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Sound power level measurements 3.0

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Summary

The apparent sound power level of a wind turbine is determined in accordance to the international standard IEC 61400-11 edition 3.0. This paper focuses on the challenges introduced in this version and how to deal with them. The main difficulties are k-factor dependent wind speed, disturbances leading to incomplete datasets, continuous full analysis necessary for determination of a complete dataset.

The standard requires 10 measurements (30 if tonal) per 0.5 m/s wind speed bin for both the total noise and the background noise. The wind speed measured at 10 meter height, used for the background measurements is now calibrated in-situ with a k-factor dependent on Turbine ON data, which means that the normalized wind speeds can change bins until the last recorded measurement. This can have a major impact if measurements stretch over multiple days due to varying meteorological conditions. Furthermore, disturbances during the measurements have to be filtered from the dataset. Manual filtering afterward can result in an incomplete dataset of sound power levels related to the required wind speed range. In cases where the difference in the sum of the 1/3-octave bands of the estimated sound power level based on the total and background noise for a given wind speed bin is less than 3 dB, the result is not reported. This can only be monitored by doing the complete analysis per 1/3-octave band on site since a measurement with enough data points can in the end still result in an incomplete dataset.

Constraints on the measuring positions of both wind speed and sound pressure level also require special attention to limit downtime during rapidly changing wind directions.

Extensive automation with a cloud based database is developed in light of aforementioned issues as a possible solution and is presented in this paper.

1. Introduction

The apparent sound power level of a wind turbine is determined in accordance to the international standard IEC 61400-11 Wind turbines – Part 11: Acoustic noise measurement techniques edition 3.0 which replaced edition 2.1. Detailed evaluation of the differences between Edition 3.0 and Edition 2.1 have been made before. [Jozwiak, R. et all, 2015]

Jozwiak, R. et all, name the most significant instrumentation changes as:

- 1/3 Octave Band centre frequencies extended down to 20 Hz;
- A resolution of 1 to 2 Hz for the entire frequency range for tonal analysis;
- Rotor RPM is now a mandatory parameter to be logged;
- A minimum sample rate of 1 Hz for turbine parameters and wind speed.

Other significant changes are:

- The implementation of 10 second averages for each interval;
- The apparent sound power level is now related to hub height instead of 10 m height;
- K-factor correction method for nacelle anemometer and 10 m anemometer

The use of the k-factor method to relate the wind speed measured at 10 m height and nacelle to hub height is on itself minor. This change however has some major implications for monitoring the progress during sound power level measurements.

2. Measurement procedure

The apparent A-weighted sound power levels, spectra, and tonal audibility at bin centre wind speeds at hub height and 10 m height of an individual wind turbine are assessed by sound power level measurements conform IEC 61400-11 edition 3.0. The standard describes where and how the sound pressure level and the wind speed at 10 m height are to be measured as well as which parameters of the turbine should be logged during the measurements. Based on the recorded data the apparent A-weighted sound power levels, spectra, and tonal audibility at bin centre wind speeds at hub height and 10 m height can be calculated.

2.1 Measurement locations

2.1.1 Microphone location

The direction of the positions shall be within ±15° relative to the downwind direction of the wind turbine at the time of measurement. The downwind direction can be derived from the yaw position. The horizontal distance (R_0=H + D/2) from the wind turbine tower vertical centreline to each microphone position shall be as with a tolerance of ±20%, max ±30m. The allowed location for the reference microphone is shown in figure 1.

2.1.2 10 m anemometer location

For measurement of background noise an anemometer mounted on a met mast of at least 10 m height shall be used. The position of the met mast should be relatively undisturbed and represent the free wind at the turbine position. The allowed location for the 10 m high anemometer is shown in Figure 1. Here the grey highlighted areas to the left and the right of the turbine show the possible location of the 10 m anemometer, the grey highlighted area directly downstream of the wind turbine indicate the allowed area where the reference microphone has to be located. If during measurements any of the two measurement positions falls outside of their allowed range the measurement position is invalid and has to be excluded from the measurement set.

2.2 Wind speed range

The wind speed range is related to the specific wind turbine. As a minimum it is defined as the hub height wind speed from 0.8 to 1.3 times the wind speed at 85% of maximum power rounded to wind speed bin centres.

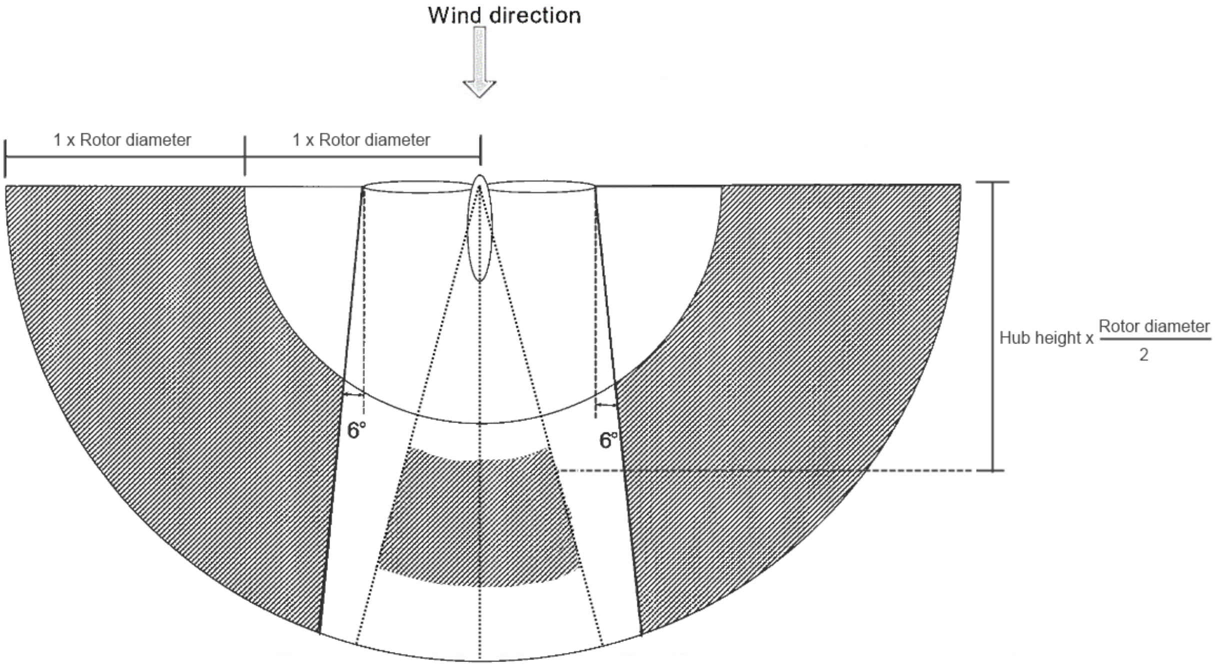

Figure 1 Allowable range for 10 m anemometer and reference microphone position.

2.3 Background noise

With the wind turbine shut down, and using the same measurement set-up, the background noise shall be measured immediately before or after each measurement series of wind turbine noise and during similar wind conditions. When measuring background noise every effort shall be made to ensure that the background sound measurements are representative for the background noise that occurred during the wind turbine noise emission measurements. It is necessary to measure the background noise several times during the measurement period to cover the same wind speed range as for the total noise.

2.4 Number of measurements

At least 180 measurement shall be made overall for both total noise and background noise covering corresponding wind speed ranges (see section 2.2). At least 10 measurements shall be made in each wind speed bin for both the total noise and background noise.

Additional noise measurements may be needed to determine the audibility of an identified tone. When a tone is found in a wind speed bin the number of required measurements depends on the number of measurements containing a tone of the same origin. 30 measurements may be required to assess the audibility of the tone if less than 6 measurements contain the tone of the same origin.

2.5 Required wind turbine parameters

During the measured several parameters of the wind turbine have to be logged. These include but are not limited to:

- power output;
- generator speed;
- rotor speed;
- nacelle wind speed;
- yaw angle.

2.6 Required site parameters

During measurements the air temperature and atmospheric pressure have to be measured.

3. Keeping track of measurements

In theory, for a wind speed range of 7.5 m/s to 12.5 m/s at hub height a minimum measurement time of 60 minutes is required to obtain enough measurements for both the total noise and the background noise (30 minutes each).

In practice however there are several factors that can influence the number of measurements inside a wind speed bin. The most important factors are discussed below.

3.1 Total and background noise

For a given wind speed interval of 0.5 m/s both the total and background noise have to be measured. Therefore the turbine must be switched off and on during a measurement. The standard states that every effort shall be made to ensure that the background sound measurements are representative and measured during similar wind conditions as the total noise. After switching the turbine on or off it typically takes about 5 minutes for the rotor to be completely stopped or sped up to normal rotational speed and pitch.

Switching the turbine state then leads to an exclusion of circa 5 minutes of measuring time. Since, with changing wind conditions, a certain wind speed interval might only occur once during the measurement day. And it might be crucial to make an accurate assessment on when to switch turbine states to ensure both total and background noise are sufficiently measured.

3.2 K-factor

The wind speed measured at the nacelle and the wind speed measured at 10 meter height, used for the background measurements is now calibrated in-situ with a k-factor. The k-factor for both the total noise and background noise is dependent on Turbine ON data. The k-factor is defined as the average value of the ratio of the wind speed derived from the power curve (V_p) and the measured wind speed (V_{nac} or V_{10m}).

For the total noise measurements the k-factor is applied to the measured wind speeds for the data points with power levels outside the allowed range of the power curve to derive the normalised wind speed at hub height. This means that the normalized wind speeds outside the allowed range of the power curve can change bins until the last recorded measurement for the total noise measurements.

With edition 3.0 of the standard the background wind speed is now calculated to hub height using the k-factor. This implies that the 10 meter high anemometer used for background measurements is dependent on the Turbine ON data. The amount of measurements inside the background wind speed bins can only be known by calculating the k-factor. Therefore the normalized wind speeds of all measurements can change bins until the last recorded measurement for the background noise.

The use of a k-factor can have a significant impact on the measurement results if measurements stretch over multiple days due to varying meteorological conditions.

3.3 Disturbances

The nature of the apparent sound power level measurements means that there are always outside influences, for example disturbing noise from birds, planes, passing cars, working farmers, rain etc.

Edition 2.1 of the standard incorporates the use of a fourth order regression best fit through the measured sound pressure levels to determine the sound pressure level at each integer wind speed. In edition 3.0 the average per 1/3 Octave (which might not be at wind speed bin center) is used instead of a best fit. Measured disturbances can significantly raise the average sound power level and influence the measurement results.

Disturbances during the measurements have to be filtered from the dataset. Manual filtering afterward can result in an incomplete dataset of sound power levels related to the required wind speed range if the amount of measurements in a bin are just above the required 10 (or 30 in order to assess the audibility of a tone).

3.4 Calculation criteria

In cases where the difference in the sum of the 1/3-octave bands of the estimated sound power level based on the total and background noise for a given wind speed bin is less than 3 dB, the result is not to be reported. This can only be monitored by doing the complete analysis per 1/3-octave band on site as a measurement with enough data points can without real time analysis afterwards still result in an incomplete dataset.

3.5 Other parameters

Constraints on the measuring positions of both the wind speed measured at 10 meter height and the sound pressure level also require special attention to limit downtime during rapidly changing wind directions. Measurements with invalid measurement locations because of ±15° constraint for the microphone position or 10 m nacelle position outside the specified range become excluded from the calculations. When the wind direction is changing a measurement position may soon become invalid. One can anticipate and move a measurement location prior to the change in wind direction to limit downtime and possible miss measuring a certain wind speed.

3.6 Drawbacks of post processing measurement data

Measurements based on post processing data according to IEC 61400-11 edition 3.0 have the following drawbacks:

- The in-situ calibration of the k-factor leads to possible shifting of measurements between wind speed bins;
- Due to a change of wind direction the measurement position could afterwards be found outside the allowable range;
- Disturbance correction is done on an energy basis instead of a statistical basis (edition 2.0) leading to a higher chance of exclusion of background measurements during specific wind speeds;
- Third octave band analysis may even show that specific bands should be excluded because of narrow banded disturbance noise;
- If after post analysis missing wind speed bins are found, additional measurements need to be done, leading to delay because one should wait for the specific wind conditions to occur;
- Additional measurements lead to increased lead time of (for instance) prototype testing which may be considered inefficient.

In chapter 4 a measurement procedure and monitoring system is described in which the aforementioned drawbacks are negated.

4. Solutions

As discussed in Chapter 3 there are several factors that have to be known in order to assess if a measurement dataset is complete. Being able to accurately monitor the measurement process is key in decision making in the field which will not only reduce measurement time but improve the quality of the measurements.

In order to achieve accurate monitoring and be in control at the site about all measurement constraints extensive automation is required. The solution of the authors is presented below.

4.1 Cloud database

Data collected from the turbine, 10 m anemometer and sound pressure levels are stored in a central database based on a 1 Hz sample rate. The microphone position is, depending on wind turbine hub height and rotor diameter, up to approximately 200 m downwind of the turbine and can frequently change due to changing wind direction during a measurement. Wireless transfer of the data is therefore the most practical solution. Therefore all logged acoustic, wind speed, and wind turbine parameter values are independently and real-time sent to a remote cloud database. Measurement data and audio files are stored locally for redundancy. Due to the large size of the raw audio files, tonal analysis is performed post-measurement. Multiple microphone positions can be used simultaneous to determine the effect of directivity on the sound power levels.

4.2 Real time computing

With all the measurement data collected in a central storage, monitoring software continuously runs full data processing in accordance to the international standard IEC 61400-11 edition 3.0. In short the following steps are performed real-time:

- time synchronisation;
- 10 s averaging of 1 Hz measurement data;
- Analysing noise measurement data to exclude disturbances;
- Analysing wind turbine measurement data to determine turbine status;
- Checking for invalid measurement positions;
- Normalizing measured wind speeds based on k-factors;
- Sort measurement data to wind speed bins;
- Calculate values at wind speed bin centers;
- Calculate total noise and background noise;
- Perform background correction;
- Calculate total and 1/3-Octave band apparent sound power levels;
- Calculate uncertainties.

Logged variables and calculation results can be viewed real time via a web portal: “Peutz monitoring portal”.

4.2.1 Wind turbine status (ON/OFF)

Based on the collected data from the wind turbine (Figure 2), the wind turbine state (ON/OFF) is automatically determined. By analysing the power output and the generator speed the current state of the wind turbine is deducted. Changes in wind turbine state are also accurately determined and automatically excluded from calculations (see Figure 3).

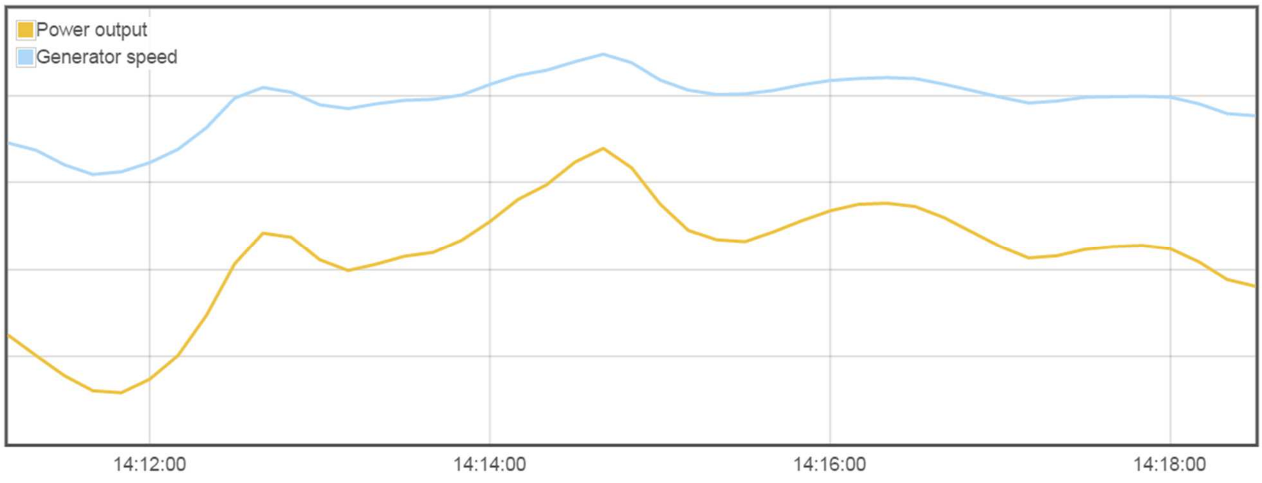

Figure 2 logged generator speed [rpm] and power output [kW] of last 10 minutes

4.2.2 Acoustic disturbances

The acoustic data is processed and analysed and obvious disturbances of birds etc. are automatically filtered out. The equivalent sound pressure level during a 10 second interval is compared to the peak sound pressure level that occurred inside that 10 second interval. Disturbances that are short and high in intensity can easily be distinguished as the difference between the peak level and the equivalent sound pressure level will be high. Disturbances can also be set manually (see Figure 3).

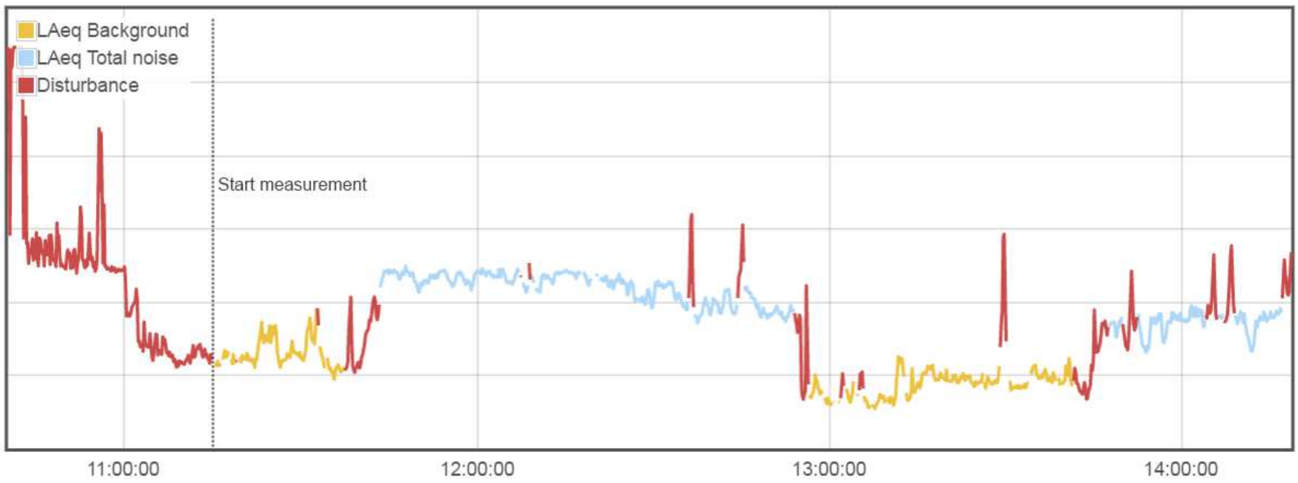

Figure 3 Recorded sound pressure level at the reference microphone position [dB(A)]. With distinction between total noise, background noise and disturbances.

4.2.3 Measurement positions

The location of the reference microphone and the 10 m anemometer is monitored by the software. Their location is on placement determined with GPS and stored in the database. The yaw angle is projected on the preferred measurement location and is monitored and checked real time. The valid locations are dynamically calculated based on the wind turbine parameters stored in the database. Measurements where the measuring locations are outside the valid area are excluded from the calculations. When the wind direction is changing and a measuring position might soon become invalid, one can anticipate and move a measurement location prior to limit downtime and possible miss measuring a certain wind speed. Not only is the validity of a measurement position easily distinguishable, the possible new location can be easily picked, with an interactive web tool located at the monitoring portal, as the projected wind direction can be manually changed to be able to take into account terrain obstacles such as waterways, ditches, tree lines, buildings, etc.

Figure 4 current measurement positions and their allowable range. (left: all valid, right: microphone position not valid)

4.2.4 K-factor

All measured wind speeds are known and can be monitored (Figure 5). The k-factors for both the nacelle wind speed and the 10 m anemometer wind speed are continuously calculated. The normalized 10 m and nacelle wind speed are continuously updated.

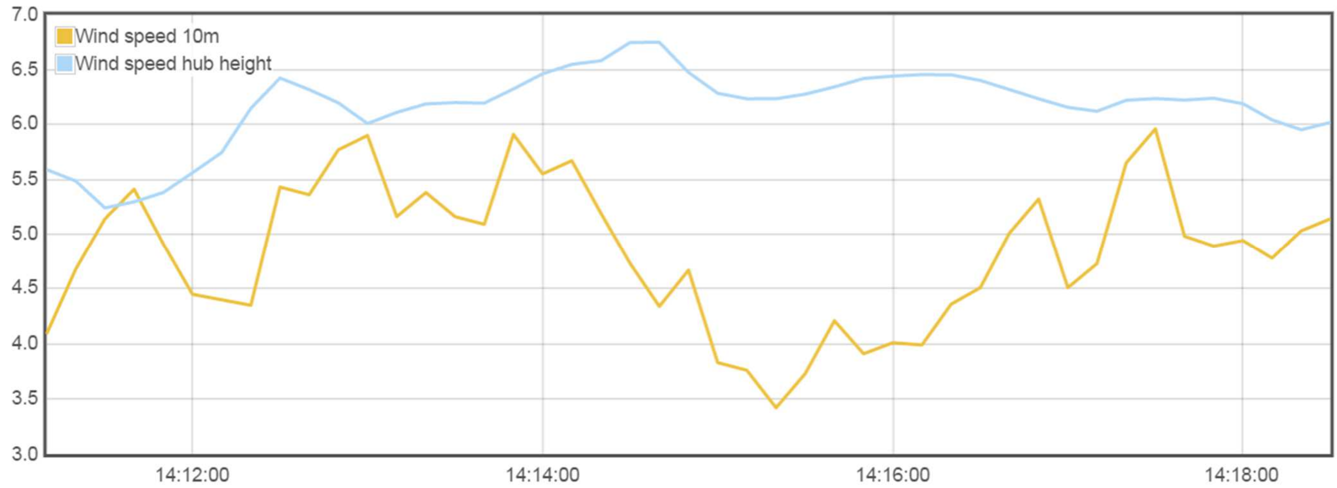

Figure 5 Measured wind speed at 10 m height and hub height (not normalized)

4.2.5 Number of measurements

An overview of the amount of valid measurements in wind speed bins for the total noise and background noise is continuously updated (Figure 6). The required wind speed range is always shown. If wind speed measurements are recorded outside the required wind speed interval the table is extended. For each wind speed bin the number of measurements excluding disturbances and invalid measurement positions are given. If the minimum required amount of measurements to assess the apparent sound power level (10 measurements) is reached the value turns orange. If enough measurements have been recorded to assess the audibility in case of a recorded tone the number turns green. The total number of measurements in the required wind speed range is given as a total which will turn green if it meets the measurement requirement of 180 measurements.

Wind speed	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	Total
Count total noise	0	4	20	58	87	47	43	60	91	72	31	20	4	0	0	0	0	321
Count background noise	6	14	29	43	59	53	31	30	26	19	25	12	11	4	0	0	0	158

Figure 6 Overview of the number of valid measurements in a wind speed bin for the measured total and background noise

4.2.6 Apparent sound power level

If an apparent sound power level can be calculated for a given wind speed bin the total LWA and the 1/3-octaves are shown in the monitoring portal. Marked with * where the difference in the sum of the 1/3-octave bands of the estimated sound power level based on the total and background noise for a given wind speed bin is between 6 and 3 dB or [ ] for the cases where a background correction of 3 dB is applied for a given 1/3-octave.

Cases are not reported where the difference in the sum of the 1/3-octave bands of the estimated sound power level based on the total and background noise for a given wind speed bin is less than 3 dB. The calculated apparent sound power levels are also shown graphically for easy assessment at a glance (Figure 7).

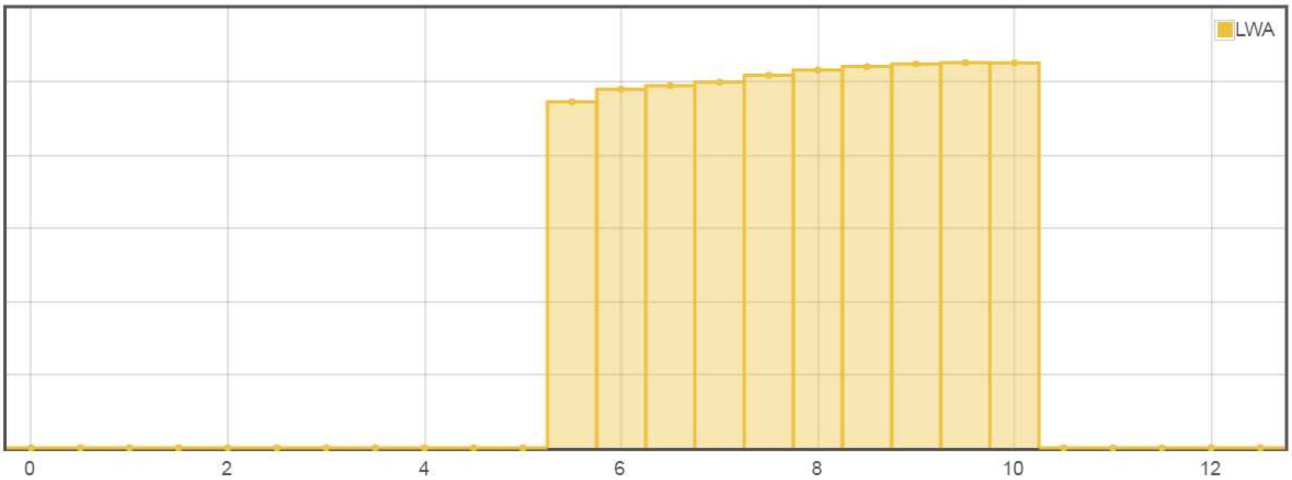

Figure 7 Apparent sound power level [dB(A)] per wind speed bin [m/s]

5. Conclusions

As discussed in Chapter 3 there are several factors that have to be known in order to assess if a measurement dataset is complete. Post processing the measurement data has major drawbacks (see section 3.6).

Switching often between wind turbine on or off will ensure that the background measurements are performed under similar conditions as prescribed by the standard. Each switch will however take some time in which measuring is not possible. Being able to monitor the measurement process real-time greatly assists in decision making in the field.

To be in control during measurements a real-time monitoring portal (“Peutz monitoring portal”) is implemented wherein all measurement data is processed real time according to the standard including correction for disturbances and third octave band calculations.

The location of the reference microphone and the 10 m anemometer in relation to the yaw angle (wind direction) is shown real time in the monitoring portal. Measurements with invalid measuring locations are excluded from the calculations. When the wind direction is changing and a measuring position might soon become invalid. One can anticipate and move a measurement location prior to limit downtime and possible miss measuring a certain wind speed.

An overview of the amount of valid measurements in wind speed bins for the total noise and background is provided in the monitoring portal. The status of the measurement progress is visible at a glance.

If an apparent sound power level can be calculated for a given wind speed bin the total LWA and the full 1/3-octaves are shown in the monitoring portal. Possible points of interests can be immediately assessed.

The system can be easily used in the field and extended with multiple microphone locations. With enough microphones unmanned measurements can be performed as the whole range can be covered. Noise monitoring at residents can also be added.

The system is currently in the progress of being accredited for wind turbine measurements conform IEC 61400-11 edition 3.0 and has been used to perform several acoustic measurements on prototype wind turbines.

The system allows for efficient measurements which will not only reduce measurement time but improve the quality of the measurements as the ability to limit measurements to one day will ensure equal environmental conditions.

Results are readily available during and immediately after a measurement.

References

Jozwiak, R. et all. (2015) *Field comparison of IEC 61400-11 Wind turbines – Part11: Acoustic noise measurement techniques: Edition 3.0 and Edition 2.1* 6th International Meeting on Wind Turbine Noise Glasgow 20-13 April 2015

IEC 61400-11:2006 edition 2.1 Wind turbines – Part 11: Acoustic noise measurement techniques.

IEC 61400-11:2012 edition 3.0 Wind turbines – Part 11: Acoustic noise measurement techniques.