PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

PROMOTioN – EXECUTIVE SUMMARY OF PERIODIC REPORT

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Meshed high-voltage, direct current (HVDC) network technology is a potential candidate for the future electrical power infrastructure required to enable Europe to transition to a clean, reliable and affordable energy future. It supports the optimal exploitation of geographically spread renewable energy sources by enabling countries to efficiently and cost-effectively trade the electrical energy. Particularly, the rapid development of offshore wind power in the Northern Seas, which requires transporting large amounts of electrical power over long distances via submarine cables, is a key application. Traditionally, European companies have pioneered the application of offshore wind and HVDC technology through innovation, and applying this to meshed networks is the next logical step to maintain a competitive advantage.

In the past, several studies have shown the socio-economic benefits and technical implications of such a meshed HVDC network. The studies often assumed that the technology required to build a meshed HVDC network would be ready and available, and that regulatory hurdles could be overcome. PROMOTioN, Progress on Meshed Offshore HVDC Transmission Networks, aims to advance on those studies, by determining all technical, regulatory, legal and financial actions that are to be taken in order to implement a meshed HVDC grid, using the Northern Seas as an example case.

In PROMOTioN, the technical and operational requirements for meshed HVDC networks are developed to a deeper and realistic level of detail, and the key technical choices to be made are identified and supported. The technology maturity of main technical components, such as HVDC grid protection schemes, HVDC grid control strategies, HVDC circuit breakers and HVDC gas insulated systems is demonstrated, and recommendations for standardization, improving both technology and vendor interoperability, are provided. Current member state and EU level regulations and methodologies for cost-benefit analysis concerning the development of transnational transmission infrastructure are analysed to identify hurdles towards the implementation of a meshed offshore HVDC network. Based on this, changes are proposed to the existing EU financial and regulatory frameworks, to foster a healthy investment climate. Finally, a deployment plan and roadmap up to 2050 is developed, including both offshore wind generation as well as interconnection capacity between North Sea countries, in order to illustrate the meshed offshore HVDC grid development for different regulatory and technical concepts.

Whereas in the first reporting period PROMOTioN laid out the modelling and requirements groundwork, in the second reporting period, which runs between January 2017 and June 2018, PROMOTioN has focussed on carrying out a deep analysis of the technical, regulatory, economic and legal aspects of meshed offshore HVDC grid development. The analysis serves to act as a basis for the demonstration work packages and development of a deployment plan up to 2050. The following distinct points of progress can be noted:

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Formulation of a common set of requirements and scenarios

- The previously established qualitative requirements for the meshed offshore HVDC grid were where possible and necessary completed and quantified based on the knowledge gathered in the technical work packages.

- Based in part on the quantified requirements, a draft roadmap for the development of a meshed offshore HVDC grid was created in order to provide insight into the planning criteria and the offshore wind development and onshore grid scenario requirements which will be needed to develop the final deployment plan.

Modelling of key components and technologies

- System level and detailed models of HVDC circuit breakers, HVDC grid control strategies, HVDC grid protection systems and fault clearing strategies, and HVDC connected offshore wind farm controllers were completed and validated. Different types of HVDC circuit breakers (mechanical and hybrid) and different types of HVDC converters (VSC half bridge and full bridge, and diode rectifier) were considered. Different control strategies for the offshore windfarms and HVDC grid were modelled with the intention to study normal operation (steady-state and response to variation in inputs) as well as the response to emergency events such as faults on the AC onshore, DC offshore and AC offshore grids. The ability of the meshed offshore grid to deliver ancillary services to the onshore AC grid was included in the models.

- Detailed component level models of the mechanical and hybrid HVDC circuit breakers focussing on the thermal and mechanical behaviour were developed.

- Scaled kW-level hardware prototypes of the mechanical HVDC circuit breaker with active current injection and a hybrid breaker have been created and tested with a purpose-built power electronic test circuit. The prototypes will be used to demonstrate novel control strategies, thermal behaviour as well as failure modes.

- A parametric design model for the mechanical and hybrid HVDC circuit breaker has been developed, relating the required components to the required functionality and the voltage, current and energy rating of the HVDC circuit breaker. The model will be used as basis for bottom-up cost models.

Formulation of compliance evaluation and test procedures and methods

- Compliance evaluation procedures and criteria, as well as associated test cases for HVDC grid protection and fault clearing strategies, HVDC grid control strategies, and offshore wind farm control strategies have been developed.

- Based on the models, test cases and compliance evaluation procedures, detailed simulation studies have been performed to assess the dynamic and steady-state performance of different types of technical implementations of meshed HVDC offshore grids. Based on the simulation results the system level (RMS) and detailed models (EMTP/PSCAD) have been cross-validated.

- Requirements and a procedure for testing the DC fault current interruption capability of HVDC circuit breakers has been developed. The procedure is the same for all different types of HVDC circuit breakers considered within PROMOTioN (mechanical with active current injection, mechanical with voltage assisted resonance converter (VARC) and the hybrid breaker).

- The test circuit implementation at DNV GL KEMA high-power laboratory has been further fine-tuned and the maximum testing capacity assessed through further high-power tests.

- A common HVDC circuit breaker model test circuit was developed for verifying functionality and performance of HVDC circuit breaker models intended for simulation studies. Extensive simulation studies analysing the response of the mechanical, VARC and hybrid breaker to varying conditions were carried out. The model test circuit can also be used for cross-validating system level (RMS) and detailed component level (EMT/PSCAD) models of HVDC circuit breakers.

- Test requirements and a test procedure for the long-term test of an ABB 320 kV HVDC gas insulated system (GIS) prototype at DNV GL's KEMA high voltage laboratory were developed and agreed.

Development of HVDC grid protection technology

- A broad technical comparison of different fault clearing strategies and detection methods was completed based on simulation studies. This comparative analysis indicated different requirements and relative benefits depending on the respective AC and DC grids connected. As a result, insights on the technical requirements for DC grid protection were gained.

- An intelligent electronic device (IED) has been set up using multiple fault detection algorithms, enabling the investigation of the best performing fault clearing strategies in practice. New unit and functional tests for DC protection equipment were developed and the developed IED (and its algorithms) have passed all these tests and is now ready for system tests.

- First steps towards more industrialized DC grid protection strategies have been made with developments related to: failure mode assessment; KPIs for DC grid protection strategies; enhanced modelling requirements for converters (including restoration), sensors and algorithms; specific operating modes for different strategies (e.g. pole rebalancing, limiting mode of hybrid breakers,…); AC impact of DC grid protection strategies.

- A tool was developed for the preliminary risk assessment of fault clearing strategies as input to a techno-economic comparison based guide for the selection of the best performing strategy.

Demonstration of key technologies

- The HVDC circuit breaker test circuit's operation was demonstrated by testing the DC current interruption capability of a Mitsubishi Electric prototype of a mechanical HVDC circuit breaker with active current injection in DNV GL's KEMA high-power laboratory.

- The DC current interruption capability of a SCiBreak prototype of a mechanical HVDC circuit breaker with a voltage assisted resonance converter was successfully demonstrated.

- The basic functionality of the HVDC grid protection intelligent electronic device was demonstrated by means of type testing, and will be used for system testing in the next period.

- All equipment necessary for the demonstration of a 320 kV HVDC GIS test pole has been specified, procured and delivered and is ready for assembly at the high voltage test laboratory.

- All equipment necessary for the demonstration of HVDC grid control strategies has been specified and procured and will be ready by the end of 2018.

Development of a financial & economic framework

- A cost data collection effort was initiated to collect real cost information on components that are required in meshed offshore HVDC grids, such as converters, platforms, cables and AC equipment. The data is collected from consortium partners such as TSOs, and from publicly available sources such as press releases. The data is parametrised to develop generalised validated cost models for use in cost – benefit analyses. Bottom-up cost models are developed for components for which no cost data is available such as HVDC circuit breakers, diode rectifier converters and full bridge converters.

- A cost –benefit analysis methodology based on ENTSO-E CBA principles was developed which is suitable for assessing the costs and benefits of meshed offshore grid development. This is necessary as the current ENTSO-E methodology aims at assessing the costs and benefits of a 'project' which is limited in scope and time, as opposed to continuous grid development which is not. The methodology is in part based on previously developed recommendations for CBA methods for offshore infrastructure.

- Existing financing models of transmission grids in the EU (offshore, connection of wind farms and interconnectors) were analysed including support schemes, investments and efficiency incentives and transmission charging.

Development of a legal & regulatory framework

- An analysis was carried out of the current coordination between offshore and onshore grid planning and the participation of users in grid planning.

- An overview of different meshed offshore grid governance and ownership models was developed.

- A preliminary suggestion was made to create a new legal definition/asset for hybrid assets (combined wind farm export and interconnector). This topic has been picked up by NSEC and the ministries/regulators are putting proposals forward which could/should be used in the context of the clean energy package.

- A close liaison with the North Seas Energy Forum was set up to ensure PROMOTioN results are directly transferred to key stakeholders.

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Development of a roadmap and deployment plan

- An initial roadmap for the development of a meshed offshore HVDC transmission network in the North Sea was drafted and resulted in some important conclusions. It highlighted the importance of the cost of HVDC circuit breakers and diode rectifier converter systems in determining economic viability. It was also concluded that AC technology will continue to play a significant role in offshore transmission infrastructure. Furthermore, it was shown to be likely/possible that several smaller radial and meshed HVDC grids may appear, rather than one large interconnected one. Lastly, the roadmap development highlighted the need to a discussion on planning requirements for offshore grids which may defer significantly from onshore grids and hence lead to different grid topologies.

- A preliminary analysis of the key technical, regulatory, legal and market barriers to the implementation of a meshed offshore HVDC grid has been completed based on the current status of the work packages 2-7.

- Four concepts were developed for potential offshore grid development which illustrate various degrees of international cooperation and coordination of offshore wind generation development and grid planning, as well as different tendencies towards clustering offshore wind resources. The concepts will serve to illustrate different potential political and regulatory environments and will be used as starting points for the topology development, subsequent technology selection and cost-benefit analyses.

- A bottom-up approach to determining an offshore wind generation scenario up to 2050 was started based on suitability (such as water depth, average wind speed, etc.) of different North Sea sectors for exploitation.

Increasing technology readiness level of key technologies

- With the successful demonstration of the DC current interruption of prototypes of the Mitsubishi Electric and SCiBreak HVDC circuit breakers, the technology readiness level of these components has been increased from 5 to 6. A further increase to level 7 is expected in the 3rd reporting period when more complete, functional and higher-rated prototypes will be more extensively tested.

- With the successful type testing of the HVDC grid protection IED, the technology readiness level of this technology has been increased from 5 to 6. A further increase to level 7 is expected in the 3rd reporting period when the IED will be more extensively tested in the operational environment at the multi-terminal test environment (MTTE).

- With the preparation of the HVDC GIS prototype and agreement on the test method to be followed, all things are in place to increase the TRL of HVDC GIS technology from 6 to 8 in the 3rd reporting period.

Two new demonstration work packages were added to the project concerning topics which are considered crucial for meshed offshore grid development. The first concerns gas insulated system technology for HVDC systems, which can unlock significant cost savings through physical footprint reduction. A guide for specifying such technology as well as a proposed test method to qualify the technology is developed. A monitoring and condition assessment system is developed and tested. The performance of different insulating gases is compared and demonstrated, and a 320 kV ABB commercial prototype will be subjected to long term testing at DNV GL's KEMA high voltage laboratory.

The second work package seeks to demonstrate HVDC grid control philosophies. At RWTH Aachen, a low voltage meshed DC grid supplied by scaled MMC converters is connected to linear amplifiers emulating different AC grids (or synchronous zones). The demonstrator enables the validation of grid control schemes under steady state and transient conditions, grid recovery strategies in case of faults. The impact on the AC grids both on and offshore, as well as the inclusion of diode rectifiers in meshed DC grids. Part of the demonstrator is a MW scale wind turbine inverter harmonic model validation test at DNV GL's Flex grid power laboratory.

A mid-term conference was organised by SOW. The conference was well-attended with over 150 participants from all stakeholders and received a satisfying amount of press-coverage. Prominent speakers and representatives of all stakeholder sectors led to lively and interesting discussion. Real displays of the HVDC GIS prototype and the protection IED were present to give attendees a first-hand experience with these new technologies.

A total of 18 milestones were achieved, which have been reported in 33 deliverables, as well as 16 journal papers, 37 conference papers and numerous presentations and workshops, which have been published on the project website. Three half-yearly internal project conventions were held as well as an intermediate conference, the results of which were exchanged. Various consultations with project stakeholders and reference groups were held.

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