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MODELLING LOW-FREQUENCY NOISE OF WIND TURBINES

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ABSTRACT

The industrial noise calculation method, which includes wind farm noise, is defined in Polish regulations and Directive 2002/49/EC. According to these documents, the method described in the ISO 9613-2 covering the frequency range from 63 Hz to 8 kHz should be used. However, wind turbines are also a source of the low-frequency noise in the band from a few Hz and thus well below the lower frequency of the existing models calculation range. These sounds are a source of annoyance for people living near wind turbines. Therefore, propagation of the low-frequency component should be modelled at the predicting acoustic impact stage of wind turbines on the environment. The paper reviews modelling methods in the low-frequency range and verifies the suitability of ISO 9613-2 and CNOSSOS-EU algorithms for modelling low-frequency noise including frequencies below 63 Hz. The results of the calculations were compared with the results of measurements carried out around the wind farm.

Keywords: *wind turbine, noise modelling, low-frequency noise.*

1. INTRODUCTION

One of the main disadvantages of wind turbines is the generation of infrasonic and low-frequency noise (ILFN), which can cause annoyance and nuisance to nearby residents, as well as people at a considerable distance from the turbine [1–3]. Therefore, propagation of the ILFN should be modelled at the predicting acoustic impact stage of wind turbines on the environment. Infrasound noise is defined as noise in the range from 1 Hz to 20 Hz [4,5], while low-frequency noise has no standardised definition. Different frequency range limits for this noise can be found in the literature. In the DIN 45680 standard [6], the low-frequency noise band is specified from 8 Hz to 100 Hz. According to Leventhall [7], low-frequency noise ranges from 10 Hz to 200 Hz, while according to the ACGIH threshold limits values [8] infrasound and low-frequency noise is noise in the range of 1 Hz - 80 Hz, and according to other researchers up to 100 or 250 Hz or even 500 Hz [9–12]. In Poland, the Leventhall approach has been applied to low-frequency noise.

Many methods for modelling wind turbine noise can be found in the literature. The most common are complex methods using different models. These include algorithms based on the 'ray tracing' method [13–16] and using parabolic equations [17–22], as well as the Viterna's [23, 24], and Amiet's [25] models. The Fast Field Program algorithm [20], and a numerical model developed in 2017 combining the aeroelastic model HAWC2 and the so-called Formula 1A developed by Farassat [26] are also used for this purpose. Nevertheless, research is still ongoing to improve wind turbine noise prediction methods, as exemplified by the PIBE project [27], which is being carried out in France from 2019 to 2023.

All the models mentioned above are very complex and require specialised knowledge, which makes them not commonly used in the assessment of the environmental impact of a planned investment. Therefore, there is a need to implement commonly used computational methods for the prediction of ILFN generated by wind turbines. This group of methods can include the method referred to in

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Directive 2002/49/EC of the European Parliament and of the Council of the European Union of 25 June 2002 on the assessment and control of environmental noise [28]. This is the method described in ISO 9613-2 [29]. The ISO 9613-2 calculation method has been superseded by the method presented in Commission Directive 2015/996, known as CNOSSOS-EU [30], which is ultimately intended to become a mandatory method for all European Union Member States.

Therefore, this study verified the suitability of the ISO 9613-2 and CNOSSOS-EU algorithms for modelling ILFN covering frequencies below 63 Hz.

2. RESEARCH MATERIAL

A study of the usability and effectiveness of using ISO 9613-2 and CNOSSOS-EU algorithms to model ILFN in frequency bands below 63 Hz was carried out using real measurement data. The data were recorded at one onshore wind farm operating in central Poland.

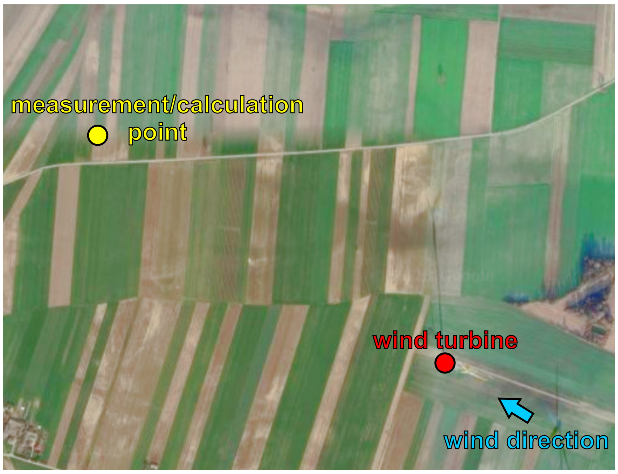

Figure 1. Location of wind turbine, measurement and calculation point.

The noise source was a 2 MW Vestas V90 turbine. The hub height of this turbine was 105 m, while the rotor diameter was 90 m. The sound power level of this turbine was determined in accordance with EN 61400-11:2013/A1:2018/AC:2019-11 [31] and was $L_{\mathrm{WA}} = 121.4$ dB.

A SVAN 958 multi-channel sound level meter equipped with 1/2 inch G.R.A.S. 40AZ microphones was used for the measurements. The measurement point was located 1000 m behind the turbine (Fig. 1). Measurements were made simultaneously by placing the microphones at two different heights above ground level. The first was mounted on a measurement board and placed at 0 m above ground level, while the second was placed at 4 m above ground level.

The entire measurement session lasted 24 hours, while a continuous time period of 5 minutes was selected for analysis. This time period was characterised by stable meteorological conditions (wind speed, temperature, humidity) with no additional acoustic events recorded (road noise, dog noise and others).

The meteorological conditions prevailing during the measurements were recorded at various heights above ground level. Meteorological stations were placed at heights of 10 m, 4 m, 1.5 m and data was also acquired from the turbine hub height (105 m). The data recorded at 10 m above ground level was used for the calculations, which are shown in Table 1.

Table 1. Meteorological conditions recorded during measurements at 10 m above ground level used in the calculations.

temperature	6.2 °C
static pressure	1014.4 hPa
relative humidity	43.7 %
wind speed	4.2–4.3 m/s
wind direction	SE, 120°–150°

The geometric-acoustic model used for the calculations was built in SoundPlan software. The model reproduced the actual land cover around the turbine and included all relevant elements affecting the calculation of sound propagation in the environment. The calculation points were located at the same locations as the measurement microphones.

3. RESULTS AND DISCUSSION

Calculations were performed using two commonly used calculation models ISO 9613-2 and CNOSSOS-EU, taking into account the atmospheric conditions prevailing during the measurement session (Table 1). The calculations were performed for 1/1 octave frequency bands with centre frequencies from 1 Hz to 250 Hz (9 bands). For

Table 2. Sound pressure level at 0 m above ground level (on board).

calculation model	indicator	sound pressure level [dB]								
		centre frequencies of the 1/1 octave bands [Hz]								
		1	2	4	8	16	31.5	63	125	250
	$L_{p,m}$	53.9	53.7	39.9	34.8	36.4	40.8	45.7	40.2	36.8
ISO 9613-2	$L_{p,c}$	42.3	49.8	46.5	44.1	39.9	37.9	33.9	31.6	30.0
	ΔL_p	-11.6	-3.9	6.7	9.3	3.5	**-2.9**	-11.7	-8.6	-6.7
CNOSSOS-EU	$L_{p,c}$	39.3	46.8	43.5	41.1	36.9	34.9	30.9	28.5	27.0
	ΔL_p	-14.6	-6.9	3.7	6.3	**0.5**	-5.9	-14.7	-11.7	-9.7

Table 3. Sound pressure level at 4 m above ground level.

calculation model	indicator	sound pressure level [dB]								
		centre frequencies of the 1/1 octave bands [Hz]								
		1	2	4	8	16	31.5	63	125	250
	$L_{p,m}$	64.7	53.6	50.8	48.4	43.8	49.1	33.7	27.9	30.1
ISO 9613-2	$L_{p,c}$	42.3	49.8	46.5	44.1	39.9	37.9	33.9	31.6	30.1
	ΔL_p	-22.4	-3.8	-4.3	-4.3	-3.9	-11.2	**0.3**	3.7	0.0
CNOSSOS-EU	$L_{p,c}$	39.3	46.8	43.5	41.1	36.9	34.9	30.9	28.6	27.0
	ΔL_p	-25.4	-6.8	-7.3	-7.3	-6.9	-14.2	**-2.7**	**0.7**	-3.1

where in Tables 2 and 3: $L_{p,m}$ - background noise corrected measured sound pressure level [dB], $L_{p,c}$ - calculated sound pressure level [dB], ΔL_p - difference between calculated and measured sound pressure level $(L_{p,c} - L_{p,m})$ [dB]

bands with centre frequencies below 63 Hz, the same propagation parameters were used for the calculations as for the band with a centre frequency of 63 Hz. The calculation results were then compared with the measurement results, as shown in Tables 2 and 3. In Tables 2 and 3, the differences between the calculated and measured results within a ± 3 dB interval are shown in bold.

For the measurements on board (see Table 2), the differences between the calculated and measured values for the ISO 9613-2 method range (in terms of absolute value) from 2.9 dB to 11.7 dB, while for the CNOSSOS-EU calculation method, they range from 0.5 dB to 14.7 dB. It can be seen that the results obtained using the CNOSSOS-EU method are 3 dB lower than those obtained using the ISO 9613-2 method.

For measurements made at 4 m above ground level (see Table 3), the differences between the calculated and measured values for the ISO 9613-2 method range (in terms of absolute value) from 0.0 dB to 22.4 dB, while for the CNOSSOS-EU calculation method they range from 0.7 dB to 25.4 dB. In this case, the same relationship as for the board measurements can be observed. The calculation results obtained using the CNOSSOS-EU method are 3 dB lower than those obtained using the ISO 9613-2 method.

In the case of calculations carried out for a point located on a board (0 m above ground level) using the ISO 9613-2 and CNOSSOS-EU methods, it was noted that for 6 frequency bands for each method, the calculation results were underestimated in relation to the measurement results. In contrast, for the calculation point located at 4 m above ground level for the ISO 9613-2 method, an underestimation of the calculation results was noted for 6 frequency bands, and for the CNOSSOS-EU method, this case was noted for 8 frequency bands.

4. CONCLUSIONS

In this study, the possibility of using ISO 9613-2 and CNOSSOS-EU computational models to predict the ILFN generated by wind turbines was analysed. For this purpose, an accurate geometric-acoustic model of a wind farm operating in central Poland was built in SoundPlan software. The results of the calculations were compared to the actual measurement results recorded at the wind farm in question.

The calculations were carried out for calculation points located 1000 m downstream of the turbine and placed at two different heights above ground level. The first was located on a measuring board and located at ground level (0 m above ground level), while the second was at 4 m above ground level.

The results were analysed in 9-octave bands with centre frequencies from 1 Hz to 250 Hz. In general, it can be concluded that the results obtained from the two calculation models analysed are underestimated in relation to the measurement results. The differences between the calculation results and the measured results (in absolute terms) for the point placed on the board range from 2.9 dB to 11.7 dB and from 0.5 dB to 14.7 dB, for the ISO 9613-2 and CNOSSOS-EU calculation methods respectively. In contrast, for a point placed 4 m above ground level, these differences range from 0.0 dB to 22.4 dB for the ISO 9613-2 method and from 0.7 dB to 25.4 dB for the CNOSSOS-EU method.

These differences may be due to a number of factors. The most important of these may include:

- location of the source at an altitude of 105 m above ground level (according to calculation methods, the maximum height is 30 m),
- the value of the ground factor G used in the calculation, due to the incidence angle of the acoustic wave on the ground,
- the difference between the actual and used for calculations values of the sound absorption coefficients by the ground and the atmosphere (mainly for frequency bands below 63 Hz),
- inability to include wind speed and direction in the model (taken into account indirectly through the value of the turbine sound power level determined at a given wind speed).

It was also noted that the results obtained using the CNOSSOS-EU method are 3 dB lower than those obtained using the ISO 9613-2 method for both analysed calculation point locations.

It is planned to carry out similar analyses for the calculation results obtained using the NORD 2000 model. After these analyses, a calculation method will be indicated, which will be recommended in the Polish legislation for the prediction of ILFN generated by wind turbines at the stage of preparing the report on the environmental impact of the investment.

5. ACKNOWLEDGMENTS

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