6.5	Production Quality Controls
6.6	Engineering Changes Requests on the Design
6.7	ISO 9001 Certificate – If Applicable
6.8	Logbooks and Registers of Wind Turbines and Main Parts
7	**Additional Marking and Documentation**
7.1	Installation and Maintenance Instructions
7.1.1	Environmental Conditions Relevant for Installation
7.1.2	Inspection Scope and Frequency
7.2	User's Manual
7.3	Transportation Specifications and Control Quality Procedures

APPENDIX A – ELECTRICAL CONFORMITY REFERENCE STANDARDS

Standards for Main Components	
Ref Doc	**Title**
UL 61800-5-1	Adjustable-Speed Electrical Power Drive System - Safety Requirements
UL 61800-5-2	Adjustable-Speed Electrical Power Drive System - Functional Safety
UL 62368-1	Audio/Video, Info and Communications Equipment - Safety Requirements
UL 1973	Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications
UL 857	Busways and Busbars (600V and Less) or IEEE C37.23 (Greater than 600V)
UL 62275	Cable Management Systems – Cable Ties for Electrical Installations
UL 1425	Cables for Non-Power-Limited Fire-Alarm Circuits
UL 1977	Component Connectors for Use in Data, Signal, Control and Power Applications
UL 1004-1, 1004-4	Primary Turbine Generator in the Turbine Nacelle
UL 499	Electric Heating Appliances
UL 810A	Electrochemical Capacitors
UL 1741, 50	Hub Enclosure/Nacelle Must Comply with Enclosure Requirements
UL 1741	Converters, Inverters, and Controllers in General
NFPA 780, IEC 6100-24	Lightning Protection Systems
UL 96	Lightning Protection System Components
UL 96A	Lightning Protection System Installation Requirements
UL 1741	Gearbox Electrical and Other Features Must Comply with General Requirements
UL 6141, IEC 61400-2	Emergency Stops in General
ANSI/NFPA 70 NEC Articles 376,392	Cable Trays and Wireways
As Applicable	Hydraulic/Pneumatic Electromechanical Components
UL 6141	Disconnect Devices in General
ANSI/NFPA 70 NEC, UL 1741	Grounding in General
UL 1741, IEEE 1547,1547.1	Utility-Interactive Systems
UL 61010-1	Electrical Equipment for Measurement, Control, and Laboratory Use, General Requirements

Standards for Subcomponents	
Ref Doc	**Title**
UL 1437	Analog Instruments, Electrical – Panelboard Types
UL 498	Attachment Plugs and Receptacles
UL 810	Capacitors
UL 60384-14	Capacitors, Fixed, for Use in Electronic Equipment – Part 14: Sectional Specification: Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains
UL 489	Circuit Breakers, Molded-Case; Molded-Case Switches and Circuit Breaker Enclosures
UL 61131	Controllers, Programmable – Part 2: Equipment Requirements and Tests

Standards for Subcomponents	
Ref Doc	**Title**
UL 353	Controls, Limit
UL 60730-1 and/or the applicable Part 2 standard from the UL 60730 series	Controls for Household and Similar Use, Part 1: General Requirements, Automatic Electrical
UL 817	Cord Sets and Power Supply Cords
UL 1283	Electromagnetic Interference Filters
UL 924	Emergency Lighting and Power Equipment
UL 50	Enclosures for Electrical Equipment
UL 486E	Equipment Wiring Terminals for Use with Aluminum and/or Copper Conductors
UL 900	Filter Units, Air
UL 514B	Fittings, Conduit, Tubing, and Cable
UL 62	Flexible Cords and Cables
UL 4248-1	Fuseholders – Part 1: General Requirements
UL 4248-4	Fuseholders – Part 4: Class CC
UL 4248-5	Fuseholders – Part 5: Class G
UL 4248-6	Fuseholders – Part 6: Class H
UL 4248-8	Fuseholders – Part 8: Class J
UL 4248-9	Fuseholders – Part 9: Class K
UL 4248-11	Fuseholders – Part 11: Type C (Edison Base) and Type S Plug Fuse
UL 4248-12	Fuseholders – Part 12: Class R
UL 4248-15	Fuseholders – Part 15: Class T
UL 248-1	Fuses, Low-Voltage – Part 1: General Requirements
UL 248-6	Fuses, Low-Voltage – Part 6: Class H Non-Renewable Fuses
UL 248-7	Fuses, Low-Voltage – Part 7: Class H Renewable Fuses
UL 248-9	Fuses, Low-Voltage – Part 9: Class K Fuses
UL 248-11	Fuses, Low-Voltage – Part 11: Plug Fuses
UL 248-12	Fuses, Low-Voltage – Part 12: Class R Fuses
UL 248-14	Fuses, Low-Voltage – Part 14: Supplemental Fuses
UL 248-15	Fuses, Low-Voltage – Part 15: Class T Fuses
UL 943	Ground Fault Circuit Interrupters
UL 1053	Ground Fault Sensing and Relaying Equipment
UL 508	Industrial Control Equipment
UL 1446	Insulating Materials, Systems of – General
UL 840	Insulation Coordination Including Clearances and Creepage Distances for Electrical Equipment
UL 496	Lampholders
UL 969	Marking and Labeling Systems
UL 1577	Optical Isolators
UL 514C	Outlet Boxes, Flush-Device Boxes and Covers, Nonmetallic
UL 514A	Outlet Boxes, Metallic
UL 67	Panelboards

Standards for Subcomponents	
Ref Doc	**Title**
UL 94	Plastic Materials for Parts in Devices and Appliances, Tests for Flammability of
UL 746D	Polymeric Materials – Fabricated Parts
UL 746B	Polymeric Materials – Long-Term Property Evaluations
UL 746A	Polymeric Materials – Short-Term Property Evaluations
UL 746C	Polymeric Materials – Use in Electrical Equipment Evaluations
UL 796	Printed Wiring Boards
UL 1077	Protectors, Supplementary, for Use in Electrical Equipment
UL 1998	Software in Programmable Components
UL 1449	Surge Protective Devices
UL 20	Switches, Snap, General-Use
UL 1054	Switches, Special-Use or
UL 61058-1	Switches for Appliances – Part 1: General Requirements
UL 60947-1	Switchgear and Controlgear, Low-Voltage – Part 1: General Rules
	Switchgear and Controlgear, Low-Voltage – Part 4-1: Contactors and Motor Starters – Electromechanical
UL 60947-4-1	Contactors and Motor Starters
	Switchgear and Controlgear, Low-Voltage – Part 5-2: Control Circuit Devices and Switching Elements
UL 60947-5-2	Proximity Switches
UL 510	Tape, Polyvinyl Chloride, Polyethylene, and Rubber Insulating
UL 8731	Temperature-Indicating and -Regulating Equipment
UL 1059	Terminal Blocks – UL 1059
UL 310	Terminals, Electrical Quick-Connect
UL 991	Tests for Safety-Related Controls Employing Solid-State Devices
UL 1439	Tests for Sharpness of Edges on Equipment
UL 60691	Thermal-Links – Requirements and Application Guide
UL 5085-1	Transformers, Low-Voltage – Part 1: General Requirements
UL 5085-2	Transformers, Low-Voltage – Part 2: General Purpose Transformers
UL 5085-3	Transformers, Low-Voltage – Part 3: Class 2 and Class 3 Transformers
UL 506	Transformers, Specialty
UL 486A-486B	Wire Connectors
UL 83	Wires and Cables, Thermoplastic-Insulated
UL 61010-2-030	Electrical Equipment for Measurement, Control, and Laboratory Use, Specific Requirements for Test and Measurement Circuits
UL 61010-2-201	Electrical Equipment for Measurement, Control, and Laboratory Use, Specific Requirements Control Equipment
UL 61496-1, 61496-2	Electro-Sensitive Protective Equipment, General Requirements, Tests, and Equipment Using AOPDs
UL 1340	Hoists
UL 2054	Household and Commercial Batteries
UL 508A	Industrial Control Panels

Standards for Subcomponents	
Ref Doc	**Title**
UL 60950-1, 60950-21, 60950-22, 60950-23	Information Technology Equipment – Safety (Multiple Parts)
UL 1066	Low-Voltage AC and DC Power Circuit Breakers Used in Enclosures
UL 248	Low-Voltage Fuses, Parts 1 – 16 as Applicable by Type of Fuse Employed
UL 61965	Mechanical Safety for Cathode Ray Tubes
UL 347	Medium-Voltage AC Contactors, Controllers, and Control Centers
UL 1558	Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear
UL 489, 489C	Molded-Case Circuit Breakers, Switches, and Circuit Breaker Enclosures
UL 746C	Polymeric Materials for Use in Electrical Equipment
UL 61131-2	Programmable Controllers, Equipment Requirements and Tests
UL 1030	Sheathed Heating Elements
UL 1989	Standby Batteries
UL 891	Switchboards
UL 723	Test for Surface Burning Characteristics of Building Materials
UL 1008	Transfer Switch Equipment
UL 1778	Uninterruptible Power Systems
Low-Voltage Switchgear and Controlgear, Part 2 Contactors and Motor Starters* UL 60947-4 (Multiple Parts)	
UL 60947-4-1, 60947-4-1A	Electromechanical Contactors and Motor Starters
UL 60947-4-2	AC Semiconductor Motor Controllers and Starters
Low-Voltage Switchgear and Controlgear, Part 2 Control Circuit Devices and Switching Elements - UL 60947-5 (Multiple Parts)	
UL 60947-5-1	Electromechanical Control Circuit Devices
Low-Voltage Switchgear and Controlgear, Part 2 Ancillary Equipment - UL 60947-7 (Multiple Parts)	
UL 60947-7-1	Terminal Blocks for Copper Conductors
UL 60947-7-2	Protective Conductor Terminal Blocks for Copper Conductors
UL 60947-7-3	Safety Requirements for Fuse Terminal Blocks
Power Transformer Specific Standards	
UL 1561	Dry Type General Purpose and Power Transformers
UL 1562	Transformers, Distribution, Dry Type – Over 600 V
ANSI/NFPA 70 NEC - Article 240	Overcurrent Protection for Power Transformers
IEEE C57.13, C57.13.2, C57.13.6	Instrument Transformers
Wire-Type Specific Standards	
UL 4	Armored Cable
UL 1425	Cables for Non-Power-Limited Fire-Alarm Circuits
UL 1277	Electrical Power and Control Tray Cables with Operational Optical-Fiber Members
UL 1277	Outline of Investigation for Flexible Motor Supply Cable and Wind Turbine Tray Cables

Standards for Subcomponents	
Ref Doc	**Title**
UL 1072	Medium-Voltage Power Cables
UL 1569	Metal-Clad Cables
UL 1651	Optical Fiber Cable
UL 13	Power-Limited Circuit Cables
UL 44	Thermoset-Insulated Wires and Cables
UL 758, 6141	Appliance Wiring Materials