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Deliverable 11.1 Harmonization catalogue

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Harmonization catalogue

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
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0.1	2018-05-07	Template and IEC TC88	Poul Sørensen

LIST OF CONTRIBUTORS

Work Package 1 and deliverables 1.1, 1.5 & 1.7 involve a large number of partners and contributors. The names of the partners, who contributed to the present deliverable or to one of its predecessors, are presented in the following table.

PARTNER	NAME
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CONTENT

1 INTRODUCTION

1.1 WP11 – HARMONIZATION TOWARDS STANDARDIZATION

In order to fully exploit the technical work within the PROMOTioN project, contribution to harmonisation is strongly encouraged. The purpose of this Harmonization Catalogue is to provide a state-of-the-art regarding harmonization of HVDC systems, identify gaps in this harmonization, and analyse how findings in the PROMOTioN project can contribute. An overall conclusion is that PROMOTioN should contribute to ongoing work in existing best practice and standard working groups rather than establish new working groups.

The Harmonization Catalogue is the first deliverable from PROMOTioN WP11 on Harmonization Towards Standardization. It is intended to found a common basis for the work in WP11.

The overall objective of WP11 is to support and establish harmonization of the industry's best practices, standards and requirements for HVDC grid systems and DC connected offshore wind power plants. WP11 aims to ensure that the experience collected through the project – including research and engineering in WP1-6, and demonstrations in WP9, 10, 15 & 16 – is utilised in ongoing and future harmonization work. Those inputs to WP11 are illustrated in the PROMOTioN work package structure shown in Figure 1.

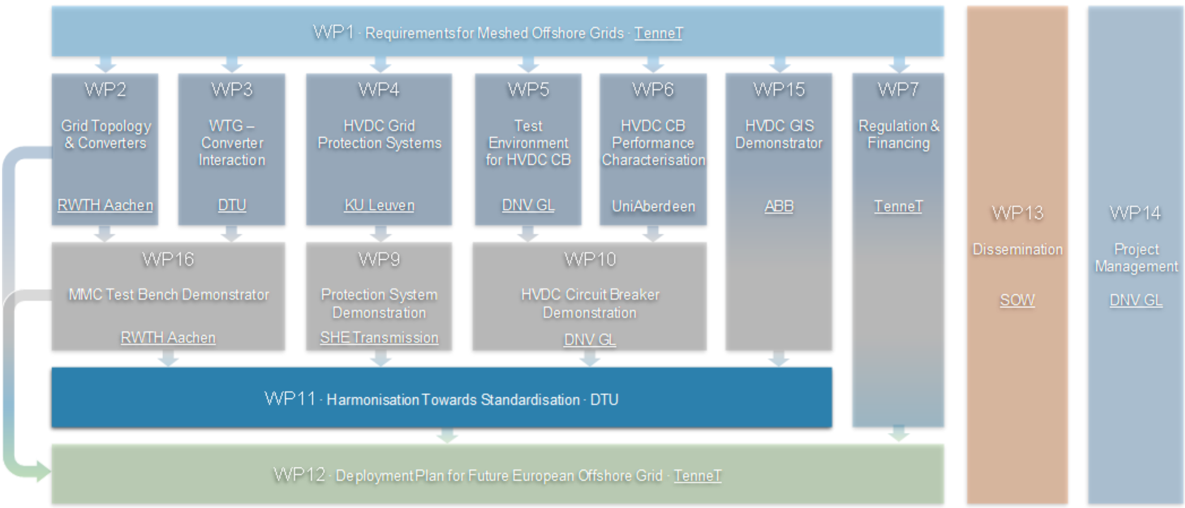

Figure 1. PROMOTioN work package structure illustrating how WP11 aims to ensure that the experience collected through the project – including research and engineering in WP1-6, and demonstrations in WP9, 10, 15 & 16 – is utilised in ongoing and future harmonization work.

WP11 also aims to contribute to the harmonization of the work in existing and future working groups in IEC, CENELEC, CIGRE, and in national as well as the European grid codes. Several of those working groups are covering overlapping topics, and there is a need to ensure that this work is aligned.

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WP11 includes the main HVDC system manufacturers and thereby ensure that the different manufacturer concepts are considered in the relevant working groups.

The more specific objectives of WP11 are:

- to provide a consistent and harmonised set of functional requirements to HVDC systems, wind power plants and other AC systems connected to the HVDC systems;
- to recommend test procedures for converters, protection systems, switchgear, wind turbines and plants in HVDC systems;
- to recommend requirements to models of HVDC systems and HVDC connected wind power plants;
- to recommend best practice for compliance validation of wind power plants connected to HVDC systems.

1.2 D11.1 – HARMONIZATION CATALOGUE

The purpose of the Harmonization Catalogue is to identify and analyse potential contributions from PROMOTioN's technical work packages to ongoing and possible new harmonization activities on offshore HVDC transmission networks.

Figure 2 illustrates how the research, development and demonstration in PROMOTioN has a potential to contribute to harmonization at different levels, in terms of "best practices", "standards" and "requirements".

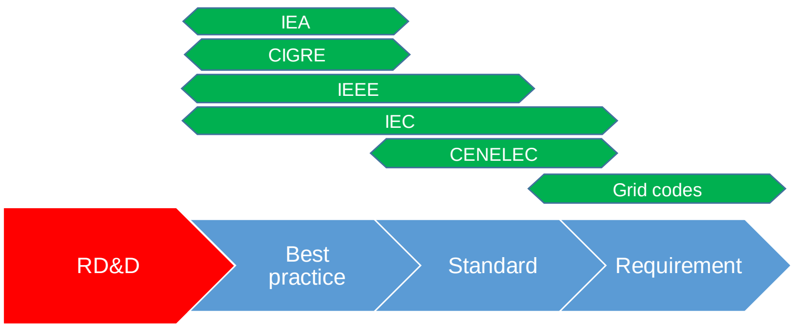

Figure 2. Research, development and demonstration (R&D&D) has a potential to contribute to harmonization in terms of "best practices", "standards" and "requirements". The figure shows where different harmonization bodies are in this harmonization scale.

Chapter 2 provides an overview of different harmonization groups and documents which have been identified as relevant for the technical work in PROMOTioN.

Chapter 3 provides an analysis of the potential new contributions which PROMOTioN could have to harmonisation.

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Chapter 4 is the conclusions including recommendations to new harmonization initiatives which will be proposed in workshops with harmonization groups.

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2 HARMONIZATION GROUPS AND DOCUMENTS

2.1 CIGRE

2.1.1 SC A3. HIGH VOLTAGE EQUIPMENT

Working group	Number CIGRE JWG A3B4-34	Title Technical Requirements and Specifications of State-of-the-Art HVDC Switching Equipment	
Timeline	Past / Ongoing / Planned Past	Begin year 2014	End year 2017
Promotion partner involvement	Person name(s) R.P.P. Smeets, N.A. Belda	Partner(s) DNVGL, Mitsubishi Electric (MEU), ABB	Role(s) Secretary, members
Scope	CIGRÉ Technical Brochure 683 extensively discusses the state-of-the-art, technical and applicational background of HVDC switchgear. It overviews and categorizes the existing HVDC switchgear in point-to-point connections in many projects. Transfer switches, earthing switches, disconnection and paralleling switches are presented. HVDC circuit breakers are discussed in greater depth, but from a conceptional point of view, because no project information was available at the time of writing. First, the nature of HVDC faults in systems have been described. Next. A definition of terminology, describing the various phases in fault current interruption is proposed. Then, a detailed overview of available technologies is presented (as present in PROMOTioN): passive oscillation HVDC circuit breakers, active current injection HVDC circuit breakers, power electronic HVDC circuit breakers and mechanical and power electronic hybrid HVDC circuit breakers are defined and discussed. Extra attention is paid to the essential building blocks: high-speed drives, surge arresters, semi-conductors and residual current breakers. A comparison is presented between the different HVDC breaker technologies, as well as gaps have been identified between requirements (as far as known) and performance specifications. The last part discusses the test methods employed so far and proposes test methods, as introduced in PROMOTioN		
Documents	Number CIGRE TB 683 (2017)	Title Technical Requirements and Specifications of State-of-the-Art HVDC Switching Equipment	
Further comments	This working group lies at the basis of the test methods, used in WP5, 10.		

Working group	Number CIGRE WG A3-39	Title Application and field experience with Metal Oxide Surge Arresters	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2017	End year 2020
Promotion partner involvement	Person name(s) N.A. Belda	Partner(s) DNVGL	Role(s) Guest
Scope	This WG will report on a field survey of application of metal oxide surge arresters (MOSA), which will include applications in HVDC switchgear. Experience form WP 10 will be reported and discussed in the WG		
Documents	Number	Title	
Further comments	-		

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Working group	Number CIGRE WG A3-40	Title Technical requirements and field experiences with MV DC switching equipment	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2018	End year 2022
Promotion partner involvement	Person name(s) N.A. Belda	Partner(s) DNVGL, SciBreak	Role(s) Member
Scope	1. Collect the field experiences of MVDC switching equipment to interrupt the DC load and fault current in MV applications up to 52 kV 2. Review the existing prototypes and state of the art of MV DC switching equipment up to 52 kV. 3. Review experiences of monitoring and diagnosing the interrupting performance with MV DC switching equipment 4. Investigate the technical requirements for MVDC switching equipment used in different system configurations such as a point-to-point or multi-terminals MV grids, and understand the switching phenomena in MVDC grids 5. Summarize the technical requirements for the MVDC circuit breakers (compared with those for AC circuit breakers and HVDC circuit breakers) 6. Recommend testing requirements for MVDC switching equipment		
Documents	Number	Title	
Further comments	-		

Working group	Number CIGRE JWG B4A3.80	Title HVDC Circuit Breakers - Technical Requirements, Stresses and Testing Methods to investigate the interaction with the system	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2019	End year 2022
Promotion partner involvement	Person name(s) R.P.P. Smeets	Partner(s) DNV GL, Mitsubishi Electric	Role(s) Member
Scope	VSC-HVDC transmission is moving fast and is considered as the technology to realize the development and integration of large-scale renewable energy sources, in order to achieve high penetration and effective integration of the renewables and to mitigate the impacts of intermittent renewables on the power system, The relatively independent and adjacent VSC-HVDC systems can be interconnected together and step by step to form an HVDC grid, such as the "Super Grid" plan in Europe and the Zhangbei ±500kV HVDC grid project in China. The key element to establish HVDC grids in terms of efficiency and reliability as well as controllability, is the realization of viable HVDC circuit breakers. In 2013, technical brochure 533 "HVDC Grid feasibility study" prepared by WG B4.52 was published. This TB points out that "technical feasibility of building a large scale HVDC Grid requires that a fault has to be isolated very fast before it affects the HVDC voltage in other parts of the grid". Further, according to technical brochure 678 "Technical requirements and specifications of HVDC switching equipment" published by JWG A3/B4.34 in 2017, some HVDC circuit breakers prototypes have been completed and four categories of topologies were established: adopting a passive oscillating circuit method, a current oscillation system with active current injection, pure power-electronic devices in the nominal current path, a hybrid mechanical and power-electronic combination. The DC fault current can be quickly interrupted by the above stated technical solutions in the order of milliseconds. However, the interruption time will be a function of the circuit chosen. The fault current interrupting requirements will be driven by the system requirements and the functional specifications. However, it is very important to define the corresponding stresses and test methods for HVDC circuit breakers to ensure that the HVDC circuit		

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	breakers do meet such requirements. It is necessary and important to provide guidelines on how and the methodology available for testing of the different types of HVDC circuit breakers will ensure that the stresses are not exceeded and the performance functions are met. This WG will work in the close collaboration of SC A3. For this purpose, SC B4 will send a liaison to participate in WG A3.40. The detailed work will take into account technologies and results reported in the recent (August, 2018) collaborated CIGRE/IEEE workshop with the EU PROMOTioN project, as well as the results reported by IEC SC17A/AHG 60 (on HVDC switchgear). Scope: The objectives of this Working Group are to perform a technical requirement and stresses study to investigate the interaction between HVDC circuit breakers and the system from both simulation and experiment approaches. Based on the results of the study, the stresses imposed on the circuit breaker will be defined. Based on the above, the detailed technical requirements and required testing methods of HVDC circuit breakers will be proposed	
Documents	Number	Title
Further comments	Will have strong input from PROMOTioN WP 5, 10 results Its tasks are: 1. Describe basic configurations and overview of the HVDC circuit technologies available in the market and under research / development, including different designs of HVDC circuit breakers investigated in PROMOTioN project and other research projects in different countries. 2 Describe possible applications of HVDC circuit breaker and define technical requirements of HVDC CBs for these different applications; 3 Study specific component stresses (relevant to testing) under continuous operation, load switching and fault current switching. Specific attention will be given to behaviours due to operation of mechanical or hybrid switches, current commutation as well as energy dissipating processes within the equipment. 4 Specify testing methods for component and equipment;	

2.1.2 SC B4. HVDC AND POWER ELECTRONICS

Working group	Number B4	Title HVDC and power electronics	
Timeline	Past / Ongoing / Planned	Begin year	End year
Promotion partner involvement	Person name(s) Kamran Sharifabadi Olivier Despouys	Partner(s) STATOIL RTE	Role(s) ? French Regular Member
Scope	The work of the Study Committee addresses all the relevant Target Groups in Power Industry interested in Power Electronics. In addition to technical aspects also economical and environmental subjects of this technology and asset management are covered. The Study Committee activities include the following subjects: HVDC: economics of HVDC, applications, planning aspects, design, performance, control, protection, control and testing of converter stations, i.e. the converting equipment itself and also the equipment associated with HVDC links. Power Electronic for AC systems and Power Quality Improvement: economics, applica-tions, planning, design, performance, control, protection, construction and testing. Advanced Power Electronics: development of new converter technologies including con-trols, use of new semiconductor devices, applications of these technologies in HVDC, Power Electronics for AC systems and Power Quality Improvement. Power Electronics used in other fields of the Electric Power Industry , interesting for other Study		

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	Committees, will be covered by demand, this Committee being the Sponsoring Committee	

Working group	Number JWG B4/B5-59	Title Control and Protection of HVDC Grids	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2011	End year 2018
Promotion partner involvement	Person name(s) Willem Leterme	Partner(s) KUL	Role(s) Member
Scope	Functional requirements for protection, short circuit phenomena, short circuit current limiting techniques, protection system components, protection system overview.		
Documents	Number TB 739	Title Protection and local control of HVDC grids	
Further comments			

Working group	Number JWG B4/B1/C1-73	Title Surge and extended overvoltage testing of HVDC Cable Systems	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2016	End year 2018
Promotion partner involvement	Person name(s) Willem Leterme	Partner(s) KUL	Role(s) Member
Scope	Cable overvoltage considerations. Including: History and present practice, stresses with new technology, severity, statistics and testing schemes and equipment.		
Documents	Number	Title	
Further comments			

Working group	Number CIGRE WG B-74	Title Guide to Develop Real-Time Simulation Models (RTSM) for HVDC Operational Studies	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2016	End year 2018
Promotion partner involvement	Person name(s) Firew Dejene	Partner(s) KUL	Role(s) Member
Scope	Introduction to operational studies, RTSM for HVDC equipment, Slow acting control system models, RTSM of AC system, Model validation and testing, guidelines for studies.		
Documents	Number	Title	
Further comments			

Working group	Number CIGRE WG B4-67	Title Harmonic aspects of VSC HVDC, and appropriate harmonic limits	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2014	End year Finalising
Promotion partner involvement	Person name(s) Jef Beerten (via Geraint Chaffey)	Partner(s) KUL	Role(s) Member

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Scope	The traditional requirement of harmonic limits is being challenged by the integration of VSCs. Particularly, the harmonic spectrum significantly varies compared to traditional loads. Besides steady-state harmonics, instabilities can appear because of the interaction between converter control dynamics and AC network resonances. The WG determines the future need to represent better the AC network and converters in order to address system stability and harmonic studies.	
Documents	Number	Title
Further comments		

Working group	Number CIGRE WG B4-68	Title DC Harmonics and Filtering	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2016	End year 2018
Promotion partner involvement	Person name(s)	Partner(s)	Role(s)
Scope	CIGRÉ Technical Brochure 92 “DC Side Harmonics and Filtering in HVDC Transmission Systems” (1994) was prepared by Task Force 2 of WG14.03. It is an extensive treatment of the subject, has been quoted in numerous Technical Specifications for HVDC Projects, and is not known to contain any technical errors. However, the typed format of the Brochure is outdated and makes it a little difficult to read and to access key information. The Brochure itself, being quite old, has slipped out of people’s knowledge – to the extent that the appropriate IEC group dealing with this area recently stated that there was no CIGRÉ publication on DC filters. There are also aspects of the document which could be improved. It is therefore proposed that a revision of this Technical Brochure should be undertaken. The revised document could then be used by IEC in the normal process of adopting the technical work which flows from CIGRÉ		
Documents	Number	Title	
Further comments			

Working group	Number CIGRE WG B4-64	Title Impact of AC System Characteristics on the Performance of HVDC schemes	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2014	End year Finalising
Promotion partner involvement	Person name(s) Jef Beerten (via Geraint Chaffey)	Partner(s) KUL	Role(s) Convener
Scope	The WG analyses the limitations of the SCR or short-circuit based calculations in giving an indicator related to the system strength. The WG has determined that networks with a large infeed of converters are significantly influenced by the AC voltage control of these converters and consequently, the system strength is also influenced by their controls. Short-circuit based calculations neglect up to a large extent the control operating mode. Therefore, other converter representations need to be used.		
Documents	Number	Title	
Further comments			

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Document	Number TB 269	Title VSC Transmission	
Timeline	Begin year	End year 2005	Stage Published
Scope	This Brochure describes VSC Transmission technology, i.e. HVDC transmission using Voltage Sourced Converters. A comparison with Line Commutated HVDC technology is provided. The WG found no technical reason why this technology could not be used at high voltage and power, and concluded that such development would depend solely on the perceived commercial return on the R&D investment.		
Further comments			

Document	Number TB 337	Title Increased System Efficiency by Use of New Generations of Power Semiconductors	
Timeline	Begin year	End year 2007	Stage Published
Scope	The TB presents the present developments of power semiconductors, with lower losses, higher switching frequency, converter modularization…, and their new application areas, in order to propose and evaluate new or enhance equipment for increased system efficiency.		
Further comments			

Document	Number TB 364	Title Systems with multiple DC Infeed	
Timeline	Begin year	End year 2008	Stage Published
Scope	The TB provides an analytical framework for the understanding of interactions amongst multiple HVDC line commutated inverter stations within a common ac system. The theoretical development is complemented by actual system examples of multi-infeed HVDC planning		
Further comments			

Document	Number TB 370	Title Integration of large Scale Wind Generation using HVDC and Power Electronics	
Timeline	Begin year	End year 2009	Stage Published
Scope	New large wind farms, both onshore and offshore, may face challenges such as, system stability issues, the need for the wind farm to provide system/ancillary services, and difficulties to build overhead lines. The TB shows how HVDC and other types of Power Electronics can help overcome these challenges, thereby helping to integrate large scale wind farms into power systems.		
Further comments			

Document	Number TB 388	Title Impacts of HVDC lines on the economics of HVDC projects	
Timeline	Begin year	End year 2009	Stage Published
Scope	The study considers the overall HVDC system economics, capital (lines and stations), losses, operation and maintenance. The most economically favorable voltages and conductor configurations are studied for several HVDC system alternatives. It is shown how the HVDC line and the converter stations selection impact each combination.		

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	Directives are presented on the 'best-solutions' for different sets of transmission parameters.
Further comments	

Document	Number TB 492	Title Voltage Source Converter (VSC) HVDC for Power Transmission - Economic Aspects and Comparison with other AC and DC Technologies		
Timeline	Begin year	End year 2012	Stage Published	
Scope	The objective of the WG was to develop an assessment process to evaluate the beneficial impact of VSC-HVDC on power systems. The proposed methodology includes a straightforward analysis of important environmental facts that have to be taken into account for an appropriate assessment. Case studies have been provided in order to demonstrate the application of the proposed methodology. This WG gives a snapshot on the current technology, application areas and economic values. With ongoing developments it can be expected that VSC-HVDC will become even more attractive for bulk power transmission and might become an economic feasible alternative to other technologies.			
Further comments				

Document	Number TB 533	Title HVDC Grid Feasibility Study		
Timeline	Begin year	End year 2013	Stage Published	
Scope	Until now most HVDC schemes have been point to point connections. A few multi-terminal schemes have been built with one extra terminal. But there have been many discussions of using HVDC for more advanced grids. The TB investigates the technical and economic feasibility to build such HVDC grids. The first question to answer is if HVDC grids offer any advantage over many point to point HVDC connections inside an AC grid. Another important question is if it will be possible to build HVDC breakers that are necessary to make the grid reliable. One more question is if one can make protections and control to the grid. These and many other challenging questions are studied in the Brochure.			
Further comments				

Document	Number TB 536	Title Influence of Embedded HVDC Transmission on System Security and AC Network Performance		
Timeline	Begin year	End year 2013	Stage Published	
Scope	This brochure highlights the gain in flexibility provided by an embedded HVDC link (defined as a DC link with at least two ends connected to a single synchronous AC network) for an existing HVAC grid. It also points out the possible technical issues that may arise, along with the different capabilities and performances depending on the underlying DC technology. Illustrations through existing or planned projects are proposed, in addition to open models for a benchmark network and VSC converters.			
Further comments				

	Number	Title

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Document	TB 563	Modelling and Simulation Studies to be performed during the lifecycle of HVDC Systems	
Timeline	Begin year	End year 2013	Stage Published
Scope	The purpose of this CIGRE TB is to provide an overview of the simulation tools, models and study procedures typically required at different stages of the lifecycle of an HVDC system. The document classifies the lifecycle of HVDC into five main phases: studies for planning and preparation of technical specification of an HVDC project; studies performed during bid process; post award studies; studies performed for commissioning, studies over the operational life of the HVDC system. For each stage the brochure presents the objectives, required input data and results of the main simulation studies as well as discusses the study related responsibilities between the entities involved to the HVDC project. The brochure also presents examples how the main simulation tools presented in the brochure are applied for HVDC lifecycle related studies.		
Further comments			

Document	Number TB 604	Title Guide for the Development of Models for HVDC Converters in a HVDC Grid	
Timeline	Begin year	End year 2014	Stage Published
Scope	This TB documents the requirements of simulation models for modular multi-level voltage-sourced converters (MMC-VSC) that would form the basis of a DC Grid and provides a framework for model development that is consistent with known MMC-VSC technologies presently used. This framework can be adapted to changing power electronic topologies and control algorithms. In addition, a 9 bus DC Grid test system was developed and documented. Two and four bus test systems that are subsets of the 9 bus system are also presented.		
Further comments	Basis for modelling of HVDC converters in WP2		

Document	Number TB 619	Title HVDC connection of offshore wind power plants.	
Timeline	Begin year	End year 2015	Stage Published
Scope	The first wave of HVDC connected offshore wind power plants (WPPs) has been commissioned and many more are planned in the North Sea, along with other sites around the world. VSC-based HVDC has become the preferred solution for large offshore WPPs, with cable distances typically above 100 km (including both offshore cable and on shore cable to the converter terminal) to the AC grid connection point. This is largely due to several technology advantages offered by VSCs, when compared to other HVAC or HVDC options, resulting in a more economically attractive transmission solution. In addition, a number of HVDC submarine cable connections for power exchange between countries are being planned and the possibility of connecting WPPs to these interconnections, and to future HVDC grids, are being seriously considered. The issues associated with expanding a WPP and HVDC connections with equipment from multiple vendors are subjects which need to be developed further, but are outside the scope of this brochure. Compliance with Grid Codes (GCs), which define the performance during normal and abnormal operating conditions, is another subject area in need of further development. Existing GCs are however written for AC connected WPPs, and for an offshore WPP these conditions typically apply only at the AC grid connection point. This raises the possibility of optimizing the overall WPP and the HVDC converter, with potential economic and maintenance benefits. However, if the HVDC connection and the WPP are provided by different vendors, such optimization cannot be done properly unless concerns about IP rights and operation benefits are clearly laid out and understood by all stakeholders involved. Guidelines and recommendation for point to point and multi terminal HVDC connection of offshore WPPs are therefore highly needed and of mutual		

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	interest for the HVDC and WTG industries in order to be able to provide the best possible solutions for all stakeholders.
Further comments	

Document	Number TB 657	Title Guidelines for the preparation of "connection agreements" or "Grid Codes" for multi-terminal schemes and DC Grids	
Timeline	Begin year	End year 2016	Stage Published
Scope	In the light of recent advancement of HVDC technology and the prospect of DC grid projects a need to address the required guide lines to develop the DC grid codes has arisen. Grid Codes or network codes are a set of rules and guidelines that govern a power system environment with multiple stakeholders, which describe e.g. the technical requirements that the equipment must fulfil in order to be integrated in the system and the rules and guidelines for interactions between the systems and stakeholders under steady state or abnormal operation conditions. This brochure provides recommendations on the models of interactions between the stakeholders and activities from planning to operation including technical aspects of planning, building and operation of a DC grid. Based on these recommendations a specific (set of) grid code(s) can be developed for the DC grid. The focus of this document is on the MTDC grids, and not on the HVAC networks which are connected to these DC grids. The objective of this brochure is to support the concerned stakeholders i.e. system planners, system operators (SO) and system users, to develop their own particular DC grid code		
Further comments			

Document	Number TB 671	Title Connection of wind farms to weak AC networks	
Timeline	Begin year	End year 2016	Stage Published
Scope	Issues with connection of wind power plants (WPP) to weak AC systems and how to improve the performance of these systems have been addressed. The working group has also investigated the interactions between wind generator converter systems, power system, and other power electronic in the vicinity. Guidelines for screening of potential connection points, selection of WPP models, and possible avenues for mitigating these issues are provided.		
Further comments			

Document	Number TB 683	Title Technical requirements and specifications of state-of-the-art HVDC switching equipment	
Timeline	Begin year	End year 2017	Stage Published
Scope	The new applications projected for future DC grids and multi-terminal DC systems at different voltages suggest that various DC equipment may be required; in particular all sorts of switching devices. However, the requirements for DC switching capabilities are different from those for AC equipment. In the brochure, a review of the technical requirements of HVDC switching equipment and an overview on the technical capabilities and limitations of existing switching equipment is given. Included are all sorts of switchgear such as disconnecting switches, earthing switches, transfer switches, and especially circuit breakers.		
Further comments	Results to be addressed by IEC TC 17A AHG60		

Document	Number TB 684	Title Recommended voltages for HVDC grids	
Timeline	Begin year	End year 2017	Stage Published
Scope	This technical brochure provides guidance for system planners and designers to choose the optimal DC voltage for High Voltage Direct Current (HVDC) grids. This includes a clear technical definition for the “DC voltage” in line with current practices and standards, a list of recommended values based on technical considerations and drivers from system planning, and a flowchart to guide the selection of the optimal voltage for individual projects.		
Further comments			

Document	Number TB 699	Title Control methodologies for direct voltage and power flow in a meshed HVDC grid	
Timeline	Begin year	End year 2017	Stage Published
Scope	This brochure provides the requirements and the classification of different control methods, including the coordinated system control, in order to ensure system security and efficient operation of the combined AC and HVDC system in an electricity market environment. In addition, a range of power flow controlling devices is described for efficient utilization of overhead lines and cables in the HVDC grid. The main focus for the technical brochure is on static control characteristics.		
Further comments			

Document	Number TB 713	Title Designing HVDC grids for optimal reliability and availability performance	
Timeline	Begin year	End year 2018	Stage Published
Scope	This Technical Brochure addresses the question of how to design a DC grid to achieve optimal reliability and availability performance. The starting point was to consider a suitable metric which could be used to assess the reliability and availability performance of the grid. Anticipating that a DC grid may not have an overall “architect”, the brochure considers the evolution of the grid from smaller radial and meshed multi-terminal systems and the factors which need to be considered when incorporating such building blocks to ensure that the grid can achieve high levels of reliability and availability. The technologies used at the AC to DC converter stations and at DC switching stations are discussed in the brochure in terms of their impact on the grid. The interconnecting medium between grid stations, whether overhead transmissionlines, underground cables or submarine cables, will also have a major impact on the grid in terms of their susceptibility to internal or external faults. The design of a DC grid will require analytical techniques to assess whether the evolving grid is able to achieve the desired levels of reliability and availability performance. The brochure includes an example of such a study, based on a deterministic evaluation of a DC grid test model, to illustrate the impacts of specific outage conditions on the energy not served by the grid. This study is presented as an illustrative example only and is not proposed as the methodology for future evaluations of DC grids, as other methods, including probabilistic techniques, may be adopted.		
Further comments			

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2.1.3 SC C1. POWER SYSTEM DEVELOPMENT AND ECONOMICS

Working group	Number WG C1.33	Title Interface & Allocation Issues in multi-party and/or cross-jurisdiction power infrastructure projects	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2016	End year 2019
Promotion partner involvement	Person name(s) Cornelis Plet	Partner(s) DNV GL	Role(s) Corresponding member
Scope	The increasing need for cross-border links and cross-sector (e.g. transmission-distribution) planning, as well as the growing diversification of relevant regulatory & market arrangements, call for deeper consideration of the evaluation principles and allocation criteria for costs, benefits and related risks on both sides of the link. The investigated dimensions for a new planned cross-jurisdiction project will be: - Allocation of cost / benefit / risk between countries and between grid operators - Allocation of asset ownership & responsibilities - Authorization / permitting of the same project in several jurisdictions - Legislation / regulation traps & gaps (for example EU/non-EU links) - Regulation and tariff applied on assets outside own jurisdiction - Investment schemes (public, private, mixed) and relevant governance (e.g. delivery company, etc.) - Business models set-up for economic feasibility and financial viability. This will be done in a structured way in order to: - Identify the challenges (in particular non-technical) for cross-jurisdiction projects; - Assess the different economic drivers for the different cases; - Explore advantages and disadvantages of the options for implementation schemes of multi-party projects; - Map the different possible business models, also considering asymmetric and unilateral investment schemes (for public lines), and the conditions imposed on Third Party Access exemptions (for merchant lines); - Study the interface issues and applicable business models for coordinated grid planning with neighbouring networks (distributors, active consumer grids, storage devices); - Try to extend the analysis from single lines to portion of grids (e.g. off-shore grids).		
Documents	Number	Title	
Further comments			

2.1.4 SC C2. POWER SYSTEM OPERATION AND CONTROL

Working group	Number JWG C2/B4.38	Title Capabilities and requirements definition for Power Electronics based technology for secure and efficient system operation and control	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2017	End year 2019
Promotion partner involvement	Person name(s) Olivier Despouys	Partner(s) RTE	Role(s) Member
Scope	The main scope of this Joint Working Group will be assessing best practices, technology capabilities and requirements for the integration of power electronics based technologies in the electrical power system, with the focus on its usage for system operations and control, taking advantage of the technical strengths, and mitigate the weaknesses. The main activities will focus on: 1. Reviewing previous CIGRE (e.g. SC B4, SC C6) and other work in this domain.		

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	2. Researching and describing world-wide implemented solutions and best operational and control practices with Power Electronics based equipment, building an overview on installed systems and developed solutions. 3. Identifying Power Electronics technology integration capabilities and control issues relevant for system operations, including further steps to better define the requirements and adequately utilise the various Power Electronics based network components. 4. Defining best practices for Power Electronics based technology used in system operation and control, including implementation in connection requirements and possible description of necessary analysis. 5. Recommending areas for further research and development, in order to gain new insights.	
Documents	Number	Title
Further comments		

2.1.5 SC C4. POWER SYSTEM TECHNICAL PERFORMANCE

Working group	Number C4.49	Title Multi-frequency stability of converter-based modern power systems	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2018	End year -
Promotion partner involvement	Person name(s) Łukasz H. Kocewiak	Partner(s) Ørsted	Role(s) Convenor
Scope			
Documents	Number	Title	
Further comments			

2.1.6 SC D1. MATERIALS AND EMERGING TEST TECHNIQUES

Working group	Number JWG N° D1/B3.57	Title Dielectric Testing of gas-insulated HVDC Systems	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2014	End year Finalising
Promotion partner involvement	Person name(s) Uwe Riechert Alain Girodet	Partner(s) ABB SGI	Role(s) Member Member
Scope			
Documents	Number	Title	
Further comments			

Document	Number TB 506	Title Gas Insulated Systems for HVDC: DC Stress at DC and AC Systems	
Timeline	Begin year	End year 2012	Stage Published
Scope	The following items are the main targets for the study in order to realize compact and highly reliable HVDC equipment:		

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	(1) Insulation characteristics in gas gap and of insulator surface, (2) Design of insulators for DC applications, (3) Charge accumulation characteristics on insulator surface and methods for their measurement, (4) Particle motions and measures for particle trapping, (5) Detection and analysis of partial discharges in HVDC applications, (6) Residual DC voltages and insulation characteristics of equipment with DC pre-stress at AC system. This Technical Brochure introduces and discusses the insulation characteristics under DC stress at DC and AC systems for gas insulated HV equipment such as GIS and GCB, considering the above issues and referring to the latest research. It summarizes the key technologies for practical GIS and GCB and will be a useful guidance to realize future compact and highly reliable high-voltage equipment.
Further comments	

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2.2 IEC

2.2.1 TC8. SYSTEM ASPECTS OF ELECTRICAL ENERGY SUPPLY

Working group	Number IEC TC8 / SC8A / AHG3	Title Roadmap of grid integration of renewable energy generation	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2018	End year 2019
Promotion partner involvement	Person name(s) Mr Ramón Blasco Giménez	Partner(s) UPV	Role(s) Member
Scope	To collect information from regulatory contents including network codes, policies, relevant issues in different countries, and work out a roadmap for SC 8A, which will mainly address the technology development tendency, nowadays best practices of RE grid integration, and the future standardization activities of SC 8A, in cooperation with the other relevant TCs and liaison organizations. Presently, there are two projects under AHG 3: 1. Roadmap of Grid Integration of Renewable Energy Generation 2. Evaluation on the standardization of DC Technology and AC/DC Hybrid systems for RE integration and other needs		
Documents	Number	Title	
Further comments	The task (project 2 above) on “Evaluation on the standardization of DC Technology and AC/DC Hybrid systems for RE integration and other needs” is allocated under SC8A/AHG3 in collaboration with SC8B/AGH2.		

2.2.2 TC17. HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR

Working group	Number IEC TC17 AHG4	Title DC switchgear	
Timeline	Past / Ongoing / Planned Past	Begin year 2016	End year 2017
Promotion partner involvement	Person name(s) R.P.P. Smeets	Partner(s) DNVGL, ABB, Mitsubishi Electric (MEU)	Role(s) Member
Scope	To investigate market relevance of DC switchgear and the need for standardization. This covers all technical aspects of air and gas-insulated switchgear for indoor and outdoor applications. Switchgear voltages above 1,5 kV d.c. The findings of the AHG were presented at the TC 17 meeting in April, 2017. This WG prepared an inventory on (pre-)standardization documents already available: 1. IEC TC 115 WG9 is drafting a standard on HVDC power system requirements for DC side equipment (including DC switchgear but excluding DC circuit-breakers). 2 Various Chinese national standards have been issued: GB/T 25307 (2010) on HVDC bypass switches; GB/T 25309 (2010) on HVDC transfer switches; GB/T 25091 (2010) on HVDC disconnecting- and earthing switches; A GB standard on HVDC circuit-breakers is being drafted.		
Documents	Number IEC 17/1032/INF (2017)	Title Final report of Ad Hoc Group 4 Switchgear	

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Further comments	Based on the outcome, IEC TC 17 decided to create a follow-up Ad Hoc Group in 2017

Document	Number IEC TC17 SC17C AHG37	Title DC switchgear assemblies		
Timeline	Begin year 2017		End year 2018	Stage running
Scope	Task: Proposal for standardization of DC switchgear assemblies. This covers all technical aspects of air and gas-insulated switchgear for indoor and outdoor applications. Switchgear voltages above 1,5 kV d.c.			
Further comments				

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Working group	Number IEC TC 17A AHG60	Title DC switchgear	
Timeline	Past / Ongoing / Planned Past	Begin year 2017	End year 2018
Promotion partner involvement	Person name(s) R.P.P. Smeets	Partner(s) DNVGL, ABB, Mitsubishi Electric (MEU)	Role(s) Member
Scope	To have a further look at document 17/1032/INF to determine if there is a need for standardization of DC switchgear. AHG 60 was formed with the task to further analyze document 17/1032/INF and make recommendations to SC 17A. Task of this WG is to make an analysis of standardization documents issued already. On of these is NB/T 42107, 2017: Chinese standard for DC circuit-breakers. This document has been analyzed, and its test requirements have been compared with HVAC breaker test-requirements laid down in IEC 62271-100. Ratings, dielectric testing and basic interruption duties were discussed. Based on the analysis outlined in this document AHG 60 makes the following recommendations to TC 17 and SC 17A. The order in which the switchgear appears does not necessarily reflect the order in which their standards or other deliverables should be developed. – To elaborate a document covering common specifications of HVDC switchgear; – To elaborate documents covering DC circuit-breakers, current transfer switches, DC disconnectors and earthing switches and DC by-pass switches; – The status of the documents, i.e. PAS, TS or IS should be decided by the TC or SC concerned.		
Documents	Number IEC 17A/1200/INF (2017)	Title Final report of Ad Hoc Group 60 Switchgear	
Further comments	Based on the outcome, IEC TC 17A decided Nov. 2018 to initiate work on four separate documents covering requirements and tests on DC switchgear		

2.2.3 TC88. WIND ENERGY GENERATION SYSTEMS

Working group	Number TC88 WG21	Title Wind energy generation systems – Measurement and assessment of electrical characteristics	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 1997	End year –
Promotion partner involvement	Person name(s) Poul Sørensen Lukasz Kocewiak Ömer Göksu	Partner(s) DTU Ørsted	Role(s) Member Member
Scope	The scope of this working group is to specify test and measurement procedures for electrical characteristics of wind turbines and wind power plants. The electrical characteristics include power quality aspects, control performance such as power control, reactive power control, voltage control, frequency control, as well as grid protection test.		
Documents	Number IEC 61400-21 IEC 61400-21-1 IEC 61400-21-2 IEC 61400-21-3	Title Wind turbines Wind turbines Wind power plants Technical Report: Wind turbine harmonic model and its application	
Further comments			

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Document	Number IEC 61400-21 Ed2	Title TC88. Wind turbines – Part 21. Measurement and assessment of power quality characteristics of grid connected wind turbines	
Timeline	Begin year 1997	End year 2008	Stage Published
Scope	This part of IEC 61400 includes: – definition and specification of the quantities to be determined for characterizing the power – quality of a grid connected wind turbine; – measurement procedures for quantifying the characteristics; – procedures for assessing compliance with power quality requirements, including estimation – of the power quality expected from the wind turbine type when deployed at a specific site, – possibly in groups. The measurement procedures are valid for single wind turbines with a three-phase grid connection, and as long as the wind turbine is not operated to actively control the frequency or voltage at any location in the network. The measurement procedures are valid for any size of wind turbine, though this standard only requires wind turbine types intended for PCC at MV or HV to be tested and characterized as specified in this standard. The measured characteristics are valid for the specific configuration of the assessed wind turbine only. Other configurations, including altered control parameters that cause the wind turbine to behave differently with respect to power quality, require separate assessment. The measurement procedures are designed to be as non-site-specific as possible, so that power quality characteristics measured at for example a test site can be considered valid also at other sites. The procedures for assessing compliance with power quality requirements are valid for wind turbines with PCC at MV or HV in power systems with fixed frequency within ±1 Hz, and sufficient active and reactive power regulation capabilities and sufficient load to absorb the wind power production. In other cases, the principles for assessing compliance with power quality requirements may still be used as a guide.		
Further comments			

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<table>
<tr><td>Document</td><td>Number
IEC 61400-21-1</td><td colspan="3">Title
TC88. Wind energy generation systems.
Part 21-1. Measurement and assessment of electrical characteristics – Wind turbines.</td></tr>
<tr><td>Timeline</td><td colspan="2">Begin year
2012</td><td>End year
2018?</td><td>Stage
CDV</td></tr>
<tr><td>Scope</td><td colspan="4">This part of IEC 61400 includes:
– definition and specification of the quantities to be determined for characterizing the electrical characteristics of a grid connected wind turbine;
– measurement procedures for quantifying the electrical characteristics;
– procedures for assessing compliance with electrical connection requirements, including estimation of the power quality expected from the wind turbine type when deployed at a specific site.

The measurement procedures are valid for single wind turbines with a three-phase grid connection. The measurement procedures are valid for any size of wind turbine, though this part of IEC 61400 only requires wind turbine types intended for connection to an electricity supply network to be tested and characterized as specified in this part of IEC 61400.

The measured characteristics are valid for the specific configuration and operational mode of the assessed wind turbine product family. If a measured property is based on control parameters and the behavior of the wind turbine can be changed for this property, it should be stated in the test report. Example: Grid protection, where the disconnect level is based on a parameter and the test only verifies the proper functioning of the protection, not the specific level.

The measurement procedures are designed to be as non-site-specific as possible, so that electrical characteristics measured at for example a test site can be considered representative for other sites.

IEC 61400-21-1 is for testing of wind turbines; all procedures, measurements and tests related to wind power plants are covered by 61400-21-2.

The procedures for assessing electrical characteristics are valid for wind turbines with the connection to the PCC in power systems with stable grid frequency.</td></tr>
<tr><td>Further comments</td><td colspan="4">This document will replace IEC 61400-21</td></tr>
</table>

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

<table>
<tr><td>Document</td><td>Number
IEC 61400-21-2</td><td colspan="3">Title
TC88. Wind energy generation systems.
Part 21-2. Measurement and assessment of electrical characteristics – Wind power plants.</td></tr>
<tr><td>Timeline</td><td colspan="2">Begin year
2012</td><td>End year
?</td><td>Stage
„Table of content“</td></tr>
<tr><td>Scope</td><td colspan="4">This part of IEC 61400 includes:
– Definition and specification of the quantities to be determined for characterizing the electrical characteristics of grid connected wind power plants;
– Measurement procedures for quantifying the electrical characteristics;
o Power quality aspects
o Steady state operation
o Control performance
o Dynamic response
o Grid protection
– Define measurement methods and requirements for fault recording
– Definition of measurement equipment, control signals & measurement points, references
– Aggregation methods for power quality aspects (Flicker, Harmonics, Switching events ? ..)
– Not included is e.g. reactive power capability of WPP, control performance for the planning phase etc. (refer to e.g. loadflow studies etc.)
– Procedures for wind power plant controller test
The measurement procedures are valid for Wind Power Plants. The measurement procedures are valid for any size of wind power plant.
– Connected to One connection point
Included:
– Turbine mix, (Aggregation method ?)
– Included HVDC connected power plants (AC side) wind power plant connection point
– Focus is the electrical characteristics on the connection point.
– Compensation equipment, Tap changer etc. if this is part of the WPP
– Storage equipment ?
Not included:
– Multi park control / cluster control
– Compliance test / Evaluation assessment (Pass / fail)
– EMC test
– Component test, SVC, switch gear, …
– Communication interface test (protocols, …)

Not included: Switch gear, SVC, Storage systems, component test, they are covered by other IEC standards.

The measured characteristics are valid for the specific configuration and operational mode of the assessed wind power plant only. If a measured property is based on control parameters and the behaviour of the Wind power plant can be changed for this property, it must be stated in the report. Example: Grid protection, where the disconnect level is based on a parameter and the test only verifies the proper functioning of the protection, not the specific level.

The procedures for assessing compliance with grid connection requirements are valid for wind power plants in power systems with fixed frequency and a sufficient short circuit power.</td></tr>
<tr><td>Further comments</td><td colspan="4">The writing of this document has never really started, MT21 has been busy with the other parts.</td></tr>
</table>

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<table>
<tr><td>Document</td><td>Number
IEC 61400-21-3</td><td colspan="3">Title
TC88. Wind energy generation systems.
Part 21-3. Measurement and assessment of electrical characteristics – Technical Report: Wind turbine harmonic model and its application.</td></tr>
<tr><td>Timeline</td><td colspan="2">Begin year
2014</td><td>End year
2019</td><td>Stage
Final draft</td></tr>
<tr><td>Scope</td><td colspan="4">This Technical Report, which is informative in its nature, provides guidance on principles which can be used as the basis for determining the application, structure, requirements for wind turbine harmonic model. For the purposes of this report, a harmonic model means a model that represents harmonic emissions of different wind turbine types interacting with the connected network.
This Technical Report is focused on providing technical guidance concerning the wind turbine harmonic model. The Technical Report describes the harmonic model in detail covering such aspects as application, structure as well as validation. By introducing a common understanding of the wind turbine representation from a harmonic performance perspective, the technical report aims to bring the overall concept of the harmonic model closer to the industry (e.g. suppliers, developers, system operators, academia, etc.).
A standardized approach of wind turbine harmonic model representation is presented in this Technical Report. It is expected that the harmonic model will find a broad application in many areas of electrical engineering related to design, analysis, and optimisation of electrical infrastructure of onshore as well as offshore wind power plants.
The structure of the harmonic model presented in this Technical Report will find an application in the following potential areas:
– Evaluation of the wind turbine harmonic performance during the design of electrical infrastructure and grid-connection studies.
– Harmonic studies/analysis of modern power systems incorporating a number of line side converters.
– Active or passive harmonic filter design to optimize electrical infrastructure as well as meet requirements in various grid codes.
– Sizing of electrical components (e.g. harmonic losses, static reactive power compensation, noise emission, harmonic compatibility levels, etc.) within wind power plant electrical infrastructure.
– Wind power plant electrical infrastructure optimisation on a system level, e.g. resonance characteristic shaping, planning levels definition and evaluation, etc.
– Evaluation of external network background distortion impact on wind turbine harmonic assessment.
– Standardised communication interfaces in relation to wind turbine harmonic data exchange between different stakeholders (e.g. system operators, generators, developers, etc.).
– Universal interface for harmonic studies for engineering software developers.
– Possible benchmark of wind turbines introduced to the academia and the industry.
– The advantage of having standardized wind turbine harmonic performance measure by means of the harmonic model is getting more and more crucial in case of large systems with different types of wind turbines connected to them, e.g. multi-cluster wind power plants incorporating different types of wind turbines connected to the same offshore or onshore substation.</td></tr>
<tr><td>Further comments</td><td colspan="4"></td></tr>
</table>

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Working group	Number TC88 WG27	Title Wind energy generation systems – Electrical simulation models	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2009	End year –
Promotion partner involvement	Person name(s) Poul Sørensen	Partner(s) DTU	Role(s) Convener
Scope	The scope of this working group is to specify generic electrical simulation models for wind turbines and wind power plants, and to specify procedures for validation of such models.		
Documents	Number IEC 61400-27-1 Ed1 IEC 61400-27-1 Ed2 IEC 61400-27-2	Title Wind turbines Generic models Model validation	
Further comments			

Document	Number IEC 61400-27-1 Ed 1	Title TC88. Wind turbines – Part 21-1. Electrical simulation models – Wind turbines.	
Timeline	Begin year 2009	End year 2015	Stage Published
Scope	IEC 61400-27 defines standard electrical simulation models for wind turbines and wind power plants. The specified models are time domain positive sequence simulation models, intended to be used in power system and grid stability analyses. The models are applicable for dynamic simulations of short term stability in power systems. IEC 61400-27 includes procedures for validation of the specified electrical simulation models. The validation procedure for IEC 61400-27 is based on tests specified in IEC 61400-21. IEC 61400-27-1 Ed1 specifies dynamic simulation models for generic wind turbine topologies/ concepts / configurations on the market. IEC 61400-27-1 defines the generic terms and parameters with the purpose of specifying the electrical characteristics of a wind turbine at the connection terminals. The models are described in a modular way which can be applied for future wind turbine concepts. The dynamic simulation models refer to the wind turbine terminals. The validation procedure specified in IEC 61400-27-1 focuses on the IEC 61400-21 tests for response to voltage dips, reference point changes and grid protection. The electrical simulation models specified in IEC 61400-27 are independent of any software simulation tool.		
Further comments			

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Document	Number IEC 61400-27-1 Ed2	Title TC88. Wind energy generation systems Part 27-1. Electrical simulation models – Generic models	
Timeline	Begin year 2015	End year 2019?	Stage CD 2016
Scope	IEC 61400-27-1 defines standard electrical simulation models for wind turbines and wind power plants. The specified models are time domain positive sequence simulation models, intended to be used in power system and grid stability analyses. The models are applicable for dynamic simulations of short term stability in power systems. IEC 61400-27-1 defines the generic terms and parameters for the electrical simulation models. IEC 61400-27-1 specifies electrical simulation models for the generic wind power plant topologies / configurations currently on the market. The wind power plant models include wind turbines, wind power plant control and auxiliary equipment. The wind power plant models are described in a modular way which can be applied for future wind power plant concepts and with different wind turbine concepts. IEC 61400-27-1 specifies electrical simulation models for the generic wind turbine topologies/ concepts / configurations currently on the market. The purpose of the models is to specify the electrical characteristics of a wind turbine at the wind turbine terminals. The wind turbine models are described in a modular way which can be applied for future wind turbine concepts. The specified wind turbine models can either be used in wind power plant models or to represent wind turbines without wind power plant relationships. The electrical simulation models specified in IEC 61400-27-1 are independent of any software simulation tool.		
Further comments	IEC 61400-27-1 Ed2 and IEC 61400-27-2 Ed1 shall replace IEC 61400-27-1 Ed1		

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<table>
<tr><td>Document</td><td colspan="2">Number
IEC 61400-27-2</td><td colspan="2">Title
Wind energy generation systems –
Electrical simulation models –
Model validation</td></tr>
<tr><td>Timeline</td><td>Begin year
2015</td><td colspan="2">End year
2019?</td><td>Stage
CD 2016</td></tr>
<tr><td>Scope</td><td colspan="4">IEC 61400-27-2 specifies procedures for validation of electrical simulation models for wind turbines and wind power plants, intended to be used in power system and grid stability analyses. The validation procedures are based on the tests specified in IEC 61400-21. The validation procedures are applicable to the generic models specified in IEC 61400-27-1 and other fundamental frequency wind power plant models and wind turbine models.

The validation procedures for wind turbine models focus on tests for response to voltage dips, voltage swells and reference point changes. Those validation procedures refer to the wind turbine terminals.

The validation procedures for wind power plant models focus on tests for response to reference point changes as well as voltage dips and voltage swells. Those validation procedures refer to the point of connection of the wind power plant.

The validation procedures specified in IEC 61400-27-2 are based on comparisons between test results and simulations, but they are independent of choice of software simulation tool.</td></tr>
<tr><td>Further comments</td><td colspan="4"></td></tr>
</table>

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2.2.4 TC95. MEASURING RELAYS AND PROTECTION EQUIPMENT

Technical Committee Activity	Number TC95	Title Measuring relays and protection equipment		
Timeline	Past / Ongoing / Planned Ongoing		Begin year -	End year –
Scope	Standardisation of measuring relays and protection equipment used in various fields of electrical engineering covered by IEC, taking into a ccount combinations of devices to form schemes for power system protection including the control, monitoring and process interface equipment used with those systems. Excluded are the following: All devices covered by standards prepared by other IEC Technical Committees, for example instrument transformers (TC 38)			
Further comments	Future activity is planned for HVDC relays (also known as HVDC protection IEDs), although there is no known active working group or document.			

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2.2.5 TC115. HIGH VOLTAGE DIRECT CURRENT (HVDC) TRANSMISSION FOR DC VOLTAGES ABOVE 100 KV

Document	Number IEC TS 63014-1:2018	Title High voltage direct current (HVDC) power transmission-System requirements for DC-side equipment Part 1: Using line-commutated converters **Technical Specification**	
Timeline	Begin year -	End year 2018	Stage Published
Scope	This Technical Specification is intended to provide an overall and consistent set of guidelines to facilitate the specification of equipment for the DC-side of a high-voltage direct current (HVDC) system using line-commutated converters. For point-to-point HVDC transmission systems, this document covers all DC-side equipment located between the converter valves and the DC overhead line or cable termination, excluding the converter valves themselves. For back-to-back HVDC systems, this document covers all DC-side equipment excluding the converter valves themselves. Throughout this publication, the terms 'direct voltage' and 'DC voltage' are used interchangeably, as are 'direct current' and 'DC current'. Traditionally, the largest items of such equipment, such as the DC smoothing reactor and DC harmonic filters, have generally been located outdoors but increasingly the trend is to locate such equipment indoors (although not in the valve hall itself) to provide protection from pollution. Although product standards exist for some DC-side equipment types, many such items of equipment have only standards written for AC applications and, in such cases, the purpose of this document is to provide guidance as to how to specify the additional requirements (particularly with regard to testing) for such equipment to cover their use in DC conditions. The converter itself is excluded from this scope, being covered by IEC 60700-1 and IEC 60700-2. Although this document includes requirements for DC disconnectors and certain types of specialised DC switching devices (such as the Metallic Return Transfer Switch (MRTS)), it excludes any type of DC circuit-breaker designed to interrupt fault currents. DC-side equipment for HVDC systems based on voltage-sourced converter (VSC) technology is excluded from this document and will be covered in a future Part 2 of IEC 63014.		
Further comments			

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2.3 CENELEC

2.3.1 TC 8X SYSTEM ASPECTS OF ELECTRICAL ENERGY SUPPLY

Working group	Number TC 8X/WG 06	Title System Aspects of HVDC grids	
Timeline	Past / Ongoing / Planned Ongoing	Begin year 2013	End year -
Promotion partner involvement	Person name(s) Frank Schettler Stephan Wietzel	Partner(s) Siemens Siemens	Role(s) Convenor Member
Scope			
Documents	Number FprTS_50654-1 & FprTS_50654-2	Title HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines & Part 2: Parameter Lists	
Further comments	The working group is divided in five subgroups: • Coordination of HVDC Grid and AC Systems (Tasks are completed – not active) • HVDC Grid Control • HVDC Grid Protection • HVDC Grid System Characteristics and HVDC Grid Equipment • Models and Validation, HVDC Grid System Integration Tests		

Document	Number FprTS_50654-1	Title HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 1: Guidelines	
Timeline	Begin year 2013	End year 2018	Stage Published
Scope	„1.1 General: These Guidelines and Parameter Lists to Functional Specifications describe specific functional requirements for HVDC Grid Systems. The terminology "HVDC Grid Systems" is used here describing HVDC systems for power transmission having more than two converter stations connected to a common d.c. circuit. While this document focuses on requirements, that are specific for HVDC Grid Systems, some requirements are considered applicable to all HVDC systems in general, i.e. including point-to-point HVDC systems. Existing IEC, Cigré or other documents relevant have been used for reference as far as possible. Corresponding to electric power transmission applications, this document is applicable to high voltage systems, i.e. .only nominal d.c. voltages equal or higher than 50 kV with respect to earth are considered in this document. NOTE While the physical principles of d.c. networks are basically voltage independent, the technical options for designing equipment get much wider with lower d.c. voltage levels, e.g. in case of converters or switchgear. Both parts have the same outline and headlines to aid the reader. 1.2 About the Present Release: The present release of the Guidelines and Parameter Lists for Functional Specifications describes technical guidelines and specifications for HVDC Grid Systems which are characterized by having exactly one single connection between two converter stations, often referred to as radial systems. When developing the requirements for radial systems, care is taken not to build up potential show-stoppers for meshed systems. Meshed HVDC Grid Systems can be included into this specification at a later point in time. The Guidelines and Parameter List to the Functional Specification of HVDC Grid Systems cover technical aspects of - Coordination of HVDC Grid and a.c. Systems - HVDC Grid System Characteristics - HVDC Grid System Control - HVDC Grid System Protection - Models and Validation		

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	Beyond the present scope, the following aspects are proposed for future work: - AC/DC converter stations - HVDC Grid System Equipment - HVDC Grid System Integration Tests” [**CENELEC**] Outline of the document: 1. Scope 2. Normative references 3. Terms, definitions and abbreviations 4. Coordination of HVDC Grid System and AC systems 5. HVDC Grid System Characteristics 6. HVDC Grid System Control 7. HVDC Grid System Protection 8. AC/DC Converter Stations 9. HVDC Grid System Installations 10. Models and Validation 11. HVDC Grid System Integration Tests 12. Bibliography
Further comments	

Document	Number FprTS_50654-2	Title HVDC Grid Systems and connected Converter Stations - Guideline and Parameter Lists for Functional Specifications - Part 2: Parameter List	
Timeline	Begin year 2013	End year 2018	Stage Published
Scope	This document contains a parameter list complementary to the guidelines in Part 1. It covers both parameters for Operating Conditions and Performance Requirements.		
Further comments			

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2.4 IEEE-SA

Working group	Number WGI10	Title HVDC Working Group		
Timeline	Past / Ongoing / Planned Ongoing	Begin year -	End year -	
Promotion partner involvement	Person name(s) Mikael Kipness	Partner(s)	Role(s) Convenor	
Scope				
Documents	Number	Title		
	1240 –	Guide for the Evaluation of the Reliability of HVDC Converter Stations		
	1378 –	Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems		
	2656 -	Guide for Functional Specification of Voltage-Sourced Converter for HVDC Stations		
Further comments	Main IEEE-HVDC working group. Check if Promotion members are involved. Sponsored by IEEE-PES			

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2.5 GRID CODES

2.5.1 COMMISSION REGULATIONS (EU)

Document	Number COMMISSION REGULATION (EU) 2016/1447	Title Network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules	
Timeline		Date of publication 09/2016	Stage Published, entered into force
Scope	This Regulation establishes a network code which lays down the requirements for grid connections of high-voltage direct current (HVDC) systems and DC-connected power park modules. It, therefore, helps to ensure fair conditions of competition in the internal electricity market, to ensure system security and the integration of renewable electricity sources, and to facilitate Union-wide trade in electricity. This regulation also lays down the obligations for ensuring that system operators make appropriate use of HVDC systems and DC-connected power park modules capabilities in a transparent and non-discriminatory manner to provide a level playing field throughout the Union.		
Further comments			

Document	Number COMMISSION REGULATION (EU) 2016/631	Title Network code on requirements for grid connection of generators	
Timeline		Date of publication 05/2016	Stage Published, entered into force
Scope	This Regulation establishes a network code which lays down the requirements for grid connection of power-generating facilities, namely synchronous power-generating modules, power park modules and offshore power park modules, to the interconnected system. It, therefore, helps to ensure fair conditions of competition in the internal electricity market, to ensure system security and the integration of renewable electricity sources, and to facilitate Union-wide trade in electricity. 27.4.2016 L 112/4 Official Journal of the European Union EN This regulation also lays down the obligations for ensuring that system operators make appropriate use of the power- generating facilities' capabilities in a transparent and non-discriminatory manner to provide a level playing field throughout the Union.		
Further comments			

Document	Number COMMISSION REGULATION (EU) 2016/1388	Title Network Code on Demand Connection	
Timeline		Date of publication 09/2016	Stage Published, entered into force

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Scope	1. This Regulation establishes a network code which lays down the requirements for grid connection of: (a) transmission-connected demand facilities; (b) transmission-connected distribution facilities; (c) distribution systems, including closed distribution systems; (d) demand units, used by a demand facility or a closed distribution system to provide demand response services to relevant system operators and relevant TSOs. 2. This Regulation, therefore, helps to ensure fair conditions of competition in the internal electricity market, to ensure system security and the integration of renewable electricity sources, and to facilitate Union-wide trade in electricity. 3. This Regulation also lays down the obligations for ensuring that system operators make appropriate use of the demand facilities' and distribution systems' capabilities in a transparent and non-discriminatory manner to provide a level playing field throughout the Union.
Further comments	

2.5.2 ENTSO-E

Document	Number	Title Report on Inter-TSO coordination in connection network codes (CNC) implementation	
Timeline		Date of publication 01/2018	Stage Published
Scope	Pursuant to Commission Regulation (EU) No 2016/631 establishing a network code on requirements for grid connection of generators (NC RfG), Commission Regulation (EU) 2016/1388 establishing a network code on demand connection (NC DCC) and Commission Regulation (EU) 2016/1447 establishing a network code on requirements for grid connection of high voltage direct current systems and direct current-connected power park modules (NC HVDC) – later on referred to as the Connection Network Codes (CNCs) – transmission system operators (TSOs) are responsible to coordinate when establishing certain requirements at the national level. For some requirements, the coordination shall take place at the synchronous area level; for others, it is required between adjacent TSOs. The objective of this report is to present the process of explicitly required coordination or reasonably undertaken collaboration between European TSOs when implementing at national level the CNCs, because of the cross-border impact of these specifications at synchronous area level. This report shall provide an overview over coordination and collaboration activities performed so far (until the date of collection of TSO's answers) between adjacent TSOs or at synchronous area level. TSOs' coordination/collaboration when implementing the CNCs consists of working closely together in specifications for national implementation to ensure that the objectives of NCs RfG, DCC and HVDC are achieved. This coordination/collaboration shall guide the national implementation but not impair the decision making prerogatives of the relevant entities at national level. Chapter 2 provides an overview over the CNC topics, which are subject to TSO coordination/collaboration, either explicitly required by each of the CNCs or reasonably undertaken, because of the cross-border impact of these specification s at synchronous area level.		

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	Chapter 3 describes the process how the relevant information/data have been collected and compiled for this report. Chapter 4 provides a detailed analysis on the extent of TSO coordination/collaboration perceived so far based on the feedback received from the TSOs. The conclusions/recommendations from this report are summarized in Chapter 5.			
Further comments				

2.6 CHINESE STANDARDS

Document	Number GB/T 25091-2010 (Chinese National standard)	Title High-voltage direct-current disconnectors and earthing switches		
Timeline	Begin year -		End year 2010	Stage Published
Scope	This national standard specifies the service conditions, rated values, design and construction, tests and guide to the selection of disconnectors and earthing switches so as to unify the basic design and test requirements of the equipments and to guarantee the system operate safely. This national standard is applicable to disconnectors and earthing switches, designed for indoor and outdoor installations in HVDC system for voltages below ±800kV. It also applies to the operating devices of these disconnectors and earthing switches and their auxiliary equipment.			
Further comments				

Document	Number GB/T 25307-2010 (Chinese National standard)	Title High-voltage direct current by-pass switches		
Timeline	Begin year -		End year 2010	Stage Published
Scope	This national standard specifies the ratings, design and construction as well as tests of high-voltage direct current by-pass switches. This national standard is applicable to the by-pass switches designed for indoor or outdoor installation and for operation in high-voltage direct current systems having voltage of ± 800kV or below. This national standard is also applicable to the operating devices and auxiliary equipment.			
Further comments				

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Document	Number GB/T 25309-2010 (Chinese Standard)	Title High-voltage direct current transfer switches	
Timeline	Begin year -	End year 2010	Stage Published
Scope	The national standard specifies the terms and definitions, the operational environment, the rating, the technical requirement, the type test, the routine test, the special test, the field test, etc. of high-voltage direct current transfer switches. The national standard is applicable to the high-voltage direct current transfer switches of HVDC transmission system under ±800kV, including metal return transfer breakers (MRTB), earth return transfer breakers (ERTB), neutral bus switches (NBS) and neutral bus grounding switches (NBGS). The national standard is also applicable to the operating mechanism and auxiliary equipment of these switches.		
Further comments			

Document	Number NB/T 42107-2017 (Chinese Standard)	Title High-voltage direct current circuit-breakers	
Timeline	Begin year -	End year 2017	Stage Published
Scope	The national standard specifies the terms and definitions, the operational environment, the rating, the technical requirement, the type test, the routine test, the special test, the field test, etc. of high-voltage direct current circuit breakers. The national standard is applicable to the high-voltage direct current circuit breakers above 6 kV. The national standard is also applicable to the operating mechanism and auxiliary equipment of these switches.		
Further comments	In Chinese, no authorized English translation available To be addressed by IEC TC 17A AGH60		

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3 POTENTIAL NEW CONTRIBUTIONS

There are numerous technical activities ongoing within the PROMOTioN project, many of which are in fields where there are known gaps in standardisation. In order to fully exploit the technical work within PROMOTioN, contribution to harmonisation is strongly encouraged. Chapter 2 of this harmonisation catalogue has evaluated relevant harmonisation working groups and bodies. This chapter will consider gaps in existing harmonisation and standardisation documents, and will include contributions from PROMOTioN technical work packages in order to evaluate possible contributions from the PROMOTioN project towards best practices, harmonisation and standardisation.

The following sections contain topics that have been identified as of interest. For each topic, the following aspects are considered:

- Introduction to the topic and perceived gaps in harmonisation
- Analysis of ongoing and planned work from PROMOTioN in this field
- Analysis of topics for which PROMOTioN work is contributing, or could contribute, to best practices and harmonisation.

3.1 SPECIFICATION AND CONTROL OF HVDC SYSTEMS

3.1.1 NOMENCLATURE

As the application of HVDC converters in multi-terminal systems is a rather new field, there is not yet complete agreement on the suitable terms for the configurations and concepts. There is still discussion ongoing about seemingly simple terms like grid and system, the naming of the monopole and bipolar configurations or circuit topologies and the definitions with regard to protection concepts among other aspects. The overall aim of the discussions is the creation of a consistent and clear set of terms to describe the HVDC grids, its components and functionalities.

3.1.1.1 RELEVANT PROMOTION ACTIVITY

The discussion on suitable terms for HVDC systems has accompanied the work in PROMOTioN from the start and has been carried on in all work packages. The topics covered among others are:

- The differentiation between grids, systems, network, configurations and topologies
- Protection system related vocabulary with regard to protection philosophies or fault handling concepts
- Specification of HVDC breakers capabilities and interfaces

3.1.1.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

All PROMOTioN members active across the range of standardisation bodies contributed to the definition of terms based on their insights in PROMOTioN. Moreover, the IEC vocabulary on HVDC was extended during the

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course of PROMOTioN due to the increased relevance worldwide. WP11 partners reviewed the existing draft and commented based on the discussions going on in all work packages. As HVDC grids are a rather new technological development, it is expected that there will be ongoing discussion and new definitions emerging over the next years.

3.1.2 FUNCTIONAL HVDC SYSTEM SPECIFICATION

Future multi-terminal HVDC systems will integrate different types of controllable equipment from different manufacturers. To allow the interconnection of different components, the interfaces between the components and the requirements on them have to be well defined. All existing HVDC links in Europe are turnkey projects, therefore there were few requirements on the DC side behaviour defined in the specifications. The specifications were mostly given for the AC side, with the basis being the relevant HVDC grid code. The extension to HVDC grids results in a need for detailed specifications for the DC side. This starts from the nominal voltage and powers and allowable voltage bands and includes the definition of the used system configuration, the definition of the DC side points of common coupling between the converters, the transmission lines, the switching stations and possible additional equipment. Furthermore, to allow a stable and optimised operation of the system, there needs to be an exchange of relevant parameters between the components and a coordinated operation of the equipment, potentially governed by an overlaying grid control, similar to existing SCADA systems and control centres for AC systems. As there is no corresponding system in operation today first the relevant data to be exchanged between all system components, the relevant control schemes implemented in each converter and the role of the overlaying grid control have to be defined.

3.1.2.1 RELEVANT PROMOTION ACTIVITY

Within WP2, and WP4 of PROMOTioN the DC-side system behaviour is analysed in detail for offshore HVDC grids. The analyses takes into account a variety of system topologies, configurations, control concepts, contingencies and fault handling strategies to be able to specify the DC side system behaviour and the requirements on it in a general manner.

3.1.2.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

The work of the CENELEC working group TC 8X WG06 is specifically dedicated to set up a set of functional specifications for HVDC systems summarising all relevant parameters in a parameter list and giving the background behind each parameter in a guidelines document. PROMOTioN has been granted liaison organisation status with CENELEC to contribute to the ongoing efforts based on the analyses undertaken in the PROMOTioN project.

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3.1.3 HVDC CONVERTER CONTROLS

Modern voltage source converters like the modular multilevel converter enable a flexible and fast control of the AC- and DC-side values within the limitations given by the design and components of the converter. While the hardware set-up of each converter might be similar the main distinction often lies in the controls used. The converter behaviour and its response to dynamic events is, in many respects, defined by its control system. When considering HVDC systems integrating converters of several manufacturers or types, it has to be ensured that there is no adverse interaction of the controls used. Therefore detailed specifications of the converter behaviour under a broad range of situations must be specified.

3.1.3.1 RELEVANT PROMOTION ACTIVITY

While in PROMOTioN the investigations are based on generic converter models, such that no direct vendor-interoperability issues between converters can be observed, PROMOTioN aims to analyse the HVDC grid system behaviour in a broad range of scenarios, including different topologies, configurations, faults and protection sequences to define the requirements on the converters in a stringent fashion. The analysis takes into account the knowledge gained on interoperability issues in the EU project Best Paths. Based on discussions at the control and protection workshop including the input from the relevant work package in Best Paths the following approaches for a standardisation of the upper level controls were identified:

As interoperability issues might not only occur under faults, but also under dynamic events such as load changes, a very detailed specification of the converter behaviour is required. The specification from the CENELEC working group TC 8X WG06 can be taken as a starting point. Furthermore, dynamic controls such as droop controls were identified as requiring further specification. A stricter approach could be pursued by standardising the upper level controls, such that only the lower level controls are vendor specific.

The developed controls in PROMOTioN will be demonstrated on the MMC test bench.

3.1.3.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

As the standardisation of converter controls is a highly sensitive topic for manufacturers, it is not expected that there will be a standardisation of the controls within the runtime of PROMOTioN. However, the above mentioned functional specifications and requirements will help to specify HVDC systems including several vendors.

3.1.4 HARMONIC MODELS FOR MMCS

Some of the early windfarm connections employing full scale converter wind turbines and MMCs have been experiencing resonance issues leading to partial destruction of equipment and disconnection of components. The cause of observed oscillations has been attributed to interactions of control systems with the AC grid or other power electronic controlled components. A promising methodology to investigate this harmonic resonance phenomena is to model the system in the frequency domain and apply classical control theory. This approach

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requires the frequency response of the investigated components modelled as impedance. These harmonic models can be either measured or derived analytically. Many analytically derived models have been developed and described in literature for this purpose. However, the confidence level is still low when offline EMT simulation tools are used for the impedance measurement and harmonic model validation. Therefore, Hardware-in-the-loop (HiL) investigations are considered for model validation.

3.1.4.1 RELEVANT PROMOTION ACTIVITY

Within WP 16 harmonic models, more specifically frequency dependent impedance models of voltage source converter (VSC) wind turbines, diode rectifier units (DRU) including wind power plants (WPP) and modular multilevel converter (MMC) will be investigated to gain a better understanding of the harmonic resonant phenomena occurring in offshore wind farm connections. Task 16.5 develops and describes the theoretical background of frequency impedance models Different approaches for modelling the frequency dependent impedances are investigated. Thereafter, task 16.6 performs studies to investigate the developed harmonic models on the test bench system including lab-scale MMCs to validate the developed models in a HiL setup by means of defined test cases. This way confidence can be gained about the applicability of the models and investigation approach when studying the phenomena in the frequency domain by means of harmonic models and classical control theory. For a more detailed insight into the relevant activities with regard to wind power plants please refer to section 3.4.1.

3.1.4.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

The outcomes of Task 16.5 with regard to MMCs will serve as input for CIGRE WG C4.49 on Multi-frequency Stability Of Converter-based Modern Power Systems.

3.2 PROTECTION OF HVDC SYSTEMS

3.2.1 DESIGN OF PROTECTION SYSTEMS

While in AC systems the used protection systems have long been standardised there is no standard protection system design for HVDC systems yet. There have been several proposals with regard to the detection and localisation of faults, the associated fault clearing process applying different devices, additional equipment needed for a selective line protection and the recovery process after the fault. As the solutions are manifold there is still the need to identify all implications of a certain protection system design choice on the overall system operation, its control, stability and availability.

There are several aspects of HVDC protection system design that have been suggested as topics where standardisation could be useful. Many of these topics are highly relevant for both control and protection:

- Fault ride-through envelopes for HVDC converters (DC- and AC-side), and associated characteristics for offshore wind farms.
- Requirements imposed on protection strategy, including requirements for redundancy and requirements for backup protection.

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- Basic requirements for protection functions (minimum pick up time, minimum sensitivity, fault cases to consider).
- Location of breakers, inductors, measurements.

3.2.1.1 RELEVANT PROMOTION ACTIVITY

Several studies in WP2, WP3, WP4 and WP5 analyse the effect of faults on the system in different scenarios taking into account a variety of proposed system designs, thereby giving insight into the different implications of the design factors.

3.2.1.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

While the standardisation of the algorithms and components might limit the development of certain technologies at this point in time, the definition of requirements on the protection systems and the relevant performance indicators have been discussed and defined in more detail, see section 3.2.3.

3.2.2 CLASSIFICATION OF PROTECTION SYSTEMS: FAULT SEPARATION CONCEPTS AND PROTECTION PHILOSOPHIES

As stated above there is no standardised HVDC protection system yet. Different approaches for classifying the different concepts have been proposed. One of the classifications has been proposed by Cigré in TB 739 which calls the different approaches “Protection Philosophies” and differentiates them into selective, non-selective and partially selective strategies. A second approach is defined by the CENELEC working group TC8X WG06. It focuses on the impact on the controllability at defined interface points. The different concepts are called “Fault separation concepts” and are distinguished into the following categories: Continuous operation, temporary stop and permanent stop.

3.2.2.1 RELEVANT PROMOTION ACTIVITY

Both classification concepts were applied to the analysis and comparison of a broad range of protection concepts in WP4. Based on the application the definitions were discussed in detail and potential modifications were derived.

3.2.2.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

Feedback on the defined classifications will be provided to the CENELEC working group TC8X WG06.

3.2.3 PERFORMANCE EVALUATION OF PROTECTION SYSTEM

When developing a protection strategy for an HVDC system there are numerous design choices, many of which are co-dependent and have various implications (e.g. cost, functionality, impact). When making such design choices, comparing the implications of each option is clearly essential to enable an informed decision. The

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importance of a specific factor is project dependent, however, the means of comparison should be applicable to all projects. Although existing projects will have used their own methods of benchmarking performance, when we move towards larger scale and multi-vendor systems, harmonisation of the performance indicators is likely to be of interest.

Standardisation of Key Performance Indicators (KPIs) would enable reliable and effective comparison between different protection strategies and also between different implementations of a particular protection strategy.

3.2.3.1 RELEVANT PROMOTION ACTIVITY

Within WP4 (Deliverable 4.3) KPIs are developed with the aim of demonstrating how effectively a protection system achieves key objectives. While many possible performance indicators have been discussed, the decided upon KPIs are as follows:

- Efficiency indicators:
  - Fault interruption time
  - Voltage restoration time
  - Active power restoration time
  - Reactive power restoration time
  - Transient energy imbalance
- Failure indicators:
  - Backup probability
  - Non-cleared fault probability
- Cost indicators

Each KPI has been defined in a robust manner to compare a diverse selection of protection strategies and also different implementations of those protection strategies. Definitions have been determined to allow comparison within the deliverable (e.g. in some cases numerical values have been given for comparison purposes), however, the KPIs can also be used in a generic manner (i.e. without specific numerical values).

3.2.3.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

Given that the core content of each performance indicator developed in WP4 can be considered generic, the PROMOTioN work could be useful to harmonisation organisations. The most valuable information for standardisation in this area is the generic definitions – i.e. the structures with which to compare – rather than the exact values which should be compared.

3.2.4 CABLE OVERVOLTAGES

Overvoltages on an HVDC network must be managed effectively to avoid damage to system equipment. Protection is provided using varistor (surge arrester) elements at strategic locations across the network – e.g. at the cable termination and/or the busbar. Protection must be provided against sustained overvoltage due to pole-to-ground short circuit faults in symmetrical monopolar HVDC systems. Overvoltages could also occur due to switching of switchgear (e.g. HVDC circuit breaker isolating a fault). Such protection must also be coordinated

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with lightning protection. The optimal solution could therefore require a co-design between system components (e.g. defining the allowable cable overvoltage characteristic), protection equipment (e.g. circuit breaker properties, controllable energy dissipation devices) and the locations and ratings (voltage, energy) of surge arresters on the network. Differences for mixed transmission medium should also be explored (cable only, mixed cable and overhead line, overhead line only).

3.2.4.1 RELEVANT PROMOTION ACTIVITY

Simulation studies have taken place to examine overvoltages on HVDC networks and methods to mitigate persistent overvoltages (e.g. using converter control or controllable energy dissipation devices). There has not been detailed study of the coordination requirements between different network locations.

3.2.4.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

The relevant PROMOTioN activity has been presented to CIGRE WG B4/B1/C4.73 “Surge and extended overvoltage testing of HVDC Cable Systems” during a WG meeting.

Existing results from PROMOTioN could be useful to standardisation organisations interested in this field. It could be possible to generate a short introductory document, providing a summary of relevant PROMOTioN work in this field and indicating why insulation coordination for multi-terminal HVDC systems is an area of ongoing interest.

3.2.5 COMMUNICATION PROTOCOLS

Operation of modern power systems is increasingly relying on digital communication to enable a more controllable and reliable system with a reduced requirement for communication conductors. IEC 61850, for example, is a standard governing digital substation communication. Due to its popularity and benefits, it seems highly probable that the intelligent electronic devices (IEDs) in a HVDC substation would communicate using a digital communication protocol such as IEC 61850. Although certain manufacturers market the HVDC circuit breaker and the protection IED as one product, as the market moves towards networks with more terminals and requires multivendor solutions, fast and standardised communication will be required for the protective devices. Some protection algorithms require fast communication between IEDs across a network. Communication is therefore of interest both within the HVDC substation and between HVDC substations.

3.2.5.1 RELEVANT PROMOTION ACTIVITY

The applicability of communication protocols to multi-terminal HVDC system protection strategies has been examined. It is shown that IEC 61850 (in its present application note IEC 61850-9-2 LE) is not fast enough for selective fault clearing strategies [Jahn2018DPSP], however, is appropriate for non-selective fault clearing strategies. It should be noted that some fast communication may still be required for any fault clearing strategy (e.g. within a converter station, where high speed and reliable communication can be relied upon) but communication between remote devices remains a challenge. The constraining factor here is the speed of

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operation, something which could be addressed in a future revision of the standard. It is known that there is an IEC workgroup developing a part of IEC 61850 for application to FACTS data modelling (including development for DC line fault sequences, power converters, and DC circuit), therefore future revisions of the standard might allow for effective use in HVDC protection. Other communication protocols were under theoretical examination as part of the HVDC protection IED work in PROMOTioN WP4. Work on implementation of a real-time Ethernet communication protocol (HSR – high availability, seamless redundancy) is currently ongoing.
Protection algorithms have been studied extensively within PROMOTioN WP4, including communication based (unit) protection. Work is ongoing to determine the application cases for which communication is of use. In such cases, faster communication is expected to be highly beneficial. Within WP9 there is work ongoing to examine the impact of communication on non-selective fault clearing strategies, with application of the existing IEC 61850 protocol.

3.2.5.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

There are no known existing contributions to standardisation.
A summary sheet will be provided to the IEC workgroup involved in the ongoing development of the IEC 61850 standard, such that they are aware of the requirements from an HVDC protection point of view. This will include contributions from WP4 and WP9.

3.2.6 COMMUNCATION INTERFACES

The interfaces for communication between different devices with protective functions should be well defined in a multivendor system. It is highly likely that a protection IED will communicate with an HVDC circuit breaker, however the types of signals to be communicated could differ (e.g. trip signal, pre-activation, status signals,…) and the format of the signals must be well defined. It is also possible that the protection IED could communicate with the converter station, or that the converter station could communicate with the circuit breaker (e.g. to coordinate current limiting, or for status transfer). Communication beyond the substation is also likely to be required (e.g. with remote substations). For each of these applications, the communication requirements, protocols, signals, and other information must be well defined.

3.2.6.1 RELEVANT PROMOTION ACTIVITY

Collaboration between WP4 and WP6 has resulted in discussion and definition of the required interfaces between a circuit breaker and a protection IED. To achieve multivendor interoperability and to avoid excluding technologies, minimally required and auxiliary interfaces have been defined, e.g., to allow the breaker to perform its basic function (interrupting a current) and other functions (pro-active opening, current limiting).

3.2.6.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

There are no known existing contributions in this field.
A publication detailing required communication interfaces between circuit breakers and protection IEDs is planned. It is hoped that this document could be used as input for future standardisation.

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3.2.7 TESTING OF PROTECTION DEVICES

Standardised testing of protection IEDs is widespread and commonplace for AC protection devices. There are numerous such tests, ranging from electromagnetic compatibility to functionality during operation, each with associated standards and test procedures. Such tests, however, are not yet well developed for HVDC protection equipment. Although existing projects are typically provided by a single vendor (and therefore there is no strong requirement for standardisation), future projects are expected to be multi-vendor, and therefore standardisation of specifications and requirements is highly desirable to ensure effective interoperability.

3.2.7.1 RELEVANT PROMOTION ACTIVITY

Within WP4, an HVDC protection IED has been developed and test routines are under development to evaluate the functional performance of HVDC IEDs. Such tests can be considered to be 'unit tests' – i.e. testing that the functionality of the device meets the expected functional requirements. Additionally, in WP9, tests will be performed on a replica system and the HVDC IED performance will be evaluated at the system level. These tests can be considered to be 'commissioning tests'. Within these activities test routines and methods have been developed to examine the functional performance of an HVDC IED in the context of the complete protection system.

3.2.7.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

There are no known existing contributions to harmonisation.
Discussion is ongoing between PROMOTioN partners and IEC TC 95 (Measuring relays and protection equipment), who are interested in developing standards for testing of HVDC IEDs. It is hoped that ongoing PROMOTioN work will contribute to harmonisation in this field in the future. A summary of the relevant PROMOTioN work could be sent to harmonisation bodies such that work will be considered as input for future standardisation. It is thought that functional testing of HVDC IEDs is a topic that is highly relevant for future standardisation.

3.3 HVDC SWITCHGEAR

The functionality of reconfiguring, isolating and/or earthing parts of networks, necessary for the optimal and safe operation of the power system is achieved by switchgear. Different types of switchgear can be distinguished based on their current interruption capability, insulating medium and speed of operation. Switchgear capable of interrupting fault currents are referred to as circuit breakers, switchgear which cannot interrupt any current are referred to as disconnectors. Typically, modern switchgear is insulated in air, or in a specific insulating gas in which case it is referred to as gas insulated switchgear (GIS). More generally, GIS often also include other components such as voltage and current measurement devices (RC dividers, Rogowski coils) and surge arrestors for overvoltage protection.

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These technologies have been developed and are mature for AC applications. For HVDC, only a few HVDC circuit breakers and HVDC gas insulated systems have been put in operation, all in Asia. Several manufacturers have developed products and started or completed qualification, but a lack of understanding of the application and hence specification of HVDC switchgear, a lack of standardisation regarding testing, and a lack of operational experience proving the technologies' robustness have hampered their uptake, especially in Europe.

PROMOTioN addresses these challenges in several work packages split into two streams dealing with HVDC circuit breakers and HVDC GIS separately.

HVDC circuit breakers are systems which are able to interrupt DC (fault) currents and isolate parts of an HVDC network. Based on their application, these two functions can be combined to achieve continuous operation of the HVDC power system in case of a fault and any desired selectivity in fault clearing (although not all topologies and configurations would achieve this). Several different technologies exist which are distinguished by the current interruption mechanism which is deployed and can be largely classed into mechanical circuit breakers (consisting of a high speed AC mechanical interrupter, passive components, and a metal oxide varistor stack) and hybrid circuit breakers (consisting of a high speed mechanical disconnector, power electronics and a metal oxide varistor stack). The main differences between different types are speed of operation, cost, functionality and size/weight.

In PROMOTioN, the development and application of HVDC circuit breakers are addressed in the following work packages:

Work Package 6 – HVDC Circuit Breaker Performance Characterisation
Work Package 4 – DC Grid Protection System Development
Work Package 2 – Grid Topology & Converters
Work Package 5 – Test Environment for HVDC Circuit Breakers
Work Package 9 – Demonstration of DC Grid Protection
Work Package 10 – Circuit Breaker Performance Demonstration

The contributions made in this field by PROMOTioN are in the modelling and design, application and specification and in the testing of HVDC circuit breakers, which will be discussed in the following sections.

3.3.1 APPROACH TO MODELLING OF HVDC CIRCUIT BREAKERS

In order to be able to study the application of HVDC circuit breakers and their subsequent specification, their behaviour and operational characteristics should first be modelled.

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3.3.1.1 RELEVANT PROMOTION ACTIVITY

In work package 6, the functional behaviour of different types of HVDC circuit breakers (hybrid IGBT-based, hybrid thyristor-based, mechanical and VARC) and their control and protection systems have been modelled. High-level models suitable for protection system studies in work package 2 and 4, as well as detailed models suitable for analysing the stresses on the component and sub-component level have been developed. The high-level models have also been implemented in RSCAD for later use in RTDS real-time simulations with protection IED hardware in the loop in work package 9. The models have been cross-checked against one another using a standardised simulation model test circuit. The detailed models will be verified by means of the results of tests on real HVDC circuit breakers in work package 10, to the extent possible. The effect of different failure modes on the HVDC circuit breaker operation has been modelled and will be demonstrated on scaled hardware models, and the scaling of HVDC circuit breakers to EHV levels is studied. Finally, a bottom-up cost model of the IGBT-based hybrid and mechanical HVDC circuit breakers has been created in order to study the techno-economic performance of different ways of application in work package 4.

3.3.1.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

It is foreseen that the models and modelling approaches including the defined levels of abstraction/detail are useful input to future standardisation activities regarding HVDC system studies including the effect of HVDC circuit breakers. Examples of such studies are switching studies, protection studies, insulation coordination studies and dynamic studies.

3.3.2 APPLICATION AND SPECIFICATION OF HVDC CIRCUIT BREAKERS

HVDC circuit breakers are likely to cost several orders of magnitude more than their AC counterparts, and the cost of implementing fully selective fault clearing schemes with HVDC circuit breakers at each line end may be prohibitive. Hence, different applications of HVDC circuit breakers which satisfy the system requirements as well as economic considerations are investigated.

3.3.2.1 RELEVANT PROMOTION ACTIVITY

In work package 2 and work package 4, amongst others, the impact of different fault clearing strategies on the HVDC power system stability and control and the connected AC power systems will be studied using the HVDC circuit breaker models developed in work package 6.

Moreover, in work package 4, the techno-economic performance of different fault clearing strategies is analysed and compared in detail, with the aim of selecting the best-performing strategies. Based on the performance of the HVDC circuit breakers and the required properties, a suitable strategy can be chosen and a guide to the specification of HVDC circuit breakers is written.

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3.3.2.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

As stated in chapter 3.2 the requirements and the key performance indicators for the different possible protection system designs were developed or extended in PROMOTioN and provide input to ongoing and future harmonisation activities.

3.3.3 TESTING OF HVDC CIRCUIT BREAKERS

The operational principle of HVDC circuit breakers, being active systems, is substantially different from AC circuit breakers, and most notably typified by being significantly faster (several ms vs 10s to 100s of ms), the active generation of a counter voltage higher than the nominal system voltage and the characteristic of having to absorb the magnetic energy stored in the HVDC system. These different characteristics place different requirements on the way that HVDC circuit breaker design is qualified and functionality is tested.

3.3.3.1 RELEVANT PROMOTION ACTIVITY

In work package 5, the electrical stresses which different types of HVDC circuit breakers are likely to experience during service life (steady-state operation and switching operations) were studied and translated to test requirements. Different tests (dielectric, operational, current interruption and special tests) were defined. A method to provide the current, energy and voltage stresses based on AC short-circuit generators (which are available in most AC circuit breaker test facilities) operated at a low frequency was developed, tested and demonstrated. In case the HVDC circuit breaker ratings exceed the laboratory's capabilities, a method to test EHV circuit breakers modularly was presented.

In work package 10, the test requirements, method and test circuit developed in work package 5 will be used at DNV GL's KEMA Laboratories to demonstrate the DC fault current interruption performance of commercial prototypes of HVDC circuit breakers from PROMOTioN partners:

- 350 kV 16 kA hybrid circuit breaker from ABB
- 160 kV 16 kA mechanical circuit breaker from Mitsubishi Electric
- 120 kV 16 kA VARC circuit breaker from SCiBreak

In addition, an experimental mechanical HVDC circuit breaker has been set up and tested to analyse and characterise the specific and unknown stresses on vacuum interrupters and surge arresters in this type of circuit breakers. The test results are used to verify the sub-component models developed in work package 6.

3.3.3.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

WP5 and WP10 participants were and are actively involved in (pre-)standardization activities through the following international committees:

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Active participation in pre-standardization (see 2.1.1):

- CIGRE JWG A3B4.34 (2014-2017) on HVDC switchgear (incl. HVDC circuit breakers)
- CIGRE WGA3.39 (2017-2020) on surge arresters (including those used in HVDC circuit breakers)
- CIGRE WG A3.40 (2018-2021) on MV HVDC systems and switchgear
- CIGRE JWG B4A3.80 (2019-2022) on HVDC circuit breaker requirements

Active participation in IEC standardization activities (see 2.2.2):

- IEC AHG4 (2016-2017), on market relevance of HVDC switchgear
- IEC AHG60 (2017-2018), on existing standards of HVDC switchgear

3.3.4 GIS

HVDC GIS has been introduced as a promising technology where the benefits of the proven HVDC transmission and AC gas-insulated switchgear/systems can be combined. Up to the present time, no international standards describing the requirements, applicable tests and test procedures of HVDC gas insulated systems (GIS) have been developed.

3.3.4.1 RELEVANT PROMOTION ACTIVITY

D15.2 on test requirements, procedures and methods is relevant for harmonization. This document provides a general guideline for listing the tests that shall be applied to HVDC GIS to verify their designed performance. Focus is given to the dielectric test requirements due to the different nature of DC electric fields in GIS compared to AC fields. Additionally, due to lack of operational experience on HVDC GIS, a long-term test method to prove the dielectric performance of a prototype installation under in-service conditions is described. The described method will be applied to a prototype HVDC GIS which will be built by a GIS manufacturer (task 15.3 of PROMOTioN) based on the specifications and ratings that are defined in deliverable D15.1.

3.3.4.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

The PROMOTioN work on GIS test procedures should be combined with test results to contribute to pre-standardization of HVDC GIS, as for example has already been started in IEC AHG 37 of IEC TC 17.

3.4 HVDC CONNECTED WIND POWER PLANTS

3.4.1 HARMONIC EMISSION AND STABILITY

Tests and assessment of harmonic emission has been an integral part of power quality standards for wind power since first edition of IEC 61400-21 was published in 2001. The purpose has been to enable validation that wind power complies with power quality requirements of grid operators. Because of the rapidly growing share of wind and solar PV, the grid is becoming increasingly power electronics dominant, and for offshore HVDC connected WPPs, the offshore AC grid has reached the ultimate 100% power electronics share. In such power

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electronics dominant systems, the concern of harmonic stability has added to the power quality challenge. Ensuring the harmonic stability relies on appropriate quantification of harmonic resonance phenomena between converters and grid.

3.4.1.1 RELEVANT PROMOTION ACTIVITY

PROMOTioN WP16 includes the following activities regarding harmonic resonances:
First, task 16.5 deals with Implementation of an analytical method for analysis of harmonic resonance phenomena. This work will be documented in the deliverable D16.5 with the same title as the task.
Secondly, development and demonstration of test methods for harmonic resonances is part of T16.6 Demonstration of defined test cases regarding interoperability, control schemes and protection. This work includes input admittance measurement of kW setup using harmonic perturbation as a first step followed by a wind turbine Controller Hardware In the Loop (CHIL) test system intended for MW systems.

3.4.1.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

The expected contribution to harmonization is a specification for CHIL Test Systems for MW wind turbine control systems and input to IEC 61400-21-3 - Wind Turbine Harmonic Models and Its Application.

3.4.2 GRID FORMING CONTROL

The expected need for new grid forming control of wind power plants and other converter connected equipment is also drawing increasing attention as the grid is becoming increasingly power electronics dominant. An example where such grid forming capabilities are needed is offshore wind power plants connected to an HVDC system through an offshore diode rectifier unit (DRU). If the offshore HVDC converter is a VSC type then the HVDC-VSC converter will form the grid where the wind turbines will follow the grid and therefore standard wind turbines developed for connection to AC grids can be used. But using an offshore DRU converter, the wind turbine grid side converters are in charge of forming the offshore AC grid, i.e. control its voltage and frequency and active power flow through the DRU. Therefore, the wind turbine control is different from standard control in the sense that WT control needs to be grid forming and not grid following.

3.4.2.1 RELEVANT PROMOTION ACTIVITY

PROMOTioN includes the following activities regarding grid forming control:

- Task 3.1 Functional requirements to WPPs reported in Deliverable 3.1: Detailed functional requirements to WPPs. This document describes operational requirements in the DRU case
- Task 3.2 General control algorithms reported in Deliverable 3.2: Specifications of the control strategies and the simulation test cases. This document provides specification of control strategies for VSC-HVDC as well as DRU-HVDC connections, i.e. both for grid following and grid forming WPPs

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3.4.2.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

Grid forming is still at an early development stage, and therefore it is not realistic to harmonize controller models or detailed performance specifications. At this stage, definition of control capability classes are established in line with ENTSO-E classes:

- Grid following: P-control, Q-control, connection to powered grid, high SCR, high inertia
- Grid supporting: frequency support, voltage support, connection to powered grid, low SCR, low inertia
- Grid forming: frequency control, voltage control, island connection, zero SCR, zero inertia

3.4.3 BLACK START CAPABILITY

Following a full or partial black-out in a power system, there is a need to restore the system in a fast and reliable way. This restoration is traditionally done using synchronous power-generating modules with black-start capabilities, i.e. the ability to start in an islanding mode and control voltage amplitude and frequency as loads are connected.

Requirements are specified for synchronous power-generating modules in ENTSO-E RFG and within each TSO's agreements with the related power plants. These requirements are considered applicable here, as well. These requirements include, among others, the following which are relevant for black-start capability:

- capability of starting from shut-down without any external electrical energy supply within a specified time frame
- capability to synchronise within defined frequency limits
- capability of automatically regulating dips in voltage caused by connection of load
- capability of frequency control

3.4.3.1 RELEVANT PROMOTION ACTIVITY

Within WP 3 several deliverables address the topic of black start capability of HVDC connected wind power plants.

- D3.6 "Report with the compliance test procedures for DR and VSC connected WPPs" describes compliance test requirements, procedures for simulation-based compliance evaluation and validation procedures for the models and simulations applied for compliance evaluation.
- D3.7 "Report with the compliance evaluation results using simulations" will include the results of simulations for various scenarios and test cases in order to verify the effectiveness of the test procedures for compliance evaluation.

In WP11 guidelines for best practice of compliance evaluation will be derived (D11.5 "Report with recommendations to best practice for compliance evaluation"). These recommendations will also include experiences of relevant parties like e.g. TSOs.

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In WP16, it is planned to demonstrate black start capability of HVAC and DRU-connected offshore wind farms.

3.4.3.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

It is assumed that ongoing PROMOTioN work will contribute to harmonisation in this field in the future. A report on justified recommendations to grid codes will be written within WP11 (D11.4) and could be sent to harmonisation bodies as potential input for future standardisation. It is expected that functional specifications and requirements for black start capability could be harmonised, but the specific hardware and control solutions will not be harmonised.

3.4.4 ONSHORE FREQUENCY CONTROL FROM OFFSHORE WIND

As opposed to onshore AC grid connected WPPs, HVDC connected WPPs do not measure the onshore AC frequency directly on the wind turbine terminals, and likewise the WPP controller of HVDC connected WPP does not measure onshore frequency in the point of connection. Two classes of solutions have been proposed to ensure that the offshore HVDC connected wind power plant can contribute to frequency control of the onshore AC grid: either communication based or communication-less. The communication-less solutions can work for two-terminal (point-to-point) HVDC connected WPPs, but for multi-terminal HVDC systems this solution becomes very complex.

3.4.4.1 RELEVANT PROMOTION ACTIVITY

Within WP2 both communication-less and communication based frequency support from wind farms and connected asynchronous grids is studied in multi-terminal cases to analyse the respective advantages and disadvantages.
Frequency support from two-terminal DR-HVDC connection is studied in WP3 and reported in Deliverable 3.5: Performance of ancillary services provision from WFs connected to DR-HVDC.

3.4.4.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

Based on the investigation recommendations on the frequency support approaches will be summarised and can serve as input for future harmonisation and grid codes.

3.4.5 FAULT-RIDE-THROUGH

The topic of “fault ride through” is addressed in WP2 and WP3 including WPP response to faults in the offshore AC system, fault in the DC system and faults in the onshore AC system. OWPP shall be capable of staying connected to the network and continuing to operate stably after the (offshore) power system has been disturbed by faults. That capability shall be in accordance with specific voltage-against-time profiles at the connection point. It is important to note that classical voltage-time profiles originate from (onshore) power system response, where the voltage ramp might take time. This profile is expected to be observed when there is connection

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(umbilical cable) to the onshore AC system. For the offshore AC faults, when there is no connection to the onshore AC (i.e. DR state) the voltage profile will depend on the response of the WTGs. However, it is also important to note that DRU-connected WTGs would possibly be tested against DRU connection, rather than a voltage-profile.

3.4.5.1 RELEVANT PROMOTION ACTIVITY

Three tasks in WP3 include parts about FRT of DR-HVDC connected WPPs . Those tasks are:

- T3.1. Functional requirements to WPPs – including requirements to WPPs on FRT of symmetrical as well as asymmetrical offshore AC faults, faults on the DC line and faults of DR-HVDC connected WPPs
- T3.2. General control algorithms – including development and simulation of control algorithms in normal operation and in FRT operation modes for DR-HVDC connected WPPs.
- T3.3. Compliance evaluation procedure – including FRT of VSC-HVDC and DR-HVDC connected WPPs.

Those WP3 contributions can be found in the following deliverables:

- D3.1 “Detailed functional requirements to WPPs” describes system stability requirements for WPP response to symmetrical as well as asymmetrical offshore AC faults.
- Deliverable 3.4: Results on control strategies of WPPs connected to DR-HVDC. This deliverable includes a section describing the FRT controls and a section with simulation of response to symmetrical as well as asymmetrical faults in the offshore AC system.
- D3.6 “Report with the compliance test procedures for DR and VSC connected WPPs” describes compliance test requirements, procedures for simulation-based compliance evaluation and validation procedures for the models and simulations applied for compliance evaluation.
- D3.7 “Report with the compliance evaluation results using simulations” will include the results of simulations for various scenarios and test cases in order to to verify the effectiveness of the test procedures for compliance evaluation.

In WP11 guidelines for best practice of compliance evaluation will be derived (D11.5 “Report with recommendations to best practice for compliance evaluation”). These recommendations will also include experiences of relevant parties like e.g. TSOs with FRT of VSC-HVDC connected WPPs.

3.4.5.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

It is assumed that ongoing PROMOTiON work will contribute to harmonisation in this field in the future. A report on justified recommendations to grid codes will be written within WP11 (D11.4) and could be sent to harmonisation bodies as potential input for future standardisation.

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3.4.6 EMT MODELLING

Stability evaluation of onshore AC systems are usually done using fundamental frequency models. However, for weak systems connections and for HVDC connected WPPs, EMT models are often required.

3.4.6.1 RELEVANT PROMOTION ACTIVITY

WP3 has developed fundamental frequency models as well as EMT models of DRU-HVDC connected WPPs. The outcome of this work is D3.3 Models for control of wind turbines / wind power plants connected to DR-HVDC" including a model and a report.

3.4.6.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

Regarding harmonization of EMT models, it is the general opinion in the industry that because of the differences in the detailed control and protection implementation, EMT models cannot be harmonized in the same way as fundamental frequency models have been. Instead, functional requirements to models and procedures for model validation could be specified.

3.5 OFFSHORE CONSUMPTION

It can also be relevant to connect offshore oil/gas installations to future offshore multi-terminal HVDC systems. An offshore oil/gas installations has an electrical load potentially ranging from 10 MW to several hundreds of MW.

Offshore Oil & Gas installations are today a significant load in the North Sea. An offshore Oil & Gas installation has an electrical load potentially ranging from 10 MW to few hundreds of MW in general supplied by gas turbine generator sets. With several offshore installations, the total generation capacity in the North Sea is significant. For example, Equinor is today a large electricity generator in the North Sea with approximately 1.5 GW installed offshore gas turbine generators capacity.

In a shift to reduced CO2 emissions, Oil & Gas installations are looking at the possibility to be connected to an electrical grid. The possibility to supply offshore installation from an offshore grid may boost electrification of installation at greater distance from shore. With an interconnection to an offshore grid infrastructure, synergies and benefits of interconnection offshore wind generation and loads may be explored. Furthermore, the offshore industry beyond O&G, for example with focus on blue industrial growth can benefit from a readily available offshore grid infrastructure.

An offshore HVDC grid infrastructure prepared (through harmonization) to supply power to the offshore load clusters will greatly promote the electrification of offshore loads. The offshore sectors (including transportation and oil/gas facilities), plus emerging sectors (including offshore aquaculture, electrical vessels, desalination plants, ocean cleaning, offshore mining) will have direct access to an offshore grid infrastructure with integrated

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wind power instead of power supplied by either their stand-alone generating systems using offshore fossil fuels or dedicated long electrical cables from an onshore site. Additional foreseen benefits of connection of offshore loads are: funding of offshore grid infrastructure from multiple industries, balancing and grid stability of offshore loads.

When the entrance level to offshore becomes lower, the offshore loads can increase, e.g. reaching several 10s of GW by 2030 in the North Sea. The distributed nature of offshore load will challenge the offshore grid topology.

3.5.1.1 RELEVANT PROMOTION ACTIVITY

The PROMOTioN project focuses on offshore connection of wind power and does as such not consider large offshore consumption such as oil/gas installations in detail.

3.5.1.2 EXISTING AND PROSPECTIVE CONTRIBUTIONS

PROMOTiON contribution to harmonization is to promote the opportunity to connect relatively small offshore load (10 MW to few hundreds of MW) to an offshore HVDC grid and influence grid codes and specifications.

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4 INITIAL WORKSHOPS AND CONCLUSIONS

4.1 WORKSHOP ON HVDC CONTROL AND PROTECTION

A harmonisation workshop considering HVDC control and HVDC protection was held at CEN-CENELEC (Brussels) on 6th December 2018 with project internal and external attendees, including representatives of harmonisation working groups.
Based on input from the PROMOTioN technical work packages (WP2, WP4 and WP9), input from external contributors, and the discussions that took place during the workshop, the scope of possible contributions to harmonisation has been determined, and existing contributions from the PROMOTioN project have been identified. New possibilities for contributions that were identified will take the form of feedback on documents from harmonisation bodies, summary documents and technical application notes to provide to harmonisation organisations and workgroups, as well as continuation of numerous personal contributions to harmonisation workgroups, each incorporating PROMOTioN work.

4.2 WORKSHOP ON HVDC CONNECTED WIND POWER PLANTS

The workshop on HVDC connected wind power plants took place 15 January 2019 in DTU Wind Energy, Roskilde.

Main conclusions from the workshop on HVDC connected wind power plants:

- It is recommended not to make specific standards and requirements to tests, controls and modelling of HVDC connected wind power plants. Instead, the existing standards and requirements should be developed ensuring that they also apply to HVDC connected WPPs. This approach will also be useful for the increasing power electronics dominant of onshore AC power systems.
- The specific implementation of new advanced control such as grid forming control and black start control should not be standardized because this would block the development of new solutions. Instead, the harmonization should focus on providing functional specifications.
- Tests of harmonic emission and resonances will be increasingly important in the future. PROMOTioN should make sure that the results expected late in the project will be used in harmonization after PROMOTioN ended.
- Grid forming control and black-start capability of WPPs is also expected to be advanced in the end of the PROMOTioN project. PROMOTioN should make sure that this work is concluded with functional specifications which can be used in harmonization after PROMOTioN ended.
- PROMOTioN should follow the development of new IEC SC8A proposals for large scale offshore wind energy integration using multi-terminal HVDC. This work is expected to focus on best-practices, for instance publishing technical reports.

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4.3 OUTLOOK

Based on the content provided in this harmonisation catalogue WP11 strives to contribute to the indicated on-going and future harmonisation activities. The work will included further workshops and discussions with relevant stakeholder groups resulting in several reports about harmonisation activities and proposals.

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