Performance Demonstration of HVDC substation equipment

Demonstration der Eignung und Leistungsfähigkeit von HGÜ Schaltanlagen

Jenny Josefsson
ABB Sweden
jenny.josefsson@se.abb.com
Sweden

Uwe Riechert
ABB Switzerland
uwe.riechert@ch.abb.com
Switzerland

Cornelis Plet
DNV GL Energy
Cornelis.Plet@dnvgl.com
Netherlands

Semere Mebrahtu-Melake
ABB Sweden
semere.mebrahtu-melake@se.abb.com
Sweden

Arman Hassanpoor
ABB China
arman.hassanpoor@cn.abb.com
China

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 the demonstrations of different HVDC Breakers, it also gives recommendations of how to test HVDC Breakers, and insight into typical requirements and expectations of HVDC 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 Breakers as well as for the non-linear resistors.

The increasing demand for HVDC technology requires the adaptation of gas insulated switchgear (GIS). Based on the development and research results combined with the service experience a new type test philosophy including insulation system tests was developed. 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 various HVDC applications.

This paper explains that the new components in an 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 as described.

Once the HVDC substation equipment has been implemented into HVDC systems, and the experience should be collected on how they are actually being used, to develop more cost efficient solutions.

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[1] www.promotion-offshore.net

1 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 breakers are expected to be required in larger HVDC grids, thus allowing faults to be cleared without first discharging the entire HVDC side.

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 committees like Cigré and performance demonstrations are planned in the PROMOTioN project aligned with this standardization work. This paper provides a comprehensive update on status of standardization and demonstration efforts and provides suggestions for future work.

2 PROMOTION

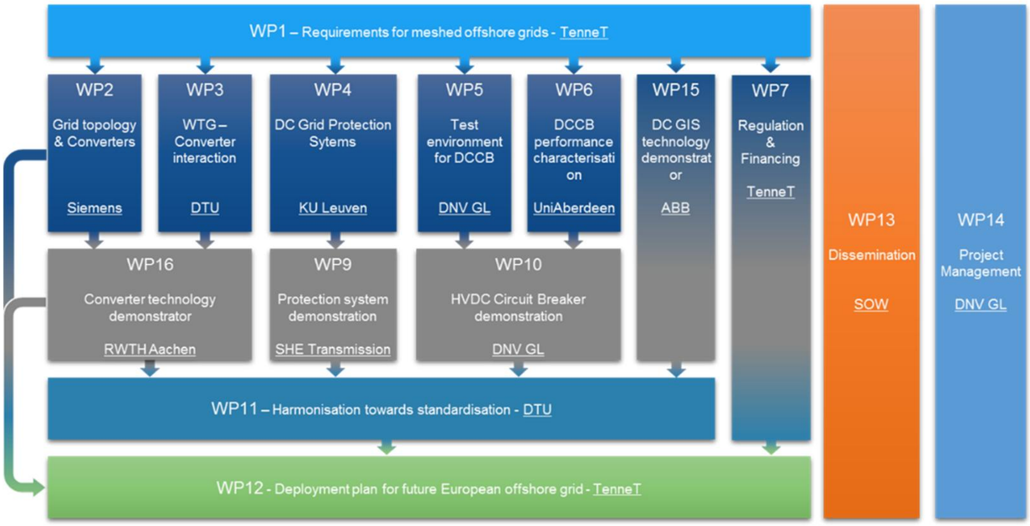

Figure 1. Working structure diagram PROMOTioN

The EU funded H2020 project "Progress on Meshed HVDC Offshore Transmission Networks" (PROMOTioN)[3] addresses the challenges for meshed HVDC offshore networks development by putting a clear focus on six ambitious objectives:

1. To establish interoperability between different technologies and concepts by providing specific technical and operational requirements, behaviour patterns and standardization methods for different technologies

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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

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 guiding principle behind these objectives is the search to bring meshed HVDC offshore grids and their associated technologies to the level of large scale real-life application. All the 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. A particular strength of PROMOTioN is the ability to take into account different relevant perspectives by bringing all relevant HVDC manufacturers, network operators along the North Sea, wind developers and consultants plus academia together with a common vision and goals. PROMOTioN's aim is to facilitate development of the technology in order to demonstrate high technology readiness level and build a bridge towards grid implementation. 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 minimal footprint substation components

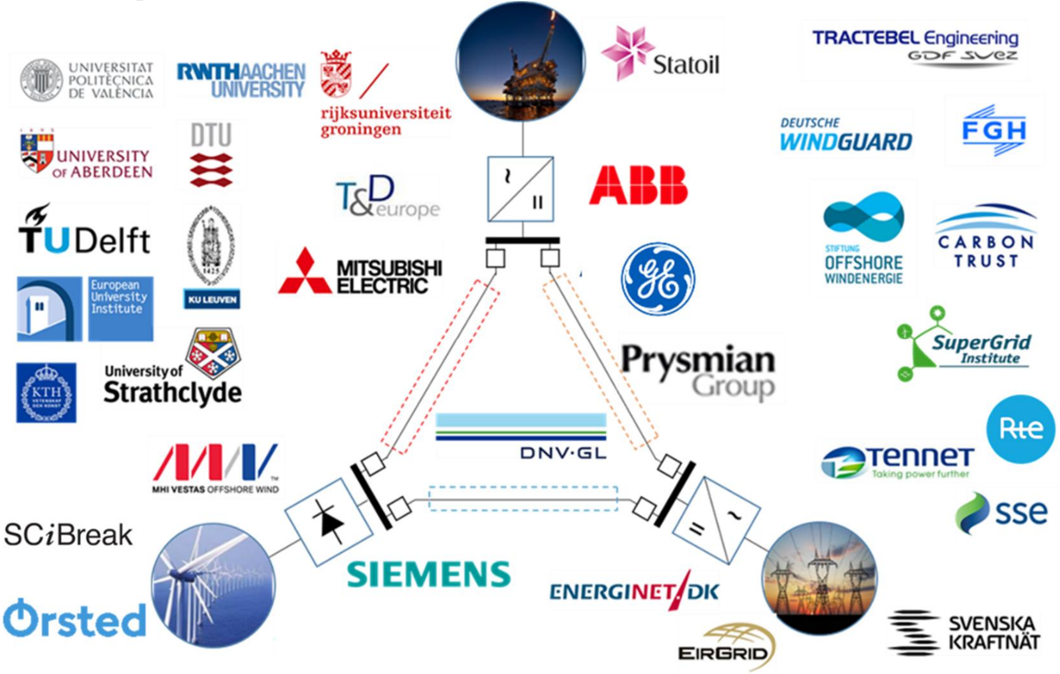


Figure 2. Concept underlying PROMOTioN combining key dimensions of meshed HVDC offshore grids – wind farm deployment, power generation & utilization and power transmission – linked to industrial partners

PROMOTioN is organized in 16 Work Packages and each Work Package includes number of tasks. Following the flow of information from offshore grid 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 (see Figure 2). 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.

3 HVDC GRID

3.1 HVDC grid configuration

The design of an HVDC substation depends on the system and cost requirements. If required, HVDC Breakers can be used to clear faults without the need for de-energizing the entire HVDC side or all converters in the HVDC grid. A likely application is in combinations with overhead lines, or in larger systems with cables (multi-terminal or HVDC Grid) in which all power transmission cannot be lost in case of a HVDC fault. Strategically placed HVDC Breakers can be used to separate the system into smaller subsystems that the grid can afford to lose, not necessarily requiring HVDC breakers at each line in every HVDC substation.

One HVDC system can have different protection strategies for different protection zones as illustrated in the example in Figure 3. In zone Z, a single line can be disconnected by HVDC Breakers, but also the large grid can be separated into two smaller grids (A and B). The HVDC links between region A and B could also be seen as two redundant lines and the HVDC Breakers can be used to ensure transmission between the two regions even if one of them has a fault.

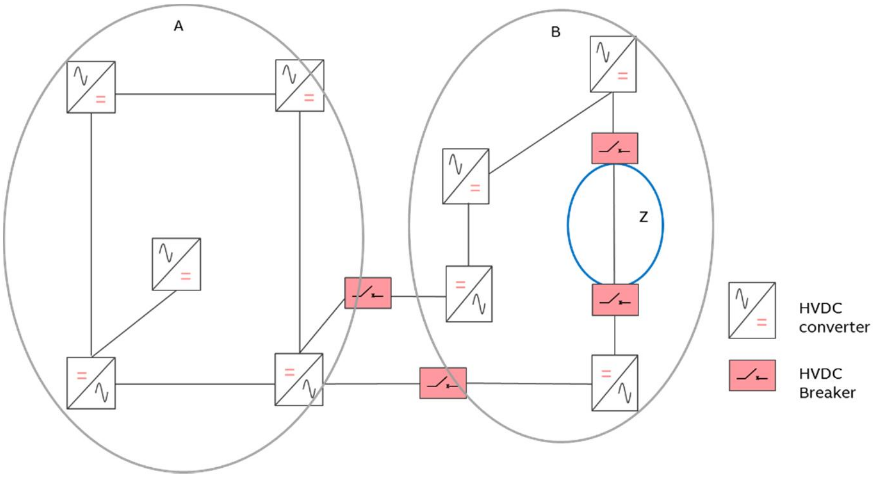


Figure 3. Example of an HVDC grid with HVDC breakers

3.2 HVDC Switchyard

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 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 Breakers are possible too [4].

3.3 Hybrid HVDC Breaker

The HVDC current offers no zero crossings which complicates a HVDC current interruption. The fastest type of HVDC Breakers consists only of semiconductors (for example IGBT's), but has higher conduction losses. The Hybrid HVDC breaker (HHB), introduced by ABB in 2011, uses power electronics to ensure a fast current interruption during a fault, while conducting the current in a parallel branch with a mechanical contact system to reduce the losses during normal operation [5]. Hence the name Hybrid HVDC breaker.

The basic design of the HHB can be seen in Figure 4. [6] During normal operation the current flows through the parallel branch with a mechanical ultra-fast disconnector (UFD) in series with a load commutation switch (LCS) consisting of semiconductors [7], [8]. When the HHB receives a trip signal from the protection system, the current is commutated by the LCS to the main breaker (MB) branch consisting of semiconductors and non-linear resistors, configured in modules that can be controlled independently.

The UFD opens to isolate the LCS from the voltage which appears across the MB during the current interruption. The interruption itself is performed by the MB. In order to ensure the maximum rated current interruption of the MB is not exceeded within the breaker operation time, typically an inductor is added in series to the HHB to limit the rate of rise of fault current.

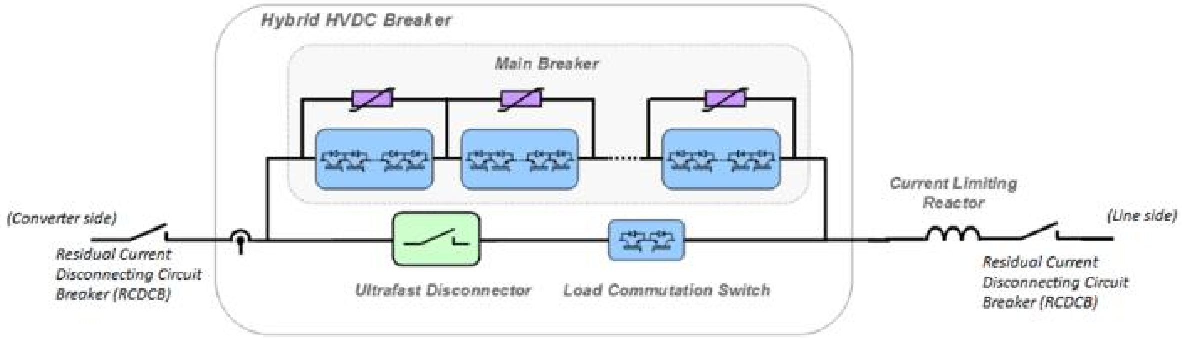


Figure 4. The Hybrid HVDC Breaker

The UFD has to operate quickly, typically around 3 ms from trip signal to fully opened contacts. The mechanical contacts inside the UFD can be opened in a fast and reliable way by using a Thomson coil actuator.

The LCS is constructed by connecting series connected semiconductors in parallel branches. If a semiconductor fails in one branch, the current will be conducted to an available parallel branch as the failed device creates a high impedance in relation to a healthy branch with lower impedance. The commutation of current between parallel branches has been proven reliable and safe by several tests of the LCS.

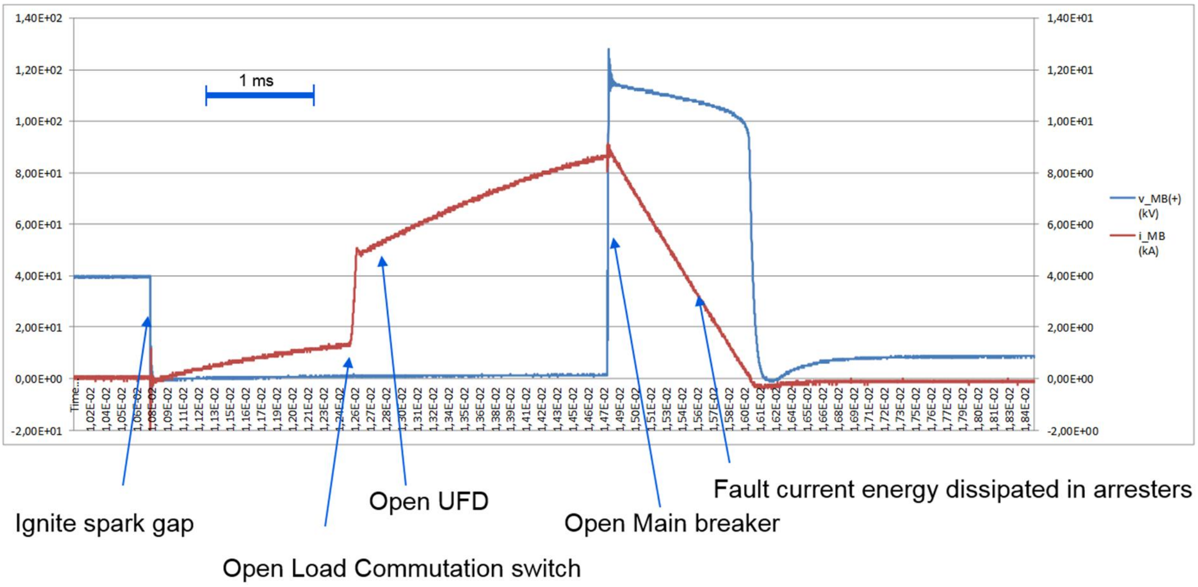


Figure 5. The hybrid HVDC breaker test results

First tests that has been done on the main breaker were current breaking test using 80 kV modules. The main breaker module, the UFD and the load commutation switch are initially closed. A capacitor bank has been charged through the HVDC supply. The capacitor bank is discharged through the hybrid HVDC breaker and then the fault is applied by igniting the spark gap. After fault initiation, the current increases. The load commutation switch opens at 1.5 kA and then the UFD is opened providing contact separation and dielectric voltage withstand capability in 2 ms. At the end the main breaker opens to interrupt the current. In Figure 5, the current commutation and interruption process can be seen. V_MR is the voltage over the main breaker and i_MB is the current through the main breaker.

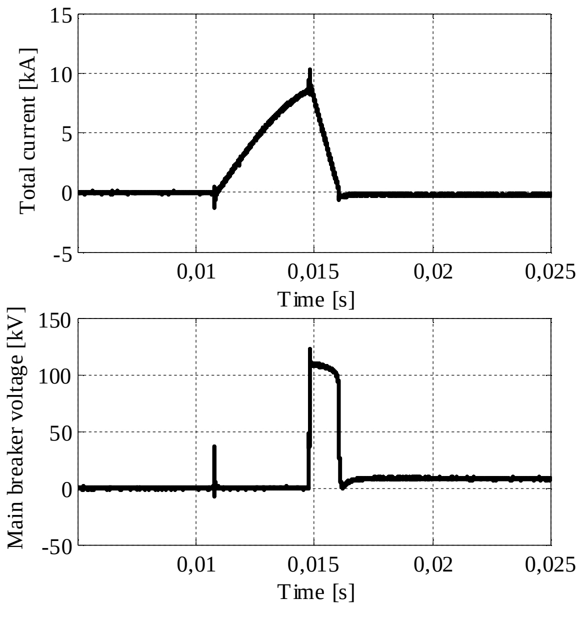


Figure 6. MB voltage and current during an HHB interruption functionality test

The results of another typical interruption test of the main HHB can be seen in Figure 6. At t = 15 ms the main breaker turns off and the current is then commutated to the non-linear resistors. A counter voltage, also referred to as transient interruption voltage (TIV), is created and suppresses the line current to zero.

The non-linear resistors of any type of HVDC Breaker need to dissipate the energy stored in the system- and series inductance during current suppression. The non-linear resistors are similar to those used in other existing HVDC applications, e.g. the HVDC line fault clearing scheme which is used to perform restarts of the Zambezi link and the non-linear resistors at neutral bus switches for HVDC LCC links since the late 1990’s [9]. Because the MB is modularized, the total energy is shared between the non-linear resistors in each module. Therefore, under certain provisions it is possible to carry out type tests on a module only, rather than the full-pole breaker.

3.4 Gas-insulated HVDC System

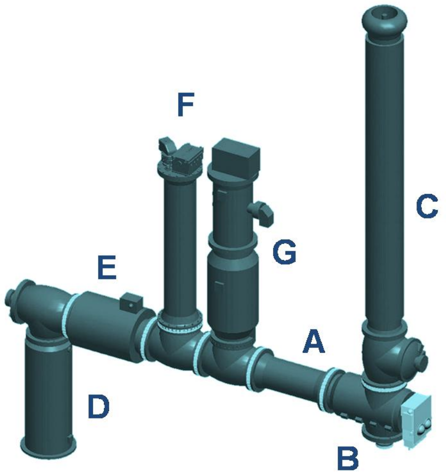
Based on the research for material characterisation and the usage of multi-physics simulation tools the analysis of electrical field distribution is now possible with high precision, taking the following parameters into consideration: temperature and electrical field depended characteristics of the used insulating materials, accumulation of space- and surface charges and the superposition of DC and impulse voltages. For the new HVDC design, the improvement shown with a significant reduction of the dielectric stress was obtained by geometrical optimization and insertion of a current collector, compared to the AC design.

With additional changes at interface components, like cable termination, and with the development of special current- and voltage transformers, it is possible to use gas-insulated HVDC systems for both onshore and offshore applications in the near future [10]. Just as in AC power systems, the HVDC-GIS technology spans a number of switchgear components as shown in Figure 7.

Based on insulation co-ordination studies, test values were defined, which take all technical aspects into account. Tests of HVDC-GIS components have now confirmed the required performance for the ratings as shown in TABLE I. The HVDC gas-insulated system was presented for the first time in 2013 [11]. The development for 500 kV GIS is on progress.

TABLE I. Rated values for 320 kV / 350 kV HVDC GIS

Rating	320 kV / 350 kV	500 / 550 kV in development	
Nominal DC voltage	± 320	± 500	kV_{dc}
Rated (maximum continuous operating) DC voltage	± 350	± 550	kV_{dc}
Rated lightning impulse withstand voltage	± 1050	± 1425	kV
Rated superimposed lightning impulse withstand voltage Lightning impulse voltage DC voltage	 ± 1050 ± 350	 ± 1425 ± 550	 kV kV_{dc}
Rated switching impulse withstand voltage	± 950	± 1050	kV
Rated superimposed switching impulse withstand voltage Switching impulse voltage DC voltage	 ± 950 ± 350	 ± 1050 ± 350	 kV kV_{dc}
Rated DC withstand voltage phase-to-earth	± 610	± 960	kV_{dc}



- Bus-ducts and high voltage HVDC conductors (A)
- Disconnect- and earthing switches (B)
- Bushings (C)
- Cable terminations (D)
- Current sensor (E)
- RC voltage divider (F)
- Surge arresters (G)

Figure 7. HVDC GIS components

A HVDC GIS installation can be built with a much higher degree of compactness and significantly lower sensitivity to ambient factors than with air-insulated switchgear (AIS). The most obvious cost-saving potential can be found on offshore converter platforms. At present nine offshore HVDC links have been delivered or are under construction ranging from 400 MW to 900 MW, all in the German Bight since 2009. A converter station rated at 800-900 MW will connect three wind farms, which appears a reasonable size for operational and investment reasons. Such converter stations are at present challenging to handle during construction and installations phases. Examples are shown in Figure 8.

Recent planning from German transmission system operator show that one new HVDC offshore connections is planned every or every second year. Such converter stations are at present challenging to handle during construction and installations phases. High dependence on weather conditions and supporting structures could be mitigated if the platforms size could be reduced and modularized. Such compactness would not only bring down the cost of the platform but also render additional cost savings due to flexibility during construction and installation. By using HVDC-GIS, the volumetric space of the switchgear installation itself can be drastically reduced e.g. by 70%- 90%, which may results in a size reduction of circa 10% of the total platform and a compact building block for planning of the offshore station layout. Together with other compacting features, the overall weight of the station can be reduced up to 60%.

Figure 8. World‘s most powerful offshore wind connection integrates 916 MW of power: DolWin2 link transmits wind power from offshore wind farms in the North Sea

If future offshore grids would be considered with multi-terminal or switching stations offshore, the gain would be considerably larger. The gas-insulated HVDC components can be applied in various HVDC applications such as:

- HVDC pole equipment in HVDC converter stations including the HVDC switchyard.
- Gas-insulated transmission lines
- Cable to overhead line transition stations.

On land, it is foreseen that operating voltages are likely to increase for voltage source converters, similar to what happened earlier classic line commutated converter HVDC installations. At higher voltages, the benefits of HVDC GIS to air insulated switchgear increase. The ability to extend HVDC into cities or populated areas will favor compactness and thus HVDC-GIS.

4 STATUS OF STANDARDIZATION OF HVDC SUBSTATION EQUIPMENT

There are ongoing activities in both standardization bodies and European funded projects to increase the TRL (see Figure 9) of HVDC equipment. The PROMOTioN project will demonstrate the functionality of HVDC GIS equipment and HVDC breakers in a laboratory environment. Cigré SC D1 has installed a working group, which should provide recommendations for testing of gas-insulated HVDC systems: JWG D1/B3.57 Dielectric Testing of gas-insulated HVDC Systems [12]. Special type tests standards for gas-insulated HVDC systems are not yet available today. The working group aims to issue recommendations for testing of gas-insulated HVDC systems. In particular, standards for dielectric development tests and possible prequalification tests have to be developed, which take into account the special characteristics of HVDC applications. After finalizing these activities during the 2018 and 2019, the TRL level for the equipment is expected to have increased to at least 8.

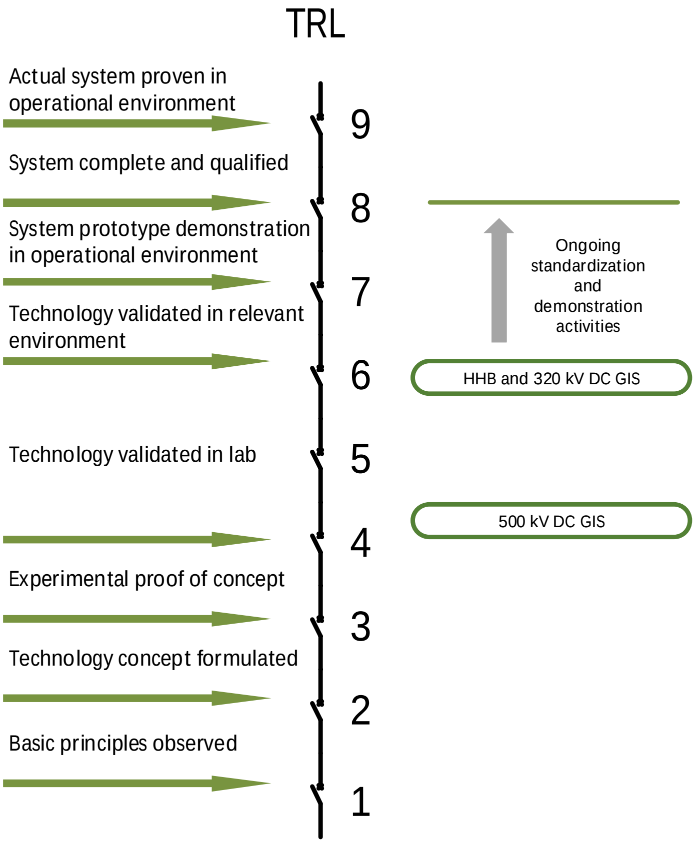


Figure 9. Technology Readiness Level (TRL) of HVDC substation equipment

4.1 HVDC Breaker

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. The test requirements did not include specific requirements for testing energy absorption or post-suppression dielectric stress.

Cigré working group A3/B4.34 published during 2017 a Technical Brochure [13] which among other HVDC Switches covers HVDC Breakers. It describes the technology behind different types of HVDC breaker and listing grid parameters affecting the HVDC 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.

The EU-funded Progress on Offshore Meshed HVDC Transmission Networks (PROMOTioN) project, which started in 2016, has defined the test requirements and developed a test environment for HVDC Breakers. HVDC Breaker models were developed for different technologies and simulated in a benchmark system model to identify the stresses exerted on the HVDC circuit breakers in case of different types of fault cases in this system.[4][5] Academia, industry and transmission grid operators are represented in the PROMOTioN project, and have participated in setting the requirements on testing of HVDC Breakers. The requirements have been classed in operational, breaking and dielectric tests, in accordance with AC circuit breaker terminology. Combining the results from the studies and the

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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

requirements from the project partners, test requirements and test procedures[6][7] have been defined and analysis and simulations of different test-circuits for testing HVDC fault current interruption have been performed.[8]

For the next phase of the project starting January 2018 different types of HVDC Breakers will be tested at an independent laboratory, the test results and procedures analyzed and the project will deliver recommendations for standardized test requirements and procedures. The HHB of ABB will be tested at DNV GL's KEMA Laboratories during this phase.

During the second phase of the PROMOTioN project (2018-2019) an operational and breaking test will be performed of the HHB at DNV GL's KEMA Laboratories. Today several testing methods have been developed to perform current interruption tests on HVDC Breaker. For the PROMOTioN project an AC 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 [16];

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 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 breaker can interrupt within the 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

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 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 bidirectionally.
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

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[6] PROMOTioN – Deliverable 5.4: Documents on test requirements

[7] PROMOTioN – Deliverable 5.5: Documents on test procedures

[8] PROMOTioN - Deliverable 5.6: Software and analysis report on candidate test-circuits and their effectiveness

test installation in case of a failure to clear. Methods to avoid potential damage to the test 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 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

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 10).

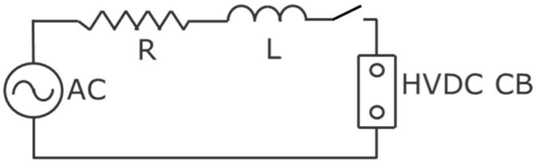

Figure 10. - Basic AC short-circuit generator based test circuit

The AC characteristic implies that an inherent limitation exists on testing HVDC circuit breakers with long breaker operation times, as the entire fault neutralisation 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 module, a prospective current test was performed the results of which are shown below (Figure 11). 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 whilst maintaining a source voltage of 80 kV to adequately test the energy absorption requirement.

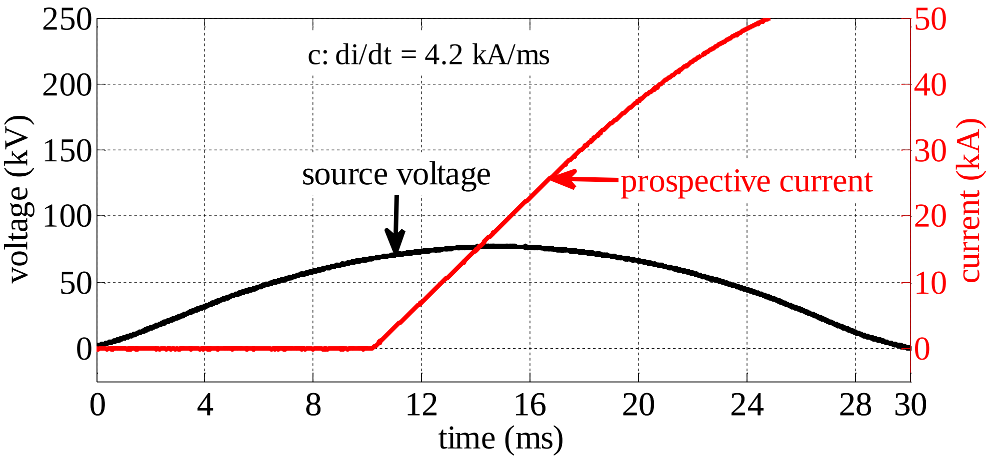

Figure 11. DNV GL's KEMA Laboratories prospective current test results

4.2 Gas-insulated HVDC System

The 320 kV HVDC GIS equipment has been tested successfully by the manufacturers. The PROMOTioN project will start HVDC GIS activities in January 2018. The project will develop testing requirements, procedures and methods by performing simulations but also gather experiences from existing HVDC systems onshore and offshore. This will be aligned with the Cigré working group and a long term test will be done at DNV GL's KEMA Laboratories to show the performance of the HVDC GIS components of ABB. By performing this test in a laboratory environment higher stresses can be achieved during a longer period of time than would be possible if the HVDC GIS would be installed in an existing HVDC system.

Based on service experience, gas-insulated HVAC systems feature a high degree of reliability and an excellent long-term performance. The user who intends to apply gas-insulated HVDC systems does expect the same reliability and long-term performance. Up to now, only some few gas-insulated HVDC systems are in operation worldwide [14]. Therefore, only few information about the long-term capability of this type of technology are available until now. That leads to the question of the necessity of long-term tests on gas-insulated HVDC systems in general. AC GIL assemblies need similar evidence for functionality to other underground line systems like cables, where the prequalification test is usually performed [15]. The main intention of the long-term test for gas-insulated systems is to confirm the reliability of the system under real service conditions. Therefore, all different major modules of the gas-insulated systems should be tested, being installed by using the same installation procedure as for future customer projects [12]. A proposal for the test set-up is shown in Figure 12

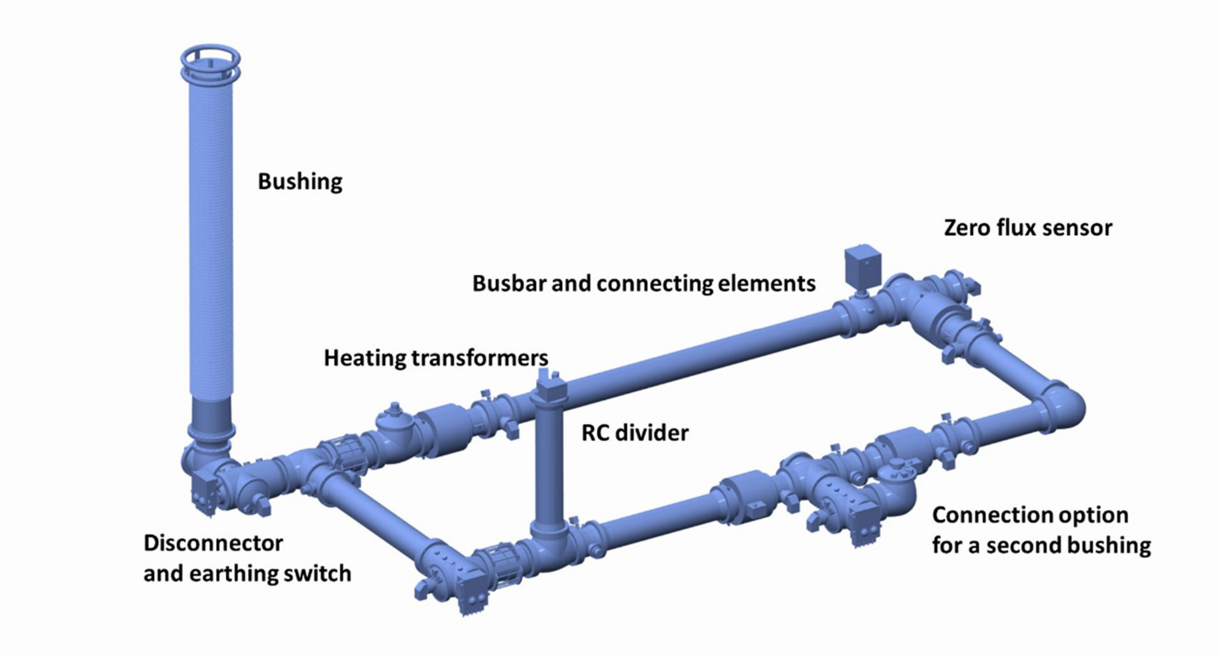

Figure 12. Proposed test set-up for the prototype installation test

Besides the dielectric stress, the maximum thermal and mechanical stress should be applied to the system. After the commissioning phase, DC voltage and a heating current (DC or AC current) are applied. A repetition of load cycles with high load and no load phases should be carried out. Additional to voltage and current measurements, it is advisable to measure temperatures, mechanical forces and extensions during the test procedure. Regarding the reproduction of overvoltages, e.g. caused by lightning strikes, switching operations or converter failures, LI and SI voltage superimposed to DC voltage shall prove the dielectric strength of the system under real installation conditions.

Beside the long-term test the PROMOTioN Work Package covers a wide range as shown in Figure 13

An analysis of function of HVDC GIS components in a MTDC network will be realized to determine number of operations, and stresses during normal operation and during emergency operation such as faults. This will be achieved by modelling the HVDC GIS system. The specific stresses on the various key-components of the test-objects (disconnectors, earthing switches, mechanical switches, protection- and snubber circuitry, surge arrestors and instrumentation for current and voltage measurements) will be identified. The analysis will be supported by a review of the environmental impact of the intended offshore application, possible HVDC substation layouts and operational strategies, simulation studies on a benchmark grid provided by a related work package and existing work done for Cigré JWG D1/B3.57 and other existing standards and recommended practices. The identified operational requirements and stresses are translated to test requirements, procedures, methods and test circuits.

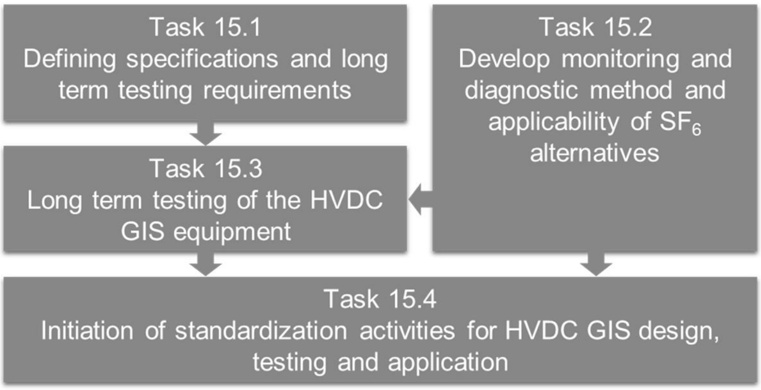

Figure 13. WP15 – HVDC GIS technology demonstrator

The identification of available monitoring and detection techniques for HVDC GIS such as suitable sensor systems for partial discharges, gas pressure, gas quality, temperature is the second major task. Identify, review and compare techniques aimed at evaluating the monitored quantities and linking this to an understanding of the progression of the ageing and failure mechanisms. Techniques such as PD pulse sequence analysis, combining conventional and UHF methods, and clustering of PD sources will be applied to better understand PD behaviour in HVDC GIS systems. Innovative methods such as PD source localization, wide band PD measurements and charge estimation will be analysed and compared. Recommendations for threshold criteria for acceptable levels of temperature, gas pressure and density and partial discharges will be developed. Recommendations for how PD measurements can be carried out during quality control checks such as factory and routine tests, or in the field during or after commissioning, and for continuously online monitoring will be provided. At the same time, the applicability of SF_6 alternatives will be scope of investigations, especially the comparison of PD monitoring systems used for HVDC GIS filled with SF_6 and alternative gas.

Results of test-requirement studies will be documented in a brochure to be delivered to Cigré and/or IEC as input for future standards

5 ACKNOWLEDGEMENT

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

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