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Validation of WindPRO implementation of Nord2000 for low frequency wind turbine noise

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Abstract

When a wind turbine park is designed reliable data for noise emission is important together with precise prediction models and software calculation tools. With a prediction model such as Nord2000 wind farms can be optimized with regard to noise and produced power. The Nord2000 model calculates the noise propagation from a wind turbine park by taking into account the terrain in detail together with the most important meteorological parameters. The Nord2000 model was originally developed in partnership between DELTA (DK), Sinteff (NO) and Statens Provningsanstalt (SE). The Nord2000 wind turbine model has been implemented in WindPRO and validated for both flat and non-flat terrain in the "Noise and energy optimization of wind farms" project. The project however focused on frequencies from 100 Hz and up. The focus for this paper will primarily be validation of the Nord2000 implementation in WindPRO for frequencies in the low frequency area for wind turbines situated in non-flat terrain.

1. Introduction

The NORD2000 model was created by a project called "Nordic Environmental Noise Prediction Methods" with participants from DELTA (DK), Sinteff (NO) and SP (SE). The overall aim was to work out prediction methods for various types of environmental noise sources, such as road and railway traffic, industrial plants and wind turbines [1]. More information about the model can be found in [3], [4] and [5]. Other prediction methods like ISO 9613-2 and General Prediction Method for Industry Noise are designed for low wind and downwind situations. It is also known that they are not performing well for high sources like wind turbines.

In 2007 work started on validation of the NORD2000 model for wind turbines and integration into WindPRO. A validation study was at the time performed with loudspeaker tests on flat terrain at the Høvsøre test site and with both loudspeakers and actual wind turbines at a non-flat terrain at Hitra in Norway [2]. The reason for using loudspeakers was that the uncertainty is relatively small, because the source is small and well known. The loudspeaker used did however not generate enough acoustic energy at low frequencies to make reliable

measurements in the low frequency area. Figure 1 shows predicted and measured noise spectra for two positions from the project.

The validation was successful in the normal frequency domain (100 Hz and up) and NORD2000 was successfully implemented in the commercial WindPRO software package. Currently the model is commercially available and is being tested and used by leading players. Furthermore the Danish guidelines from the Environmental Protection Agency dictate the use of the Nord2000 model for prediction of noise from roads and railways.

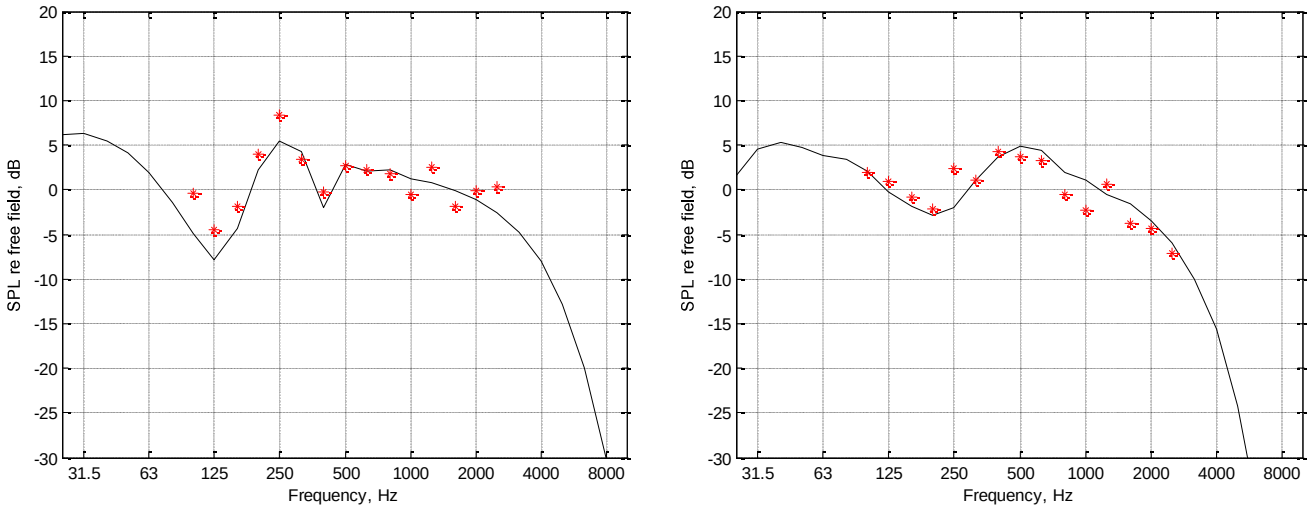

Figure 1 Predicted and measured noise spectra at position 1 (left) and 2 (right) at receiver height 2 m “Noise and energy optimization of wind farms” project [2]. The measured values are shown with red stars where the predicted values are shown with a full line.

Meanwhile low frequency noise has come up as an issue along with a demand for calculation tools and methods to predict the low frequency noise. Denmark has already implemented a noise code for low frequency noise [7], but few other countries have come this far.

As the NORD2000 model already includes more terrain and climatic elements than most models and performed well on the normal frequencies it is tempting to test if it will also perform well on the low frequency area.

2. Validation

2.1 Site

For the validation a site in non-flat terrain with more than 40 wind turbines was selected. The site is an island with very few other noise sources and little vegetation. Noise measurements were performed for three positions and for different wind speeds. Photos of two of the measurement positions are shown in figure 2 and 3. Hub height at the selected site is 70 m above ground. The distance between turbines and the measurements / calculation points is between 2 and 8 km.

2.1 Sound power measurements

Sound power measurements were performed on two turbines at the site for a large number of wind speeds. The first wind turbine was chosen at the upwind side of the wind farm and the second wind turbine was chosen at the downwind side of the wind farm.

It is presupposed that the noise radiated from the wind turbines is the same in all directions.

Figure 2 Photo of measurement position 2 in the direction of the wind farm. The wind farm can be seen along the horizon in the background

Figure 3 Photo of measurement position 3 in the direction of the wind farm. The wind farm can be seen in the background

2.2 Implementation

The noise from the wind farm has been predicted for each of the three measurement points using the Nord2000 implementation in WindPRO 2.9 [9].

In WindPRO the wind farm layout is introduced and all turbines are equipped with one of the measured source noise spectra.

All three measurement points are located to the east of the wind farm in varying distance (table 1) and these are introduced into the WindPRO project. The observation height was 1.7 m.

Measurement point	Distance from nearest turbine, m
Position 1	2685
Position 2	3397
Position 3	3225

Table 1 Distance to nearest turbine for each measurement position.

During the noise measurement campaign the meteorology was recorded on a measurement mast located southwest of the wind farm, but in close proximity of the wind farm. The mast was 65 m tall. Since the wind direction during the noise measurements was primarily from the west, the mast was undisturbed by the wind farm itself.

The calculation model was adapted to the local conditions as observed on the meteorological mast during the noise measurement campaign.

The climatic conditions have been read from the recorded data as:

Relative humidity: 70%

Temperature: 2 ^{o}C

Stability conditions: Neutral

For the terrain conditions the actual topography onsite is used in the form of detailed height contours and a uniform terrain hardness of 500 (class E, compact grass).

Wind direction is downwind from the turbines (270 degrees).

The source noise level of the turbines however is tricky to establish. With +40 turbines in operation the turbines will be located in somewhat different wind conditions plus suffer a wake induced reduction of wind speed on the back rows. This might however be countered by a possible increase in noise from higher turbulence. To keep the model simple a uniform wind speed is assumed for the wind farm. At the time of measurements the wind speed is read from the meteorological tower corresponding to 8-10 m/s at 10 m height and 10.9 to 13.7 m/s at hub height.

3. Results

Figure 4 to 5 compares the measured and predicted spectre for the three positions. The noise predictions are based on simple addition of the noise from the individual wind turbines, meaning that no interaction between the wind turbines is included. The good agreement between the spectra indicates that the noise at the neighbours can be described by simple addition and that no wind farm effects occur. The agreement is best at the lowest frequencies while the terrain interference effect above 160 Hz is more difficult to predict.

It is assumed in the prediction that the wind speed is the same at all wind turbines.
During the measurements it was possible to hear the noise from the wind turbines at all 3 positions. The noise was subjectively characterized as broadband in the mid to low frequency range. The levels were low but as the background noise also was low the noise was audible.

In table 2 predicted and measured low frequency noise is compared for the three positions for frequencies from 25 – 200 Hz.

The results show good agreement both when comparing levels and spectral shape.

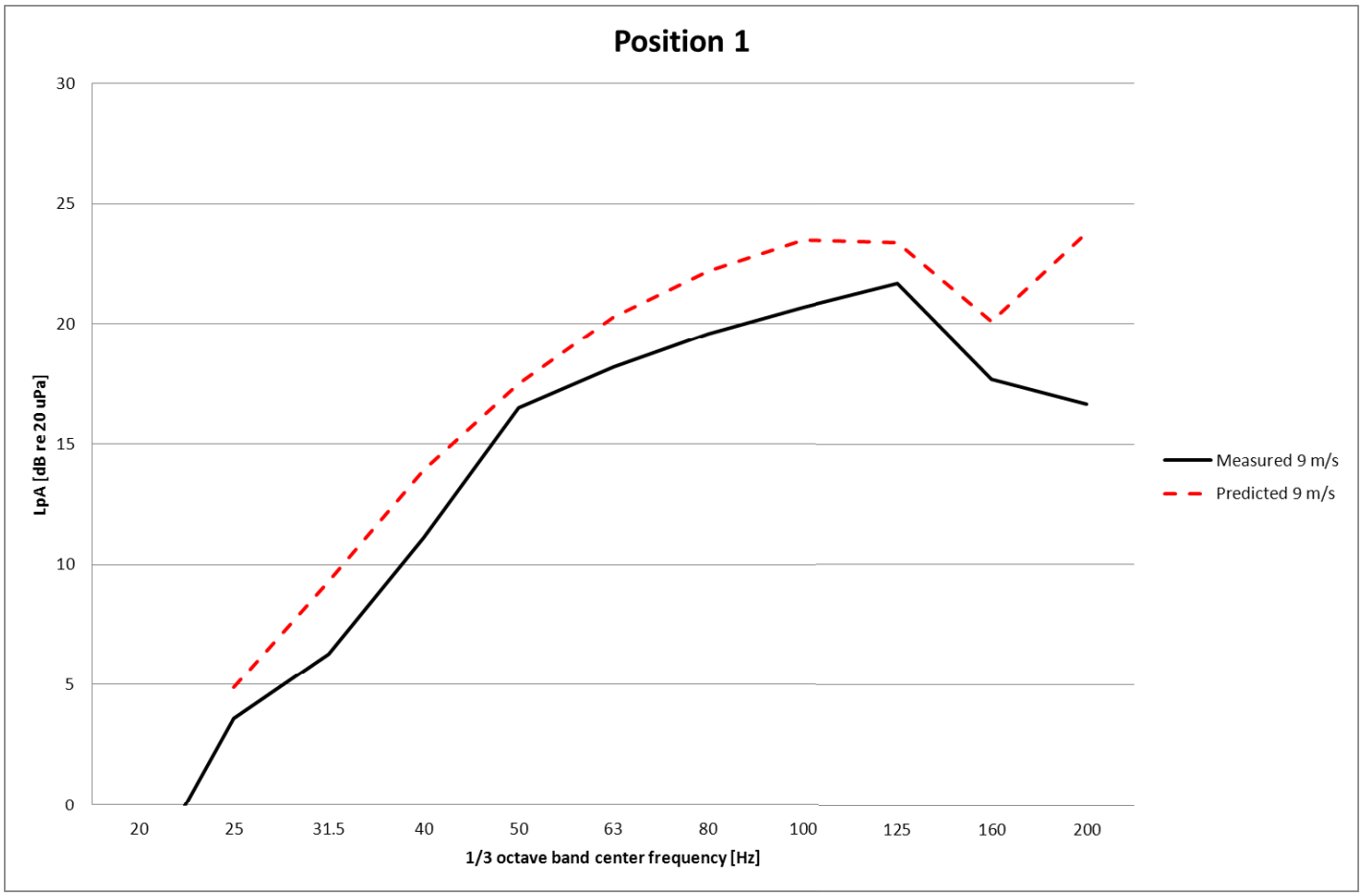

Figure 4 Predicted and measured noise spectra at position 1 for 9 m/s for frequencies from 25 – 200 Hz.

Figure 5 Predicted and measured noise spectra at position 2 for 8 m/s for frequencies from 25 – 200 Hz.

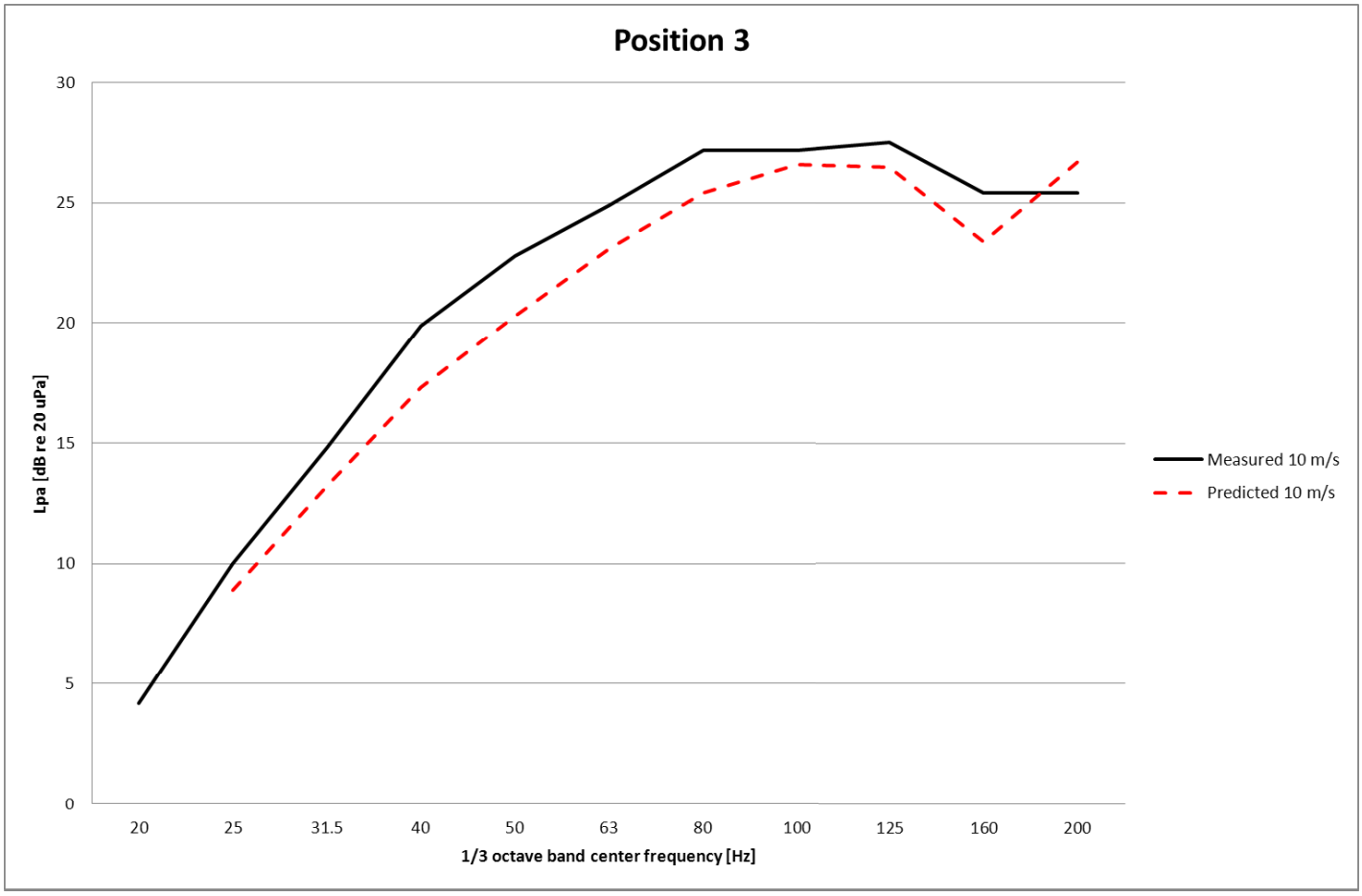

Figure 6 Predicted and measured noise spectra at position 3 for 10 m/s for frequencies from 25 – 200 Hz.

	Position 1 @ 9 m/s	Position 2 @ 8 m/s	Position 3 @ 10 m/s
Measured, $L_{pA,LF}$ [dB]	27.7	31.4	34.7
Predicted, $L_{pA,LF}$ [dB]	30.6	31.9	33.7
Difference	-2.9	-0.5	1.0

Table 2 Predicted and measured low frequency noise, $L_{pA,LF}$, position 1, 2 and 3 for frequencies from 25 – 200 Hz.

4.0 Conclusions

Comparing the predicted results with the measured results for the three measurement positions it is seen that both spectra and total level match each other considerably well, bearing in mind that the sound power level is known for only two of the + 40 wind turbines. Further the interaction between the turbines is not known.

Next step would be measurement and validation for projects where more details about the wind turbine is known – for example a site with only one or a few wind turbines.

References

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[7] Statutory Order on Noise from Wind Turbines; Statutory Order no. 1284 of 15. December 2011 (*in Danish. English translation can be seen at http://www.mst.dk/NR/rdonlyres/E8562E10-2B2D-4BF3-BAE0-A265C5A0B86E/0/engelsk_vindmoellebekendtgoerelse.pdf*)

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