

## **Guest editorial. Special Issue HVDC Transmission Systems for Large Offshore Wind Power Plants**

Offshore wind power plants have experienced an important growth in the last decade and are becoming a key energy source worldwide. Offshore wind presents clear advantages due to high and stable wind speeds offshore, enabling the use of larger wind turbines than those commonly used on inland wind power plants. However, transmitting power to load centres also brings a number of technical challenges. Depending on the distance to the shore and the power rating, AC or DC technology may be the preferable option for integrating offshore wind power to onshore grids. There are a number of issues which have to be considered requiring substantial research and development. For DC connections, (Voltage Source Converter) VSC-HVDC technology has shown advantages over (Line Commutated Converter) LCC-HVDC. The development of multiterminal HVDC grids though brings further challenges related to system operation, control and protection and coordination between HVDC converters, wind power plants and the onshore system. The development of power electronic switches has reached a point where the size, rating, and the system efficiency can meet the needs of commercial HVDC. Wind power plants connected to HVDC transmission system require specific control and protection coordination between HVDC converters and wind turbines.

In response to the call for abstracts, 110 abstracts were received. After conducting the abstract revision, 60 abstract authors were invited to full paper submission. 39 full papers were received, resulting in 14 papers accepted for publication in the special issue.

The papers have covered the following key areas of research:

- Evaluation of HVDC networks: The paper from Elliot et al. introduces a comparison of DC and AC technologies for offshore wind applications in Great Britain. Offshore wind power is in an early development stage. With the time, more and more offshore wind power plants (OWPP) will be located at large distances from shore, resulting in HVDC cable connection becoming the preferred connection solution. However, the cross-over distance at which HVDC is cheaper than AC is a subject open for debate. The investigation of the technical and economic characteristics of AC and HVDC transmission technologies for OWPP connection indicates a complex interaction between technical requirements and economic benefits. Several factors, among which are the distance from shore, the OWPP installed capacity and the steady state characteristics, are found to have an influence on the cross-over distance between AC and HVDC connection for OWPP. The work from MacIver et al. focuses on reliability issues. The reliability of different offshore grid design options for connecting OWPPs is a very timely research subject, since it is starting to receive considerable attention from a number of organisations. A methodology for such a reliability investigation for connecting a cluster of far OWPP is presented. The methodology is exemplified on a number of case studies and a cost benefit analysis that compares the capital costs, electrical losses and reliability of each is performed. The conclusions show that there is a clear value in options that have an inherent redundancy and alternative protection strategies which avoid the use of expensive DC circuit breakers are shown to be potentially viable.
- Wind turbines and HVDC converter technology: For the large offshore wind farms proposed in future, optimising the collection array is a key part of the process. Whether this is AC or DC is a currently hotly debated topic and much will depend on voltage conversion for DC systems and the optimisation voltage rating of the turbine. Bahmani et al.'s paper 'Comparative Study of a Multi-MW High Power Density DC Transformer with an Optimized High Frequency Magnetics in All-DC Offshore Wind Farm' addresses the complex topic of the converter. Beik et al.'s paper 'An Off-Shore Wind Generation Scheme with High Voltage Hybrid Generator, HVDC Interconnections and Transmission' examines the wind turbine interconnection issue.

- Protections and control in fault conditions: Managing these complex systems during faults is a challenge. Clearly such systems should support the onshore AC network during faults, an aspect that is tackled by van der Meer et al. in 'The Effect of FRT Behavior of VSC-HVDC Connected Offshore Wind Power Plants on AC/DC System Dynamics'. DC faults should also be robustly dealt with and Vidal-Albalade et al. tackle this issue in 'Analysis of the Performance of MMC under Fault Conditions in HVDC-based Off-shore Wind Farms'. A protection scheme to achieve this have been outlined by Leterme et al. in the paper 'Analysis of the Performance of MMC under Fault Conditions in HVDC-based Off-shore Wind Farms'. Complex systems using a VSC-HVDC node offshore with an LCC-HVDC node onshore have been proposed to help reduce losses and costs, but they form a particular challenge during faults. Zeng et al.'s paper 'Hybrid HVDC for Integrating Wind Farms with Special Consideration on Commutation Failure' attempts to examine some of the issues.

- Modeling and control: The introduction of any new component, such as a new power electronic converter, introduces new dynamics to the power system. These new dynamics require on the one hand adequate modeling, and on the other hand the need arises to analyse the interaction of these new dynamic components with the existing power system. These interactions can result in possible adverse effects, or can, through appropriate control means, bring benefits to the overall system. Papers from Pinares et al, Wenig et al, Song et al. and Beerten et al. focus on the modeling aspects of VSC HVDC for offshore wind applications. Pinares et al. present a novel approach for studying the stability at the DC side, focusing on the interaction between controllers in the different VSC HVDC converter stations. Wenig et al. present a MMC modeling and control concept which is suitable for transient HVDC grid studies. The model of the MMC converter, includes lower level controls such as energy balancing. Also the operation of the converter under unbalanced conditions is discussed. Song et al. present the modeling requirements of DC cable systems at high frequencies, addressing the need for distributed cable models when performing VSC HVDC grid studies involving fast transients. Beerten et al. investigate the small signal stability at the DC side. Their paper introduces a new methodology which is based on aggregated participation factors to distinguish between local modes, primarily associated with one terminal, and interaction modes involving multiple terminals, and this under various system configurations. The interactions between various systems is specifically addressed in papers by Zeni et al. and Wang et al. Zeni et al who present the possibility to use the controls of a wind farm connected through an HVDC system to provide power oscillation damping (POD) using active power modulation. The paper not only shows that POD can be provided, but also investigates the limitations imposed by the wind farm. The control presented aims at providing a robust strategy: able to deal with communication delays, avoiding possible mechanical resonances in the wind farm, avoiding a reduction in energy yield from the wind farm and incorporating power ramp rate limiters. Wang et al. present the dynamics at the DC grid side when including the reactor typically associated with DC breakers. The paper highlights the possible stability concerns when introducing these reactances and proposes a DCPSS controller to reduce their impact.

The guest editorial board included representatives from Europe, America and Asia:

- Jun Liang, Cardiff University, UK
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- Reza Iravani, Past Editor-In Chief, IEEE Transactions on Power Delivery

We acknowledge authors, reviewers, editors and the past and actual Editors in chief of IEEE Trans Power Delivery, for their valuable effort, which have led to a high quality papers. We are proud to present the special issue on HVDC Transmission Systems for Large Offshore Wind Power Plants and we hope it will be of interest for the IEEE PES community.

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