Standards for the Assessment of Acoustic Emissions of Offshore Wind Farms

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With the utilisation of offshore wind energy a new source of underwater noise is brought into the marine environment. Operating wind energy converters (WEC) will give rise for a change in the acoustic background regime on quite a low but long lasting level. Furthermore during the installation phase the hydro sound might even exceed the threshold of "only disturbing" and in the worst case might cause a persistent damage to marine animals. In order to prevent unacceptable impacts on offshore nature, several studies have been started to investigate how marine animals, with the main focus on marine mammals, are effected even by small additional acoustic immission. This report will summarise the results of a technical study, that has been launched (financed by the German Ministry of Environment) to clarify what levels of acoustic noise can be expected by offshore wind turbines and their installation, how underwater sound can be measured and evaluated in a comparable way, and what acoustic parameters should be focused on.

When the study has been started in 2002 neither a threshold for acoustic noise immissions nor standards for measurements and evaluations had been defined. Within this work the data basis of offshore noises has been extended significantly and preliminary measuring procedures have been published within the final report of the first project phase. In order to allow an estimation of noise immissions already in the planning phase of a wind park, appropriate prediction methods have been tested and compared with the results of the measurements. In addition a working party has been founded to exchange information with biologists, the regulatory authority, the ministry of environment and acoustic experts.

Introduction

Actually we face the problem, that in the discussions about offshore noise certain dB – values are published, but practically no one knows what these values mean and how they can be measured. To form a reliable basis for the biological and technical research projects concerning offshore noise, it is important to define a "common hydro acoustical language". We have suggested a standard definition base for the main physical parameters within the research project, such as sound pressure level, mean and maximum level or the bandwidth of frequency distributions. A couple of different frequency representations are common in hydro acoustics, which leads to a puzzling situation making the comparison between the measured values nearly impossible. In order to avoid this problem, we introduced 1/3-octave spectra like in classical noise protection, wherever it was physically reasonable.

Noise during the installation phase and especially noise emission of pile driving will be a main part of the following report. Another item extracted from the research project is the prognosis of the acoustic noise immission from operating offshore wind turbines based on transfer functions.

How far will offshore noise be "disturbing"

Without focussing on a certain marine species, the range of impact around a source of acoustic noise can be divided into different zones that are shown in Fig. 1. Far from a source of sound, the acoustic noise will be below the hearing threshold. Within the zone of audibility there is an area of reaction, where animals will show some kind of reaction. Closer to the source of sound important acoustic information might be masked. Moving nearer to the origin of a very loud source of acoustic noise, animals might even get harmed.

By far the highest impact is expected in context with the installation of offshore wind turbines. Early results of hydro sound measurements made during pile driving actions in Denmark had roused biologists, because sound pressure levels of more than 200 dB[1] indicate a range where a temporary or even permanent threshold shift (TTS or PTS) has to be considered. The range of the different zones can be derived by the maximum and permanent sound levels caused by the offshore activities in combination with a realistic assump-

[1] As hydro sound is evaluated in a different way, the dB values cannot be compared to air borne noise

tion for the sound propagation. A major question however, that can only be answered by biologists, is how the species under concern - in the North Sea these are mainly harbour porpoises, harbour seals, grey seals and fishes - react on the additional acoustic noise of offshore WT.

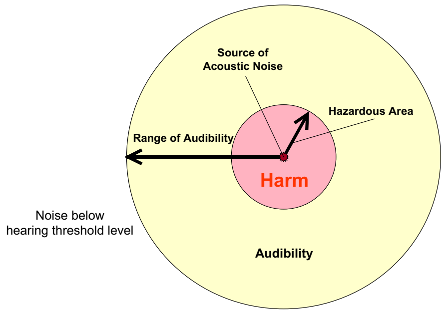

Fig. 1: Zones of acoustic noise immissions

How can noise of an offshore wind turbine be predicted

It is obvious that a realistic assumption of the future sound emission of a offshore wind turbine is a parameter that should be known already in the planning phase, where the design of the WEC is made according to certain assumptions and standards. It is not sufficient to measure the sound emission of a prototype in the conventional way as the sound propagation in the offshore environment differs drastically from the onshore case, where air and not structure borne noise is essential. Fig. 2 illustrates the underwater noise radiation of a wind turbine.

An acoustic noise immission prognosis can in principle be done by following the path of noise from the excitation in the nacelle up to the immission point in the water. The quality of such a prognosis of course depends on the reliability of the various steps that must be taken into account. The excitation sound level can be measured at a prototype wind turbine onshore, but this must be done in an appropriate and standardised way. Even more the acoustical behaviour of the prototype should equal the later installed offshore turbine.

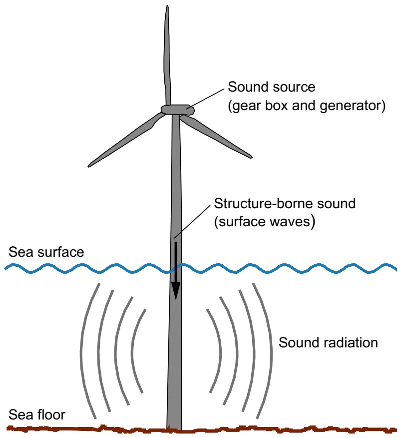

Fig. 2: Acoustic noise from operating offshore wind turbines

For the transfer function different approaches can be used as performed during the research project. A more theoretical approach is to make an extensive finite element calculation of the offshore structure in order to model the frequency dependend attenuation of the acoustic vibrations from the nacelle into the water. As an alternative way the transmission losses has been measured at real offshore wind turbines. The theoretical modeling of course gives the advantage to calculate whatever structure is needed once the fundamental effects are represented in the right way. First results from finite element calculations have shown a good correlation with the measured levels, but the procedure must be tested for more systems in the ongoing research project to guarantee a validated prediction method. The heuristic approach on the other hand has the advantage to be obviously accurate for the offshore structure where the measurement has been done but it can only be applied to towers and foundations with a similar acoustic behaviour.

Keeping in mind the described limitations an estimation of the sound immission of a future offshore wind farm can be done. In Fig. 3 the octave levels are shown for a hypothetical wind farm consisting of 70 wind turbines of the MW class. The transfer function used is based on measurements at real offshore plants. The highest immission levels can be found for the 250Hz octave with levels of about 100dB (re 1 μPa) in a distance of 10km. The 95 dB isoline is about 20km away from the wind farm. Once again it should be pointed out that these dB levels cannot easily be compared with acoustic dB levels in the air. From measurements we find an acoustic background level for the same 250Hz octave of about 97dB, which means that the underwater noise in 10km distance is in the same range as the acoustic background.

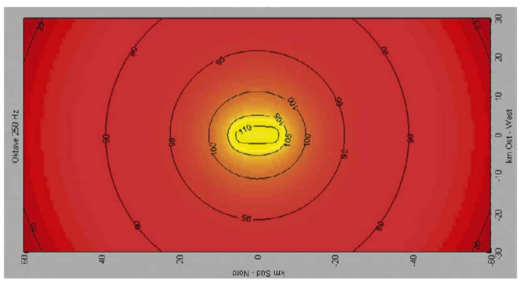

Fig. 3: Example: Prognosis of underwater sound pressure levels of a hypothetical wind farm of 70 turbines for the 250 Hz octave band

Noise during Construction of Offshore Wind Turbines

The noise emission during the erection phase of offshore wind structures could be studied during the installation of the two offshore research platforms. The foundations have been realised by pile driving. The first platform (company GEO) was erected in the Baltic Sea while the second one “FINO1” has been founded in the North Sea. Therefore the influence of different pile constructions and different marine environments could be studied. The immission values were measured in different distances during the whole pile driving procedure in order to get information about the propagation losses with the distance and also to see changes within the sound level as the pile penetrates into the ground. A picture of the pile driving action for the FINO1-Platform is shown in Fig. 4. The whole action lasted approximately two hours including some intermission with no intensive sound radiation.

The acoustic noise caused by pile driving obviously has an impact type character. A sequence of the sound pressure level during 60 seconds is shown in Fig. 5. During the measurement peak levels of 193 dB (re 1µPa) could be observed in a distance of about 400m from the pile. Quite similar levels could be noticed during the pile driving procedure of the GEO-platform in the baltic sea. The sound pressure was measured a bit nearer in a distance of 300m and revealed peak levels of about 196 dB(re 1µPa).

Fig. 4: Pile driving FINO 1 (jacket, working platform, pile hammer helmet)

These dB-values show evidence that special care must be taken to avoid harm for animals in the direct vicinity of the building site. For a quantitative study one has to encounter the impact of the single event "one hit" (Fig. 6) together with the cumulative effect of a series of these single events. The continuous equivalent sound pressure level L_{eq} is a common parameter in acoustics to study combined effects by integrating the sound pressure level for a certain time and normalise it to that time. The integration time should be chosen short enough in order not to screen the change within the single events but long enough to show the cumulative impact. We found 10sec to be a good time interval when pile driving takes place with a frequency of about one hit each second. Such a time series measured during the building activities for the FINO1-platform and is shown in Fig 7. The L_{eq} level is clearly connected with the excitation energy that may change during the action. For the FINO1 erection a variation of about 4-6dB during the whole pile driving can be noticed. Though the hammering energy will tend to increase with the penetration depth of the pile, the "loudest" part can be seen in the beginning of the action. This obviously must not be the case for instance for a mono pile, that is not buried into the ground and therefore has a constant contact area between pile and water. The driving of a mono pile will be investigated in the next future, when the second research platform in the North Sea at the „Amrumbank West" will be erected.

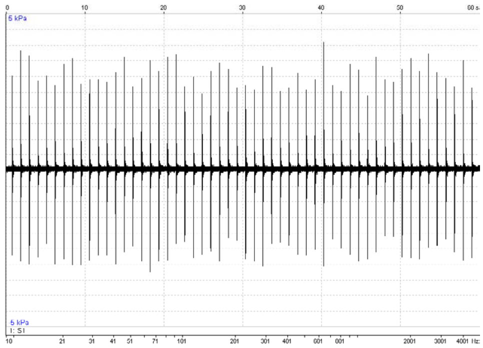

Fig. 5: 60 seconds plot of pile driving (sound pressure)

When evaluating the single event "one hit" it is necessary to avoid that the noise energy of the single "hit" is smeared out within the time. Therefore we have introduced the Single Event Sound Pressure level L_E, which is almost like the L_{eq}, but there is a significant difference. Irrespective of the integration time that is chosen in a way to assure that exactly one event takes place within the boundaries, it is always normalised to 1 sec. The L_E can for example be used to study the frequency distribution of single events. When regarding the averaged 1/3 octave spectrum of a pile driving "hit" at the building site of the FINO1-platform in Fig. 8 the maximum immission levels are found at lower frequencies between 100-400Hz.

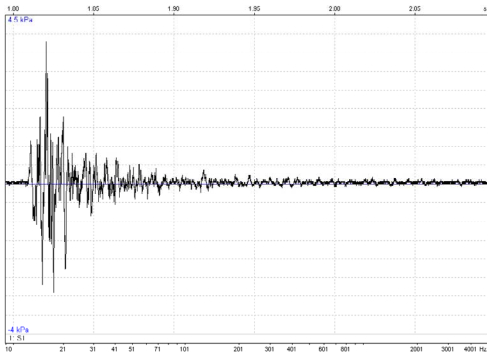

Fig. 6: Pile driving FINO 1 (plot of sound pressure of a single blow)

Conclusion

There is an ongoing discussion among acoustic experts, biologists and authorities in order to establish a regulatory framework to avoid harm to marine animals by offshore wind energy activities. Therefore a reliable data base of the expected noise emission during the installation of large offshore wind turbines is needed.

The authors have performed hydro sound measurements during the pile driving of the platform FINO 1 in the North Sea and another platform in the Baltic Sea. Requirements for measurements and evaluations have been worked out. This stan-

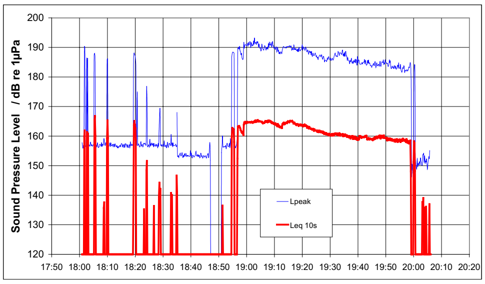

Fig. 7: Pile driving FINO 1 (plot of sound pressure levels measured at a distance of 400 m)

dardisation is necessary, because the evaluated critical distance for the same building activity may easily be two or four times higher, depending on the measurement configuration, the evaluation and the regarded parameters.

German authorities demand to keep certain noise reduction standards also for the operating phase of offshore wind turbines. Within this research project, recommendations for measurement and evaluation as well as prediction methods for noise immissions during the construction and operation of wind turbines have been worked out. The research project has been prolonged in order to complete the acoustic data basis and to study a variety of means to reduce noise especially within the pile driving procedure.

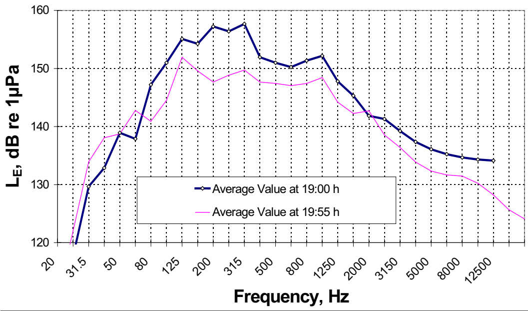

Fig. 8: Pile driving of FINO 1 (1/3 octave band spectra measured at 400m distance)

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