ACP 111-1 202X

Wind Turbine Sound Modeling

November 2021

AMERICAN CLEAN POWER ASSOCIATION

Standards Committee

202.383.2500 | 1501 M St. NW, Suite 900, Washington DC 20005 | cleanpower.org

AMERICAN NATIONAL STANDARD

Approval of an American National Standard requires verification by ANSI that the requirements for due process, consensus, and other criteria for approval have been met by the standards developer. Consensus is established when, in the judgment of the ANSI Board of Standards Review, substantial agreement has been reached by directly and materially affected interests. Substantial agreement means much more than a simple majority, but not necessarily unanimity.

Consensus requires that all views and objections be considered, and that a concerted effort be made toward their resolution.

The use of American National Standards is completely voluntary; their existence does not in any respect preclude anyone, whether he has approved the standards or not, from manufacturing, marketing, purchasing, or using products, processes, or procedures not conforming to the standards.

The American National Standards Institute does not develop standards and will in no circumstances give an interpretation of any American National Standard. Moreover, no person shall have the right or authority to issue an interpretation of an American National Standard in the name of the American National Standards Institute. Requests for interpretations should be addressed to the secretariat or sponsor whose name appears on the title page of this standard.

Caution Notice: This American National Standard may be revised or withdrawn at any time. The procedures of the American National Standards Institute require that action be taken periodically to reaffirm, revise, or withdraw this standard. Purchasers of American National Standards may receive current information on all standards by calling or writing the American National Standards Institute, 11 West 42nd Street, New York, NY, 10036, phone (212) 642-4900.

AMERICAN CLEAN POWER ASSOCIATION STANDARDS

Standards promulgated by the American Clean Power Association (ACP) conform to the ACP Standards Development Procedures adopted by the ACP Board of Directors. The procedures are intended to ensure that ACP standards reflect a consensus to persons substantially affected by the standard. The ACP Standards Development Procedures are intended to be in compliance with the American National Standards Institute (ANSI) Essential Requirements. Standards developed under the ACP Standards Development Procedures are intended to be eligible for adoption as American National Standards.

Attribution: No part of this standard may be reproduced or utilized in any form without proper attribution to the American Clean Power Association. Credit should be acknowledged as follows: “ACP 111-1 202X Wind Turbine Sound Modeling© The American Clean Power Association.”

Disclaimer: ACP Standards are developed through a consensus process of interested parties administered by the American Clean Power Association. ACP cannot be held liable for products claiming to be in conformance with this standard.

Published by:

American Clean Power Association

1501 M Street, N.W.,

Suite 900

Washington D.C. 20005

www.cleanpower.org

NOTICE AND DISCLAIMER

The American Clean Power Association ("ACP") has provided this Document for the use subject to important notices and legal disclaimers. This Document is proprietary and its use is subject to a legally binding license agreement and disclaimer ("Agreement") described herein and available on ACP's website at https://cleanpower.org/standards-development/, which may be updated from time to time. Do not use this Document for any purpose unless and until you read the agreement. By viewing or otherwise using this Document, you hereby warrant and represent that you have read and agree to be legally bound by the agreement and are authorized to bind not only yourself to the agreement, but the organization for which you are accessing this Document.

Notice and Disclaimer Concerning ANSI Process

Certain ACP standards and best practice publications, of which the Document contained herein is one, are developed through a voluntary consensus standards development process. ACP administered the process in accordance with the procedures of the American National Standards Institute (ANSI) to promote fairness in the development of consensus. This process brings together volunteers and/or seeks out the views of persons who have an interest in the topic covered by this Document. The information in this Document was considered technically sound by the consensus of persons engaged in the development and approval of the Document at the time it was developed. Consensus does not necessarily mean that there is unanimous agreement among every person participating in the development of this Document.

Notice and Disclaimer Concerning Accuracy of Information and Liability Concerning the Use of ACP Publications

Every effort has been made to assure the accuracy and reliability of the data and information contained in this Document; however, ACP does not write this Document and it does not independently test, evaluate or verify the accuracy or completeness of any information or the soundness of any judgments contained in its publications. ACP disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein.

In publishing and making this Document available, ACP is not undertaking to render professional or other services for or on behalf of any person or entity. This Document, and ACP publications in general, necessarily address problems of a general nature. ACP disclaims and makes no guaranty or warranty, express or implied, as to the accuracy or completeness of any information published herein, and disclaims and makes no warranty that the information in this Document or its other publications will fulfill any of your particular purposes or needs. ACP does not undertake to guarantee the performance of any individual manufacturer or seller's products or services by virtue of this Document.

Users of this Document should not rely exclusively on the information contained in this Document and should apply sound business, scientific, engineering, and safety judgment in employing the information contained herein or, as appropriate, seek the advice of a competent professional in determining the exercise of reasonable care in any given circumstances. Information and other standards on the topic covered by this Document may be available from other sources, which the user may wish to consult for additional views or information not covered by this Document.

Use of this Document is strictly voluntary. ACP has no power, nor does it undertake to police or enforce compliance with the contents of this Document. ACP does not certify, test or inspect products, designs or installations for safety or health purposes. Any certification or other statement of compliance with any health or safety–related information in this Document shall not be attributable to ACP and is solely the responsibility of the certifier or maker of the statement.

ACP disclaims liability for any personal injury, property or other damages of any nature whatsoever, whether special, indirect, consequential or compensatory, directly or indirectly resulting from the publication, use of, application, or reliance on this Document or on any of its other publications, even if advised of the possibility of such damage and regardless of whether such damage was foreseeable. In addition, ACP does not warrant or represent that the use of the material contained in this Document is free from patent infringement. ACP publications are supplied "AS IS" and "WITH ALL FAULTS."

Laws & Regulations

When using this Document, local, state and federal laws and regulations should be reviewed. Compliance with the provisions this Document does not constitute compliance to any applicable legal requirements. In making its publications and this Document available, ACP does not intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so. Users of this Document and other ACP publications should take into account state, local, Federal, or international data privacy and data ownership requirements in the context of assessing and using the publications in compliance with applicable legal requirements.

ACP Wind Technical Standards Committee members, at the time the standard was approved:

Company Name	Primary	Alternate
Acciona Energy USA Global LLC	Brian Mathis	Richard Heier
Advanced Insulation Systems LLC	Mike Sherman	
Alimak Group USA Inc.	Luke Metzinger	
ArcVera Renewables	John Bosche	Gregory Poulos
ARESCA	Brian McNiff	Robert Sherwin
Avangrid Renewables	Christopher Morris	Agustin Melero
Barr Engineering Company	Kirk Morgan	Cordelle Thomasma
Bergey Windpower Co. Inc.	Mike Bergey	
Boulder Wind Consulting	Sandy Butterfield	
Clear Wind	Matt McCabe	
Clobotics Corporation	Nicholas Acorn	Rogers Weed
CTE WIND USA, Inc. - CIVIL ENGINEERING	Jomaa Ben Hassine	Alexander Martin
DNV	Brian Kramak	Dayton Griffin
Elevator Industry Work Preservation Fund	Carisa Barrett	Eric Rogers
ENERCON Canada Inc.	Tarik Daqoune	
Energy Systems Integration Group (ESIG)	Cody Craig	Stanton Peterson
Exponent	Timothy Morse	Bernard Roesler
GE Renewable Energy	Mark Helton	Toby Gillespie
HSB - Hartford Steam Boiler	Linkesh Diwan	Simon Krebs
Leeward Renewable Energy	Ronald Grife	
Marmon Electrical - RSCC Wire & Cable	Damian Billeaudeau	
MotorDoc LLC	Howard W. Penrose	Branka Stemack
National Renewable Energy Laboratory	Jeroen van Dam	Paul Veers
NRG Systems	Rob Cole	Steven Clark
nVent ERICO	Tom Bendlak	Dan Holm
Pattern Energy Group Services, LP	Michael Edds	
Penn State University	Susan W. Stewart	
RE Innovations LLC	Joseph Spossey	
Sargent & Lundy L.L.C.	David Jolivet	
Siemens Gamesa Renewable Energy	Masoud Sharifi	
Small Wind Certification Council	Shawn Martin	
Spire Engineering Services LLC	Robert Sheppard	
Terra-Gen LLC	Yuanlong Hu	
U.S. Department of Energy	Jim Ahlgrimm	Michael Derby
UL LLC	Tim Zgonena	Jason Hopkins
University of Texas at Austin	Lance Manuel	
Vestas North America	Trevor Taylor	John Eggers
WSB-Hawaii	Warren Bollmeier	

ACP Sound Subcommittee members, at the time the standard was approved:

Organization	Name
Aercoustics	Payam Ashtiani
Apex Clean Energy Inc.	Marcel Mibus
DNV	Justin Puggioni
Epsilon Associates Inc.	Richard Lampeter
Hankard Environmental	Michael Hankard
JACOBS	Mark Bastasch
RSG	Kenneth Kaliski
Siemens Gamesa Renewable Energy	Kaveh Habibi
Vestas Wind Systems A/S	Erik Sloth

FOREWORD and BACKGROUND

The Foreword and Background sections are included with this document for information purposes only and are not part of the American Clean Power Association (ACP) ACP 111-1 202X Wind Turbine Sound Modeling.

Foreword

The goal of this standard is to provide a uniform calculation method of wind turbine sound levels at far-field locations, typical of residences or other noise-sensitive uses evaluated during project permitting. Establishment of a uniform set of modeling parameters is anticipated to reduce confusion when one evaluates predicted sound levels during permitting proceedings as well as in peer-reviewed scientific literature. While current practice in the United States yields relatively minor differences, standardization of predictions is anticipated to result in a robust and repeatable process that increases regulatory confidence.

Although specific methodology and modeling parameters are presented in this standard, the decision regarding which modeling methodology to use lies solely with the practitioner and may vary from project to project. The approach developed in this document utilizes international standard engineering calculation methods (i.e., International Organization for Standardization [ISO] 9613) with parameters that have been found to yield reasonably conservative results for wind turbines. That is, the methods proposed tend to overestimate, rather than underestimate, project sound levels. Therefore, this standard and the methodology described herein are not intended to invalidate any previous or future study and should not be retroactively relied upon or in any way interfere with the status of a project or the future ability of a project to pass the permitting process. The content of this standard should only be used as a guide for practitioners and should not (1) be assumed to serve as the industry standard of care or; (2) supersede permitting requirements, required variations in standard modeling assumptions, and engineering best practices. Other calculation methods or parameters have been used and the development of this calculation standard does not indicate that other methods are flawed or erroneous. Rather, this document provides one standardized method that can allow existing and future project sound levels to be translated into easily comparable results that developers, researchers, neighbors, and regulatory agencies can recognize as a proper method of calculation and comparison.

Background

ACP is recognized by the American National Standards Institute (ANSI) as an Accredited Standards Developer. This standard was developed based on input from a variety of stakeholders.

This document outlines the consensus on a preferred method of predicting project sound levels during the siting and permitting process. The goal of this document is to develop a uniform method of predicting future project sound levels such that predevelopment sound assessment results can be readily compared. A standardized calculation method makes calculated results repeatable, uniform, and more easily understood by all interested parties. This standard focuses on a “realistic worst case condition” with turbines operating at their highest rated sound power levels.

The ISO 9613 method of calculation and the International Electrotechnical Commission (IEC) 61400-11 turbine sound power level standard are both based on the evaluation of downwind conditions (wind blowing from the turbine to the receptor) given this meteorological condition enhances propagation. Methods to evaluate sound levels for other wind directions, such as upwind or crosswind conditions, are beyond the scope of this document.

Table of Contents

1 General Information

1.1 Purpose

Modeling of wind turbine sound levels at far-field positions (e.g., residences) is conducted to support preconstruction permitting analysis as well as various research efforts. The purpose of this standard is to establish a uniform set of modeling parameters for the International Organization for Standardization (ISO) 9613 propagation modeling procedures to ensure a uniform and comparable basis. The establishment of these standard modeling parameters does not imply that work conducted prior to the establishment of this standard is incorrect. Rather, the intent of this standard is to avoid potential future confusion by providing consistency of predicted sound levels published in research or permitting documentation given the potential for different modeling parameter settings to result in disparate results.

1.2 Overview

1.2.1 This standard provides a method for predicting sound pressure levels based on the ISO 9613-2 standard for propagation of sound outdoors utilizing the apparent wind turbine model-specific sound power level determined in accordance with International Electrotechnical Commission (IEC) 61400-11 for the downwind location.

1.3 Scope

1.3.1 This standard is for utility-scale wind turbine projects where individual turbines have nameplate capacity exceeding 1 megawatt.

1.3.2 This standard is specific to horizontal-axis, upwind, onshore turbines.

1.3.3 This standard specifies procedures to estimate the equivalent free-field continuous sound level (Leq) over periods between 10 minutes and 1 hour. The results yield a sound pressure level that is unlikely to be exceeded under normal operating conditions. For other metrics, see Appendix A.

1.4 Definitions

1.4.1 Definitions contained in ISO 9613-1, ISO 9613-2, IEC 61400-11, ed. 3, and ANSI/ASA S1.1 are hereby incorporated by reference.

1.5 Units

1.5.1 The primary units shall be SI (metric). The inclusion of secondary units in the English system is recommended, for example, 10 meters per second (m/s), equal to 22.4 miles per hour (mph).

2 Sound Modeling Methodology

Informative note: The main objective of a sound assessment is typically to predict the sound level generated by the wind energy project at relevant sound-sensitive receptors. An assessment is typically prepared when one or more receptors are located within about 1.6 to 2 kilometers (1 to 1.25 miles) of a potential wind turbine location. A variety of methods are available to identify the location and coordinates of receptors, including:

- Review and analysis of aerial or satellite imagery or available address databases to identify dwellings.
- Site visits to confirm the building type and status (e.g., abandoned, habitable, not occupied); and
- Review of local land use/permitting records to identify building permits or site plan approvals for approved, but not yet constructed, receptors.

The goal is to establish the point of evaluation, which is typically taken as the approximate center of the receptor. Both existing and planned receptors (with valid building permits or approvals) at the time of the wind farm permit application would be considered in the sound assessment. A revised sound assessment would be conducted when changes to the project description result in increased sound levels (e.g., material changes to the turbine layout or turbine model). This method can also be used to predict sound levels at other locations, such as property lines.

ISO 9613-2, Acoustics—Sound Attenuation During Propagation Outdoors Part 2: General Method of Calculation (1996) has generally been accepted by the acoustics community, wind developers, and regulatory agencies as a standard calculation method. The ISO 9613 method provides several configurable parameters that influence the predicted value. To provide consistency in a wind energy project sound assessment, two sets of standardized model parameters are established. Option 1 and Option 2 yield nearly identical results that differ by tenths of a decibel, a difference which is neither reliably measured nor discernable. Option 2 is provided as some jurisdictions have a precedent of adjusting model inputs or results and requiring such adjustments to Option 1 is not supported.

2.1 ISO 9613-2 modeling parameters are:

2.1.1 Option 1:

A. Ground factor of G=0

B. While modeled receptor height does not influence model results with G=0, it can be stated as 1.5 meters for consistency with existing standards with respect to the microphone position for measurements or as 4 meters for consistency with Option 2.

C. Turbine modeled at hub height using vendors apparent downwind Sound Power Level specified consistent with IEC 61400-11.

D. No other model adjustments.

2.1.2 Option 2:

A. Ground factor of G=0.5.

B. Receptor height of 4 meters.

C. Turbine modeled at hub height using vendors apparent downwind Sound Power Level specified consistent with IEC 61400-11.

D. A model adjustment of + 2 decibels.

2.2 Atmospheric absorption per ISO 9613-1 for conditions of 10 degrees Celsius (50 degrees Fahrenheit) and 70 percent humidity.

2.3 Care should be taken to ensure all relevant project sources have been included in the calculation when establishing a calculation radius or search area.

2.4 The predicted levels are in the form of an A-weighted Leq (LAeq) sound level metric unless another metric is identified consistent with Appendix A.

3 References and Appendices

3.1 References

Reference Title
International Electrotechnical Commission (IEC). 2012. IEC 61400-11. Wind turbines—Part 11: Acoustic noise measurement techniques.
International Organization for Standardization (ISO). 1993. ISO 9613-1. Acoustics—Sound Attenuation During Propagation Outdoors. Part 1: Calculation of the Absorption of Sound by the Atmosphere. Geneva, Switzerland.
International Organization for Standardization (ISO). 1996. ISO 9613-2. Acoustics—Sound Attenuation During Propagation Outdoors. Part 2: General Method of Calculation. Geneva, Switzerland.

Appendix A

1 Metric

While this standard is appropriate for the modeling of equivalent continuous sound levels with averaging times between 10 minutes and 1 hour, it can be used with other metrics and averaging times, which in turn may necessitate appropriate adjustments. Some metrics such as the L10 (sound level exceeded for 10 percent of the time of the measurement period) are noted to be inappropriate for use in modeling or measuring noise from wind turbines, as they present many measurement challenges (i.e., high variability given influence of nonproject sources yields low repeatability). For modeling under full acoustic power, when it is mandated that the L10 must be specifically addressed, the hourly L10 can be assumed similar in level to the hourly equivalent free-field continuous sound level (Leq), or as a practical matter model results could be adjusted upwards. The acoustician must use discretion when determining the basis of the adjustment, if any. The MassCEC study found that such an adjustment would be 1.3 decibels on an A-weighted scale (dBA) (RSG et al. 2016). Those jurisdictions that have L10 requirements may also have L50 or Leq requirements, which are generally at least 5 dBA lower and therefore would be the controlling criteria. Overall, the relevance of L10 style limits for wind energy facilities has not been established; rather, the limits are often a carryover from existing regulations. No robust basis has been established for evaluating L10 style limits at wind energy facilities.

Similar to other sound power level standards relied on internationally for reciprocating engines, heating, ventilation, and air conditioning (HVAC), and electrical equipment, the International Electrotechnical Commission (IEC) 61400-11 standard reports sound power levels based on measurement of short-duration Leq sound pressure levels. As such, the Lmax, a sound level that is less than 1 second in duration, is not predictable for wind turbines or other environmental sound sources. Averaging times less than 10 minutes have not been found to be appropriate for regulatory use on wind turbines, given the inherent inaccuracies in subtracting background sound levels from short-duration events. The Lmax has not been found to be a repeatable metric in that it is inherently an outlier and for wind turbines the measured Lmax is often related to nonproject sources. This standard therefore does not address nor recommends that instantaneous maxima, such as LFmax, LSmax, or LImax, be relied on in regulatory settings. Additionally, where the plain simple, conventional language of “the sound level shall not exceed” or similar is established, the recommended interpretation is one that is consistent with this standard, namely an Leq with an averaging time between 10 minutes and 1 hour.

Assessment of averaging times longer than 1 hour will result in sound levels less than those predicted by this standard as this standard relies on the full-acoustic output and conservative meteorological conditions. Modeling averaging times longer than 1 hour, such as annual averages, may be calculated based on this standard but the practitioner will need to determine how to address various factors such as meteorology, windspeed distribution, and operating time. This standard does not establish how these attenuating factors are incorporated into such calculations. Rather it is noted that the longer (e.g., annual) average would be less than the full acoustic power conditions identified in this standard.

Note that measurement methods and intervals are out of scope for this standard.[1] In the event that measurements are required, one would likely need to consider data logging or measurement intervals of less than 1 hour to ensure that intermittent ambient sources can be filtered out of the measurement results. The L90 and L50 metrics are also useful to collect during field measurements and where appropriate, predictions made consistent with this standard may be deemed conservative assessments of these metrics. Additionally, care is warranted to ensure that measurement locations are representative of free-field conditions or consider appropriate adjustments.

[1] IEC is currently drafting IEC 61400-11-2, which is intended to provide guidance for field measurements at far-field conditions.

2 Apparent Sound Power Levels

Apparent wind turbine sound power levels based are based on IEC 61400-11. In most cases, the sound power levels are determined up to a hub height wind speed of approximately 20 meters per second (m/s) (45 miles per hour [mph]). This range of wind speeds is more than sufficient as turbines will typically ramp up in sound power level until the wind speed is 8 to 10 m/s (18 to 22 mph) and cut out or shut down under much higher wind speeds. At these extreme wind speeds, the ground-level wind speeds are also high, which complicates collection of reliable data as the noise from the wind itself or through vegetation is substantial. The use of the highest sound power level within this range yields a predicted sound pressure level that is unlikely to be exceeded under normal operating conditions. Operations under conditions that yield different apparent sound power levels tend to be short lived and related to meteorological conditions such as icing or operational and maintenance issues.

In most cases, the full acoustic sound power should be used. For pitch-regulated wind turbines, the maximum wind speed considered should not exceed 15 m/s. While conditions such as tail lift[2] may increase the sound power above 15 m/s (34 mph), measurements made under such conditions are generally unreliable given accompanying high ground wind speeds and associated wind-induced contaminating noise

3 Combination of Different Turbine Sound Power Levels

When different turbine models or turbines operating in differing modes are proposed, basing the analysis on the maximum sound power level of each turbine or operating mode may be overly conservative as these conditions may not be realized simultaneously. For a more realistic evaluation, one would need to consider what can occur simultaneously.

4 C-weighted and Octave Band Sound Levels

Field measurement programs of wind turbine sound levels measured have shown that any statistical difference between analysis based on either C- or A-weighted data is unlikely (Keith et al. 2016a). For modeling at dwellings, C-weighted levels are approximately linearly related to A-weighted levels. Given this one-to-one relationship between A- and C-weighted values, there is no statistical advantage to using one metric over the other for modeling wind turbine sound at receptors (Keith et al. 2016b; RSG et al. 2016).

Field studies have compared measured and modeled octave band sound levels. Modeling based on the methodology outlined in this standard agrees reasonably well with measured octave band sound levels. Specifically, the low-frequency octave bands were found to be less than predicted. Additionally, in situ sound power levels are often found to be less than specifications in the lower frequencies. However, care should be taken, as the number of octave band calibration studies is limited, and many manufacturers do not warranty or guarantee octave band sound emissions.

5 Anomalous Operations

The conservative parameters used in this standard were selected to cover a wide range of operating conditions, including turbulence, wind shear, and temperature. However, certain anomalous events that may occur infrequently, or over a short time duration, are not considered. These include extreme conditions such as icing and tail lift. In the event that on/off testing methods are utilized, one may need to adjust the analysis intervals to focus on typical operations rather than the forced start/stop conditions (RSG et al. 2016).

6 Vegetation

Given the height of wind turbines, vegetation rarely thoroughly or substantially blocks the line of sight between source and receiver. Even if it did, the angle through the vegetation combined with the relative distance to the wind turbine and the potential for sound rays arcing over the forest yield a low potential for

[2] Tail lift is an aeroacoustic phenomenon that results in a positive slope in the sound curve at higher wind speed.

significant vegetative sound attenuation. As a result, inclusion of vegetation in sound propagation modeling for wind turbines is not recommended.

7 Shielding Considerations

Care should be taken to ensure barrier or terrain attenuation is not overestimated. This can occur when the line of sight between the source and receiver is slightly blocked. Where there is potential for terrain shielding, it is recommended that (1) predictions be compared to flat ground and/or (2) the source height be adjusted to tip height, to evaluate the potential influence of terrain shielding.

References

Reference Title
Keith, S. E., K. Feder, S. A. Voicescu, V. Soukhovtsev, A. Denning, J. Tsang, N. Broner, W. Richarz, and F. van den Berg. 2016a. "Wind turbine sound power measurements." The Journal of the Acoustical Society of America. Vol. 139, No. 3. pp. 1431–1435.
Keith, S. E., K. Feder, S. A. Voicescu, V. Soukhovtsev, A. Denning, J. Tsang, N. Broner, W. Richarz, and F. van den Berg. 2016b. "Wind turbine sound pressure level calculations at dwellings." The Journal of the Acoustical Society of America. Vol. 139, No. 3. pp. 1431–1435.
RSG, Epsilon Associates, and Northeast Wind. 2016. Massachusetts Study on Wind Turbine Acoustics. Massachusetts Clean Energy Center and Department of Environmental Protection.