Department of
ENERGY TECHNOLOGY
Aalborg University

PhD Public Defence

Title:	Harmonics from large offshore wind farms
Location:	Pontoppidanstræde 101, room 23
Time:	Thursday 2nd February 2012 at 13.00
PhD defendant:	Lukasz Kocewiak (industrial PhD student, DONG Energy and Dept. of Energy Technology, Aalborg University)
Moderator:	Associate Professor, Birgitte Bak-Jensen, Dept. of Energy Technology, Aalborg University
Opponents:	Professor Frede Blaabjerg, Aalborg University (chairman)
	Professor Neville R. Watson, University of Canterbury, New Zealand
	Section manager, PhD Paul Thøgersen, KK-Electronic, Denmark

After the public defence there will be an informal reception at **Pontoppidanstræde 101 room 25/27** where assessment committee chairman Professor Frede Blaabjerg will read aloud the assessment statement.

All are welcome. The defence will be in English.

ABSTRACT

The number of wind turbines with full converters in the MW range used in large offshore wind farms is rapidly increasing. They are connected through a widespread MV cable network with practicably no consumption and connected to the transmission system by long HV cables. This represents new challenges to the industry in relation to understanding the nature, propagation and effects of harmonics. Recently wind power sector is rapidly developing. This creates new challenges to the industry and therefore more and more research projects including harmonic analysis especially focused on wind power applications are conducted and that is why the project was initiated and successfully developed. Also experience from the past regarding offshore projects developed in the company and various harmonic aspects caused a need to carry out extensive harmonic research.

The research project was initiated by the industry and carried out in cooperation with the academia. In order to organize project development process the research development framework was suggested based on rationalistic tradition approach in order to provide knowledge and better understanding of different aspects (e.g. measurements, data processing, data analysis, modeling, models application) in harmonic studies. Based on the framework also the structure of the report was organized. This allows the reader to go through all of the stages in project development starting from measurements, thru data processing and analysis, and finally ending up on modeling and models application. Different aspects of validation in time domain, frequency domain, and by application of statistical methods are mentioned in relation to respective problems.

Measurements constitute a core part in industry-oriented research. The research project due to this fact owes its uniqueness and contributes new insight to the academia. It is proven that an analysis of such systems as large offshore wind farms considers many aspects related to extended and accurate models, complex measurement campaigns and of course appropriate and more suitable data processing methods. Before any of the above aspects could be seriously taken into consideration, a reliable and robust measurement system is needed. This is achieved by careful designing of the hardware and the software layers of the measurement system.

It is explained in the report that of great importance is to know the nature of generated harmonics in large offshore wind farms in order to apply the most suitable data

processing technique. Time-frequency analysis based on multiresolution wavelet transform is used in order to perform time-frequency domain analysis helpful to distinguish harmonic origin and observe short-term variation. Non-parametric spectrum estimation is successfully applied on interpolated signals adjusted according to the varying power system frequency. Different data processing techniques are presented and applied depending on signal (i.e. stationary or non-stationary) or harmonic nature (i.e. spline resampling or direct spectrum estimation). Based on deep investigation of measurements it is observed that certain harmonic components generated by the grid-side converter in the wind turbine are affected by two driven frequencies, i.e. the power system fundamental frequency and the carrier signal fundamental frequency. Therefore harmonic assessment by major part of commercial power quality meters is to some extent inappropriate and affects misleading measurement interpretation.

Different statistical tools were used in order to analyze the origin and nature of various harmonic components. A comprehensive comparison of harmonic voltages and currents based on probability distribution estimation and appropriate statistics calculation (e.g. mean, variance, probability density function, etc.) is applied. Such approach gives better overview and comparison of harmonic components variation and occurrence frequency.

Several frequency domain methods of describing wind farms comprising of various components such as wind turbines, transformers, cables, etc. are shown and compared. It is explained that large offshore wind farms can introduce additional unwanted resonances within low frequency range. This can significantly affect overall system stability. Therefore analysis and design optimization of large offshore wind farms is more complex than smaller onshore wind farms.

Nowadays wind turbines are complex devices equipped with the newest technologies. Therefore also harmonic analysis of such devices is not straight forward task. Harmonic studies, due to the complexity of wind turbine structure, can be focused on several parts such as control strategy, modulation technique, converter build, and hardware implementation.

Various control strategies are taken into consideration and their impact on possible harmonic emission and overall system stability. Analysis is done mainly in frequency domain. One analyzes how particular components in the control structure (e.g. filters, controllers, etc.) can affect the control and its harmonic rejection capability. The influence of control strategies on overall wind farm stability is also deeply investigated. Appropriate stability indices are suggested and applied in several study cases.

Carefully modeled and aggregated large wind farms in frequency domain together with wind turbines frequency response give a good overview about large offshore wind farm

behavior for different frequencies. Such approach is successfully used in studies of real-life existing wind farms.
Since harmonics in wind turbines and wind farms are characterized by different origin and nature comparison of them may be problematic. Therefore sometimes selective validation of particular frequency components is more suitable. It was observed that comparison of result in frequency domain and time domain as well as application of statistical methods is the core part of results understanding.
Based on presented studies one can see that large offshore wind farms, in comparison to typical onshore wind farms, can affect more unwanted resonance scenarios. Unwanted resonances can affect overall wind farm stability and performance (e.g. unwanted harmonic excitation and amplification). Therefore it is of great importance to carefully analyze wind farms, especially large offshore wind farms, also form harmonic perspective.
This industrial PhD project is focused on investigating the best possible way to perform various harmonic studies of offshore wind farms including some conditions not taken before under consideration. Application of new methods and widening the range of models contributes to achieve the necessary higher reliability of offshore wind farms as large power generation units in electrical power systems.