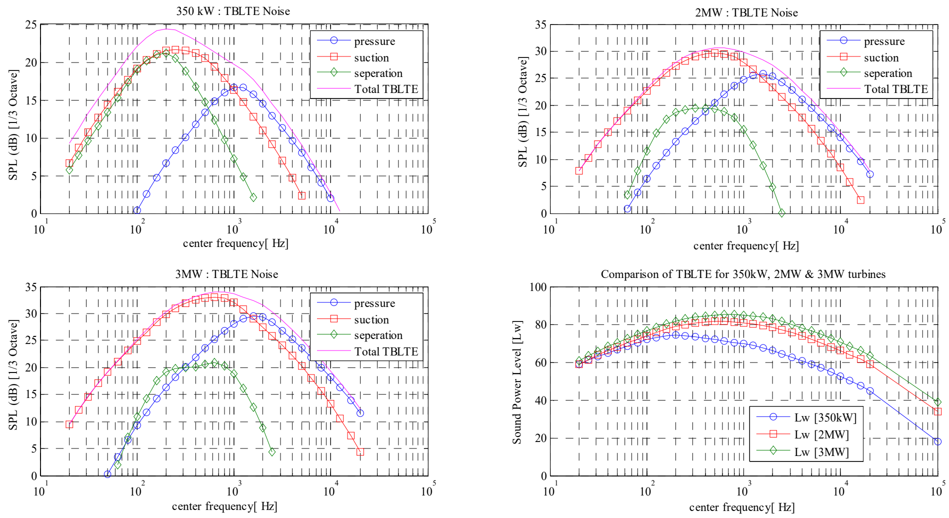

Figure 6: 1/3 Octave band; TBLTE Sound pressure & power levels for 350kW, 2MW, 3MW turbines

The geometric spreading describes about the attenuation of sound levels [7] and characterized with spherical and cylindrical propagation. Sound intensity refers to average amount of sound energy transmitted per unit time through a unit area in a specified direction. The sound levels tend to decrease with doubling distance. In case of spherical, it is ~6B and occurs rapidly with a higher attenuation, while for the cylindrical spreading; it is ~3dB per doubling distance and usually occurs in downwind direction and for distances greater than 750m from the source (Hubbard & Shepherd, 1991) [13]. They are often coupled with low level jet where the wind speed ranging from 10-20m/s.

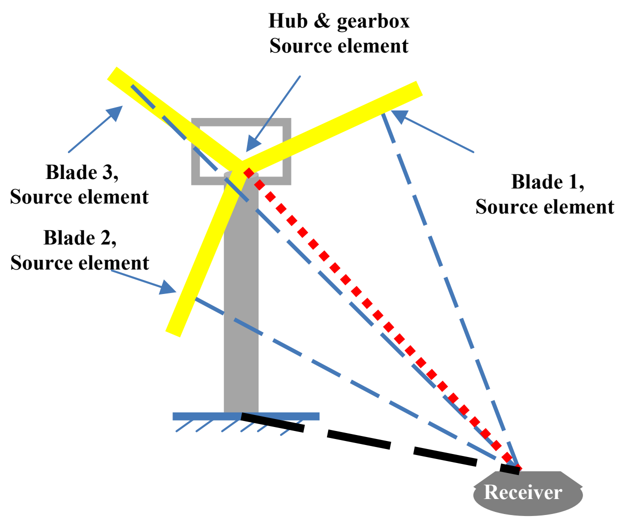

Figure 7 Schematic diagram of perceived acoustic source levels from a wind turbine in open space

The fig 8 shows the sound characteristic as perceived acoustic level from a receiver located at a height above the ground. The ground surface roughness is important to analyze the sound propagation in the atmosphere and resulting wind shear due to velocity gradients. Further, atmospheric conditions such as the temperature, wind speed and size of obstacles also influence the sound rays to travel in all directions. It is observed that the sound rays diverge in upward direction for upwind conditions while the waves deflect downward in downwind conditions and treated as point source for distances less than 750m [13].

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Table 2: Summary SPL data for 3 machines

Sound pressure level (dB) [1/3 Octave]				
Machine	**Observer Distance, m**			**Receiver position, downwind, m**
	80	**140**	**200**	
350kW	34.27	29.12	23.45	5
2 MW	40.93	35.19	29.86	5
3 MW	44.10	38.81	33.44	5

The rotating blade source elements form an integral part of the aerodynamic noise in particular from the trailing edge of airfoil. The sound power level from total turbulent boundary layer trailing edge source is compared with theoretical approximation as shown in fig 9 for three machines. The geometric divergence from a rotating blade source at 90 deg observer position for 50%, 75 % & 95 % of normalized blade radius are compared and found to be higher for mid span blade section than towards the tip of blade. The reduction in the sound pressure level for distances is of order, ~5-6dB per doubling distance which indicates the spherical spreading for distances less than 750m and upwind direction. Further, the attenuation of sound pressure levels with distance is based on the atmospheric absorption reaching the shadow zone. The attenuation is used to estimate the magnitude of transmission loss which prevails higher in shadow zones and dependent on frequency. The assumed distances at which the receiver is located from the turbines are 80m initially. Later the sound pressure levels are also compared for only one machine, 2MW at different distances of receiver position. The attenuation of sound pressure levels is dependent upon the ground effect where the source is located. It is modeled according to the wind shear exponent for terrain class assumed as presented in table 3.

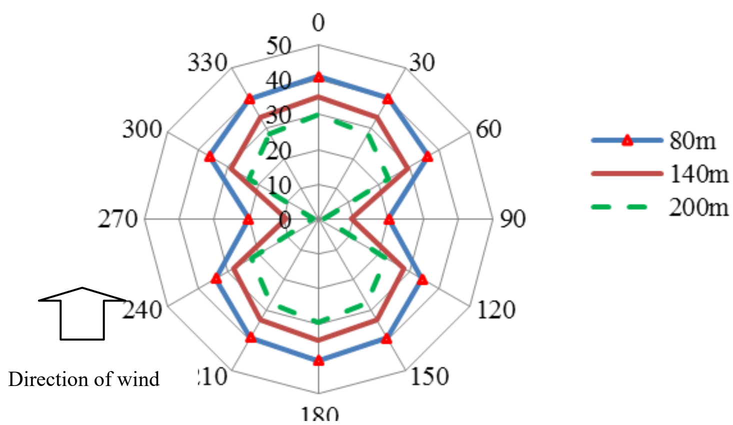

Figure 8 Attenuation of sound pressure level [dB] with distance for 2MW machine

Table 3: Assumptions for atmospheric variables

Parameter	**350kW**	**2 MW**	**3 MW**
Wind shear	0.18	0.13	0.1
Wind speed	8 m/s	8 m/s	8 m/s
Terrain type	Plain land ; Dwellings,	Light vegetation	Near a coast

The sound intensity is calculated using the inverse square law, $I = I_0\left(\frac{r_0^2}{r^2}\right)$ [3, 8] where I_0 is the acoustic source level at reference, r_0 is taken to be 1m, r is distance between the source and receiver position. The theoretical approximation of sound power level as function of turbine size is given by relation

$$LwA = 11.\log_{10}\left(\frac{RatedPower}{MW}\right) + 101.1 \ \ dB$$ [7, 9]

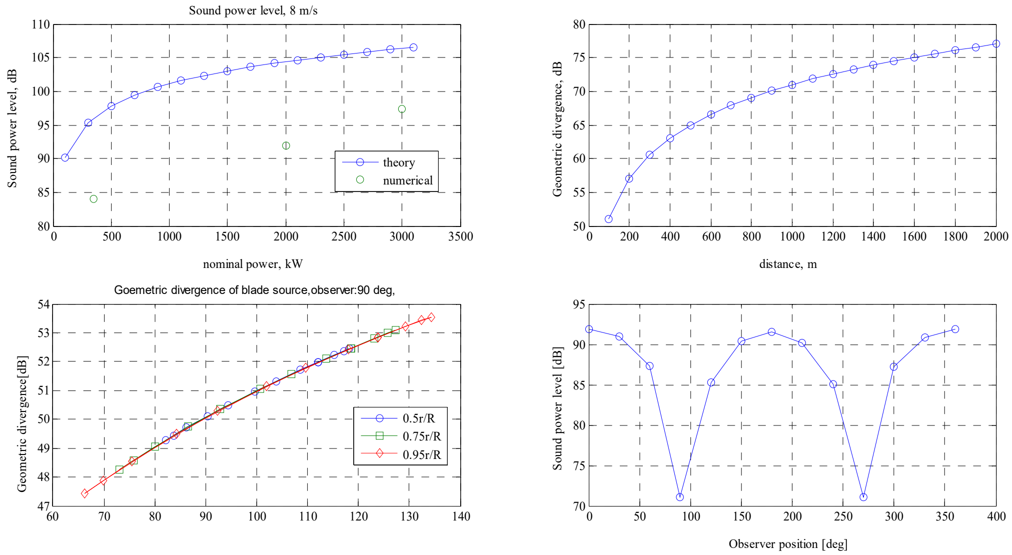

Figure 9: Comparison of Sound power levels & Geometric divergence, dB

V. CONCLUSIONS

The turbulent boundary layer developed due to the trailing edge as noise source mechanism was studied in order to predict the aerodynamic noise radiated for different frequency range components. Trailing edge noise from blade airfoils was found to be dominant at high frequencies only and magnitude of sound pressure levels depend on the angle of attack definitions. The directivity of sound, boundary layer properties and distance between the source and receiver are essential to evaluate the sound pressure levels at different perceived observer positions. The noise intensity is found to decrease higher in cross wind direction of the rotor plane rather than upwind and downwind directions. The model described is applicable to all wind turbines regardless of its size. At low frequencies the separation stall noise is found to be as significant as suction side noise radiation from blades of smaller turbines compared to large MW size turbines. Sound waves are assumed to propagate in atmosphere like optic rays and influenced by the atmospheric conditions. They act as point source or line source depending upon the distance between the source and receiver and the upwind or downwind calculated values.

VI. NOMENCLATURE

SPL – Sound Pressure Level
dB – Decibel
Lw – Sound Power Level
LwA – A weighted
BPM – Brooks, Pope, Marcolini

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