Compact switchgear for meshed offshore HVDC networks – between vision and reality

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SUMMARY

The EU funded project “***Progress on Meshed HVDC Offshore Transmission Networks***” (**PROMOTioN**)[1] addresses the challenges for meshed HVDC offshore network development. The project does not only perform demonstrations of different HVDC switchgear, it also gives recommendations of how to test HVDC switchgear, and insight into typical requirements and expectations of HVDC switchgear and especially circuit-breakers in a grid. The project will finish in 2020 and all public material can be found on the project website. There is a need to move this work into standardization bodies to get an agreed and satisfactory testing procedure for the HVDC switchgear.

An option to decrease the footprint of HVDC substations is to use Gas Insulated Switchgear (GIS). Even though GIS can be used both onshore and offshore, the limited space on offshore platforms makes the technology particularly attractive for offshore applications. If future offshore grids would be considered with multi-terminal or switching stations offshore, the gain would be considerably larger. Moreover, the gas-insulated components can be applied in other HVDC applications like cable transition stations. Although GIS components have been developed, their performance is today relatively unknown to the market. The paper shows that the new components in a HVDC substation are far into the development phase and are on a clear path to an even higher Technology Readiness Level (TRL). The activities to increase the technical assurance to implement these components in the grid are described.

Based on the development and research results combined with the service experience a new type test philosophy including insulation system tests was developed. Standardization work has been started in committees like CIGRE and performance demonstrations are planned in the PROMOTioN project aligned with this standardization work. The paper provides a comprehensive update on status of standardization and demonstration efforts and provides suggestions for future work.

KEYWORDS

HVDC, Gas Insulated Switchgear (GIS), HVDC Circuit-Breaker (HHB), HVDC offshore grid, prototype installation test, PROMOTioN, standardization

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[1] *www.promotion-offshore.net*

I. Introduction

Migration towards renewable energy generation is an ongoing global mission. The total installed wind power capacity was 487 GW in 2016 and is expected to increase to 817 GW in 2021 [1]. Photovoltaic installations were 307 GW in 2016 and is expected to increase to 936 GW in 2021 [2]. The installed hydropower generation is at the same time expected to increase by 108 GW [3]. Suitable locations for large-scale renewable generation can typically be found in remote areas and requires efficient transmission such as High Voltage Direct Current (HVDC).

Today this is done by radial HVDC for both wind and hydro energy. However, there are potential benefits in terms of transmission system availability and decreased investment cost if several wind parks and electricity interconnectors between countries are joined into a HVDC Grid[2].

A significant difference between point-to-point HVDC systems and future HVDC grids will be the HVDC substations. In addition to the equipment associated with multiple feeders (e.g. cable terminations), HVDC circuit-breakers are expected to be required in larger HVDC grids, thus allowing faults to be cleared without first discharging the entire HVDC side.

The PROMOTioN project does not only perform the demonstrations of different HVDC circuit-breakers, it also gives recommendations of how to test HVDC circuit-breakers, and insight into typical requirements and expectations of HVDC circuit-breakers in a grid. As part of the PROMOTioN project, the ABB hybrid HVDC circuit-breaker will be tested in DNV GL's KEMA Laboratories for 350 kV and 16 kA. These tests demonstrate the proper functioning of the control and protection system for the HHB itself and also the performance of the semiconductor devices for such a current and voltage level. Moreover, testing the full energy absorption capability at full-scale appropriately stresses the UFD during the current suppression period, which cannot be demonstrated in tests on module level. There is a need to move this work into standardization bodies to get an agreed and satisfactory testing procedure for the HVDC circuit-breakers.

An option to decrease the footprint of HVDC substations is to use Gas Insulated Switchgear (GIS). Even though GIS can be used both onshore and offshore, the limited space on offshore platforms makes the technology particularly attractive for offshore applications. Although GIS components have been developed, their performance is today relatively unknown to the market. Unlike similar HVAC components, there has been until recently little standardization work to ensure the performance. Standardization work has been started in Cigré and is proposed to start in IEC [15].

Aligned with this standardization work, PROMOTioN Work Package 15 defined a test procedure for a HVDC GIS performance demonstration. The long-term (> 1 year) test is conducted at DNV GL's KEMA Laboratories using ABB's 320 kV HVDC GIS. This paper presents the test procedure and gives an update on the current test status.

II. The PROMOTioN Project

The EU funded H2020 project ***"Progress on Meshed HVDC Offshore Transmission Networks" (PROMOTioN)***[3] addresses technical, regulatory, legal, economic and financial challenges to the realisation of meshed HVDC offshore transmission networks. The project has six main objectives:

1. To establish interoperability between different technologies and concepts by providing specific technical and operational requirements, behavior patterns and standardization methods for different technologies
2. To develop interoperable, reliable and cost-effective technology of protection for meshed HVDC offshore grids and the new type of offshore converter for wind power integration
3. To demonstrate different cost-effective key technologies for meshed HVDC offshore grids and to increase their technology readiness level by investigating and overcoming early adopter issues and pitfalls
4. To develop a new EU regulatory framework, both in accordance with EU wide energy policy objectives and those of the Member States, and to increase the economic viability of meshed HVDC projects by providing a suitable financial framework
5. To facilitating the harmonization of ongoing initiatives, common system interfaces and future standards by actively engaging with working groups and standardization bodies and actively using experience from the demonstrations.
6. To provide concrete deployment plan for "phase two" in bringing key technologies for meshed HVDC offshore grids into commercial operation in Europe, taking into account technical, financial and regulatory aspects

The main aim is develop technologies to a sufficiently high technology readiness level that they can be readily integrated in real HVDC systems through analysis and demonstration. At the same time, the project aims to show that solutions exists for differences in national

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[2] *European Commission – Study of the benefits of a meshed offshore grid in northern seas region - Final Report - 2014*

[3] *www.promotion-offshore.net*

regulatory frameworks, gaps in legislation, that business models can be built and that financing can be achieved.

PROMOTioN brings together all relevant HVDC manufacturers, network operators along the North Sea, wind developers and consultants plus academia together with a common vision and goals. All 33 partners of PROMOTioN are convinced that successfully addressing these six ambitious objectives will significantly accelerate the deployment of meshed HVDC offshore grids in the North Sea area and beyond towards continental power corridors and will be a major step in bringing them into commercial application in near future.

There are several components of the future offshore grid which are required for meshed offshore grid operation:

- Converter technology for on/offshore application providing affordable wind power integration
- Cables for interconnection of offshore generators, loads and onshore grids
- Converter interoperability, control philosophies and regulations
- Identified interaction between HVAC and HVDC systems for reduction of technological risk
- Protection systems for fault detection
- HVDC switchyards including HVDC circuit-breakers for fault clearance and
- HVDC gas insulated systems for minimal footprint substation components.

PROMOTioN is organized in 16 Work Packages following the flow of information from developing offshore grid functional requirements through development into technology demonstration and finally future grid deployment plan (Figure 1). The project runs since 2016 and will be finished in 2020. The project partners are properly representing its technical key dimensions of wind farm deployment, power generation & utilization and power transmission. Together the consortium will address the missing links to overcome the obstacles in order to push for a swift commercial operation of offshore grid crucial technologies.

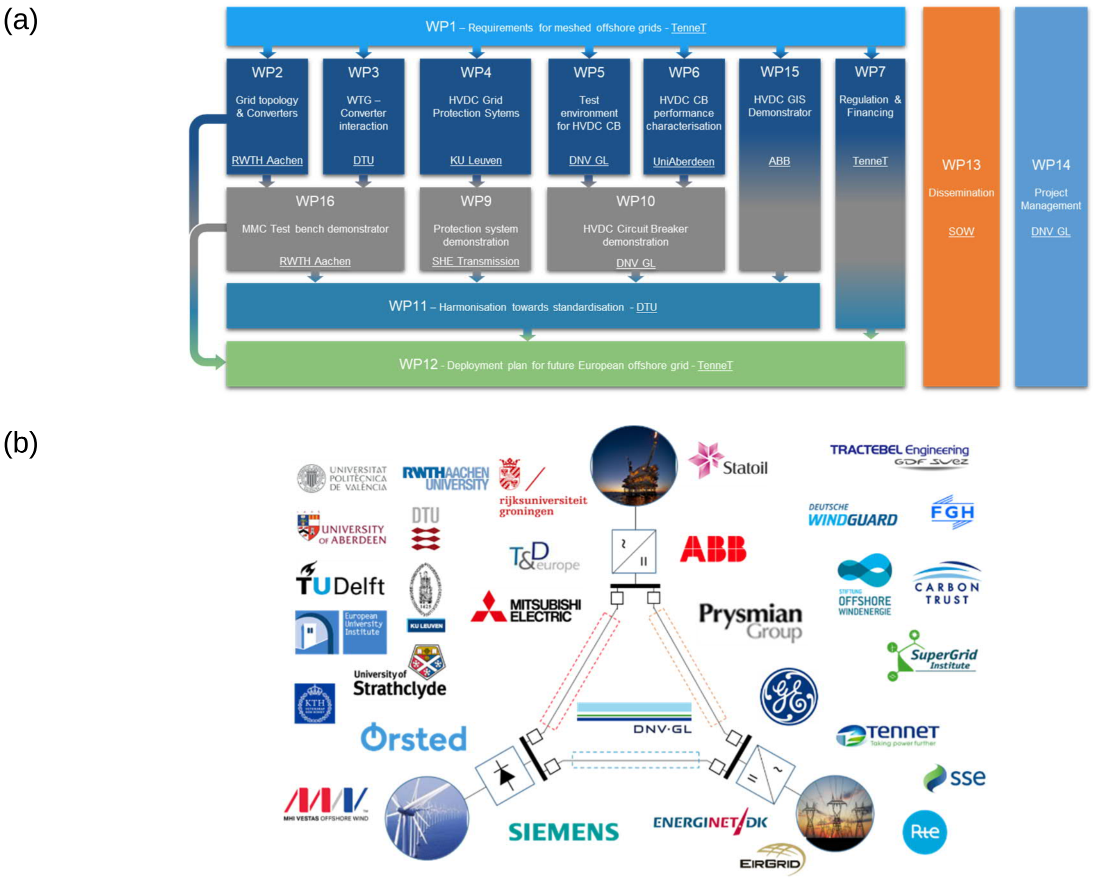

Figure 1 Working structure diagram PROMOTioN (a) and concept underlying PROMOTioN combining key dimensions of meshed HVDC offshore grids – wind farm deployment, power generation & utilization and power transmission –linked to industrial partners (b)

III. **HVDC Grid**

The design of an HVDC grid depends on its functional requirements. In addition to its topology (i.e. radial or meshed), aspects like fault clearing strategy (number, type and location of HVDC circuit-breakers) and the type of converters must be chosen, to minimize the disruption caused by faults to an acceptable level. For example, fast HVDC circuit-breakers can be placed at the end of each line in a fully selective protection strategy of high impact networks, guaranteeing continuous operation in case of faults and provided sufficient redundancy is available. Alternatively, HVDC circuit-breakers can be placed at strategic locations only, realizing a partially selective fault clearing strategy. In the latter case, a part of the HVDC network is allowed to de-energize (temporarily) as a consequence of the fault. In this case normal disconnectors could be used to remove the faulty part from the grid.

One HVDC system can have different fault clearing strategies for different protection zones as illustrated in the example in Figure 2. In zone Z, a single line can be disconnected by HVDC circuit-breakers, but also the large grid can be separated into two smaller grids (A and B). The HVDC links between region A and B can be seen as two redundant lines and the HVDC circuit-breakers can be used to ensure transmission between the two regions even if one of them has a fault.

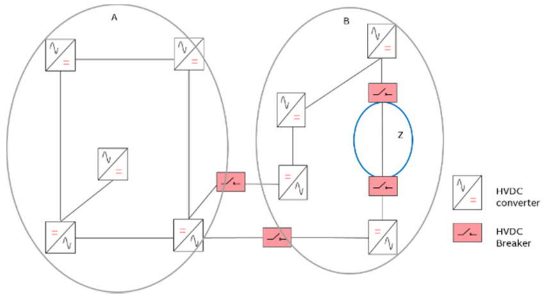

Figure 2 Example of an HVDC grid with HVDC circuit-breakers

HVDC substations form the nodes in the HVDC network. The primary function of such a node is to connect the incoming links together and distribute the link currents. Hence, the node, depending on its insulation medium, must be connected to the links by means of bushings, terminations and/or sealing ends. The main difference between HVAC and HVDC substations is the absence of a transformer in case of a HVDC substation. Typically, these nodes are further equipped with switches which can be used to reconfigure the network, or circuit-breakers to commutate or interrupt fault current to disconnect a failed component from the network. To prevent overvoltages on the lines or cables, surge arrestors or other overvoltage mitigating or discharging and pole rebalancing equipment are normally placed at the nodes. Lastly, substations provide a chance for monitoring the state of the HVDC network by means of voltage and current sensors. This instrumentation is typically connected to a substation control & protection system which continuously monitors the operating mode of the node.

Another typical characteristic of a substation is the main insulation medium which is used. For HVDC installations this has typically been in air, which has a cost advantage but requires a relatively large footprint and is susceptible to environmental influences, as opposed to gas insulated installations which have been in use for AC applications for decades.

In AC applications, nodes are often implemented in double, split or ring busbar configuration to provide redundancy. Depending on the design philosophy and fault clearing strategy in HVDC networks, similar approaches may be adopted, although innovative new substation structures which optimally exploit the system design of Hybrid HVDC circuit-breakers are possible too [4].

IV. HVDC GIS

A. Aim of the prototype installation test

Based on service experience, gas-insulated HVAC systems feature a high degree of reliability and an excellent long-term performance. In comparison, HVDC GIS is a new technology with limited operational experience [9]. The user who intends to apply gas-insulated HVDC systems does expect the same reliability and long-term performance as in HVAC GIS.

From a high-voltage engineering perspective the main differences between HVAC and HVDC GIS are the long periods required to reach steady state DC electric fields and charge accumulation phenomena. Thus, HVDC GIS requires adapted design and testing. Until today, no tests have been standardized for HVDC GIS systems. However, CIGRE JWG D1/B3.57 is currently finalizing a technical brochure TB on "*Dielectric Testing of Gas-Insulated HVDC Systems"*. The TB will include adapted type test procedures (e. g. insulation system test). A special "prototype installation test" is also proposed as a demonstration test.

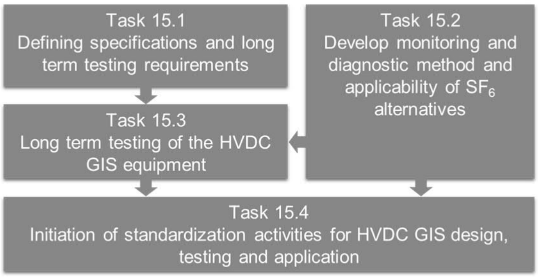

Figure 3 WP15 HVDC GIS technology demonstrator

The scope of PROMOTioN WP15 includes the definition of HVDC GIS specifications based on input from TSOs as well as the definition of HVDC GIS long-term testing requirements derived from these specifications and lab experience (Task 15.1, Figure 3). Subsequently, a long-term test of an ABB HVDC GIS is conducted at DNV GL's KEMA Laboratories in Arnhem (Task 15.3).

In close alignment with CIGRE activities, deliverable D15.2 of PROMOTioN exemplarily defines the complete test procedure for a "prototype installation test" [14] – a long-term demonstration test with a duration of more than one year. AC GIL assemblies need similar evidence for functionality to other underground line systems like cables, where the prequalification test is usually performed [10]. The main intention of the prototype installation test for gas-insulated systems is to confirm the reliability of the system under real service conditions. Real service conditions refers to:

- the components included in the test object (details in section B)
- installation and commissioning procedures (details in section B)
- as well as the dielectric, thermal and mechanical stresses applied in the test itself (details in section C).

Thus, the prototype installation test is not an additional type test, but rather a one-time, non-mandatory test performed after successfully completing the type tests to verify the effectiveness of the HVDC GIS specific type and routine test procedures.

Additionally, a successful prototype installation test demonstrates the performance of the manufacturer as a supplier of a HVDC gas-insulated system with a certain rated voltage U_r. That means the test's scope extents towards the manufacturer's HVDC GIS technology and is not limited to one specific product, provided the following conditions are fulfilled [14]:

- The rated voltage U_r of the tested gas-insulated system is not surpassed.
- The limiting temperature of the various parts is not higher than that of the tested gas-insulated system.

B. **Test Setup**

The test pole for the prototype installation test should include all major modules of the gas-insulated systems that would be needed for a HVDC substation. Installation and commissioning should be performed by the manufacturer, using the same procedure as for future customer projects [7].

For PROMOTioN WP15 the ABB HVDC GIS with ratings according to the 320 / 350 kV DC voltage level is tested (*Table 1*). These ratings are in line with the specification defined in WP15 deliverable D15.1 [13].

Table 1: Ratings of ABB HVDC GIS

Rating	*Value*	*Unit*
Nominal DC voltage U_n	± 320	$\mathrm{kV_{dc}}$
Rated DC voltage U_r	± 350	$\mathrm{kV_{dc}}$
Rated lightning impulse withstand voltage	± 1050	kV
Rated superimposed lightning impulse withstand voltage		
Lightning impulse voltage	± 1050	kV
DC voltage	± 350	$\mathrm{kV_{dc}}$
Rated switching impulse withstand voltage	± 950	kV
Rated superimposed switching impulse withstand voltage		
Switching impulse voltage	± 950	kV
DC voltage	± 350	$\mathrm{kV_{dc}}$
Rated DC withstand voltage phase to earth U_w	± 610	$\mathrm{kV_{dc}}$

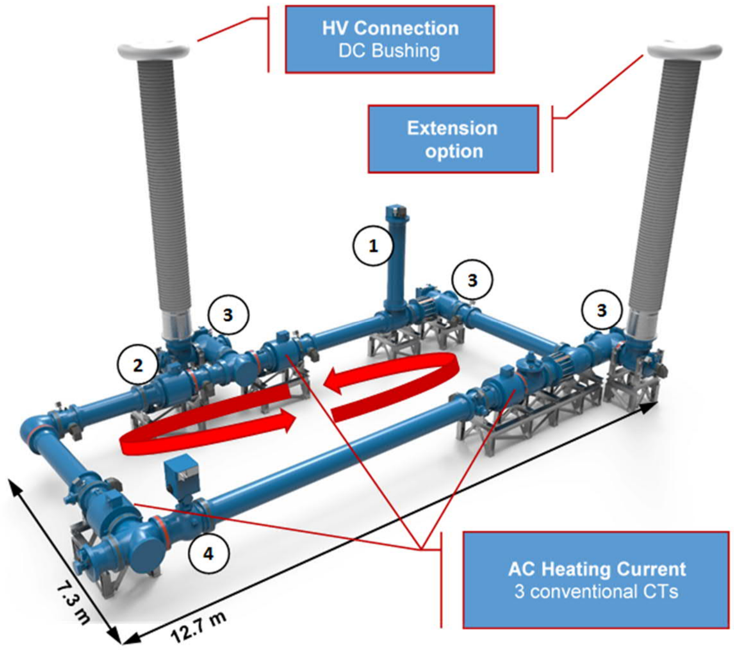

Figure 4 HVDC GIS prototype installation

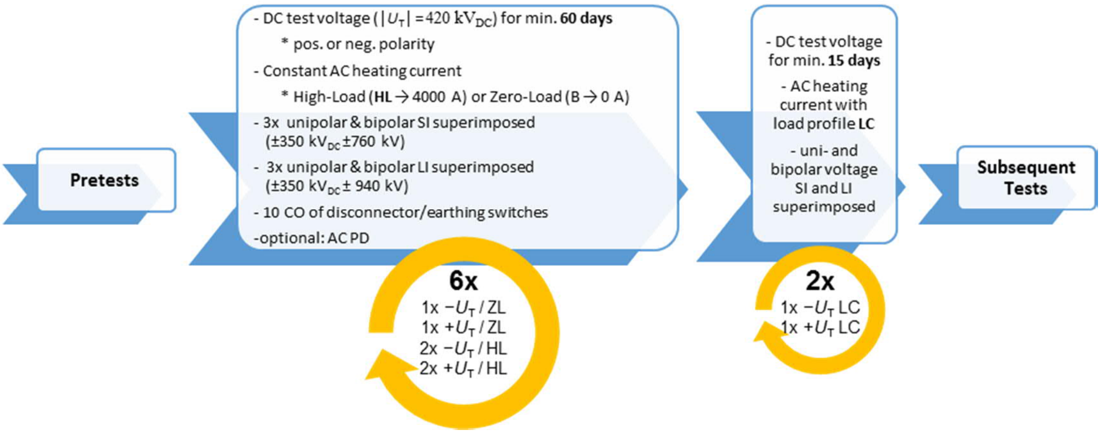

Figure 5 HVDC GIS prototype installation test program, voltage and current values used for the test of ABB's HVDC GIS; Long-term voltage test: min. 390 days at test DC voltage U_T = 420 kV

The HVDC GIS test pole consists of a bus-duct ring that is connected to HV via SF_6 to air bushings (Figure 4). To achieve a thermal regime typical for high load condition, an AC heating current can be induced in the ring using conventional current transformers. The dielectrically decisive quantity – temperature difference inner conductor to enclosure (at the insulator) – will be generated with at least the same magnitude compared to a DC current load [12].

The GIS ring includes (Figure 4):

- 8 gas compartments
- 31 m busbar with straight, L, T, X elements and dismantling units)
- 8 partition insulators
- 14 support insulators
- DC Instrument transformers:
  ① VT: RC-divider
  ② CT: Zero-Flux Sensor
- Switching devices:
  ③ Combined disconnector and earthing switches
  ④ Fast-acting earthing switch
- Complete secondary technology including PD monitoring, internal arc detection and density monitoring

C. Test Procedure and Current Status

The prototype installation test consists of three phases (Figure 5):

- Pretests
- Long-term voltage test
- Subsequent Tests

Pretests verify sound installation and commissioning of the HVDC GIS as well as lab setup. They include: Zero-Load (ZL, 0 A), High-Load (HL, rated current) and Load Cycle (LC, Figure 6) current load, AC and DC PD measurement. Lightning and Switching Impulse voltages, LI and SI superimposed voltages and DC polarity reversal.

The **long-term voltage test** is the main part and contains a minimum of 390 days total DC voltage stress. The test consists of eight 60-day or 15-day blocks with constant test DC voltage U_T (Figure 5). Each block is concluded by uni- and bipolar superimposed impulse voltages as well as 10 no-load operations of the disconnector and earthing switches. It is a representation of realistic in-service operation and conditions. Since even the long term test's duration of min. 390 days is still considerably shorter than the expected service life of a HVDC GIS, the test DC voltage (U_T) is higher than the rated DC voltage (U_r) by a factor of 1.2 (420 kV vs. 350 kV, compare Figure 5 and *Table 1*). Factor 1.2 U_r is a compromise which can largely prevent charging processes that do not occur in practice at 1.0 U_r.

Subsequent tests conclude the prototype installation test. They include impulse voltage tests as well as DC and AC PD measurement to verify the condition of the HVDC GIS after the long-the test.

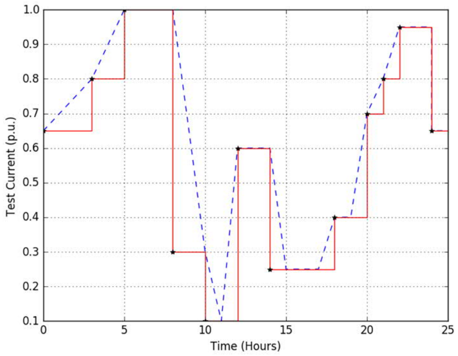

Figure 6 Load cycle LC, 1 p.u. = rated current [14]

Currently (February 2019), all pretests have been successfully completed and the long-term test has started (Figure 7). The HVDC GIS is currently in the first 60 day cycle with a test DC voltage of constantly U_T = −420 kV and Zero Load condition (0 A heating current). The test is expected to conclude in the first half of 2020.

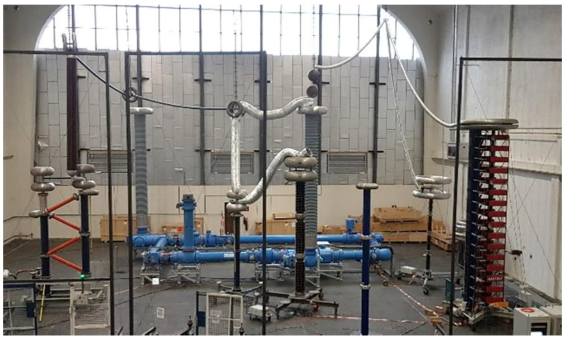

Figure 7 HVDC GIS with test setup for long-term test

V. HVDC circuit-breaker

A. Project aim

The development of HVDC circuit-breaker technology is reflected by initiation of standardization activities such as the EU funded Twenties project deliverable 11.2, in which in 2014 test requirements and test circuits for testing the thyristor based hybrid HVDC circuit-breaker are developed, based on existing standards for AC circuit-breakers. These test requirements did however not include specific requirements for testing energy absorption or post-suppression dielectric stress.

The CIGRE working group A3/B4.34 published a Technical Brochure [8] in 2017 which among other HVDC switchgear covers HVDC circuit-breakers. It describes the technology behind different types of HVDC circuit-breakers and lists grid parameters that affect the HVDC circuit-breaker design. In China, a standard for testing HVDC circuit-breakers is in draft form. The standard includes a description of terminology and test requirements for operational tests, breaking tests, dielectric tests, and mechanical tests. Voltage and current classes are introduced. The test requirements did not include specific requirements for testing energy absorption or post-suppression dielectric stress. The actual status of this standard is unknown. Finally, a CIGRE Joint working group between B4 and A3.80 (2019-2022) was started on HVDC circuit-breaker technical requirements, stresses and testing methods to investigate the interaction with the system**.**

The PROMOTioN project has defined the test requirements and developed a test environment for HVDC circuit-breakers. HVDC circuit-breaker models were developed for different technologies and simulated in a benchmark system model to identify the stresses experienced during current interruption in case of different types of fault cases in this system. The resulting test requirements have been classed in operational, breaking and dielectric tests, in accordance with AC circuit-breaker terminology. Combining the results from the studies[4],[5] and the requirements from the project partners, test requirements and test procedures have been defined and analysis and simulations of different test circuits for testing HVDC fault current interruption have been performed. In the next phase of the project, different types of HVDC circuit-breakers will be tested at DNV GL's KEMA Laboratories. The test results and procedures will be analyzed and the project will deliver recommendations for standardized test requirements and procedures.

B. High power circuit-breaker testing

Today several testing methods have been developed to perform current interruption tests on HVDC circuit-breakers. For the PROMOTioN project an AC short-circuit generator based test circuit will emulate the behavior of a transient current during a fault, which includes the validation of the energy absorption rating. In general, to stress the HVDC circuit-breakers as in service, a test circuit should provide sufficient current, voltage and energy. The specific details are mainly dependent on the system under consideration. However, the most important functionalities of an HVDC circuit-breaker which must be tested are [11];

1. Capability to create a local current zero without restrike/breakdown of mechanical switches/interrupters or thermal overload of power electronic components at rated DC fault Current
2. Generation of sufficient counter voltage to initiate fault current suppression
3. Capability of energy absorption components to absorb energy during fault current suppression wave trace as in service. Depending on the rated test sequence, this capability must be demonstrated several times within a defined sequence.
4. Capability to withstand the rated DC voltage after the current interruption process
5. The circuit-breaker operation time: the minimum time at which the circuit-breaker reaches the TIV withstand level after trip order
6. The maximum current interruption: The maximum current the circuit-breaker can interrupt within the circuit-breaker operation time
7. The maximum energy that the circuit-breaker can absorb
8. The number and frequency of operation: the number of interruption operations that the circuit-breaker can perform before thermal run away occurs in its surge arresters. The interruption interval needs to be defined, e.g. like auto reclosure in AC circuit-breakers.

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[4] *PROMOTioN – Deliverable 5.1: HVDC Network Fault Analysis*

[5] *PROMOTioN – Deliverable 5.2: Fault stress Analysis of HVDC Circuit Breakers*

A test circuit for HVDC circuit-breaker short-circuit current breaking testing should reproduce the stresses that are relevant for current breaking operations up to the rated values including a test factor where applicable. Furthermore, the test circuit must be able to withstand any stresses such as TIV which are produced and determined by the HVDC circuit-breaker itself. For a test circuit to provide adequate stresses to HVDC circuit-breakers, it should fulfil the following requirements:

1. Pre-condition the HVDC circuit-breaker to mimic worst case normal service conditions, and ensure internal systems are powered up and charged
2. Produce a test current which rises somewhat linearly from anywhere up to the rated load (or short-time withstand current) to the intended test duty within the circuit-breaker operation time. The most difficult interruption may not necessarily be the highest current. Thus, test circuits have to provide a wide range of quasi–DC currents, from the rated load current (or less) to the rated short circuit-breaker current of an HVDC circuit-breaker. The test circuit must be able to apply the test current bi-directionally.
3. Supply rated energy to the HVDC circuit-breaker and withstand TIV
4. Supply rated dielectric stress immediately after current suppression
5. Avoid damage to the HVDC circuit-breaker and test circuit in case of failure - if the prospective short-circuit current from a test circuit can exceed the HVDC circuit-breaker's rated short-circuit breaking current, it is necessary to limit the damage to the HVDC circuit-breaker as well as the test installation in case of a failure to clear. Methods to avoid potential damage to the test circuit-breaker as well as the test installation have been proposed
6. Be implementable / economical – the test circuit must be technically feasible, practical and economical.

The above requirements should be fulfilled whilst respecting practical circuit-breaker operation times which are currently assumed to be in the range of 2 – 8 ms. These stresses do not have to be supplied by the same source, in which case it is referred to as a synthetic test.

The modular construction of HVDC circuit-breakers may under certain conditions allow the verification of functionality and/or ratings by testing a reduced number of modules, which is referred to as modular testing. In this case, the test requirements need to be prorated according to the ratings per module by using the following high level guidelines:

- Current sharing
  - In series connected modules, current is not divided
  - Commutation duty between parallel full pole branches must be adequately represented
- Voltage grading
  - Divided by number of series connected modules
  - Determined by surge arrestors
  - Full-pole components need to be dielectrically tested separately
- Energy grading
  - Divided by number of series connected modules
  - Margin required determined by small differences in timing

Such modular tests can be used to verify current interruption capability or energy absorption ratings, but are not substitute for a full pole test to verify the correct function of all control and communication systems.

In PROMOTioN, it is shown that AC short-circuit generators operated at reduced frequency offer flexible control of the rate of rise of test current and the amount of energy delivered to the HVDC circuit-breaker by carefully choosing the generator frequency, the test circuit impedance, the generator source voltage magnitude, and the making angle (Figure 8). A parallel synthetic test circuit consisting of a charged capacitor bank which can be connected to the test object through the triggered spark gap 3 is included to realize the DC voltage stress after suppression.

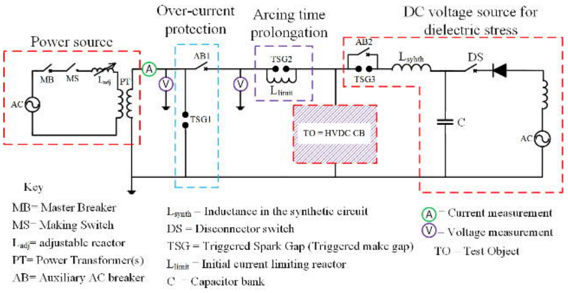

Figure 8 AC short-circuit generator based test circuit

The AC characteristic of the driving source voltage implies that an inherent limitation exists on testing HVDC circuit-breakers with long circuit-breaker operation times, as the entire fault neutralization time must be less than the longest possible half wave period of the applied test current. To check whether DNV GL's KEMA Laboratories set-up is capable of testing the HHB, several prospective current tests and simulations were performed the results of which are shown below (Figure 9). The test confirmed that at 16,7 Hz generator frequency a sufficiently high rate-of-rise of current could be achieved to test the current interruption capability of 16 kA whilst maintaining sufficient source voltage to adequately test the energy absorption requirement.

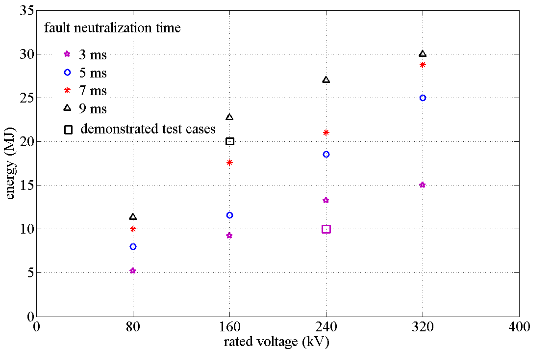

Figure 9 DNV GL's KEMA Laboratories HVDC circuit-breaker direct testing capabilities

C. Hybrid HVDC circuit-breaker (HHB)

The hybrid HVDC circuit-breaker (HHB) was introduced by ABB in 2011 [5]. The modular nature of this concept makes it suitable for all voltage ranges. As shown in Figure 10, the HHB consists of three major units: load commutation switch (LCS), ultra-fast disconnector (UFD) and main circuit-breaker (MB). Load current is conducted through the LCS and UFD path during normal operation and whenever the current interruption is triggered, the current will be commutated to the parallel main circuit-breaker path for interruption.

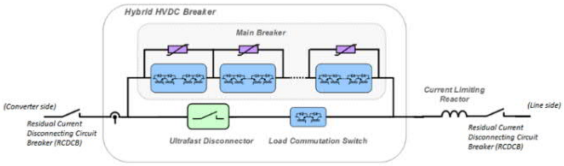

Figure 10 The hybrid HVDC circuit-breaker

The LCS design offers high reliability and availability by using parallel and series connected semiconductors [6]. The LCS is a relatively small and compact switch which can handle load currents continuously and fault current for a certain time interval. In series to the LCS, a mechanical gas-insulated ultra-fast disconnector (UFD) is available to realize the high voltage insulation strength during the current interruption. The current rating of the UFD is similar to the LCS's to ensure reliable current conduction. In parallel to the UFD-LCS path, a main circuit-breaker is placed to interrupt the current via series connected semiconductor devices and, ultimately, absorb the fault energy in parallel connected surge arresters. Each HHB module utilizes the well-developed and commercialized components in HVDC field to ensure high reliability of the complete design.

As part of the PROMOTioN project, the HHB will be tested in DNV GL's KEMA Laboratories for 350 kV and 16 kA. The test object consists of 5 main circuit-breaker modules of 80 kV, LCS designed for 3.3 kA continuous current and dead-tank UFD for the corresponding voltage. The mechanical structure is designed to resemble the final product of HHB for 350 kV system. One standing structure includes all main circuit-breaker modules plus LCS and UFD is located separately with two 350 kV isolating bushings.

Even though it is possible to perform the type tests on module level rather than full-scale, the test object for DNV GL's KEMA Laboratories corresponds to a full-scale 350 kV HHB product. Operational type test including nominal current and fault current interruption is planned to be done (see section B). These tests demonstrate the proper functioning of the control and protection system for the HHB itself and also the performance of the semiconductor devices for such a current and voltage level. Moreover, testing the full energy absorption capability at full-scale appropriately stresses the UFD during the current suppression period, which cannot be demonstrated in tests on module level.

VI. Acknowledgement

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

VII. References

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Zusammenfassung

Kompakte Schaltanlagen für vermaschte Offshore-HGÜ-Netze – zwischen Vision und Wirklichkeit

Das EU-finanzierte Projekt „**Entwicklung von vermaschten HGÜ-Offshore-Übertragungs-Netzen“ (PROMOTioN)**[6] befasst sich mit den Herausforderungen, die bei der Entwicklung von HGÜ-Offshore-Übertragungsnetzen bestehen. Das Projekt zielt nicht nur auf die Demonstration verschiedener HGÜ-Schaltanlagen ab, sondern gibt auch Empfehlungen zum Prüfen von HGÜ-Schaltanlagen und Einblick in typische Anforderungen und Erwartungen von Schaltanlagen und insbesondere von HGÜ-Leistungsschaltern im Netz. Das Projekt wird im Jahr 2020 abgeschlossen sein und die aktuellen Ergebnisse können auf der der Internetseite des Projektes verfolgt werden. Die Ergebnisse werden in die Normierung einfliessen, um abgestimmte und zufriedenstellende Prüfverfahren für Schaltanlagen zu erhalten.

Um den Raumbedarf von HGÜ-Schaltanlagen zu verringern, können gasisolierte Schaltanlagen (GIS) verwendet werden. Obwohl die GIS-Technologie sowohl an Land als auch Offshore eingesetzt werden kann, macht die begrenzte Fläche auf Plattformen die Technologie besonders für Offshore-Anwendungen interessant. Wenn zukünftige Offshore-Übertragungsnetze mit Multi-Terminal-Anwendungen oder Schaltstationen im Offshore-Bereich in Betracht gezogen werden, wäre der Vorteil erheblich grösser. Darüber hinaus können die gasisolierten Komponenten auch in anderen HGÜ-Anwendungen eingesetzt werden, wie zum Beispiel für Kabelübergangsstationen. Obwohl GIS-Komponenten bereits entwickelt sind, sind sie heute auf dem Markt relativ unbekannt. Im Beitrag wird dargelegt, dass sich die neuen Komponenten aus der Entwicklungsphase begeben und damit für den Einsatz bereitstehen. Massnahmen zur Erhöhung der technischen Sicherheit, um diese Komponenten wie beschrieben im Netz implementieren zu können, werden beschrieben.

Basierend auf Entwicklungs- und Forschungsergebnissen in Verbindung mit ersten Betriebserfahrungen wurde eine neue Prüfphilosophie einschließlich spezieller Isolationssystemtests entwickelt. In Gremien wie CIGRE wurde breites mit der Normungsarbeit begonnen, und im PROMOTioN-Projekt laufen Demonstrationsversuche zum Nachweis der Leistungsfähigkeit der einzelnen Komponenten. Der Beitrag wird einen umfassenden Überblick über den Stand der Normungsarbeit und die technischen Demonstrationen geben und leitet Empfehlungen für die weitere, zukünftige Arbeit ab.

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