Wind turbine noise – a pilot study in India

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In the context of achieving a national set target of 60 GW by 2022, a study was carried out in Kayathar, Tuticorin district, Tamil Nadu, India on noise propagation from wind turbines. Acoustic and non-acoustic parameters were measured according to IEC 61400-11 at wind speeds of 4–13 and 0.7–8.6 m/s. The onsite measurements were compared with ISO 9613-2; this showed a difference of ± 5 dB(A) for every increment in the distance. An equation was derived to obtain sound pressure level (dB(A)) at the base of the tower for wind turbines at varying distance of measurement.

Keywords: Acoustic and non-acoustic parameters, noise propagation, sound pressure level, wind turbine.

INDIA ranks fifth in wind power global capacity. According to the Ministry of New and Renewable Energy, Government of India (GoI) with an installed capacity of 23.44 GW (March 2015) of wind energy, renewable energy sources (excluding large hydro) currently account for over 14% of India's overall installed power capacity of 228 GW. Wind energy holds 67% among all renewables and continues to be largest supplier of clean energy[1–3]. Though wind energy is considered as a techno-economically mature energy, it is not entirely free from impacts of noise which is encountered in the wind farms.

Wind turbine noise is due to a combination of both mechanical and aerodynamic operations. In general, mechanical noise is caused due to the interaction of the internal gears of the turbine, mechanical and electrical parts. Aerodynamic noise is caused by blades passing through air; it is generally broadband in nature, which can have a swishing character[4,5].

Generally, the level of noise and its diffusion are influenced by the type of terrain and meteorological conditions of the respective site. Sound from wind turbine noise can either be reduced or enhanced depending on certain factors such as area type (i.e. rural or urban), domiciles residing near the wind farms and type of community affected such as residents, industrial, tourists, etc.[6–8]. Different acoustic properties not fully described by the equivalent A-weighted level can also be related to perception and annoyance characteristic of wind turbine in operating condition. This hypothesis was supported by Persson Waye and Agge[9]. It was found that differences in perception and annoyance were due to the presence of sound characteristics such as lapping, swishing and whistling.

The perception of wind turbine noise could be covered by wind generated noise. However, even if wind speed and background noise level are low, the wind turbines will have a constant or variable rotor speed which results in steady-state noise emission[10]. In this article we evaluate a set of real-field noise measurements and modelled results acquired from three wind turbines of different installed capacity, make, height, rotor diameter and year commissioned (ageing of the turbine), located in the flat terrain.

Generally, there is a complex propagation path and additional noise sources that interfere between the source of acoustical noise (wind turbines) and receptor of acoustical signal (surrounding area). Thus, to get a clear picture on noise propagation from wind turbines, sound pressure level (SPL) from the source and receptor has been compared with background SPL[11,12].

Emphasis was given to obtain an accurate and reliable experimental procedure according to IEC 61400:11 2002-12 acoustic noise measurement technique; and also on the estimation of the real-field noise impact of existing wind turbines disassociated from the background noise for several wind speed values, in both high and moderate wind seasons. Finally wind turbine noise emission was predicted at varying distances of measurement by comparing the simulated results derived by the application module of standard software tool ISO 9613-2 with the available onsite measurements. At present time, there are no international standards or regulations for wind turbines. Though Europe and USA follow fixed noise limits, in most countries noise regulations define probable upper limits for the noise to which people may be exposed. These limits depend on the country and may be different for day and night-time[13]. In India, the Ministry of Environment, Forest and Climate Change, GoI has issued a notification on 'The Noise Pollution (Regulation and Control) Rules, 2000' stating the noise limits (dB(A) Leq) with respect to daytime and night-time for various categories of area/zone (industrial, commercial, residential and silence zone). However, no specific characterization and control levels of wind turbine noise in the habitat are provided, since noise emanates from different sources[14]. The present study also compares the simulation results with real acoustic noise emission measurements, to obtain the accuracy of wind turbine noise prediction models.

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Site description and noise measurement survey

Emphasizing the studies on noise survey carried out all over the world, the present study focuses on noise propagation in India. For this we used wind turbines located at Kayathar, Tuticorin district, Tamil Nadu, in a flat terrain at 92 m amsl (Figure 1).

The terrain is flat and gently sloping from the turbine location towards the western direction. The surroundings include type of terrain, soil, reflecting surfaces and non-acoustic parameters, viz. mean wind speed, temperature and pressure for three wind turbines (200 kW, 600 kW, 2 MW; Figure 2). The following wind turbine types were used in the study:

1. Model-1 (M1): 200 kW, stall regulated, 18 years old, constant speed with asynchronous generator wind turbine.

Figure 1. Location map of the study area.

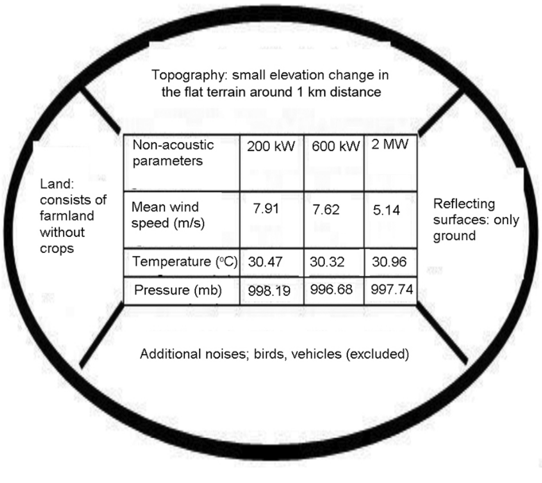

Figure 2. Description of the site surroundings.

2. Model-2 (M2): 600 kW, pitch regulated, 7 years old, constant speed with asynchronous generator wind turbine.
3. Model-3 (M3): 2 MW, pitch regulated, variable speed with synchronous generator wind turbine.

Methodology

The wind turbine acoustical measurement procedure adopted during high and moderate wind seasons is described in the following.

Noise measurement test procedures from wind turbines at the noise receptor location were conducted according to IEC 61400-11. Prerequisite preparation of the site included cleaning and marking, foundation, installation of weather monitoring tower, fixation of data-logger (NRG, USA) and respective sensors (NRG, USA) as shown in Figure 3.

The anemometer (to measure wind speed), wind vane (to measure direction), thermistor (to measure temperature) and barometer (to measure pressure) were placed before the wind turbine at a height of 10 m above ground level and at a distance greater than two (2*D*) and less than four times (4*D*) the diameter (*D*) of the wind turbine rotor[15]. Using the measurement procedure and methodology guided by the standard[15], measurements of wind speed and noise level at the wind turbine site were made. Non-acoustical measurements, viz. local meteorological conditions (wind speed, temperature and pressure) were recorded using the data-logger. Based on the wind turbine dimension, the measurement points were selected along a side with the distances in a radial direction. This can be seen in Figure 4 and Table 1 according to the standard where the horizontal distance (R_0) between the measurement point and tower of the wind turbine is recommended to be equal to the hub height (*H*) plus half the diameter (*D*) of the rotor, i.e. ($R_0 = H + (D/2)$) with a tolerance of ±20%. The inclination angle ϕ between the measurement point and hub height is determined to be in the range 25–40° and direction of downwind measurement point ±15° of the wind turbine[16].

Acoustical measurements were carried out in the downwind direction under two stages for the three wind turbines, i.e. when the wind turbines are in 'on condition' (operating phase) and 'off condition' (parked phase), i.e. immediately after the wind turbines are stopped. In this way ambient background noise is accounted for the same weather conditions. Wind speed at 10 m from the ground is generally recommended to be around 8 m/s for an average of 1 min. Table 1 provides details on the installed capacity, make, hub height, rotor diameter, reference distance and mast height for the three wind turbines.

One of the problems while measuring noise emission from wind turbines is the influence of background noise from the microphone, surrounding vegetation, transportation and habitual activities. Such background noise was measured at the site under turbine 'off condition'[17,18].

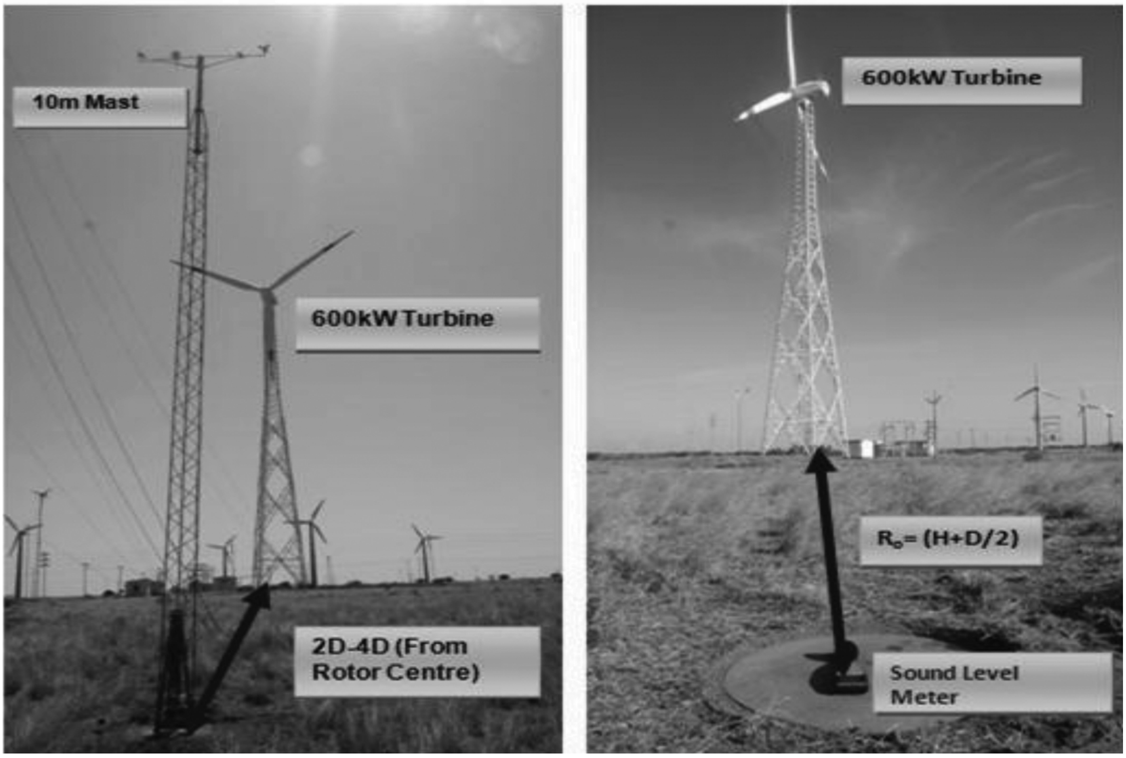

Figure 3. Onsite measurement settings according to IEC 61400-11.

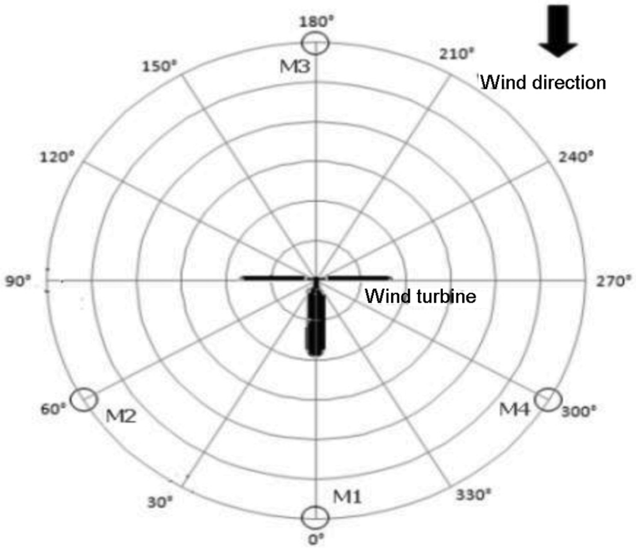

Figure 4. Study area – measurement points.

Table 1. Wind turbine noise measurements

Capacity	200 kW	600 kW	2 MW
Model no.	1	2	3
Hub height (H, in m)	30	75	80
Diameter of rotor (D, in m)	24	52	82
Reference distance (R_o, in m)	42	101	121
Mast range b/w 2D–4D (m)	48–96	104–208	164–328

All sensors and instruments of the acoustic and non-acoustic measurement equipment (Appendix 1) were calibrated according to national and international standards.

Results and discussion

Wind turbine noise studies during high and moderate wind seasons

By applying the methodology according to IEC 61400-11 as discussed earlier in the article noise, measurements for different wind turbines were obtained under varying wind speeds, i.e. during high (4–13 m/s) and moderate wind (0.6–8.6 m/s) seasons. An analysis of the results obtained with the wind turbines in operation provides the recorded sound power level (L_w) and SPL.

As analysed by Dawson and Mackenzie[19], noise regulations of a wind farm stipulate wind speed dependent criteria which is referenced to wind speed at hub height of the turbines, i.e. wind turbines generate higher noise level under the assumption of high wind speed conditions, thereby making noise level at nearby receivers. Figure 5 shows that the sound pressure level (58.02, 58.38 and 58.64 dB(A)) measured for the three wind turbines (2 MW, 600 kW and 200 kW) increases as the wind speed (4–13 m/s) increases in the high wind season.

According to the measured data, maximum SPL obtained for three wind turbines M1 – 200 kW, M2 – 600 kW and M3 – 2 MW during high wind season was 61.21, 63.42

and 66.73 dB(A). While minimum SPL was 57.42, 53.18 and 50.94 dB(A) respectively. Among the three wind turbines, stall regulated wind turbine (M1-200 kW) showed maximum noise emission. Under moderate wind season, SPL measured for M3-2 MW was 55.10 dB(A) at wind speed range (0.9–8.6 m/s), whereas there was no significant value from wind turbines M1-200 kW and M2-600 kW because of low wind speed perceived during the season. Figure 6 shows the scatter of noise data and background data measured at downwind direction for the three wind turbines. Scatter of noise data and background data was recorded for M1, M2, and M3 during high wind season (101, 212, 72) and moderate wind season (62, 193, 59).

Noise measurements for the operating wind turbine (background noise) were correlated with background noise measurements at standardized wind speeds according to IEC 61400-11. The noise measurements made for 30 data pairs of equivalent continuous SPL at the respective reference positions were then corrected for background noise using the following equation

$$L_{\mathrm{s}} = 10 \log[10^{(0.1 L_{\mathrm{s+n}})} - 10^{(0.1 L_{\mathrm{n}})}], \quad (1)$$

where L_{s} is the equivalent continuous SPL (dB) of the wind turbine operating alone, $L_{\mathrm{s+n}}$ the equivalent continuous SPL (dB) of wind turbine plus background noise, and L_{n} is the equivalent continuous SPL (dB) of the background noise.

Figure 5 shows the apparent sound power level, maximum and minimum wind turbine SPL and background noise level for the three wind turbines.

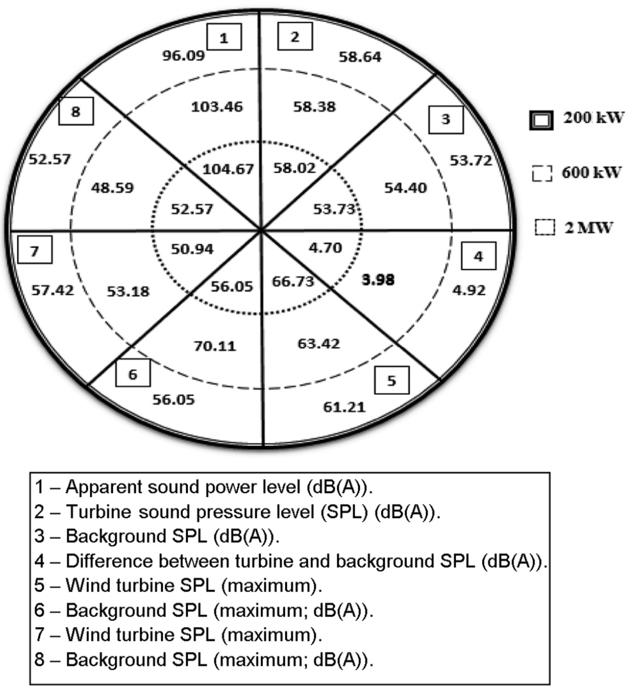

Figure 5. Noise level measurements of three wind turbines.

The SPL measurement data obtained for three wind turbines during both high and moderate wind seasons were corrected for background noise using eq. (1). At downwind direction, the background noise for the three model wind turbines at distinct wind speeds showed difference in the range 3.98–4.92 dB(A), which is less than 6 dB(A) but more than 3 dB(A) compared to the background level. $L_{\mathrm{s+n}}$ was corrected by subtraction of 1.3 dB(A), but according to standard IEC 61400-11, the corrected data were not used for the apparent sound power level or directivity[20–22].

Propagation of noise from wind turbine

For assessing the noise propagation from wind turbines, an atmospheric propagation model was used to derive the expected noise level in the surroundings from the sound power level at the wind turbine at varying distances. The noise prediction software WindPRO–DECIBEL can carry out calculation based on eight models. Model ISO 9613-2 is a general and internationally accepted tool to estimate far-field noise levels under conditions favourable to the propagation of noise with respect to performance and the project planning stage[23–25]. The WindPRO module DECIBEL for noise impact calculations is based on noise emission data at 10 m height or at hub height of the wind turbine[26]. The feasible distance for dwelling or residential location from the wind turbine can be calculated using this module. In this context, necessary settings are required as shown in Figure 7. Then, by the terrain conditions, roughness of the area, potential obstacles and other meteorological conditions, noise generated by the wind turbines at the ground or at a specific height was found at varying distances and wind speed.

Comparison between onsite noise level measurements and modelled results

Figure 8 presents a comparison between measured and model output (o/p) of noise levels with varying distances, recorded at wind speed range from 4 to 13 m/s during high wind season. The intensity of noise from turbine depends on the distance between the source and the point. As expected, when the distance between the source and the receiver increases, SPL decreases. At this point, the noise level of the three wind turbines which may be perceived by a receptor was measured with varying distances away from the respective turbine. Propagation path is another factor deciding noise intensity. Thus, in case of flat terrain assuming a hemispherical path for noise propagation without obstructions, SPL at a distance R from a wind turbine radiating noise at an intensity of L_{w} is obtained as

$$L_{\mathrm{p}} = L_{\mathrm{w}} - 10 \log(2\pi R^2) - \alpha R, \quad (2)$$

where L_{p} is sound pressure level (dB(A)), L_{w} the sound power level (dB(A)), R the distance between source and

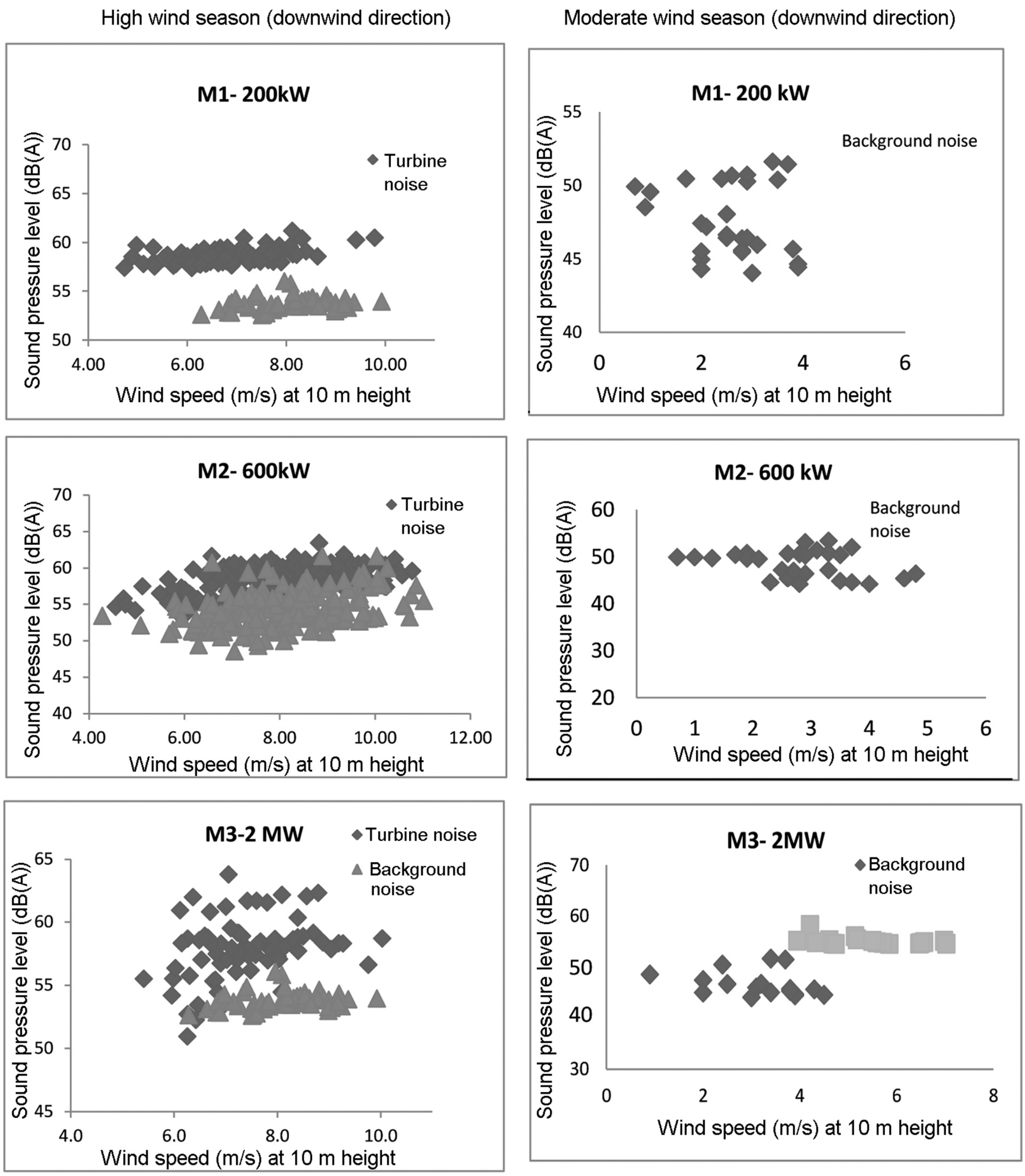

Figure 6. Wind turbine noise studies – high and moderate wind seasons (200 kW, 600 kW and 2 MW).

receiver (m), and α is the absorption coefficient, 0.005 dB(A)/m.

Figure 8 presents a comparative graph showing modelled and measured SPL at wind speed range from 4 to 13 m/s (high wind season). For the three wind turbines, initial distance of measurement was taken according to the standard. SPL recorded for M1, M2, M3 was 59 dB(A) at 42 m, 58 dB(A) at 101 m and 58 dB(A) at 121 m respectively. Using the software WindPRO-DECIBEL close proximity distances for measurement of noise emission were found for all the three wind turbines. Further, using eq. (2), SPL for the above-mentioned wind turbines was calculated for the respective distances obtained from the software. The measured and model SPL values for M1, M2 and M3 were 35 dB(A) at 425 m, 36 and 35 dB(A) at 630 m, and 32 and 35 dB(A) at 840 m respectively. This shows fairly good agreement between the measured (in the study area) and modelled data (using relevant software WindPRO module DECIBEL–ISO 9613-2 general international standard) at varying distances and the respective wind speeds. The results of the ISO model indicate wind speed range between 4 and 13 m/s with a difference of ±5 dB(A) for every consecutive increment in distance formulated, as mentioned earlier. This variation may be due to local meteorological effects around the study area.

Figure 9 shows the decay constant (β) for both measured and model o/p derived for the three wind turbines, at varying distances of measurement. In is obtained by dividing the measured/model sound pressure level to the respective distance. It ranged between 0.04 and 0.79 dB(A)/m. For wind turbines of varying installed capacity, i.e. M1 – 200 kW, M2 – 600 kW, M3 – 2 MW, with increase in their hub height-of 30, 75 and 80 m at the respective distance of measurement 70, 100 and 140 m, there was a gradual decrement in decay constant with respect to the above-mentioned conditions (0.75, 0.55 and 0.36 dB(A)/m)).

Alternatively, by measurement and model o/p fitting a simple exponential decay equation can be evolved in the form as

$$L_{\mathrm{p}}(x) = Lpk \cdot \mathrm{e}^{-\beta x}, \tag{3}$$

where $L_{\mathrm{p}}(x)$ is SPL(dB(A)) at the respective distance (m), Lpk SPL at the base of the tower (dB(A)), β the

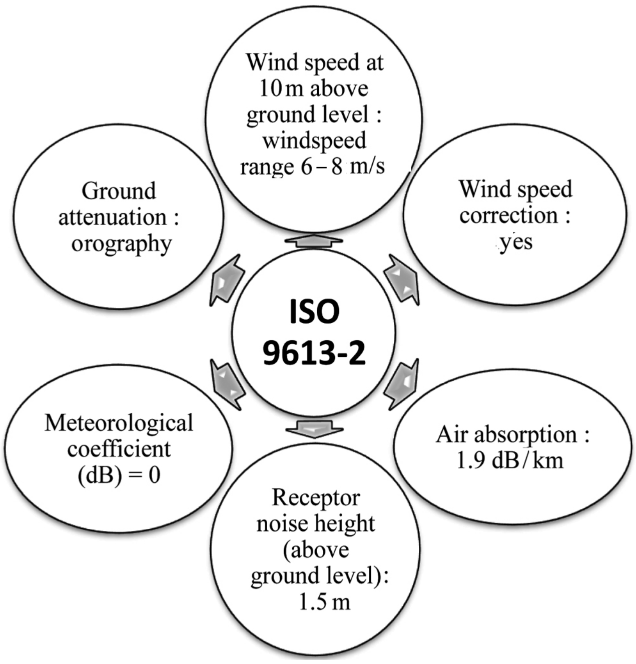

Figure 7. Settings of software tool.

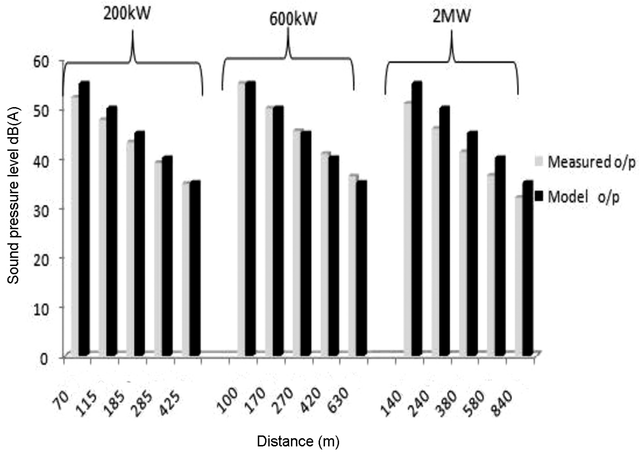

Figure 8. Comparison of wind turbine noise propagation (M1 – 200 kW, M2 – 600 kW and M3 – 2 MW capacity machines).

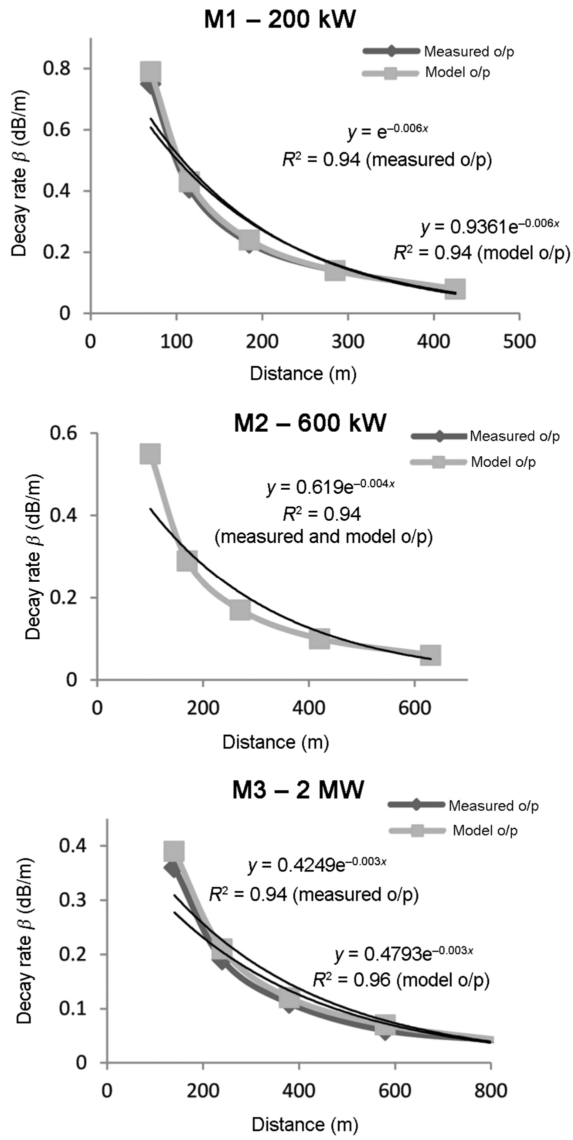

Figure 9. Decay rate for measured and model output for M1 – 200 kW, M2 – 600 kW and M3 – 2 MW.

Appendix 1. Instruments of acoustic and non-acoustic measurements

Anemometer (NRG #40C, USA)	Type: Three-cup anemometer, accuracy: ±0.1 m/s. Output signal: alternate signal or frequency pulse train.
Wind vane (NRG, USA)	Dead-band maximum 8°. Output signal: analog voltage equivalent to the angular position of the instrument.
Thermistor (NRG, USA)	Accuracy: ±1°C. Measurement range 0–45°C. Output signal: optical indication.
Barometer (NRG, USA)	Accuracy: ±10 mbar. Measurement range 850–1100 mbar. Output signal: optical indication.
Audio calibrator (Bruel & Kjaer)	According to IEC 60942. Sound pressure level: 94 dB.
Microphone (Bruel & Kjaer)	IEC 60804 microphone with diameter not greater than 13 mm.
Acoustic sound-level meter (Bruel & Kjaer)	Analysis according to IEC 60651:1979 noise-level meter and 60804 class 1.

decay rate (dB(A)/m), and x is the distance of measurement (m).

SPL at the base of the tower can be obtained at varying distances using eq. (3). For example, for M1 – 200 kW at a distance of 70 m, the measured SPL and derived β were 52.2 dB(A) and 0.75 respectively. Thus, SPL at the base of the tower at the respective distance obtained using eq. (3) was 56.45 dB(A). Similarly, Lpk can be derived for the different wind turbines at varying distances of measurement.

Conclusion

This pilot study in India pertains to estimation of noise measurements due to the operation of wind farms located in a flat terrain. Comprehensive onsite measurements were carried out at different measuring points, where the distance was derived from the standards for the most prevalent wind speed range in the area. Special emphasis was given to evaluation of noise level at varying measuring distances and the existing background noise. SPL was derived by the 'on operation' status of wind turbine and background noise was determined on the basis of measurements during the 'off condition' of the wind turbine. It should be mentioned that noise under the same wind speed conditions for both seasons, i.e. high wind season at wind speed 4–13 m/s and moderate season at wind speed 0.7–8.6 m/s for the three wind turbines indicated an uncertainty range of ±5 dB(A) as the distance of measurement increased. It should be noted at this point that there was no SPL recorded for 600 kW and 200 kW wind turbines, since wind speed was relatively low. Hence, according to the results obtained, SPL increases with increase in wind speed and decreases when the distance of measurement increases. We also derived an equation to obtain SPL at the base of the tower for the different wind turbines at varying distances with the measured or model SPL and the respective decay rate.

Nevertheless, to attain a clear trend of noise propagation from wind turbines, the ongoing work will be continued at greater wind speed variation range as well as multiple reference points of measurement during day and night for high and moderate wind seasons. Finally, the availability of detailed onsite measurements with respect to acoustical and non-acoustical parameters in flat terrain allows for comparisons to be made with modelled results at varying distances. The study shows a fairly good agreement between experimental and modelled results with incremental validation of the prediction models.

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