Justification for Updates to ANSI/ACP Small Wind Turbine Standard

Brent Summerville,[1] Jeroen van Dam,[1] Robert Preus,[1]
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1 National Renewable Energy Laboratory
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Technical Report
NREL/TP-5000-79775
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Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

Acknowledgments

Ian Baring-Gould, National Renewable Energy Laboratory (NREL) and Mike Bergey, Bergey Windpower and president of the Distributed Wind Energy Association (DWEA), organized the meetings that initiated the revision of the ANSI/ACP 101-1 standard and helped carry the project forward.

Thanks to the American Clean Power Association (ACP), previously the American Wind Energy Association (AWEA), Wind Technical Standards Committee (WTSC), for moving ANSI/ACP 101-1 through the ANSI process. The WTSC is supported by Michele Myers-Mihelic, senior director, policy and regulatory affairs, asset management and standards development for the ACP and Sabrina Morelli**,** manager, standards and asset management, ACP.

Thanks to the many testing organizations for supplying or publishing the 31 duration test reports that informed and enabled analyses of duration test parameters providing the backbone and justification for changes to the ACP 101-1 standard duration test requirements.

The ACP WTSC created an SWT subcommittee led by three co-chairs:

- Brent Summerville, NREL
- Jeroen van Dam, NREL
- Mike Bergey, Bergey Windpower

Subcommittee members met in person on February 13, 2020, in Denver, Colorado, to kick off the revision process and again, along with larger participation, on February 28, 2020, in Arlington, Virginia, following the DWEA Business Conference, to work on the revision. Several virtual meetings were held to finalize the draft revision, review and resolve comments from the WTSC and the public. The subcommittee roster includes:

- Dean Davis, Windward Engineering
- Ian Baring-Gould, NREL
- Joe Spossey, RE Innovations
- Ken Kotalik, Primus Windpower
- Robert Preus, NREL
- Thom Fleckenstein, Niagara Wind and Solar
- Tod Hanley, Bergey Windpower
- Trudy Forsyth, Wind Advisors Team

List of Acronyms

ANSI	American National Standards Institute
ACP	American Clean Power Association
AWEA	American Wind Energy Association
CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
DWEA	Distributed Wind Energy Association
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IECRE	IEC Renewable Energy
kW	kilowatt
MW	megawatt
NREL	National Renewable Energy Laboratory
OEM	original equipment manufacturer
OTF	operational time fraction
PV	photovoltaic
RTC	Regional Test Center
SWT	small wind turbine
SLM	simplified loads methodology
TC	technical committee
TCP	technical collaboration program
UL	Underwriters Laboratories
USDA	United States Department of Agriculture
V_{ave}	wind speed averages (as specified in IEC 61400-2)
W	watt
WTSC	Wind Technical Standards Committee

Executive Summary

Using AWEA SWT-1-2016 as a starting point, small wind turbine stakeholders developed a revised standard, ACP 101-1-2021. The focus of the revision was to streamline the requirements and minimize the cost and time required to comply with all requirements while maintaining the quality of certified wind turbines in the U.S. market and assuring that the industry can rapidly bring innovation to market and drive down the cost of energy.

This effort was managed by the American Clean Power Association (ACP) Wind Technical Standards Committee, and the work was performed by an SWT subcommittee that includes test-site personnel, a certification body, small wind turbine manufacturers, national lab researchers, consultants, and a developer.

The scope of the standard was changed from an upper limit of 200 square meters of rotor swept area to a peak power of 150 kilowatts (kW), capturing a group of turbines too small to be grouped with multimegawatt turbines and better defining maximum mechanical and electrical loads. Different requirements were set for subcategories, including microwind (up to 1 kW), 1 kW–30 kW, 30 kW–65 kW, and 65 kW–150 kW. For example, microwind turbines are exempt from a design analysis, loads testing, acoustic testing, and blade testing, while the larger categories utilize aeroelastic modeling and a comprehensive suite of testing.

Turbine design assumptions were simplified to International Electrotechnical Commission small wind turbine Class II (or S for special), the assumed turbulence intensity was increased to more accurately reflect real-world conditions, and limits to the use of the simplified loads methodology were delineated.

Small changes to power performance testing, acoustic testing and safety and function testing requirements add up to a more streamlined and cost-effective field test. Based on International Energy Agency Task 41 Standards Forums, duration testing was highlighted as the top barrier to market entry and innovation. More than 30 duration test reports from national and international testing agencies were analyzed and were the basis for informing duration test reforms. A reduction in duration test requirements was balanced with the addition of an expanded post-certification surveillance process, which will now require a 3-year field inspection process in addition to factory inspections and annual reporting requirements of design changes and field failures.

This report documents the rationale for changes to the U.S. national standard for small wind turbines and intends to help inform global distributed wind energy stakeholders as they work to improve global harmonization and streamline testing and certification for wind turbines used in distributed applications.

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1 Background

U.S. small wind turbine stakeholders developed and adopted American Wind Energy Association (AWEA) Standard 9.1 in late 2009. This began an active period of testing, design, and certification to this new U.S. national standard, which incorporated the suite of International Electrotechnical Commission (IEC) standards for small wind turbines but with U.S.-specific exceptions and additions. During this decade of work, industry players learned a lot about AWEA 9.1. These lessons helped the AWEA Wind Technical Standards Committee (WTSC) draft a revision to the Standard that was completed on December 21, 2016. This revision, AWEA SWT-1-2016, included:

- Changes to bring the standard in line with the updated IEC 61400 standards incorporated within the Standard
- Revisions and clarifications from lessons learned during the use of AWEA Standard 9.1–2009
- Segregation of the technical requirements from the conformity assessment requirements.

In February 2019, the Distributed Wind Energy Association (DWEA) and the National Renewable Energy Laboratory (NREL) hosted a certification standards workshop following DWEA's annual meeting to gain feedback from industry stakeholders on experience and problems identified with AWEA 9.1–2009. More than 30 stakeholders attended the workshop, and the consensus was the Standard was overly burdensome and expensive and represented a barrier to market entry and innovation. Consequently, the Standard was in dire need of updating. Meanwhile, international experts working on small wind turbine research such as IEA Task 41, identified issues within the IEC 61400-2 standard that needed further research and validation. Findings included needs to better understand the impact of turbulence on wind turbine design, characterize the inflow models to be more representative of consumer sites, and preliminary identification of vertical inflow and its impacts. All of this global research also called for revising the standards.

Because of issues with the American National Standards Institute (ANSI) standards development process, AWEA SWT-1-2016 was withdrawn in the summer of 2019. In January 2020, DWEA, with support from NREL and the U.S. Department of Energy Wind Energy Technologies Office, launched an effort to review and revise SWT-1 based on lessons learned to reduce its burdens without reducing its value. DWEA convened a panel of subject matter experts that reviewed and evaluated AWEA 9.1/SWT-1 in detail and produced a draft revision that was circulated to industry and other stakeholders. The draft revision was then discussed in detail and further perfected at a half-day review meeting that was held following the DWEA annual business conference on February 29, 2020. A "final" draft was then submitted to the ANSI-accredited AWEA Wind Technical Standards Committee (WTSC) for formal review and approval as a new national standard.

In late 2020, AWEA was renamed the American Clean Power Association (ACP); thus, the draft standard was renamed ANSI/ACP 101-1-2021, The Small Wind Turbine Standard.

2 Summary of Changes in 101-1-2021

The focus of the revision was to streamline the requirements and minimize the cost and time required to comply with all requirements while at the same time maintaining the quality of certified wind turbines in the U.S. market and assuring that the industry can rapidly bring innovation to market and drive down the cost of energy.

The approach was to review the decade of experience that the industry has had applying the AWEA 9.1-2009, AWEA SWT-1-2016, and IEC 61400 standards and weigh each requirement against the effort required to meet that requirement – both time and cost – to determine which requirements add value.

This report lists some of the major changes that were implemented and provides information on why the changes were made. While we implemented these changes to solve immediate cost and innovation barriers for the U.S. market, we strive for global harmonization and as such would aim to have as many of the changes listed in this report adopted on a global level through IEC TC 88 and IEC Renewable Energy (IECRE).

The ACP 101-1 standard contains some conformity assessment requirements in the annex. If international agreement can be reached on those requirements, the authors recommend implementing as many of the requirements as possible in operational documents created by the IECRE stakeholder group 554.

2.1.1 Establishing New Scope and Size Categories

It was recognized that rotor swept area is not the best method to distinguish the different size categories of distributed wind turbines, in part because of a variation between recent technology trends toward low specific power and extended rotor swept area compared with older technology. Instead, peak power was determined to be a better descriptor for size delineation because it also provides a key metric for electrical and mechanical design. Peak power is defined as the highest bin-averaged power output of all filled wind speed bins during a power performance test.

Additionally, it was recognized that there are wind turbines that fall just outside of the current IEC definition of a small wind turbine that are closer to a large “small wind turbine” than to a state-of-the-art large wind turbine, which now approaches 5 megawatts (MW) on land and 10 MW–15 MW offshore. Wind turbines beyond the 200-m^2 upper limit of the existing standard must certify to IEC 61400-1, the standard covering all sizes of wind turbines but primarily applied to MW-scale wind turbines. The cost of certifying to IEC 61400-1 can be 4–5 times the cost of certifying to IEC 61400-2, providing a sizable barrier to market entry for these medium-scale wind turbines. Looking at the wind turbines that are on the market and accounting for the scalability of the IEC 61400-2 requirements, it was decided that including wind turbines with a peak power up to 150 kilowatts (kW) would cover wind turbines in that gap.

It was also recognized that the risks, operating regimes, unit costs, and sensitivity to the cost of energy production varies greatly across the scale from 100-W to 150-kW wind turbines. The low end of the size range can be very different relative to wind turbines on the high end of the size range. The wind turbine price varies as well, with smaller systems being much lower in price, reducing financial risk to customers. The physical size naturally is smaller, reducing risk to society. There is also very little control over where the smallest wind turbine systems are deployed. All of these points led to a new wind turbine class for microwind turbines; the limit was set at a peak power of 1 kW.

2.1.2 Limiting Wind Turbine Classes

Review of the wind turbine classes that were listed for certified products showed that the wind turbine class was almost always dictated by the duration test requirements that could be met. In addition, there is limited control by the manufacturers where the wind turbines are installed, especially for the smaller sizes. Most wind turbine manufacturers target an IEC Small Wind Turbine Class II design, but some end up with a different wind turbine class during the certification process because of the current duration test requirements. It was decided that Class II provides wind turbines that are suitable for installation in most locations in the United States; thus, the option for Classes I, III, and IV designs have been removed. If a special high wind or extreme weather design is developed, Class S remains an option; likewise, if a low wind speed turbine is designed, Class S is thought to better draw attention to this fact.

Based on work conducted under IEA Task 27, when measurements were taken for a variety of high-turbulence sites, typical consumer sites could show an I_{15} (mean turbulence intensity at 15 meters per second [m/s]) from 20% and up. The assumed I_{15} value is reflecting these data with a change from 18% to 20%.

2.1.3 Raising of Reference Annual Energy Production Wind Speed

In many cases, small wind turbines directly compete with solar photovoltaic (PV) and using a conservative 5-m/s annual average wind speed to estimate the Reference Annual Energy for marketing material gives an immediate disadvantage to SWTs compared to the less conservative marketing ratings PV uses. This can lead to SWTs being dismissed before a true comparison of both systems is performed. Changing the annual average reference wind speed from 5 m/s to 6 m/s will allow small wind turbines to be considered on more equal footing. In the end, for both PV and small wind turbines, a site-specific assessment of expected energy should be conducted.

2.1.4 Duration Test

The duration test is a major hurdle to get innovative technology to market. At a minimum, the duration test must take 6 months but, in most cases, it takes much longer. A thorough analysis was conducted of 31 duration test results from tests conducted over the last decade. The idea was to identify which portion of the duration test was most helpful in separating good from bad wind turbine designs and which elements could be amended or removed. In an effort to optimize the test and thus remove a barrier to industry growth and success, recommendations are made to consolidate and simplify the existing duration test requirements.

Duration Test Analysis

Thirty-one duration test reports were collected for analysis. Of the 31 tested wind turbines, 25 successfully met the duration test requirements and six did not. The test periods ranged from January 2007 to May 2018, covering a period of 11.3 years. The tests were conducted according to IEC 61400-2 edition 2, IEC 61400-2 edition 3, AWEA Standard 9.1-2009, and BWEA Small Wind Turbine Performance and Safety Standard (2008). Figure 1 shows the Xzeres 442SR, adjacent to its meteorological tower, under test at the UL Advanced Wind Turbine Test Facility, Canyon, Texas. Testing was performed at the following test sites:

Figure 1 Xzeres 442SR under test at the UL Advanced Wind Turbine Test Facility (photo by B. Summerville, NREL)

- Alternative Energy Institute/West Texas A&M University Regional Test Center (RTC), Canyon, Texas, United States
- BRE Global Limited, witnessed testing, Shetland, Scotland
- CIEMAT Center for the Development of Renewable Energies, Soria, Spain
- Ingenieurbüro Frey, Ihrhove, Germany
- High Plains RTC, Colby, Kansas, United States
- Intertek RTC, Otisco, New York, United States
- NREL, National Wind Technology Center, Boulder, Colorado, United States
- Technical University of Denmark Wind Energy, Denmark
- TUV-NEL, Myres Hill, Scotland
- U.K. National Renewable Energy Centre West Yorkshire, United Kingdom
- UL Advanced Wind Turbine Test Facility, Canyon, Texas, United States
- U.S. Department of Agriculture Agricultural Research Service, Bushland, Texas, United States
- Wind Energy Institute of Canada, Prince Edward Island, Canada
- Windward Engineering RTC, Spanish Fork, Utah, United States.

IEC Class of Duration Test

Table 1 lists the average wind speeds per IEC small wind turbine class according to IEC 61400-2. As shown in Figure 2, the majority of sampled test reports were conducted according to IEC small wind turbine Class II requirements. There was one successful Class I test; there were three attempts at a Class I test but, because of the wind distribution that occurred during the test period, it was not possible to demonstrate Class I wind conditions; therefore, the tests were performed according to Class II requirements. There was one attempt at a Class III test but, because of the wind distribution that occurred during the test period, it was not possible to demonstrate Class III wind conditions; therefore, the test was performed according to Class IV requirements.

Recommendation: These data support limiting the design to IEC SWT Class II or S.

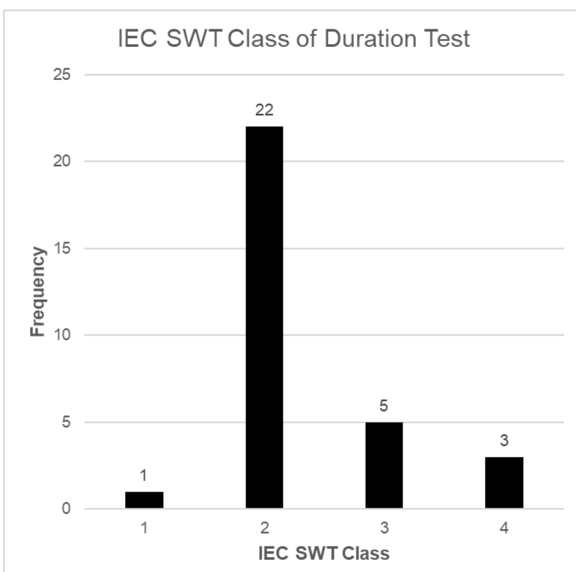

Figure 2. IEC small wind turbine class of sampled duration tests

Table 1. IEC Small Wind Turbine Classes and Wind Speeds from IEC 61400-2 ed. 3

IEC SWT Class	V_{ave} (m/s)	1.2 V_{ave} (m/s)	1.8 V_{ave} (m/s)	2.2 V_{ave} (m/s)
Class IV	6.0	7.2	10.8	13.2
Class III	7.5	9.0	13.5	16.5
Class II	8.5	10.2	15.3	18.7
Class I	10.0	12.0	18.0	22.0
Class S	Values to be specified by the designer			

Maximum Reported Gust

The highest instantaneous wind speed (3-second gust) during the test period must be reported. Figure 3 shows a maximum gust for the Class I duration test of 31.7 m/s; 24.5 m/s to 47.7 m/s with a mean of 34.6 m/s for Class II tests; 26.5 m/s to 41.9 m/s with a mean of 34.5 m/s for Class III tests; and 25.4 m/s to 27.4 m/s with a mean of 26.9 m/s for Class IV tests. The reporting of the maximum 3-s gust was generally found to be a quick indication of the duration test rigor and is an inexpensive parameter to measure and report.

Recommendation: Continue to report the maximum wind gust during the test period.

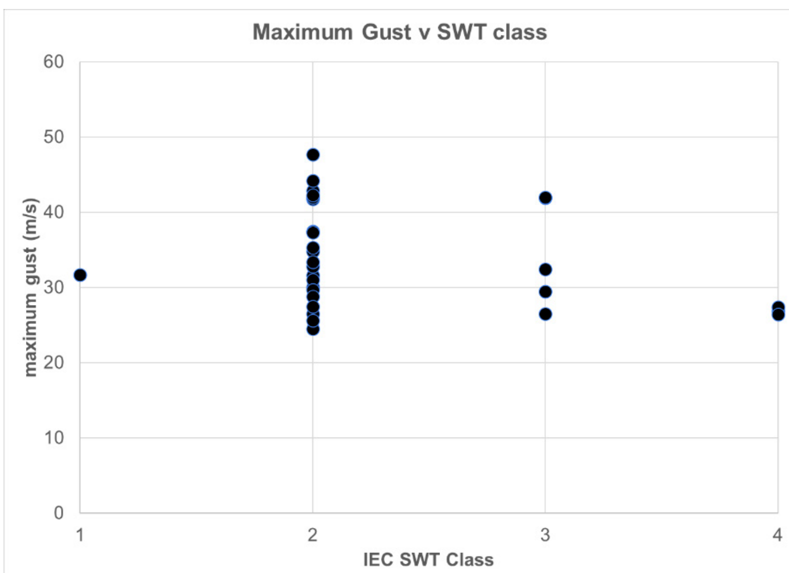

Figure 3. Maximum reported gust per IEC small wind turbines class

Turbulence Intensity

The average turbulence intensity at 15 m/s (I_{15}; wind speed range of 14.5 m/s and 15.5 m/s; 10-minute [min] averages) during the test period must be reported. Figure 4 shows range of turbulence intensity from 4% to 19.7% with a mean of 13.8%. Even relatively smooth and clear test sites can report an I_{15} approaching 20%, and data provided from IEA Task 27 show that many customer sites can typically have a higher-than-20% turbulence intensity.

Recommendation: Raise the assumed I_{15} from 18% to 20%.

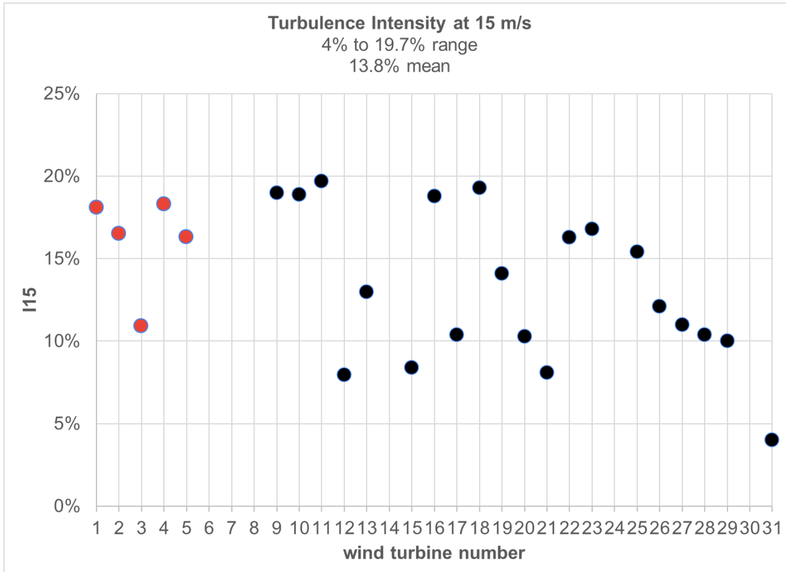

Figure 4. Test site reported turbulence intensity at 15 m/s (failed turbines shown in red)

Six-Month Minimum Test Period

To pass the duration test, the wind turbine must operate reliably for a minimum of 6 months in a variety of wind conditions. The actual length of the test period is a factor of the wind distribution during the test period and turbine downtime. Table 2 shows a summary of results for the 31 test reports. Totals that did not meet the requirements are colored red. Totals that are close to the requirements are colored blue, this indicating a critical test requirement that may have contributed to an extension of the test period.

As shown in Table 2 and Figure 5, the sampled test periods ranged from 4.3 months (aborted test) to 18.5 months with a mean of 8.9 months. Tests 1 through 6, in red, failed to meet the test requirements. Tests 1 and 6 were aborted because of an inability to resolve a major component failure. Tests 2, 3, and 5 successfully completed the duration test requirements but failed during post-test inspection. Test 4 failed to achieve the 90% operational time fraction (OTF) to demonstrate reliable operation during the test period. The 6-month requirement seems to be one driver for the duration test period (7 out of 31) without being a clear distinguisher; removing it can offer a direct benefit for time to market.

Recommendation: Delete the requirement for a minimum number of months.

Table 2. Summary of duration test results

Wind Turbine (and notes)	Test Period (months) (6-months reqd.)	Final OTF (%)	PP hours (2,500 h reqd.)	PP hours 1.2 V_{ave} (250 h reqd.)	PP hours 1.8 V_{ave} (25 h reqd.)	Hours of operation 15 m/s (25 h reqd.)	PP min 2.2 V_{ave} (10 min reqd.)
1 aborted	4.3	93.2	831	133	12.0		
2 post-test	7.5	98.8	4092	401	50.0	50.0	
3 post-test	6.1	99.6	2529	1641	676.0	30.7	
4 OTF	15.3	83.5	1269	443	81.7	81.7	
5 post-test	6.0	100.0	3009	613	88.0	102.0	
6 aborted	7.5	100.0	3975	192	7.6	8.6	
7	14.2	90.8	3350	473	26.5	26.5	
8 attempted Class I	7.4		2927	397	41.0	41.0	

Wind Turbine (and notes)	Test Period (months) (6-months reqd.)	Final OTF (%)	PP hours (2,500 h reqd.)	PP hours 1.2 V_{ave} (250 h reqd.)	PP hours 1.8 V_{ave} (25 h reqd.)	Hours of operation 15 m/s (25 h reqd.)	PP min 2.2 V_{ave} (10 min reqd.)
9	9.8	90.8	2705	711	215.0	136.0	
10	9.9	91.2	3240	552	156.0	156.0	
11	18.5	98.9	2808	686	162.0	162.0	
12	6.7	100.0	4384	849	218.0	238.0	
13 attempted Class III	7.2	90.0	3150	562	59.0	25.8	
14	8.1	99.6	4458	452	29.0	33.0	
15	8.9	100.0	5348	402	60.0	60.0	
16	10.3	99.0	3206	809	262.0		
17	6.8	97.5	2561	542	116.0	39.0	
18	13.1	96.4	2732	533	112.0	112.0	
19 attempted Class I	6.1	100.0	3366	255	25.5	25.5	
20	8.1	100.0	4371	510	34.0	40.0	
21	13.9	92.7	4659	2594	649.0	237.0	
22 attempted Class I	6.3	100.0	3634	720	95.0	95.0	
23	7.0	97.0	3663	559	37.0	44.0	
24 low-cutout	7.1	100.0	5089	412	2.3		
25	11.1	96.4	5568	826	30.5	38.2	
26	6.1	100.0	4248	730	60.0	60.0	
27	10.0	99.7	6140	438	28.2	36.3	
28	6.1	99.8	3296	308	29.0	37.0	
29	6.2	99.6	4107	379	33.7	38.0	
30	12.7	94.0	4456	733	79.0		620
31 only Class I test	8.2	96.1	2961	543	67.8		529

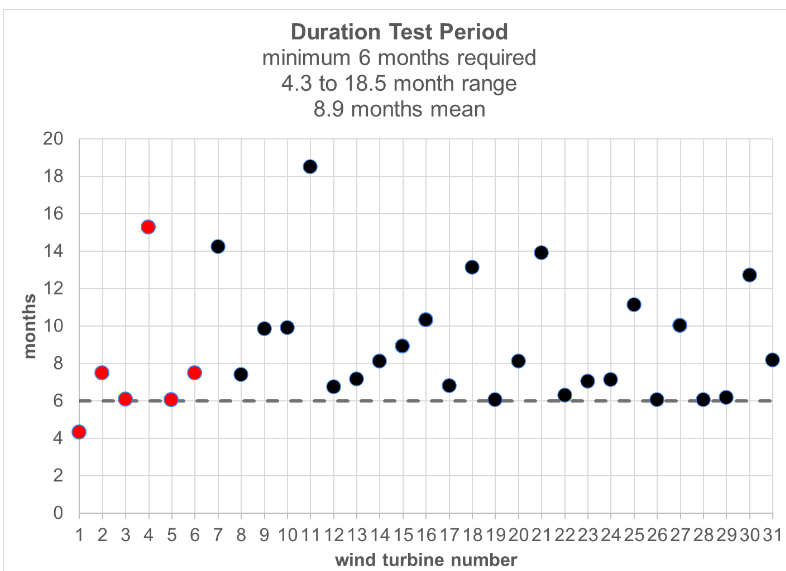

Figure 5. Duration test period in months (failed turbines shown in red)

Hours of Power Production

To pass the duration test, the wind turbine must achieve at least 2,500 hours of power production. As shown in Figure 5, most tests achieved hours of power production much greater than 2,500 hours while trying to meet high wind or operational time fraction requirements. Hours of power production ranged from 831 hours to 6,140 hours, with a mean of 3,617 hours, with only two wind turbines failing before meeting the requirement. The power production requirement does not seem to be a challenge for almost all turbines tested.

Recommendation: Revise duration test to require 1,000 hours of power production.

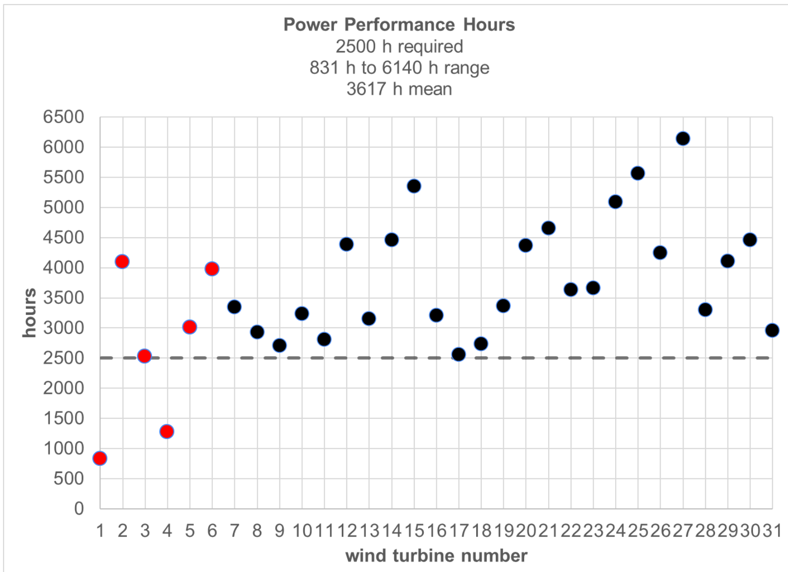

Figure 6. Hours of power production during the test period (failed turbines shown in red)

Power Production, 1.2 V_{ave}

To pass the duration test, the wind turbine must achieve at least 250 hours of power production in winds of 1.2 V_{ave} and above. As shown in Figure 7, hours of power production for this wind requirement ranged from 133 hours for an aborted test to 2,594 hours with a mean of 626 hours.

As shown in Table 2, the test for Turbine 1 was aborted before the power production requirements at 1.2 Vave and 1.8 Vave could be satisfied. Turbine 6 met the power production hours requirement but the test was aborted prior to completing the 1.2 V ave requirement. Turbine 19 achieved 255 hours of power production at these wind speeds—the only passing wind turbine that did not significantly surpass the 250-hour requirement. All other wind turbines seemed to have no issues with this requirement; it does not appear to be driving wind turbine test failure.

Recommendation: Remove specific requirement to operate in moderate wind speeds, 1.2 V_{ave} and above.

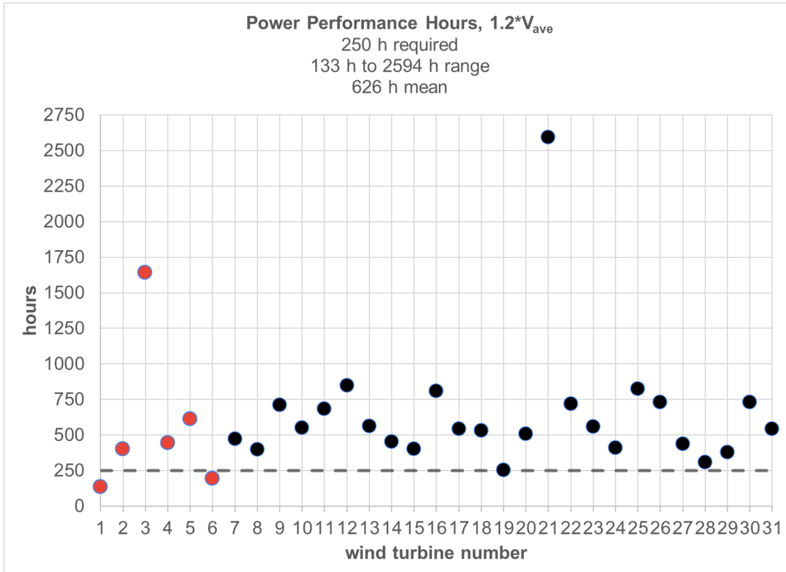

Figure 7. Hours of power production, winds 1.2 V_{ave} and above (failed turbines shown in red)

Power Production, 1.8 V_{ave}

To pass the duration test, the wind turbine must also achieve at least 25 hours of power production in winds of 1.8 V_{ave} and above. As shown in Figure 8, hours of power production for this wind requirement ranged from 2.3 hours for an aborted test to 676 hours with a mean of 114 hours. Turbine 24 was designed to cut-out at 14 m/s, so the 1.8-V_{ave} requirement is not applicable. Satisfying this high wind requirement can extend the testing period considerably and speaks more to the wind regime of the test site than the wind turbine under test. Table 2 shows the 1.8 Vave as the critical requirement, thus extending the test period, for wind turbines 7, 14, 19, 25, and 27.

Recommendation: Reduce high wind requirements to 10 hours of normal operation in winds 15 m/s and up, while adding 3 years of additional surveillance to track operational experience as part of the post-certification surveillance done in the field. (This consolidates the 1.8Vave requirement and the operation at 15 m/s requirement)

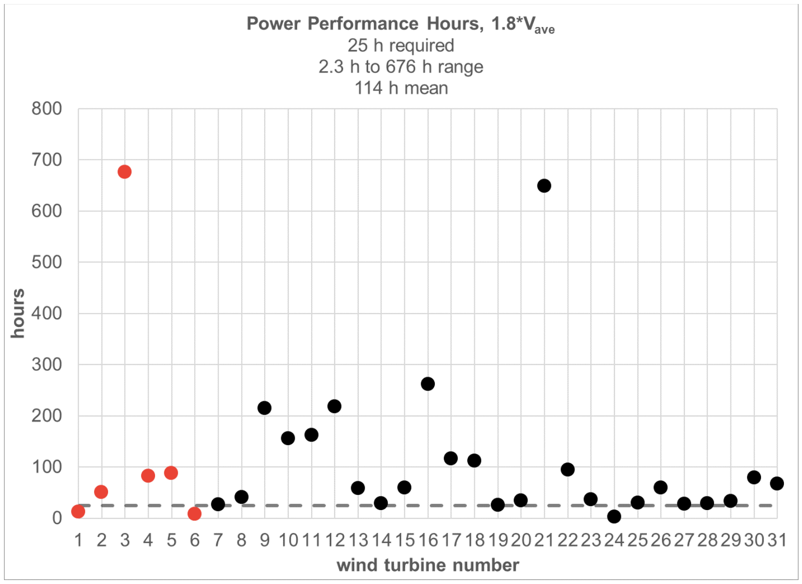

Figure 8. Hours of power production, winds 1.8 V_{ave} and above (failed turbines shown in red)

Normal Operation, 2.2 V_{ave}

The third edition of IEC 61400-2 added an additional duration test requirement: the wind turbine must achieve at least 10 minutes of normal operation in winds of 2.2 V_{ave} and above but not less than 15 m/s. As shown in Table 2, hours of operation for this high wind requirement for Turbines 30 and 31 were 529 minutes and 620 minutes, respectively. Satisfying this high wind requirement speaks more to the wind regime than the wind turbine under test.

Recommendation: Remove this requirement.

Normal Operation, 15 m/s

AWEA Standard 9.1-2009 added an additional duration test requirement: the wind turbine must achieve at least 25 hours of normal operation in winds of 15 m/s and above. As shown in Figure 9, hours of operation for this wind requirement ranged from 8.6 hours for an aborted test to 238 hours, with a mean of 75 hours. Satisfying this requirement can extend the testing period considerably and speaks more to the test site wind regime than the wind turbine under test. Table 2 shows this requirement as a critical metric, perhaps extending the test period, for Turbines 7, 13, and 19.

Recommendation: Reduce this requirement to 10 hours in wind of 15 m/s and above. (This consolidates the 1.8Vave requirement and the operation at 15 m/s requirement)

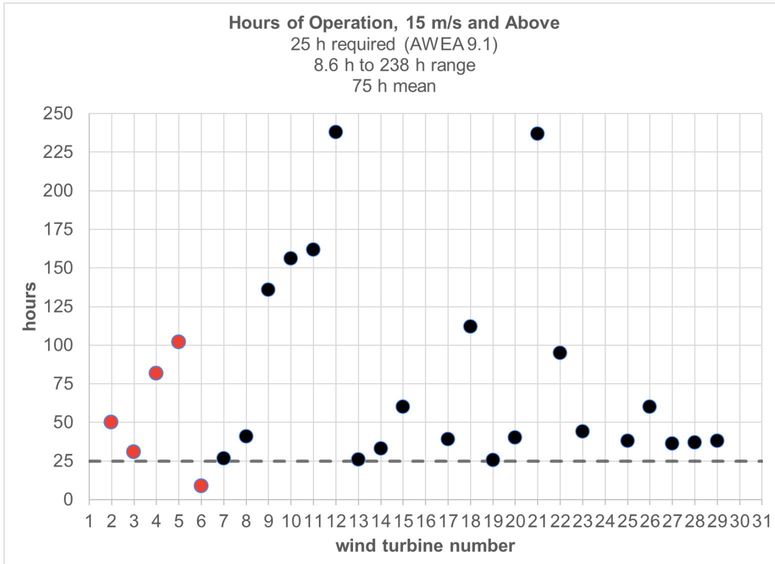

Figure 9. Hours of operation, winds 15 m/s and above (failed turbines shown in red)

Operational Time Fraction

To demonstrate reliable operation during the test period, the wind turbine must achieve an operational time fraction of 90% or greater. Figure 10 shows an operational time fraction range of 83.5% to 100% with a mean of 96.8%. Only one wind turbine failed the test because of the OTF requirement; the majority of test wind turbines had no issues with reaching a higher-than-90% requirement. OTF is not related to safety but reliability and performance instead. OTF adds significant effort, and several tests were extended to get this metric back up to 90% after experiencing some initial issue early in the test period. Also, there is a certain amount of ambiguity in the characterization of time categories. A more representative indication of reliability can be assessed during the in-field surveillance, leading to the recommendation to delete this requirement since it is not a limiting factor.

Recommendation: Remove the OTF requirement to simplify the definition of reliable operation.

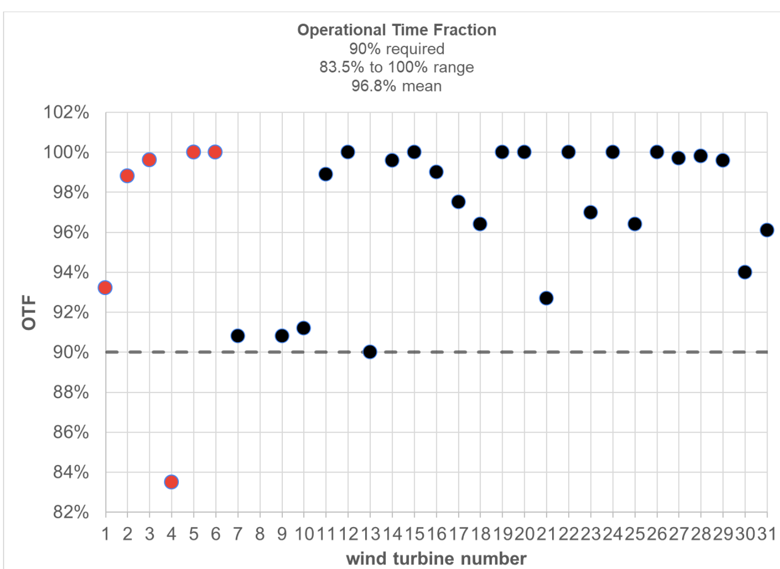

Figure 10. Final operational time fraction at the end of the duration test (failed turbines shown in red)

Power Degradation

To determine reliable operation of the wind turbine under test, a power production degradation analysis must be performed. The 31 test reports in this study demonstrate that the power degradation study typically shows a trend attributed to seasonal air density changes—or no trend at all. Overall, there has been little variation shown in the graphs but anomalies are seen in these data, which are attributed to:

- Issues identified in the post-test inspection, such as failed brake resistors and broken welds
- Accuracy issues with the power transducer
- Seasonal variation in winds (e.g., storms that bring highly variable winds)
- Wind turbine faults (e.g., high wind cut-out or generator over-temperature)
- Neighboring wind turbine switched off during the test
- Possible aging blade pitch spring
- Improvements to power because of changes to turbine setpoints
- Fewer data points for some wind speeds.

Power degradation trends indicating hidden wind turbine problems are rarely observed in this analysis and mostly overshadowed by seasonal effects.

Recommendation: Remove the power degradation analysis requirement to simplify the definition of reliable operation.

Dynamic Behavior Observation

To determine reliable operation of the wind turbine under test, observations of dynamic behavior must be performed and documented. The 31 test reports in this study show that the observations performed by test site personnel typically resulted in a declaration of "no excessive vibration or behavior." Numerous anecdotal observations were recorded, including:

- Leading-edge tape separation
- Unknown vibration from the foundation
- Tower noise observed three times per revolution
- Blade noise
- Mechanical whine
- Bouncing tail
- Tower noise (not harmful)
- Generator hum
- Mechanical growling noise
- Tower sway in gusty winds
- Tower shadow thump
- Minor tail vibration
- Occasionally running downwind (upwind machine)
- Stable yaw
- Power cable vibration
- Failure of a downwind machine to yaw with wind direction change
- Yaw error
- Slight tower excitation during furling

- Significant gearbox noise
- Mechanical braking noise
- Tip brake noise
- Running upwind (downwind machine)
- Motoring noise
- Tail rattle
- Dynamic tower top movements during furling.

On one occasion, tower loads were measured and compared with tower design loads. On another occasion, accelerometers were used to measure tower vibration and tail movement.

In general, it is hard to link any of the observations to dynamics that would clearly exceed design limits and thus be "excessive"; as such, the added value is minimal.

Recommendation: Remove the requirement for dynamic observations and rely on normative Annex I in IEC 61400-2 ed. 3 on natural frequency analysis, thus simplifying the definition of reliable operation.

Major Failures

Major failures present a clear way to end a duration test and fail a wind turbine. Major wind turbine issues that led to failure to satisfy the duration test requirements in the sample of 31 reports include:

- Inverter board components failed in sustained high winds, test aborted
- Excessive rotor friction, preventing the rotor from turning, discovered in post-test inspection
- Inverter failure led to an aborted test, broken welds, broken washer, loose nuts found post-test inspection
- Tail damage (from extreme tail action in gusty wind conditions), blade damage/stress cracking, corrosion/degradation in yaw mechanism, discovered in post-test inspection
- Failed anemometer, failed power supply, failed compressor and faults, failed to meet 90% operational time fraction
- Blade failure (severe cracking close to root, loss of integrity, other blades showing signs of distress), discovered in post-test inspection.

Minor Issues

Minor issues and repairs are allowed during the test and must be reported. Reporting of minor failures provides useful information for the original equipment manufacturer (OEM) and certification body and helps target specific items in the field surveillance program. Minor issues that arose during the test period include:

- Failed bridge diode rectifiers
- Communication board issues
- Minor corrosion
- Loose nacelle cowl
- Twisted brake cable
- Faults (vibration, temperature, voltage, overspeed)
- Replaced yaw rollers
- Contactor failure

- Failed
- Replaced solid-state relays
- Leading edge crack in one of the blades at post-test inspections
- Faulty capacitors in the power factor correction unit
- Failed wire nut.

Test site personnel anecdotally reported that many wind turbines started the duration test but failed early. The manufacturers reportedly responded by unsuccessfully attempting to improve the design, aborting the certification testing process, or going out of business. These early failures did not result in a published duration test report. Listed below are some notable anecdotes from test site personnel regarding the duration test:

- *"I think the duration test is an extended shakedown test on the control system and infant mortality of turbine components, but it will not capture fatigue issues."*
- *"Our challenge (which I'm sure is not so uncommon) is that when major issues relating to duration came up at our site, it would sometimes kill the testing campaign due to funding issues and resulting detailed documentation might also be minimal."*
- *"I would suggest that duration testing be seen as part of the turbine shakedown and not something the certification body would certify in a pass/fail sense, but simply note."*
- *"[The duration test is] intended to catch undesirable emergent behaviors, at any scale, that would not otherwise be found by design analysis; simulation; model testing; system testing; or lab testing, including issues that were not foreseen in the standard(s)."*
- *"I am guessing that many of those found issues with their designs during the duration testing and decided to discontinue their designs."*

Final Duration Test Proposal

Upon review of the sample of 31 duration test reports, the test requirements were greatly reduced to a required 10 hours of normal operation in wind speeds of 15 m/s and above and 1,000 hours of power production. To align with averaging intervals for the other required tests, the duration test is now based on 1-minute averaged periods. The wind turbine must achieve reliable operation during the test period but calculation of operational time fraction, analysis of power degradation, and observation of dynamic behavior have been removed to streamline the testing effort. Reliable operation is now defined as no major failure(s) and no significant wear, corrosion, or damage to wind turbine components. The requirements remain for reporting average turbulence intensity at 15 m/s, the highest gust during the test period, and conducting a post-test inspection.

Potential Impact of New Duration Test Requirements

To assess how the new duration test requirements would have impacted the 31 tests analyzed in this study, an analysis was performed on the 16 reports that contained a monthly summary table of test parameters. Table 3 shows an example summary table for "Turbine 9." The second column in Table 3 shows hours of power production at any wind speed. After 9.8 months of testing, the wind turbine had achieved 2,704 hours of power production.

Table 3. Example of Monthly Summary Table for Turbine 9

Month	Hours of power production above: 0 m/s	9 m/s	13.5 m/s	max gust (m/s)	TI @ 15 m/s (%)	# Data points	T_T (hours)	T_U (hours)	T_E (hours)	T_N (hours)	O (%)
Overall	2704.9	710.6	215.0	41.9	19.0	255	7094	172.5	152.0	624.6	90.8
Jun 2008	238.2	36.2	3.8	28.6	18.5	5	518	11.3	7.8	3.3	99.3
Jul	256.0	8.5	0.3	23.9	-	0	744	78.2	2.2	38.8	94.1
Aug	115.8	4.5	0.0	19.2	-	0	744	6.3	20.0	323.0	55.0
Sep	120.5	11.7	1.8	22.4	-	0	720	36.2	30.3	174.7	73.3
Oct	236.0	45.0	12.2	32.8	17.3	10	744	0.7	1.3	0.0	100.0
Nov	348.0	98.7	22.5	37.0	20.9	40	720	22.1	0.0	0.0	100.0
Dec	339.7	160.5	54.8	41.4	17.4	68	744	7.9	27.2	32.8	95.4
Jan 2009	385.0	155.5	56.0	38.8	19.9	76	744	4.9	32.0	36.5	94.8
Feb	333.2	107.3	36.8	41.9	20.0	23	672	3.2	27.0	0.0	100.0
Mar	332.5	82.7	26.8	36.7	18.0	33	744	1.7	4.2	15.5	97.9

Using Turbine 9 as an example of the what-if analysis, Figure 11 shows that the test period would have been shortened from 9.8 months to 5.3 months for this wind turbine if the required hours of power production had been 1,000 hours. This wind turbine experienced downtime from minor issues during July, August, and September 2008, which led to reduced hours of power production, thus extending the test period.

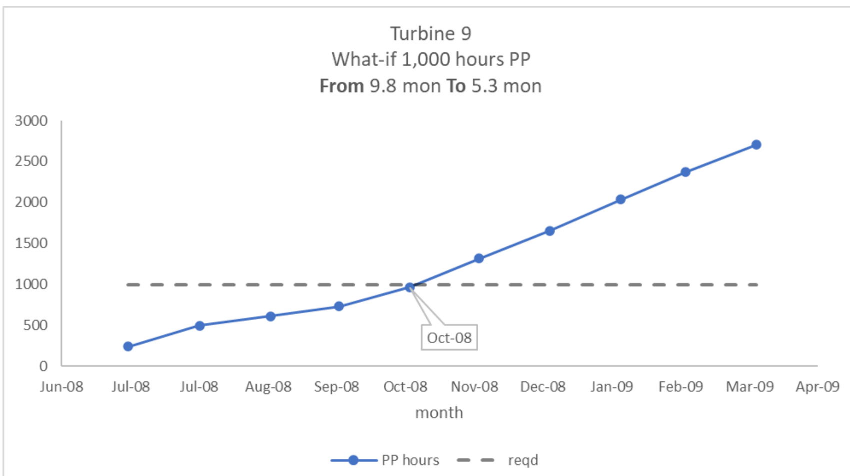

Figure 11. What-if analysis of the Turbine 9 duration test

Five of the 16 test reports containing a monthly summary table also contained monthly data on hours of normal operation in 15-m/s winds and above. Figure 12 shows the what-if analysis for Turbine 28. In this example, the 1,000-hour requirement would have shortened the test period from 6.1 months to 2.0 months, but the requirement of 10 hours of normal operation in 15-m/s winds and above would have taken 3.2 months to satisfy.

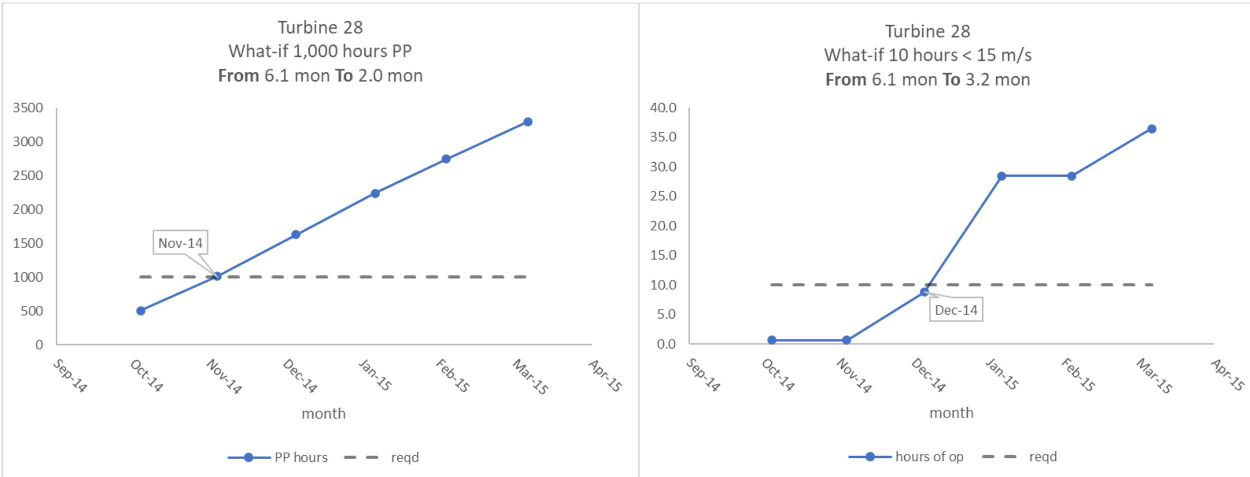

Figure 12. What-if analysis of the Turbine 9 duration test

Figure 13 summarizes the analysis. For the test reports considered in the what-if analysis, the test period ranged from 6.1 months to 18.5 months with a mean of 10.2 months. The what-if analysis results in test periods ranging from 1.6 months to 13.2 months with a mean of 4.2 months. Turbine 4 failed the duration test because of a final operation time fraction less than 90%. For Turbine 4, downtime from numerous minor issues resulted in reduced monthly hours of power production—it would have still taken 13.2 months to achieve 1,000 hours of power production.

Turbine 11 experienced the longest test period in this study at 18.5 months. The wind turbine eventually passed the test despite faulty capacitors in the power factor correction unit and a temporary suspension of testing. The 18.5-month test would have been shortened to 8.6 months. When test sites have a strong wind regime and wind turbines do not experience downtime, the new duration test requirements could have been achieved in about two months (e.g., wind turbines 3, 6, 20, 24, 29). Many tests ran quite long without major issues (e.g., wind turbines 16, 18, 21, 27, 30). The new test requirements would have successfully shortened the test period; thus, considerably reducing the time and cost for these tests.

For the six wind turbines that failed the test, perhaps only Turbine 4, which failed to achieve a 90% operational time fraction, would have passed the test with the new requirements. The other five test failures were because of major component failures that either aborted the test or were discovered in the post-test inspection.

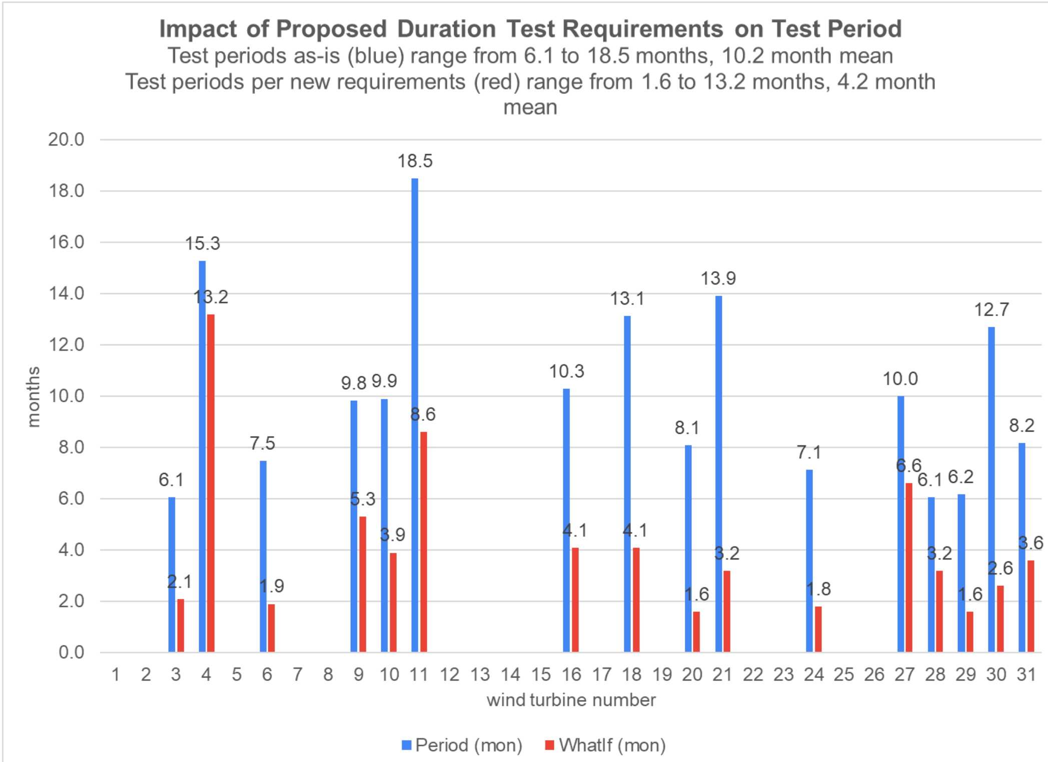

Figure 13. Summary of duration test what-if analysis

2.1.5 Microwind Turbines

For microwind turbines, the price of the wind turbine is relatively low; thus, it allows taking some additional verification risk without significant financial consequences.

For microwind turbines, the structural analysis was completely removed. Thus, the entire validation will be through the testing and then the follow-on field inspections. This is an improvement because the level of effort for structural analysis was not in line with the financial and safety risks.

For turbines in this size category, as shown in figure 14, the acoustic sound measurements are relatively expensive in comparison to the cost of the wind turbine. The underlying thought for removing this requirement is that the market will self-regulate and noisy turbines will be known.

Figure 14 Microwind turbine on a sailboat. NREL PIX 09687

2.1.6 Simplified Loads Methodology

It was noted that the use of the simplified loads methodology option for structural analyses can lead to overbuilding of the structure and has denied certification for pre-existing and field-proven designs, primarily because of the higher required safety factors as compared to the lower safety factors allowed when the aeroelastic loads modeling option was employed. The use of the simplified loads methodology was limited to the specific size range of 1 kW–30 kW and not recommended for wind turbines greater than 10 kW. Above 10 kW, wind turbines become so overdesigned that they result in products that are undesirable in the market. The simplified loads methodology does not require the designer to understand wind turbine dynamics or controller behavior, which is undesirable for wind turbines over 10 kW and is unacceptable for wind turbines over 30 kW. Because of these higher safety factors, many OEMs have defaulted to developing aeroelastic models to meet the certification requirements with a more optimized design. As mentioned earlier, for wind turbines below 1 kW, loads analysis is no longer required.

2.1.7 Aeroelastic Modeling

The discussion is ongoing about which level of model validation of aeroelastic models is needed for which configuration, control methodology, and size. There is a comfort level in the industry that a sufficient amount of validation can occur through the measurements of rotor speed and power as a function of wind speed. For larger wind turbines, adding measured natural frequencies becomes more crucial and, therefore, is required. For the next stepup, additional validation through measurement of tower bending moments is added.

It is recognized that a study of aeroelastic models of specific wind turbines with loads measurements can help better define necessary data for model validation.

2.1.8 Acoustic Sound Measurements

For microwind turbines, it was decided not to require an acoustic sound measurement. The underlying idea is that a lot of these wind turbines are located in marinas where word of mouth spreads quickly about a particular wind turbine that is loud, and the market would self-regulate. The other application for microwind turbines is remote, stand-alone charging stations where sound is not a significant issue.

For the remaining wind turbines covered under 101-1, the uncertainty analysis for a sound measurement is made optional ("should"; thus, optional but recommended). Since test laboratories invest in the analysis tools, this analysis is more or less automated for test laboratories that take these measurements on a regular basis. For test laboratories that do not conduct this analysis regularly, the effort is deemed significant without any value added.

2.1.9 Power Control at High Wind Speeds and Peak Power

The AWEA 9.1 standard requires measuring power performance 5 m/s beyond the wind speed at which the power curve peaks out. This procedure also results in the measurement of Peak Power. This requirement was moved to the safety and function test because the objective of this requirement is to demonstrate power control. In most cases, moving this requirement will not have any impact because the two tests are often conducted simultaneously, but there may be impact in the case of design changes which could result in needing to redo power performance testing and not safety and function testing (e.g., a change in the cut-in behavior of a wind turbine).

2.1.10 Field Inspection

Reliability of certified wind turbines has caused problems for end users. The testing and certification process does a good job of evaluating wind turbine design and performance but is not a perfect process. Therefore, the post-certification surveillance process should be made more robust. Historically, the duration test was an attempt to cover a wide variety of early wind turbine problems, but most test sites do not exercise the wind turbine as much as a typical consumer site will over several years. With the proposal to reduce the run time and high wind requirements of the duration test, there needed to be additional processes to catch wind turbine field problems.

In addition to the current surveillance requirements (factory inspections and reporting of complaints, design changes, and field issues), a limited field inspection program, conducted by qualified personnel, was added. Field inspections of five wind turbines at different sites are required, with annual inspections, for 3 years. An Inspection Report will be delivered to the OEM and the certification body. The report will cover major components as identified by the OEM and certification body and operational impacts during the 3-year period of field surveillance. The purpose of the field inspection is to conduct an inspection per the requirements of IEC 61400-2 ed. 3 clause 11.2.5.3, *Routine Inspections*, which requires inspection of the tower, drivetrain, controller, and rotor. Personnel conducting the inspection will document any signs of cracking, degradation, or significant wear of these major components. The Inspection Report will be accompanied by a report on annual energy production for the prior year and estimated annual average hub wind speed during that time period. The report will provide the source of the wind speed estimate (e.g., NREL Wind Prospector or turbine-mounted anemometer). The purpose of the reported energy production and wind speed is to provide the OEM and certification body some information that describes the conditions at the field inspection site during the prior year.

3 Next Steps

The need to update the U.S. Small Wind Turbine Standard is a microcosm of a larger issue related to international certification for wind turbines. Based on extensive industry discussions, members of the International Energy Agency (IEA) Wind Technical Collaboration Program (TCP), Task 41: Enabling Wind to Contribute to a Distributed Energy Future, have identified the design and testing standards for distributed wind as a barrier to innovation and a source of increased cost of energy for distributed wind technologies.

Although we quickly implemented these changes to solve immediate cost and innovation barriers for the U.S. market, we strive for global harmonization and as such would aim to have as many of the changes listed in this report adopted on a global level through IEC TC 88 and IECRE. This will ensure that the effort for certification will have maximum impact and mutual recognition of certification and the underlying testing and design evaluation will be in place.

Sometimes, especially for wind turbines that have a rotor swept area greater than 200 m^2, company representatives do not see the value of certifying their wind turbine models under current market conditions because the costs of doing so outweigh the value that certification provides. Even if companies see the value in obtaining certifications, the cost and time commitments to do so, combined with a lack of a defined conformity assessment that is approved through the IECRE, hinder bringing more advanced technology to the market in a timely fashion.

Although many national governments maintain their own standards relative to small and large wind turbines, the IEC 61400-2 standard and any conformity requirements defined through the IECRE stakeholder group 554[1] working group generally serve as a baseline for small wind turbines. As the markets for distributed energy technologies expand to serve more applications, including weak and off-

[1] https://www.iecre.org/sectors/windenergy/sg554/

grid applications in developing energy markets, the need for lower cost and more flexible international standards intensifies.

The implementation of an updated U.S. standard defined under 101-1 provides staging for a wider assessment of both need and recommendations to apply to the international standards. Through dialogues implemented under the IEA Wind TCP Task 41, several significant challenges were identified, which are summarized in Table 4.

Table 4. Key Technical Challenges and Gaps of IEC 61400-2 ed. 3 and/or AWEA 9.1/SWT

	North American Forum	European Forum
Meeting duration test requirements slows innovation and time to market. *Number-one challenge for domestic and international stakeholders*	X	X
Use of simplified loads methodology (SLM) has made the engineering design heavier because of high safety factors, and SLM does not sufficiently address fatigue, a common failure mode for small wind turbines. *Need vertical axis wind turbine SLM with fatigue case*	X	X
Validated aeroelastic modeling is the most accurate method of understanding design loads, dynamics, and structural strength but is currently limited for U.S. manufacturers because of weaknesses with FAST modeling modern wind turbines. *Need aeroelastic models of directly coupled generators, a common Danish design, especially for drivetrain fatigue loads*	X	X
Tower dynamics are not addressed well in IEC 61400-2, leaving wind turbine systems vulnerable to system dynamics initiated by the tower.		X
Power performance results are rarely matched at consumer sites, leading consumers to assume that small wind does not work. *Based on Task 27 work, the typical small wind turbine site has a wind shear alpha of 0.2 or higher, which directly impacts the power curve and production*	X	X
Currently, medium wind turbines are kept out of the market for certified wind turbines because of the current limit for IEC 61400-2, 200 m^2 of rotor swept area. (NPS NW 100 is just shy of 500 m^2.) *Need certifications for small wind turbines up to 100 kW or 500 m^2 and classifications for microwind turbines with reduced requirements*	X	X
Many of the current requirements found in the design classification, normal turbulence model, and turbulence intensity do not reflect the commercial reality that microwind and small wind turbines are installed in locations that have high turbulence intensity because of human clutter. *Need to validate preliminary work done under Task 27*	X	X
There are no defined considerations for conformity assessment. *This was not really discussed at the North American forum outside of needing a more defined way to address conformity if minor changes are made to a turbine design*	X	X
Acoustic testing is considered the most difficult of all of the small wind turbine test methods and the output data are not self-explanatory to consumers.		X

Although some of these challenges have been addressed within 101-1, leading research organizations under the coordination of IEA Task 41 will be working to conduct needed research to inform future standards-making bodies. The intent is to have technical results from IEA Task 41 be evaluated by technical experts developing a new draft revision of IEC 61400-2 and its supporting IEC standards.

There will be a continued need to focus on revising existing international standards with representatives from IEC Technical Committee 88, Wind Energy Generation Systems, and focus on the creation of operational documents with IECRE stakeholder group 554. Standards evolution is a natural occurrence with industrial products and, with the inclusion of global experts, can lead to more rapid adoption of harmonized standards and operational documents.

Near-term work will be to improve how aeroelastic models can support certification of distributed wind technology. Although aeroelastic models are identified as recommended for wind turbines over 10 kW, the modeling space is not clear. The use of validated aeroelastic models has been important in allowing rapid innovation for large wind turbines while maintaining turbine certifications. Because of the larger variability in distributed wind turbine architectures, developing and validating wind turbine specific models can be expensive and time consuming, a large investment, which will provide longer-term payoff but will still be difficult for small, distributed wind companies to implement.

A final key element will be an effort to work with the larger distributed wind certification community to document not only successful certification efforts but those that are not successful, allowing continued evolution of the standards as more experience is gained within the distributed wind community. This will need to be an effort coordinated through many of the internationally recognized small wind turbine test centers in collaboration with domestic and international wind turbine certification organizations.

Through these efforts, not only will small and distributed wind turbine technology be allowed to continue to improve, but higher reliability products will be made available to the world market, just in time for a large international push to expand the availability of clean energy technologies.