Offshore Wind Farm Research at the NWO Institutes

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Abstract

Fundamental scientific research is essential to take the necessary next step in offshore wind farm innovation. The NWO scientific research institutes play a central role in the Dutch knowledge infrastructure for disseminating scientific discoveries into industrial innovations. Multiple research groups at CWI, NIOZ, FOM, and DIFFER are already active in the fields connected to offshore wind power. The objective of this report is to improve the coordination between these groups by informing them of each other's research activities.

1. Introduction

The Dutch government is actively promoting innovation within economic sectors where Dutch businesses hold a leading international position, to further advance the competitiveness of the Dutch society. One of these so-called Topsectors is "Energy" in general and offshore wind power in particular. The resulting Topconsortium for Knowledge and Innovation (TKI) Wind-at-Sea has formulated the shared ambitions of this sector in the Innovationcontract Wind-at-Sea. The overarching objective of this initiative is to reduce the cost of energy from offshore wind power by as much as 40% in 2020 to make wind farms at sea competitive. The ambition of the TKI is to reach this target by achieving 25% lower costs for both the installation, and the management and maintenance, as well as 33% lower finance costs and 21% higher power output. The recently presented National Energy Agreement further specifies the Energy targets to reach 14% renewable energy in 2020, and 16% in 2023. The Innovationcontract Wind-at-Sea organizes the discovery, development, and deployment activities of interest into the following six Innovationthemes:[1,2,3]

1. Support structures;
2. Optimization of the wind power station;
3. Intern electrical grid and connection to the transmission network;
4. Transportation, installation, logistics;
5. Management and maintenance;
6. Wind farm development.

The Netherlands Organization for Scientific Research (NWO) is vital in the discovery phase of the overall innovation-chain by facilitating the necessary long-term fundamental scientific research on offshore wind farms. Especially the NWO scientific research institutes have a unique position in effectively transferring knowledge generated by scientific research to innovations in industry, also in the area of offshore wind power. The Center for Mathematics and Computer Science (CWI) is mentioned in particular by the TKI Wind-at-Sea in the NWO Proposition Topsector Energy 2014-2015 to play a coordinating role in the national offshore wind farm research, because multiple groups at CWI are already active in this field. Therefore, I have been asked by the Scientific Director of the TKI Wind-at-Sea, Dr.ir. Michiel Zaaijer, to make an overview of all groups at the NWO institutes which perform scientific research relevant to offshore wind power. This report gives this overview as of October 2013. The primary objective of this document is to inform the different groups of each other's work as a first step in improving the coordination and collaboration between their research activities.[4]

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2. NWO offshore wind farm research

The NWO research institutes are listed below for completeness:

1. Center for Mathematics and Computer Science (CWI);
2. Royal Netherlands Institute for Sea Research (NIOZ);
3. Foundation for Fundamental Research on Matter (FOM);
4. DIFFER: Dutch Institute for Fundamental Energy Research;
5. FOM institute for Atomic and Molecular Physics (AMOLF);
6. National Institute for Subatomic Physics (Nikhef);
7. Netherlands Institute for Radio Astronomy (ASTRON);
8. Netherlands Institute for Space Research (SRON);
9. Netherlands Institute for the Study of Crime and Law Enforcement (NSCR).

The following of these institutes are conducting research on offshore wind farms. The work of the respective scientists involved is summarized below.

2.1 Center for Mathematics and Computer Science (CWI)

- The Scientific Computing research group at CWI has multiple activities that are relevant for research on offshore wind farms. The responsible researchers are listed below:

    - Dr.ir. Jeroen Witteveen from the Scientific Computing group is responsible for the offshore wind farm research at CWI. He is contributing to the scientific progress and technological developments necessary for the transition of our society into a sustainable energy economy from his background in uncertainties of wind power generation. One of his main research activities is the optimization and uncertainty reduction for offshore wind farm designs using methods from uncertainty quantification and computational fluid dynamics. This includes the minimization of the negative impact of the wind direction uncertainty on the mutual interaction of the turbines and their aerodynamic wakes. To that end, he is in contact with the Energy research Center of the Netherlands (ECN), Delft University of Technology (TU Delft), and Eindhoven University of Technology (TU/e).[5,6,7]

    - Recently, Dr.ir. Benjamin Sanderse obtained his PhD degree with honors for his research performed in the Scientific Computing group at CWI under the supervision of Prof.dr.ir. Barry Koren. Dr.ir. Sanderse has developed advanced mathematical methods able to produce reliable simulations of offshore wind farms. Wind turbines affect each other through their wakes, which can be up to hundreds of meters long. Wakes are highly variable turbulent wind flows consisting of numerous large and small vortices. Reliably predicting these wind flows is a huge challenge. Wakes are responsible for lower energy production and higher loads on downstream turbines. On the other hand, they can also cause additional inflow of air, amplifying the overall amount of wind present within the farm. Because of the vast number of vortices, considerable computational power is needed to determine the flow inside the wakes. The mathematical methods he has developed are capable of not only predicting the turbulent airflow in the wakes, but can also simulate different designs and configurations in a “virtual wind farm”. These simulations allow for the more efficient design of large-scale wind farms. His research also enables the study of emerging research questions such as ascertaining the ideal distance between turbines, and their optimal adjustment. The work was carried out for ECN.[8,9]

    - Dr. Daan Crommelin leads the Scientific Computing group and works on two main themes: (i) stochastic methods for atmosphere-ocean modeling, and (ii) robustness and reliability of power grids with uncertain generation. The first theme involves the

inclusion of randomness in dynamical models for atmospheric and oceanic flow, in order to account for uncertainty due to e.g. small-scale turbulence, atmospheric convection and clouds. Collaborators include prof. Pier Siebesma (KNMI and TU Delft) and prof. Harm Jonker (TU Delft), who are experts in high-resolution (LES) modeling of atmospheric convection, clouds and turbulence. Another topic is parameter estimation for stochastic models for wind strength at the sea surface, carried out in collaboration with prof. Adam Monahan (Univ. Victoria, Canada), an expert on sea surface wind modeling. The second theme centers on the question how the probability of electricity network failures (due to e.g. overloads) is impacted by the intermittency and uncertainty of renewable energy sources such as wind turbines and solar panels. Network failures are rare events, so that efficient quantification of their (very small) probabilities requires dedicated computational techniques (so-called rare event simulation). This work is carried out in collaboration with DNV-KEMA and partly funded by the NWO-Shell Computational Sciences for Energy Research program.

- The ambition of the TKI Wind-at-Sea is to decrease the finance costs of offshore wind farms by 33%. MSc student Steven Hoyer works on wind power derivatives and cost-benefit insights concerning offshore wind power. For example, whether it is beneficial to increase the wind turbine size from 60m to 100m. He is expected to graduate at the end of October 2013. This work is being continued by PhD student Fei Cong, MSc, who started September 1, 2013. Fei Cong's research focuses on cost-benefit analysis and portfolio optimization, which includes wind at sea. These students are supervised from CWI by Prof.dr.ir. Kees Oosterlee in the Scientific Computing group: c.w.oosterlee@cwi.nl.

- The Multiscale Modeling group (led by Prof.dr. Ute Ebert, with staff members Prof.dr. Willem Hundsdorfer, tenure tracker Dr. Enrico Camporeale, and senior scientific programmer Drs. Margreet Nool) concentrates on multiscale plasma modeling and scientific computing. While the group does not work on wind energy yet, it has modeling expertise for two relevant problems: plasma actuators, and lightning protection.
  Plasma actuators at the front edges of wings can enhance the laminarity of airflow at minimal energy input. The technique is presently developed in the aviation industry (e.g., by Boeing), and it is also under consideration to increase the range of wind speeds at which wind turbines can operate. Plasma actuators are particular surface discharges that precondition the air in the boundary layer on the wing by momentum transfer and heat. Similar surface discharges are the subject of our STW-project 12119 in the context of high voltage technology (with contributions by ABB Corp. Res.).
  Lightning protection of tall buildings and the attachment process of a lightning leader to a structure is one of two subjects of STW-project 10757.
  Both projects are collaborative projects with plasma physics or electrical engineering at TU/e where at least one PhD student works experimentally at TU/e and at least one PhD student develops theory and simulations within the CWI group. The Multiscale Modeling group would be happy to apply its knowledge to wind turbines and to develop it further.

- CWI is also very active in the area of the TKI Smart Grids, with which the Innovationtheme "Intern electrical grid and connection to the transmission network" of the TKI Wind-at-Sea has strong links. This research is headed, among others, by Prof.dr.ir. Han La Poutré, leader of the Intelligent Systems group, and Dr. Daan Crommelin, leader of the Scientific Computing group: han.la.poutre@cwi.nl, daan.crommelin@cwi.nl.[10,11]

- For more information, CWI has appointed a dedicated Theme Coordinator Energy who coordinates all energy-related activities internally and who is also the CWI contact for external industrial and academic collaborations. The coordinator of the CWI-theme Energy is Prof.dr. Ute Ebert: ute.ebert@cwi.nl.[12]

2.2 Royal Netherlands Institute for Sea Research (NIOZ)

- In 2006, the Offshore Windfarm Egmond aan Zee (OWEZ) was constructed in the Dutch coastal zone by the NoordzeeWind (NZW) consortium consisting of Nuon and Shell. An extensive monitoring campaign, the Monitoring and Evaluation Program (NSW-MEP 2003-2012), documented the environmental impact of the OWEZ wind farm on the marine ecosystem. A scientific research group at the Department Marine Ecology of NIOZ monitored the possible effect of OWEZ on the local macrobenthos community, comprised of organisms larger than 1mm that live on the seafloor. The main conclusions of the research are that the local biodiversity has increased and that no negative effects have been found. This five-year project was successfully completed in October 2012 and the lead authors Ir. Magda Bergman and Drs. Gerard Duineveld continue to be interested in wind farm research: magda.bergman@nioz.nl, gerard.duineveld@nioz.nl.[13,14]

2.3 Foundation for Fundamental Research on Matter (FOM)

- FOM is an NWO foundation which finances fundamental physics research. It awarded a Young Energy Scientists (YES!) fellowship to Dr. Richard Stevens in 2012 to investigate the highly intermittent turbulent flow in wind farms. With the help of computer simulations, he will investigate how a group of wind turbines can best be positioned with respect to each other and how fluctuations in the amount of electricity generated are influenced by changes in the wind speed as well as wind flow caused by other wind turbines. Wind turbines exert a strong influence on each other. With the help of detailed computer simulations, he wants to examine which physical aspects are important in large wind farms. For example, he will assess fluctuations in the wind speed and electricity production. Such knowledge is required in order to make a good design of the backup power that must be made for large wind farms. As soon as a society is going to rely on a wind farm supplying a certain quantity of electricity, there must be a backup system. For example, if you expect that the wind will lessen then there must be an alternative supply of electricity. Dr. Stevens will perform this wind farm research for three years in Prof. Charles Meneveau's group at Johns Hopkins University in Baltimore, USA. In the fourth year, he will continue his work as a postdoc at the University of Twente: R.J.A.M.Stevens@utwente.nl.[15]

- FOM also chairs the NWO-theme Sustainable Energy, which aims to stimulate fundamental scientific research on renewable energy by funding multidisciplinary scientific research programs. The contact person is the FOM Knowledge Secretary of the Topteam Energy: Dr. Jasper Reijnders, jasper.reijnders@fom.nl.[4]

2.4 DIFFER: Dutch Institute for Fundamental Energy Research

- The DIFFER research institute performs leading fundamental research in the fields of fusion energy and solar fuels. For a society relying on sustainable energy provided by solar panels or (offshore) wind farms, the storage of (excess) sustainable energy is part of the energy mix. Energy storage mitigates the intermittent character of these renewable sources, but also allows for continuous operation of solar parks and offshore wind farms by peak shaving in case of excess of power when connected directly to the energy grid.
  In its solar fuels research, DIFFER is working on innovative storage technologies that convert H_2O and CO_2 in reactions driven by sustainable energy into chemical gaseous or liquid (carbon-containing) fuels. This research connects offshore wind to power-to-gas (P2G) technologies relevant for TKI Gas, but also to the concept of *carbon capture and utilization* (CCU). Especially, since energy transport in the form of gas from offshore wind farms to land is almost a factor ten less expensive than by means of a power cable, the direct conversion/storage of wind power into chemical fuel locally at the offshore farm has economic potential.[16]

- DIFFER is also active in building a national community of researchers working in the fundamental energy research. The aim is to connect researchers with different scientific backgrounds who are already active in energy research, but also those excellent researchers working in fields that have a large potential to contribute to the energy challenge.
  One of the activities currently initiated by the institute is the workshop series *"Science & the Energy Challenge"*, preferably organized in close collaboration with university groups and (research) institutes. The aim for the workshop is to define those fundamental and multidisciplinary research questions to which the Netherlands research expertise has the potential to come to breakthroughs that could accelerate innovation regarding the global energy challenge. The contact person is: Dr.ir. Erik Langereis, e.langereis@differ.nl.

3. Conclusions

The NWO scientific research institutes form an essential link in the Dutch innovation-chain for disseminating scientific discoveries into practical industrial applications. Many research groups at the NWO institutes are already active in the field of wind farms at sea. For example at CWI, multiple groups are performing directly relevant scientific research on optimization and uncertainty reduction for wind farm aerodynamics, atmosphere-ocean modeling, electrical grid integration, plasma actuators, lightning protection, and wind power derivatives. There are also various complementary research activities on offshore wind power in groups at NIOZ, FOM, and DIFFER concerning the impact on seafloor organisms, wind farm computer simulations, and efficient energy storage concepts for sustainable energy. Summaries of the multidisciplinary research performed by these scientists are brought together in this document. This report is therefore a successful first step in improving the coordination between these related research activities by informing the different groups of each other's work. A promising next step would be to organize one of the FOM workshops in the series "Science & the Energy Challenge" on offshore wind power at CWI.

Acknowledgments

I would like to acknowledge all colleagues involved for their kind contributions.

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