Seismic applications in the era of wind energy

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The growing importance of sustainable energy is encouraging the wind industry market to aim for larger wind turbines and bigger wind farms. Driven by the search for larger construction areas, the offshore market began to spike investors’ interest. However, it quickly became obvious that this dynamic working environment is associated with new challenges and uncertainties for planners and operators, especially with regard to finding suitable subsoil conditions for safe yet cost-efficient foundations. In order to ensure feasibility, reveal uncertainties, and assess as well as minimize risks, subsoil imaging techniques such as multichannel seismic methods are becoming increasingly important throughout the entire life cycle of a wind farm project and are set to shape market opportunities.

To reach its full potential while striving for a comprehensive subsurface assessment predominantly based on seismic data, in the upcoming years the industry will have to face the challenge of implementing fit-for-purpose seismic methods derived from the oil and gas industry while continuing to remain cost-efficient in a growing market.

How to acquire good seismic data for high-resolution subsurface imaging

A marine seismic survey consists of generating sound pulses and recording echoes from the subsurface close to the surface of the water from different positions. It is then possible to generate an accurate ‘image’ of the subsoil from the travel times and other characteristics of the recorded wavefield. The accuracy, resolution, and penetration of a seismic survey are dependent upon the range of frequencies generated. Higher resolution and accuracy require the use of higher frequencies. Unfortunately, the energy from these higher frequencies is lost rapidly to dissipative and scattering effects during wave propagation.

This generates a fundamental trade-off in seismic prospecting between seismic resolution on the one hand and signal penetration on the other. Regardless of the scenario, certain characteristics are universally desirable in a seismic source: a short pulse and wide bandwidth, good sound level, good repeatability, and reliability in the field. The market is flooded with a myriad of marine seismic-acoustic sources, all with their own characteristic sound signature, which generate sound pulses through different phenomena: release of highly pressurized air, piezoelectric crystals, high-voltage ionization of water, magnetically excited plates, etc.

Over the past few years, sparkers have become a widely used seismic source for multichannel seismic surveys, as they are reliable and suitable for a wide range of scenarios related to wind farm site assessment. In certain survey acquisition setups, or when penetration past highly reflective interfaces is necessary (i.e., saturated biogenic gas fronts, shallow bedrock, etc.), louder, lower frequency sources are preferred, as in the case of low-volume air guns.

The next fundamental aspect of seismic
acquisition is the recording strategy. The simplest way is to record the reflected wavefield at a single location with every pulse (shot). This is known as mono- or single-channel seismics and these days is rather restricted to hydro-acoustic prospection methods like sediment echo sounders and boomer surveys. The target of single-channel seismo-acoustic surveys is typically ultra-high resolution 2D profiles of the shallowest approx. 15 m of sediment. Despite the high resolution, the penetration is usually very limited.

One way to enhance the seismic penetration is by increasing the signal-to-noise ratio. This can be achieved either by using a louder source or by recording data redundantly. Multichannel seismic surveys record seismic energy, which illuminates the same area of the subsoil more than once, usually in combination with louder sources than those used for single-channel seismics.

Currently, 2D multichannel seismics is a standard survey strategy for wind farm site assessment. In addition to the improved signal-to-noise ratio, multichannel seismic methods add a new dimension to the recorded data: the distance between the source and the receivers. This allows the inference of additional information about the subsoil (i.e., seismic velocities, etc.) which in turn can help the interpreter improve stratigraphic information.

Additionally, by locating the source and receivers in separate positions and recording at many positions, it is possible to illuminate dipping seismic interfaces better in areas of complex geology and, through data processing, to derive a more accurate image. A marine 2D multichannel seismic acquisition setup is achieved by towing a cable of hydrophones behind the survey vessel (streamer). Despite its many advantages, this method is only capable of delivering 2D profiles of the subsurface. Therefore, it has limitations in its capability to map cross-dipping reflectors, and interpolation is usually required during interpretation of geologic interfaces.

The maximum amount of information can be derived from 3D seismic data. In this particular case, several streamers are towed and an additional dimension of data is added: the azimuth. The great advantage of 3D seismics is that full coverage of an area can be achieved in the most accurate way. Interpolation between seismic profiles is not required, meaning better understanding of the geology suddenly becomes possible. The oil industry has understood that with 3D seismics the benefits greatly exceed the costs, which is why 3D surveys are now the primary exploration tool employed by most operators.

To achieve high-resolution, accurate results, it is not only necessary to use the correct source and recording strategy, but the seismic wavefield must also be sampled correctly in time and space. Time sampling is achieved at the time of digitizing the recorded sound, and for wind farm site assessment requirements it is usually in the order of one sample every few microseconds. Shot and receiver spacing has to be sufficiently dense to allow for the correct reconstruction of the recorded wavefield. Correct shot rates and narrowly spaced single-point hydrophones are becoming standard for high- and very high-resolution seismic surveys, as this allows proper wavefield sampling without the detrimental effects of hydrophone arrays.

For the above-mentioned reasons, the Fraunhofer IWES operates a flexible 2D/3D multichannel seismic system developed specially for the IWES with a design based on the extensive experience of the University of Bremen in high- and very high-resolution seismic acquisition. The potential spread of the systems includes both air gun and sparker seismic sources. The streamer itself consists of modular sections measuring 12-24 m with a hydrophone group spacing of 1 m. Combined with several state-of-the-art global navigation satellite systems, this
setup guarantees high-quality data sets as demanded by the offshore wind industry market.

Applications for seismic imaging methods in the world of wind energy

Around the turn of the year, the Fraunhofer IWES, in cooperation with the University of Bremen, acquired the first full-field 3D high-resolution seismic data set for a wind farm area in German waters. This campaign marks the beginning of a new way of thinking in the offshore wind farm industry: moving from the assessment of single locations to field-wide subsurface characterization, companies are ideally prepared to cope with late changes in the wind farm layout and design.

3D subsoil models generated from geophysical and geotechnical data represent the ideal tool for increased flexibility in the planning and development of offshore wind farms. This applies, for example, to changes in the layout of offshore wind farms, which are very likely and very frequent due to long planning cycles and, at the same time, short cycles for technical innovations in turbine and foundation design. These changes regularly present planners and developers with major challenges with regard to the project schedule and budget.

After finalizing the construction site, investigating the prevailing wind conditions and nature conservation requirements and compiling the legal planning basis, the technical project management optimizes the site plans of the wind turbines. The result is a refined plan, which serves as a starting point for the approval process. In this situation, the use of seismic imaging contributes to a drastically improved understanding of the subsoil conditions, including the estimation of hazards affecting plant locations and design in the micrositing process.

The investigation of geohazards has become crucial in recent years with the aim of improving construction designs and reducing potential risks during the installation as well as for planning export cable routes. Established methods for subsurface boulder and object detection present themselves as cost- and time-intensive as well as limited in their subsurface penetration. One potential solution to this challenge is presented by the proprietary Manta Ray G1 system operated by the Fraunhofer IWES and the University of Bremen. This novel, integrated seismo-acoustic boulder detection system is capable of identifying hazardous objects measuring between approximately 0.5 m and approximately 5 m to a target depth of approximately twice the water depth in the area of interest.

Full-field wind farm seismic assessment: the future?

The growing application of marine high-resolution 2D multichannel seismic surveys for offshore wind farm assessment and the first-time application of 3D high-resolution data last year were important steps towards flexibility and cost-efficiency in wind farm planning. To leverage the full potential of seismic imaging techniques, wind farm planners and project managers should consider the acquisition of seismic data early on in the planning phase.

The early availability of a comprehensive subsoil model will facilitate tailoring a targeted geotechnical analysis based on the encountered imaged stratigraphic units reducing the required amount of subsurface sampling. In turn, the geotechnical characterization of key stratigraphic units and key structural elements, through CPT (cone penetration tests) measurements and sampling, will allow reliable synthetization of CPT information throughout the area following spatial variation of geologic structures as recorded in the subsoil model.

As a result, the repetition of geotechnical campaigns with changing wind farm layouts would become obsolete. Furthermore, cutting-edge methods such as boulder
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Detection through diffraction imaging or probabilistic modeling on the constraints of subsurface models enrich the possibilities of risk assessment on wind turbine placement.

**Conclusion**

Over the past decade, the offshore wind energy market has developed into a highly specialized industry. Larger turbines, rotor diameters, and wind farms, improved wind farm layouts, tighter development plans, and the integration of new technologies are challenges for the industry. The use of seismic imaging contributes to a drastically improved understanding of the subsoil geology, including the estimation of geohazards affecting turbine locations and foundation designs. Nowadays, the multichannel seismic methods are increasingly applied throughout the entire wind farm construction process. The quality of high-resolution seismics is dependent in a complex way upon several acquisition factors, source, recording strategy, and technical aspects of seismic acquisition. To ensure optimal data quality, the Fraunhofer IWES applies multichannel seismic imaging methods ranging from conventional 2D/3D high-resolution seismics to specialized spreads for subsurface object detection. This allows high-quality research services to be provided, which drive the development of novel imaging techniques as required by the demanding offshore wind industry market.

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