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Spectrum analysis of wind turbine noise in Vydmantai

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Wind energy is an auspicious technology which helps to transform today's society to the use of environmental friendly energy. However, sound emissions from wind turbine have been one of the most important challenges in wind energy engineering. As technology has advanced, wind turbines have become quieter, but sound from wind turbines is still an important sitting criterion. In present work efforts have been taken to indentify features of wind plant noise that may be the reasons of public concern. The noise generated by wind plant located near Vydmantai was analyzed. It was shown that although wind plant noise does not exceed recommended noise pressure levels at least at the distances larger than 200 m, however, in some frequency ranges the increase of noise can be distinguished in wind plant noise spectra. Comparison of noise spectra of different environmental noise sources, particularly, comparison with spectra of traffic generated noise shows that intensification of some wind plant noise spectral components may be the reason for public annoyance. The impact of the presence of audible tones in noise to the annoyance relative to the same noise (level) without audible tones is reviewed. It is justified that a penalty of 3–6 dB should be added to the measured sound pressure levels to compensate for the extra annoyance due to the clearly audible in the noise.

Key words: wind plant noise, noise masking, noise assessment, spectra

INTRODUCTION

Wind power plays a continuously increasing role in the ongoing conversion to renewable energy sources. The number of operational wind turbines is rapidly growing. However, wind turbines are by some viewed upon as visual and audible intruders, destroying the landscape scenery and emitting noise [1]. Some studies indicate that annoyance from wind turbine noise occurs to a higher degree at low noise levels than noise annoyance from other sources of community [2]. Most people listening to an unwanted noise of a certain level find the noise more annoying if it contains audible tones. Therefore, spectrum analysis of wind turbine generated noise should be carried out to find out possible features of noise that may have impact to increased public annoyance.

In addition, noises from other sound sources that are located near wind plant are one of such conditions which are not studied well and thoroughly. An example of such noises is traffic noise. Road traffic noise is one of the major environmental concerns of densely populated areas all over the world. The noise of wind plants located near roads with significant traffic can be masked with the noise produced by passing cars [3]. However, the physical properties of noises produced by different sources and masking conditions are not studied in detail.

In present work noise measurements in the vicinity of wind plant located near road are presented. For the measurements wind plant near Vydmantai was chosen which is located near road A11 Šiauliai–Palanga. Noise levels were measured downwind from the wind plant and upright to the road. Spectra of measured noises were analyzed. It is shown that acoustic spectra of wind plant noise as well as traffic noise have pecularities at the different frequency ranges. Because of this the audibility of wind turbine noise cannot be easily masked at short distances from the plant. However, at larger distances wind turbine noise becomes weaker, therefore masking can play an important role increasing acceptance of wind plant.

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THE SPECTRUM OF WIND TURBINE NOISE

Wind turbines generate two types of noise: aerodynamic and mechanical. A turbine sound power is the combined power of both. Aerodynamic noise is generated by the blades passing through the air. The power of aerodynamic noise is related to the ratio of the blade tip speed to wind speed. Manufacturer specs for today's 100 m, 1.5–2 megawatt wind turbines indicate that the "source level" of their noise emissions is generally 98–104 dB [4]. However, this noise source is not at a ground level, it emanates from high above the ground; therefore, it dissipates quickly with a direct, unobstructed path to a very large surrounding area. Therefore, at ground level noise levels exceeding 60 dBA are possible only in the very proximity of wind plant in the direction opposite to the wind.

The sound spectrum of wind turbine loses the high frequency components due to atmospheric absorption, and is dominated by frequencies below 1 000 Hz. At one mile, most of the sound energy is below 200 Hertz. The 160 Hertz octave band was found to be elevated when compared to adjacent bands [5].

In noise assessments, noise levels are usually measured and calculated as A-weighted sound levels or as levels for frequency bands of one- or one-third-octave bandwidth. It is common to add some decibels in penalty to the result if the sound is tonal or impulsive. Although a sound level meter with standardized octave-filter is sufficient for the level measurement, it will in general not be sufficient for judging the tonality [6]. The method is based on the psychoacoustic concept of critical bands, which are bands defined so that tones outside a critical band do not contribute significantly to the audibility of tones inside that critical band. The result of the assessment of each tonal component is a level correction in the range 0 to 6 dB, which shall be added to measured frequency-weighted level.

MEASURING METHODOLOGY

For the comparison of the contribution of environmental masking noises wind plant near Vydmantai was chosen since it is located near the road Šiauliai–Palanga. Enercon E-40 wind power plant is installed at this location. The power of this plant is 630 kW. Tower height is 76 m, wind screw axle at 78 m.

Noise measurements were taken four times at different wind speed. Measurements included the following records: traffic flow evaluation, vehicles per hour, air speed measurement, m/s, and noise measurement, dBA, at different distances from wind plant. For noise measurements analyzer BruelKjaer-2250 was used. Noise levels were measured at the following distances from wind plant, (in m): 0, 50, 100, 200, 300, 400 and three directions: downwind, upwind and upright the road. Wind speed was measured at 1.5 m height with anemometer Amprobe TMA10A for 1 min and the lowest, highest and average values were recorded. Then the wind speed records were recalculated to the "standardized" height of 10 m using the following equation:

$$v = v_{\mathrm{ref}} \ln(z/z_0) / \ln(z_{\mathrm{ref}} / z_0) \quad (1)$$

where v – wind speed at height z above ground level; v_{ref} (v_{min}, v_{max}, v_{ave}) – reference speed, i. e. a wind speed we already know at height z_{ref} = 1.5 m; z – height above ground level for the desired velocity, v; z_0 – roughness length in the current wind direction; z_{ref} – reference height, i. e. the height where we know the exact wind speed v_{ref}. Roughness z_0 was chosen equal to 0.05 since wind plant site is an open agricultural area without fences and hedgerows.

Acoustic spectra were extracted from analyzer BruelKjaer-2250 and transformed with appropriate software for convenient representation of results.

RESULTS

Due to various environmental impacts (e. g. chirp of birds in spring or sound of grasshoppers in summer) measurements of noise produced by wind plant were conducted in different seasons: spring and summer. Summary of environmental conditions is presented in Table 1.

In Figs. 1–2 A-weighted sound pressure levels (SPL) are presented for two cases where acoustic spectra were analyzed: Fig. 1 SPL at the distances upright the road (0 m – wind plant location, 430 m – position of road) and Fig. 2 at the distances upwind. The upwind direction was opposite to the direction to the road in all cases (approximately NW or NE).

Obtained results lead to the following conclusions. It is seen that in all cases that were investigated, wind turbine noise can be taken into account only in the area limited by 200 m from the wind plant (Fig. 1). At larger distances traffic noise is the main factor of noisiness of the environment. Since wind direction (W) points towards the

Table 1. **Summary of measurement details. v corresponds to v_{ref}, v_{10} corresponds to wind at height of 10 meters**

Case	Wind direction	T, °C	v_{min} m/s	v_{max} m/s	v_{ave} m/s	v_{10min} m/s	v_{10max} m/s	v_{10ave} m/s	Traffic flow, Veh / hour
1.	W	28	1.5	2.5	2.0	2.2	3.7	3.0	850
2.	S	21	3.5	5.5	4.5	5.2	8.2	6.7	720
3.	W	23	1.5	2.5	2.0	2.2	3.7	3.0	650
4.	N	17	1.0	2.0	1.5	1.5	3.0	2.2	600

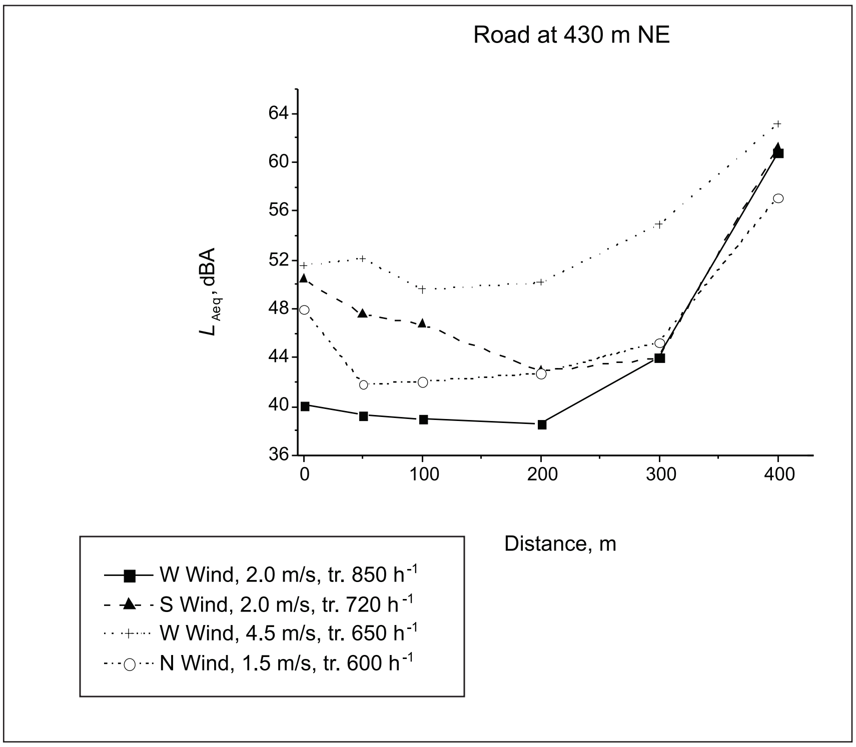

Fig. 1. SPL upright the road: 0 m – wind plant location, 430 m – position of road

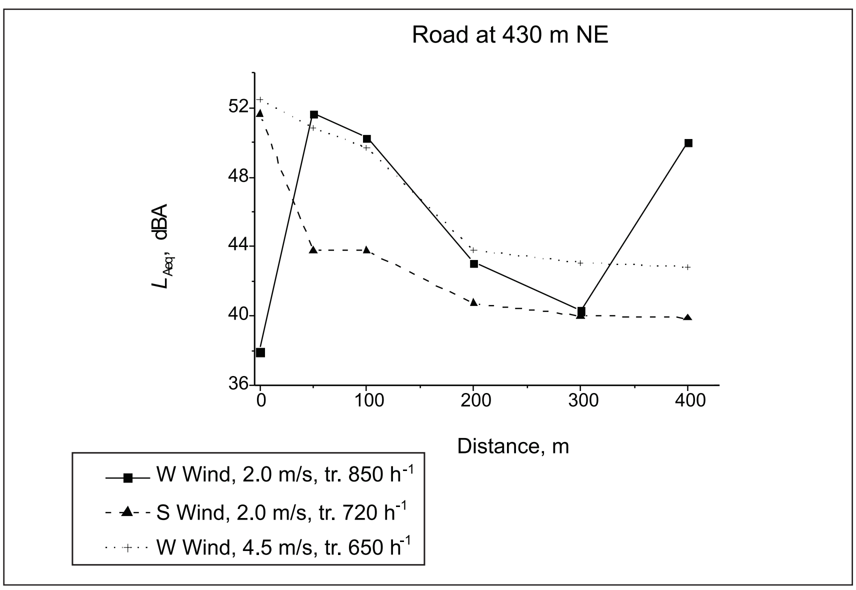

Fig. 2. SPL upwind: 0 m – wind plant location

road (still, not perpendicularly), downwind noise measurements show slight increase in noisiness at distances larger than 200 m.

Upwind noise measurements show that with the increase of distance from wind plant (in adverse direction from the road) SPL decreases to the background level (Fig. 2). It is seen that at a larger wind speed background noise level is larger than at a smaller one. Also, it should be noted that field measurements can largely be affected by environmental factors: unpredictable form of curve in Fig. 2 is due to notable "symphony" of grasshoppers during time of measurement in summer.

To explain some peculiarities of SPL results, spectrum analysis was carried out. The results are presented in Figs. 3–5. It follows from the graphs (Figs. 3–5 a) for all cases) that the noise of wind plant has higher components

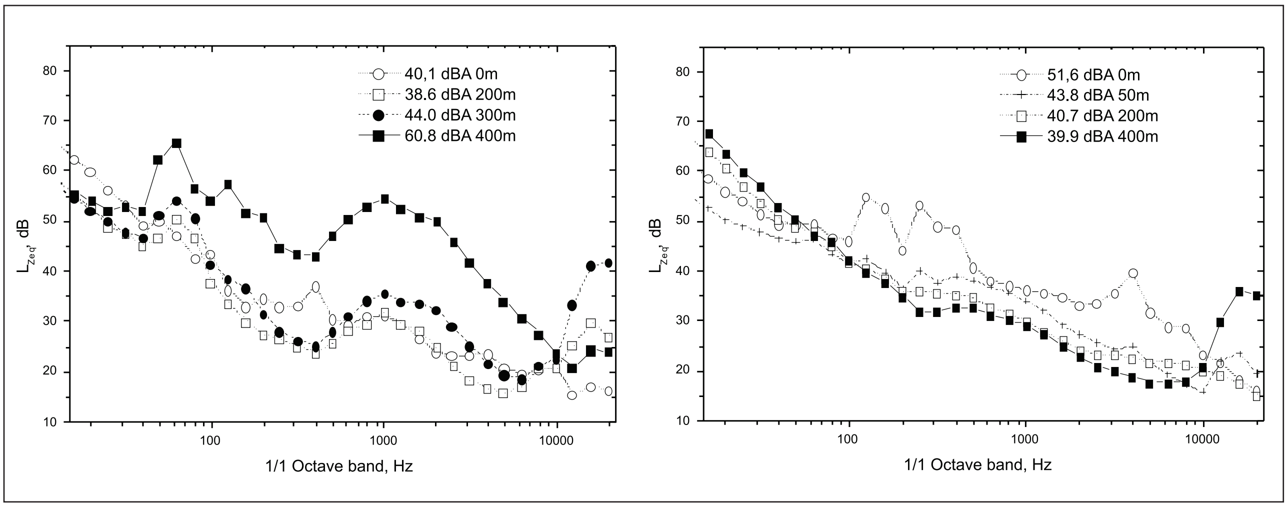

Fig. 3. The changes of noise spectrum with the distance from wind plant: a) upright to the road; b) upwind (opposite to the road) for case 1 (curve with the black square)

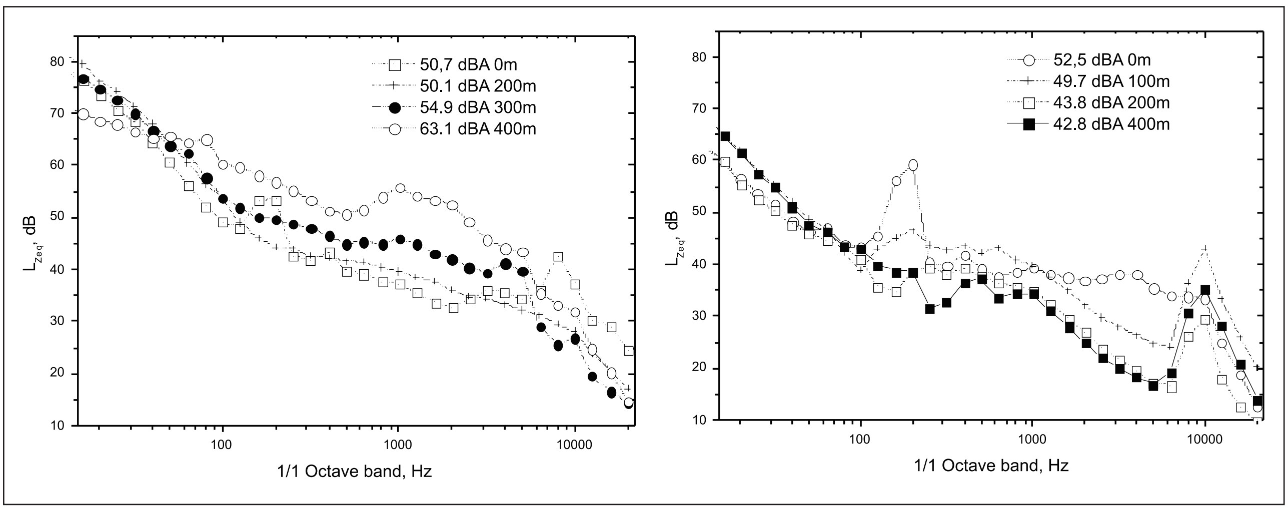

Fig. 4. The changes of noise spectrum with the distance from wind plant: a) upright to the road; b) upwind (opposite to the road) for case 1 (curve with the cross)

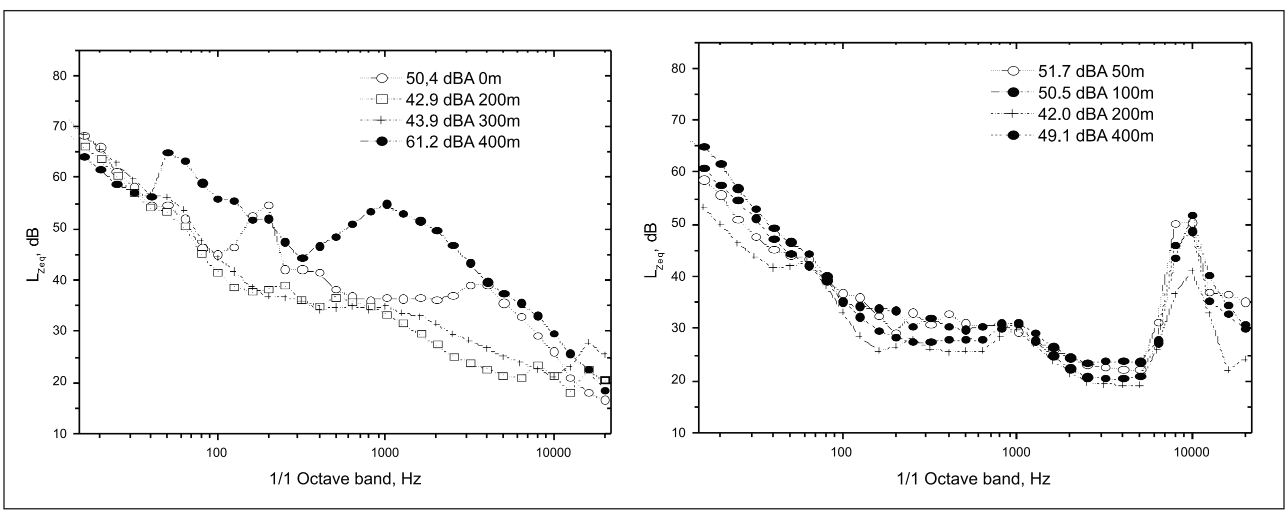

Fig. 5. The changes of noise spectrum with the distance from wind plant: a) upright to the road; b) upwind (opposite to the road) for case 1 (curve with the black triangle)

of low (< 100 Hz) frequency sounds whereas traffic noise has broad maxima at 1 000 Hz. Audibility of wind plant in the presence of traffic noise vanishes at the distances larger than 300 m.

In the opposite direction (upwind, NW, NE), the noise of wind plant decreases at large distances (larger than 200 m) to the background level. Notable, the peak in wind turbine spectrum at high frequencies (4–5 kHz) is caused by the bird chirp which was very intense in springtime when measurements were taken. At higher frequencies (>10 kHz) the increase of sound intensities is caused by the grasshopper chirp which was very intense in summertime when measurements were taken. However, these sounds are at very high frequencies and therefore cannot mask effectively wind plant noise.

DISCUSSION

Remote places with low population density were considered suitable locations for wind plants, but long distances to the existing power grid are costly. Also, remote places often are otherwise unspoiled landscapes with high values for recreation and tourism that could decrease with the construction of a wind plant.

Suitable places for wind plants are therefore more often sought after also in populated areas. It seems reasonably plausible that high levels of background sound can reduce annoyance by masking the noise from a wind plant, because the annoying sound physically cannot be heard [3]. It follows that wind plants could cause less noise annoyance when placed next to a motorway instead of a quiet agricultural area. One modern 2–3 MW turbine at high speed produces a sound power level (105–108 dBA) that is approximately equal to a car on a motorway [7].

Present study shows that road traffic can indeed mask wind turbine sound, but it is not yet clear to what extent. Amplitude modulations in a sound are more easily detected by the human ear than a constant sound. Masking will also depend on the spectral distribution of the masking sound relative to the masked sound. Wind turbine and road traffic sounds are not very different in this respect as both have high levels of sound at roughly 1–2 kHz (due to trailing edge and tire noise, respectively) at close distance and high levels at low frequencies due to inflow turbulent sound and engine sound.

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VYDMANTŲ VĖJO ELEKTRINĖS KELIAMO TRIUKŠMO SPEKTRINĖ ANALIZĖ

Santrauka

Dabartinei visuomenei vėjo elektrinės suteikia galimybę gauti energiją neteršiant aplinkos, tačiau jų skleidžiamas triukšmas tapo viena svarbiausių problemų. Technologijoms patobulėjus vėjo elektrinės tapo tylesnės, tačiau vis dar domimasi skleidžiamu triukšmu. Pasirinkus vėjo elektrinę Vydmantuose, šiame darbe bandoma išsiaiškinti tas jos triukšmo savybes, kurios gali būti visuomenės nepasitenkinimo priežastimi. Matavimų rezultatai rodo, kad vėjo elektrinės keliamas triukšmas neviršija leistinų normų esant 200 metrų atstumu nuo jos ir priklausomai nuo vėjo krypties 200–300 metrų atstumu nuo vėjo elektrinės pasiekia aplinkos triukšmo lygį. Tačiau analizuojant triukšmo spektrą, ypač žemo dažnio diapazone, vėjo elektrinė, lyginant su važiuojančio transporto skleidžiamu triukšmu, gali būti erzinančio triukšmo priežastimi. Apžvelgus girdimų ir negirdimų tonų spektrus, galima patvirtinti, jog norint užmaskuoti girdimą triukšmą kitu garsu, reikalingas 3–6 dB didesnis garsas.

Raktažodžiai: vėjo elektrinės triukšmas, triukšmo maskavimas, triukšmo įvertinimas, spektras