D15.1 RECOMMENDATIONS FOR SPECIFYING DC GIS SYSTEMS

Report for Task 15.1 (Work Package15)

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
Mail info@promotion-offshore.net
Web www.promotion-offshore.net

This result is part of a project that has received funding form the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

CONTACT
Yash Audichya
SHE Transmission
Email: yash.audichya@sse.com

DOCUMENT INFO SHEET

Document Name:	Deliverable
Responsible partner:	SHE Transmission
Work Package:	WP 15
Work Package leader:	ABB
Task:	15.1
Task lead:	SHE Transmission

DISTRIBUTION LIST

APPROVALS

	Name	Company
Validated by:	Dumisani Simfukwe	SHE Transmission
Task leader:	Yash Audichya	SHE Transmission
WP Leader:	Uwe Riechert	ABB
Reviewer:	Ralf Puffer	RWTH
Reviewer:	Nicolaos Cutululis	DTU

DOCUMENT HISTORY

Version	Date	Main modification	Author
1.0	31/07/2018	First Version	SHE Transmission
2.0	06/12/2018	Second Version	SHE Transmission

WP Number	WP Title	Person months	Start month	End month
WP15	DC GIS Technology Demonstrator	164.5	23	48

Deliverable Number	Deliverable Title	Type	Dissemination level	Due Date
D15.1	Defining specifications and long term testing requirements	Report	PROMOTioN	14/12/2018

LIST OF CONTRIBUTORS

PARTNER	NAME
ABB	Uwe Riechert, Michael Gatzsche
DNV GL	Hong He, Konstantinos Dimitropoulus
TU Delft	Armando Rodrigo Mor, Luis Castro Heredia, Fabio Munoz
SHE Transmission	Yash Audichya, Dumisani Simfukwe
SGI	Alain Girodet, Paul Vinson, Thanh Vu
TenneT	Kees Koreman

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

NOMENCLATURE

ABBREVIATION	EXPLANATION
GIS	Gas Insulated Switchgear
AIS	Air Insulated Switchgear
HVDC	High Voltage Direct Current
PD	Partial Discharge
UHF/VHF	Ultra High Frequency/ Very High Frequency
VSC	Voltage Source Converter
LCC	Line Commutated Converter
HVAC	High Voltage Alternating Current
IEC	International Electrotechnical Committee
IP	Ingress Protection
IK	Impact Protection
PROMOTION	Progress on Meshed HVDC Offshore Transmission Networks
TRL	Technology Readiness Level
WP	Work Package
D15.1	PROMOTioN deliverables 15.1
HL/ZL/LC	High Load/ Zero Load/ Load Cycles
SI	Superimposed Impulse Tests
SF_6	Sulphur Hexafluoride

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

EXECUTIVE SUMMARY

The global trend towards decarbonisation and increased penetration of renewable energy resources has posed new challenges. The need to connect offshore renewable resources in deeper waters and longer connections to shore has led to increased demand for Voltage Source HVDC converter technology. Compact DC switchgear is needed for HVDC cable connections to remote offshore wind farms and onshore projects close to city centres. The compact design of gas insulated HVDC systems is therefore very attractive for applications where space comes at a high premium. Also, HVDC GIS based solutions will need to be developed to facilitate the realization of multi-terminal meshed HVDC grids. It has been estimated that space requirements for switchgear can be reduced by 70% - 90% compared to air insulated switchgear (AIS). This could lead to space saving of up to 10% for overall offshore platform.

However, there are no international standards describing the specification requirements, applicable tests and test procedures for HVDC GIS. This document provides a specification for PROMOTioN project HVDC GIS and general guidelines for specification requirements. The requirements for partial discharge measurement (PD) are also included in the document. ABB will supply the 320 kV HVDC GIS for testing at Arnhem. The tests will be conducted at DNV GL KEMA test facility in Arnhem, Netherlands. Task 15.3 will report the outcome of the performed tests on the ABB supplied HVDC GIS.

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

1 INTRODUCTION

The increasing demand to connect remote offshore renewable energy using HVDC technology requires adaption of gas insulated switchgear (GIS) or lines (GIL), which were originally developed for the AC grid. GIS is particularly relevant for applications where building volume or right-of-way are critical issues, e.g. for mega-city in-feed or densely populated areas in general.

Direct current gas insulated switchgear (HVDC GIS), for use in HVDC transmission, has been under development by various manufacturers for several years. It has the potential to bring significant space savings making it highly attractive for offshore installations where space comes at a high premium. It has been estimated that space requirements for switchgear can be reduced by 70% - 90% compared to air insulated switchgear (AIS). This could lead to space saving of up to 10% for overall offshore platform.

Traditionally, HVDC switchgear for HVDC applications have used AIS. For HVDC grids, AIS can be used to realise an HVDC hub for connecting various HVDC circuits. However, AIS requires larger clearance and creepage distances resulting in a large switchgear footprint. HVDC GIS would minimise clearance and creepage requirements leading to a more compact station design.

1.1 WORK PACKAGE 15: OBJECTIVES

Work Package 15 aims to achieve the following:

- To develop guidelines for specification requirements for HVDC GIS;
- To develop requirements and procedures for testing HVDC GIS;
- To apply existing or develop new monitoring and diagnostic methods for HVDC GIS such as monitoring and evaluation of partial discharge, gas density or pressure, and temperature;
- To evaluate performance of SF_6 alternatives;
- To carry out long term testing of HVDC GIS;
- Improve models and develop understanding of failure modes and;
- To increase HVDC GIS equipment Technology Readiness Level (TRL) from 6 to 8.

The work under Task 15.1 contributes to the first two aims listed above.

1.2 CHALLENGES TO REALISING HVDC GIS SYSTEMS

Some of the main challenges that have hindered the development of HVDC GIS thus far are:

- Difficulty in testing the effects of DC stress on GIS systems. The effects tend to vary with temperature and geometry of the insulating materials.
- Difficulty in monitoring and interpretation of partial discharge under DC. New methods have been suggested to overcome this challenge. Some novel ideas will be tested in Task 15.2
- Lack of operational experience in application of HVDC GIS poses a significant risk for HVDC projects.

Some of these challenges will be addressed through the work undertaken under WP15.

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

2 HVDC GIS EQUIPMENT

The HVDC GIS shall comprise of at least the following equipment: bus-bars/bus-ducts, disconnectors, earthing switches, DC current transformers, DC voltage transformers, bushings, and appropriate insulation medium and enclosure. In addition, connections and sensors should be provided to facilitate monitoring and testing of partial discharges. The ABB supplied 320 kV HVDC GIS model is shown in Figure 2.1. This set-up will be used for testing the HVDC GIS equipment in the PROMOTioN project.

Note that circuit breakers will not be included in the DC GIS. On-load interruption of DC current is not possible without specialised DC circuit breakers.

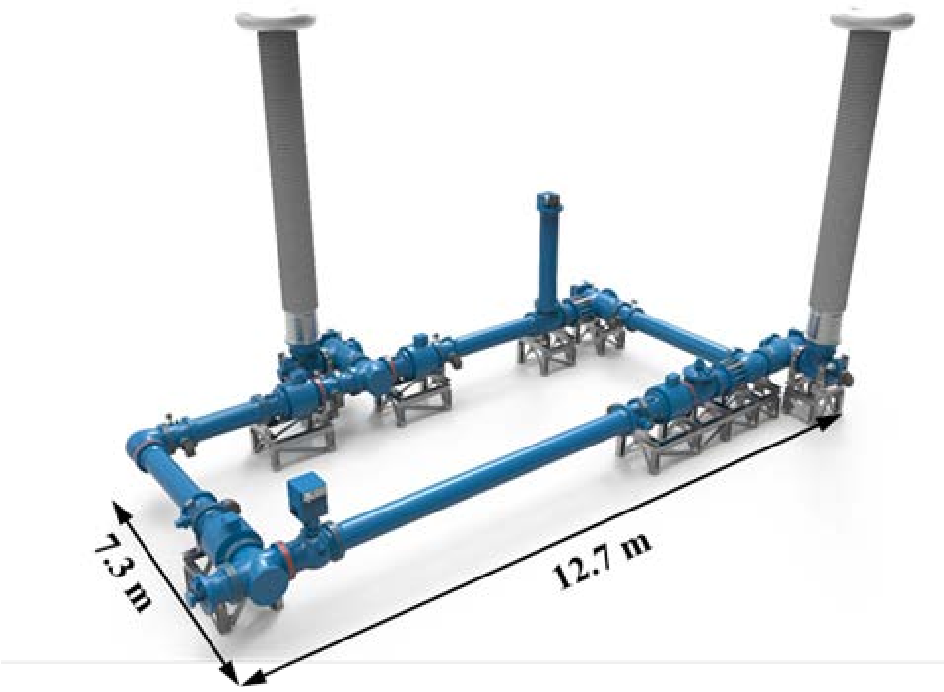


Figure 2.1: ABB supplied 320 kV HVDC GIS for Testing

2.1 ENCLOSURES

The design of the enclosure is such as to keep loss of SF_6 gas to minimum. It is expected that replenishment of insulating gas is not necessary for at least 10 years. Gaskets and seals are designed for a life expectancy of at least 30 years and this is demonstrated by tests or otherwise.

It should be ensured that the switchgear gas enclosures are sectionalized into gas zones with gas tight barriers between sections or compartments. The sections are arranged to minimize the extent of plant rendered inoperative when gas pressure is reduced, either by excessive leakage or for maintenance purposes, and to

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

minimize the quantity of insulating gas that must be evacuated and then recharged before and after maintaining any item of plant.

It should be ensured that the gas-tight support insulating barriers can withstand a pressure differential of atmospheric pressure on one side and on the other a pressure equal to the design gas pressure or the maximum gas pressure under conditions of an internal fault, whichever is greater.

The design of the enclosure assemblies is such that in the event of a fault, the damaged items can be replaced with minimum disturbance to the adjacent compartments.

Overpressure created by arcing within an enclosure is preferably relieved by means of bursting discs (pressure relief) venting into the atmosphere. This method of pressure release prevents permanent distortion of adjacent enclosures. Pressure relief by collapse of internal gas barriers is not acceptable.

The arrangement of any pressure relief device is such that any expulsion of disc debris or gas is directed in a manner that does not endanger any personnel and relief vents are provided with deflectors or vent pipes as appropriate to satisfy this requirement.

2.2 BUSBARS AND CONNECTION CHAMBER

To minimize the extent of dismantling necessary to remove a part of a main busbar, it is required that discrete lengths of busbar can be withdrawn.

2.3 DISCONNECTORS

Disconnectors are fitted with position indicators visible from ground level. A means for viewing the positions of disconnector switches contacts should be provided.

The disconnector switches are provided with electrically operated mechanisms. The power operation of the disconnector switches are capable of being controlled from a local or remote point.

2.4 EARTHING SWITCHES

Earth switches are provided with power and manually operated mechanisms. The electrical operation is performed from their control cubicles. Position indicators are clearly visible from the permanent working platform level.

Each separate section of switchgear that can be disconnected has provision for earthing in accordance with the following requirements. All incoming and outgoing supply circuits are earthed by a device having a making current rating and short time rating equal to that of the associated disconnector switch.

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

Where appropriate earth switches are fully insulated and the connection to earth brought out through the enclosure by means of an insulating bushing in order that the earth switch may be used for various test purposes.

A removable bolted link is provided for connecting the insulated earth switch connection to the actual earthing terminal.

The earthing switch and the test injection point arrangement are suitable for a test current equal to the rated normal current of the connected busbars for a duration of 5 minutes' minimum.

The earth switch operating mechanism is capable of being locked in the open or closed position.

2.5 VOLTAGE AND CURRENT TRANSFORMERS

Suitable voltage and current measuring transformers or devices capable of measuring DC voltage and current should be provided.
Where necessary to ensure accuracy, burden resistors are to be fitted. All such parts are accommodated within the secondary terminal box.

2.6 SULPHUR HEXAFLUORIDE GAS (SF_6) & OTHER INSULATING GASES

Apart from SF_6 gas, other insulating gases may also be used in the testing. Results from using other gases must be benchmarked against results for SF_6 in all the performed tests. Further details will be provided in Reference [8].

As a minimum appropriate impurity levels and gas handling requirements as per IEC 60376 must be used.

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

3 RATING REQUIREMENTS

3.1 RATED VOLTAGES AND CURRENTS

There are presently no standard transmission voltages for VSC-HVDC. Voltages ranging from ±150 kV DC to ±525 kV DC have been used recently and in projects under commissioning [1]. The DC voltage used is mostly determined by the amount of power required to be transferred through the link and is limited by the available voltage rating of the cable technology.

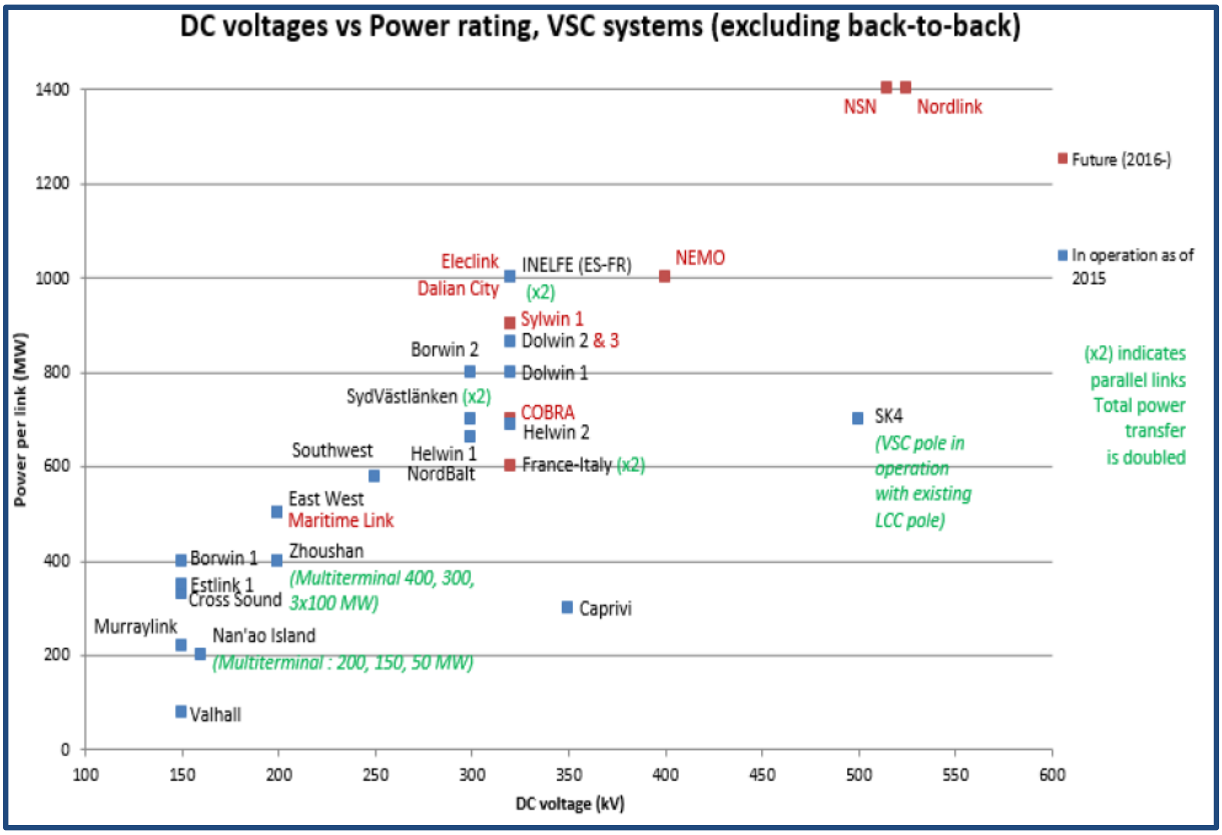


Figure 3.1: DC Voltage rating of recent and planned VSC-HVDC projects [1]

The current rating of HVDC link is usually limited by the IGBT devices used. Typically, existing devices are rated up to 2000 A but this is usually de-rated to achieve a safe operating area.

However, several HVDC converters may be connected in parallel onto a common HVDC transmission grid, hence, the HVDC grid and its associated switchgear would be rated for current more than 2000 A.

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

3.2 LIGHTNING AND SWITCHING IMPLUSE WITHSTAND VOLTAGES

Lightning and switching phenomena determine the maximum transient voltages and currents experienced by the switchgear.

Required Lightning Withstand Level (LIWL) and Switching Withstand Level (SIWL) vary depending on insulation coordination study. Standard withstand levels provided in IEC 60071 for AC systems, shown in Tables 3.1 and 3.2, may be used as reference for HVDC systems. Appropriate insulation withstand level should be ensured through insulation coordination and transient overvoltage studies. SIWL and LIWL levels selected should maintain a margin to the maximum calculated Switching Impulse Protection Level (SIPL) and Lightning Impulse Protection Level (LIPL) respectively. Typically, a margin of 15% to 30% is applied.

Table 3.1: Standard insulation levels range I [Table 2 of IEC60071-1]

Highest voltage for equipment (Um) (kV) (r.m.s. value)	**Standard rated short duration power- frequency withstand voltage (kV) (r.m.s. value)**	**Standard rated lightning impulse withstand voltage (kV) (peak value)**
3.6	10	20 40
7.2	20	40 60
12	28	60 75 95
17.5	38	75 95
24	50	95 125 145
36	70	145 170
52	95	250
72.5	140	325
100	185	450
123	230	550
145	230 275	550 650
170	275 325	650 750
245	360 395 460	850 950 1050

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

Table 3.2: Standard insulation levels range II [Table 3 of IEC60071-1]

Highest voltage for equipment (Um) (kV) (r.m.s. value)	**Standard switching impulse withstand voltage**			**Standard rated lightning impulse withstand voltage (kV) (peak value)**
	Longitudinal insulation (kV) (peak value)	**phase-to-earth (kV) (peak value)**	**phase-to-phase (ratio to the phase-earth peak value)**	
300	750	750	1.5	950 950
	750	850		950 1050
362	650	850	1.5	950 1050
	650	950		1050 1175
420	850	850	1.6	1050 1175
	950	950	1.5	1175 1300
	950	1050	1.5	1300 1425
550	950	950	1.7	1175 1300
	950	1050	1.6	1300 1425
	950	1175	1.5	1425
	1050	1175	1.5	1550
600	1175	1300	1.7	1675 1800
	1175	1425	1.7	1800 1950
	1175	1550	1.6	1950
	1300	1550	1.6	2100
1100	-	1425	-	1950 2100
	1475	1550	1.7	2100 2250
	1550	1675	1.65	2250 2400
	1675	1800	1.6	2400 2550

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

4 TEST REQUIREMENTS

Unlike AC, the accumulation of charge over surfaces for DC can take long time. This is highly dependent on the atmospheric conditions, temperature, physical design and construction: shape and material used. The accumulation of charge can range from few minutes to months. This makes testing extremely challenging.

There is currently no standard for testing of HVDC GIS. However, sections of IEC62271-1, and IEC 62271-203 for testing of gas-insulated metal-enclosed switchgear for rated voltages above 52 kV could be used as a reference for HVDC.

4.1 ROUTINE TESTS

Routine tests must be carried out on all items of the HVDC GIS. They prove that the performance of the components being tested agrees with the base design for which type tests have been performed. They serve to eliminate defects introduced by the manufacturing process which may result in failure in operation. As such AC GIS routine testing standards for this purpose are sufficient [2].

Routine tests shall be conducted in accordance to IEC62271-1 Clause 8, and IEC 62271-203 Clause 7 as follows, with some deviations.

- Dielectric test on the main circuit: power frequency voltage or DC voltage and partial discharge tests.
- Tests on auxiliary and control circuits
- Measurement of the resistance of the main circuit
- Tightness test
- Design and visual checks
- Pressure tests of enclosures
- Mechanical operation tests
- Tests on auxiliary circuits, equipment and interlocks in the control mechanism
- Pressure test on partitions.

4.2 TYPE TESTS

Most of the type tests listed in IEC 62271-1, and IEC 62271-203 are suitable to be performed for HVDC GIS as stated. However additional tests to prove withstand to DC stresses should also be performed as described below.

Type tests suitable to be performed for HVDC GIS are as follows.

- Tests to verify the insulation level of the equipment and dielectric tests on auxiliary circuits.
- Tests to prove the radio interference voltage (RIV) level (This test applies only to bushings.)
- Tests to prove the temperature rise of any part of the equipment and measurement of the resistance of the main circuit.

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

- Tests to prove the rated peak and the rated short-time withstand current
- Verification of protection (IP/IK coding)
- Gas tightness tests
- Electromagnetic compatibility test
- Tests to prove the satisfactory operation of the included switching devices
- Insulator tests.

4.3 ADDITIONAL TYPE TESTS

Most of the type tests listed in IEC 62271-1, and IEC 62271-203 are suitable to be performed for HVDC GIS as stated.

4.3.1 DIELECTRIC TEST WITH DC PRE-STRESS APPLIED

DC voltage leads to accumulation of surface charges on insulators. It may take a long time for the charge to fully accumulate. The period could even take several months. This accumulation of charge tends to lower the switching impulse and lightning impulse flashover voltage. Typically, the DC voltage must be applied for a longer period [3]. However, an appropriate charging time must be derived and verified through a multi-physics simulation with consideration to the GIS geometries and prevailing environmental conditions. A higher voltage or higher temperatures may be used in the test to shorten the period of charge accumulation after it is first demonstrated through appropriate simulation. Lightning impulse and switching impulse tests under 4.2.1 may then be carried out.

Superimposed DC voltage and lightning/switching impulse tests should also be conducted to test such conditions which are likely during operation of the HVDC GIS.

The insulator/gas interface superimposed tests shall be performed at high load conditions. The tests shall be performed as shown in Table 4.1

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

Table 4.1: Dielectric testing

	Description	Test Voltage	Duration
Type tests Gas insulation	DC voltage withstand test	1.5 x U_n	1 min
	Lightning impulse (LI) voltage test	IEC 60071-1/-5	15 impulses.
	Switching impulse (SI) voltage test	IEC 60071-1/-5	15 impulses
	Superimposed voltage test	1.0 x U_n + rated LI/SI voltage	15 impulses
	Polarity reversal test*1	1.25 x U_n	30 minutes
Insulator/gas interface	Insulation system test: DC voltage test	1.0 x U_n	90% charging time
	Super imposed voltage tests (worst case conditions)	U_r + rated LI/SI voltage	3 impulses

*1 The polarity reversal test is applicable for LCC systems only. The dielectric stresses are covered by more critical tests like superimposed voltage tests. Therefore, polarity reversal tests are optional tests and not mandatory.

4.3.2 LONG DURATION TESTS

For HVDC gas-insulated systems a verification of the electrical lifetime (V-t characteristic) is of insignificant importance, because the electrical lifetime (V-t characteristic) of solid insulating material used in GIS/GIL is equal or even better under DC voltage stress compared to AC at typical service stress.

Experiences with AC gas-insulated systems show that all parts of the insulation system, assuming sound manufacturing quality requirements, do not reveal any ageing mechanisms which cause critical ageing. Therefore, overall the entire sound insulation system should not exhibit an increase of the failure rate with time. After 30 years of operation there is no general ageing which recognizably affects the long-term performance. The lifetime can be estimated to be much higher than 30 years. This is in line with the findings based on considerations about the critical physical phenomena and investigations of the statistical long-term performance.

Additional mechanical stresses caused by load cycles similar to those in cables are of minor interest for GIS/GIL applications and are covered by thermal cycles performance tests of each insulator design according to IEC 62271-203 (6.106). Additional tests are not necessary. Nevertheless, a combination with the insulation system tests under high load conditions could be performed.

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

5 SPECIFICATION EXAMPLE: HVDC GIS FOR THREE TERMINAL HVDC HUB

The following gives a specification for a 320 kV HVDC GIS for a HVDC hub forming part of a 3 terminal HVDC grid. The schematic for the system is shown in Figure 5.1. The system comprises three VSC stations: Station 1 and 2 are rated at 600 MW, and Station 3 is rated at 1200 MW. The three stations are connected through a HVDC hub. The configuration of the hub is shown in Figure 5.2. The hub concept is for illustration only.

The HVDC hub consists of HVDC GIS with two buses: a positive bus and a negative bus. Each bus shall be able to carry three circuits connected to the GIS through a ± 320 kV HVDC cable bushing.

Each circuit connection to the bus shall comprise a disconnector, two earthing switches and a high speed switch which will act as a by-pass circuit breaker for a pre-insertion resistor.

Connection points shall be provided, through appropriate bushings, for connecting pre-insertion resistors, surge arrestors and HVDC cables.

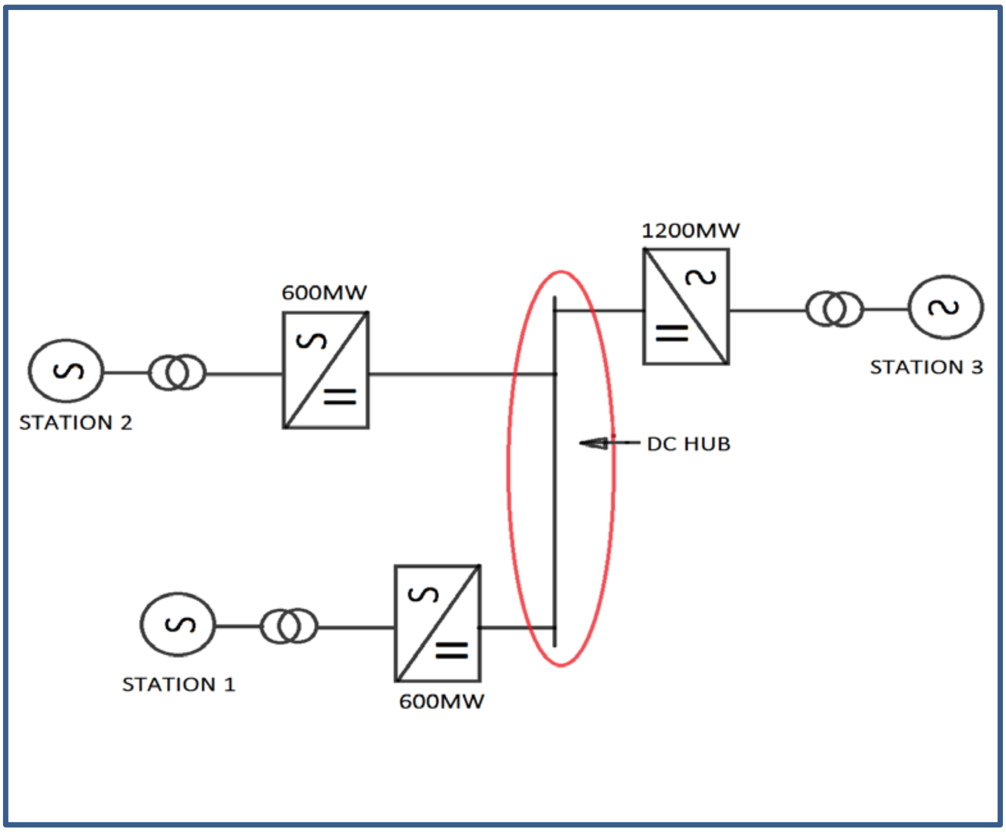


Figure 5.1: 3 Terminal HVDC grid

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

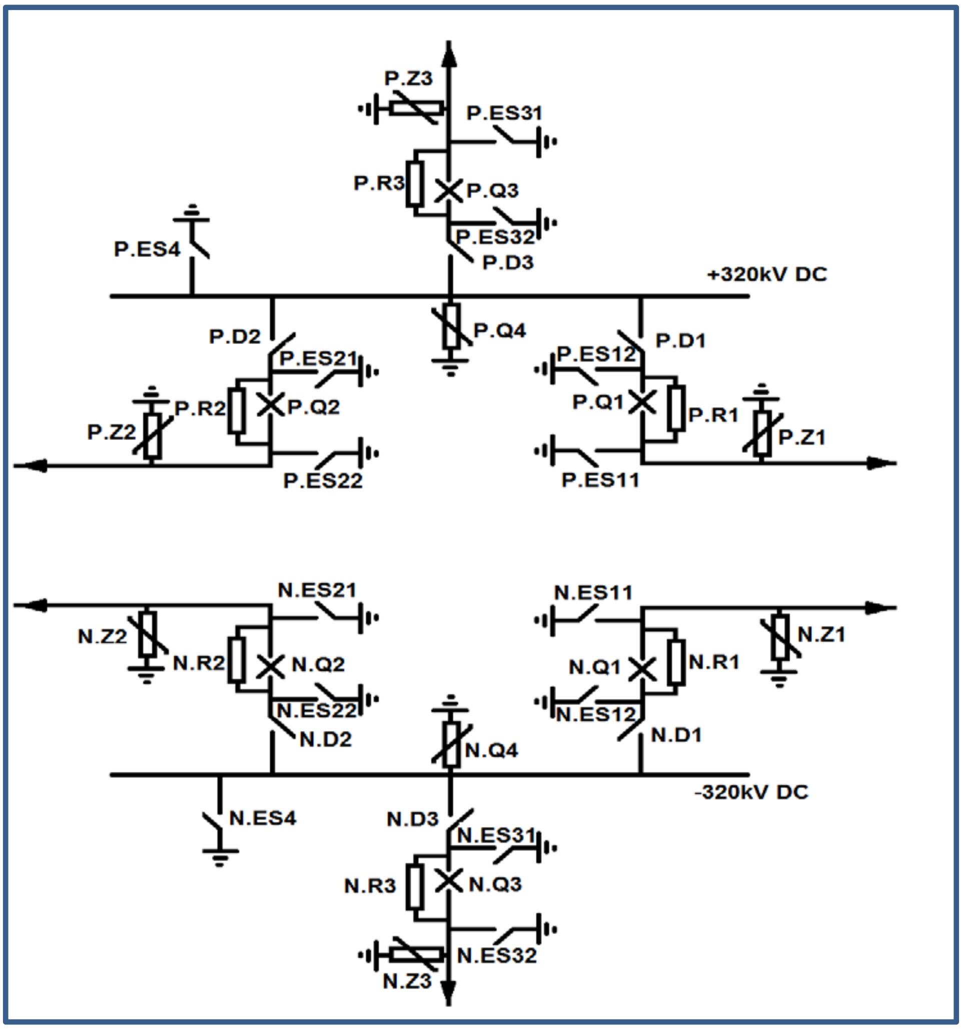


Figure 5.2: HVDC hub

5.1 TECHNICAL REQUIREMENTS

The components of the HVDC GIS hub shall meet requirements on components stated in Sections 2.1 to 2.6. Ratings, withstand levels and other requirements for components are summarised in Table 5.1.

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

Table 5.1: HVDC GIS rating requirements

DC GIS Switchgear	
U_n Nominal Voltage	±320 kV
U_r Rated dc operation voltage	±350 kV
U_p Rated lightning impulse withstand voltage	±1050 kV
U_s Rated switching impulse withstand voltage	±950 kV
I_r Rated normal current	4000A
I_{sc} Rated short-time withstand current, 1 second	50kA
Rated superimposed lightning impulse withstand voltage Lightning impulse voltage DC voltage	 ±1050 kV 350 kV
Rated superimposed switching impulse withstand voltage Switching impulse voltage DC voltage	 ±950 kV 350 kV
Leakage rate per year and gas compartment	≤ 0.5 % routine test; ≤ 0.1 % type test
Rated DC withstand voltage phase-to-earth	±480 kV
Ambient temperature range	-5 to 40 °C (indoor) -25 to 40 ºC (outdoor)
Disconnector	
Rated current	4000A
Rated short-time withstand current, 1 second	50kA
Closing time	≤ 6 s
Opening time	≤ 6 s
Type of motor drive	DC Motor
Earthing Switch/High Speed Earthing Switch	
Rated short-time withstand current, 1 second	50kA
Closing time	≤ 7 s / ≤ 100ms
Preferred type of motor drive	DC Motor

Rated DC withstand voltage phase-to-earth shall be applied for 1 minute. The withstand capability shall be tested for both polarities.

For avoidance of doubt, 1.2/50 µs impulse waveform shall be applied for lightning impulse withstand test and 250/2500 µs impulse waveform for switching impulse withstand test. For each test, 15 impulses of both polarities shall be applied. The test procedure B of IEC 60060-1:2010, adapted for test objects that have self-restoring and non-self-restoring insulation, is the preferred test procedure.

- The superimposed lightning impulse voltage tests shall be performed with bipolar superposition; 15 impulses of each polarity at both zero load and high load.
- The superimposed switching impulse voltage tests shall be performed with bipolar superposition; 15 impulses of each polarity at both zero load and high load.

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

However, high load tests are not mandatory, because the test is covered by superimposed voltage tests at zero load and the DC insulation system test. Dielectric tests of the gas insulated system under high load condition shall be carried out at ambient temperature and equivalent DC or AC current, only in case of doubt.

The electric field in all areas that personnel may access shall be limited to 25 kV/m at a height of 2m above ground level, under all operating conditions.

The selection of parameters is dependent on over-voltages in the HVDC transmission system and considerations related to insulation characteristics of gas gaps and insulators. The testing of the 320kV HVDC GIS, supplied by ABB for the PROMOTioN project, will be performed to these specifications.

5.2 TESTING

5.2.1 ROUTINE TESTS

Routine tests shall be performed on all components of the HVDC GIS per Clause 4.1.

5.2.2 TYPE TESTS

Type tests shall be conducted on all components of the HVDC GIS as stated in Clause 4.2 and 4.3. Where practically possible, type tests shall be performed on the exact set-up as the final installation.

No disruptive discharge on non-self-restoring insulation should occur during any of the tests. Visual inspection of the spacers at various times and during final disassembly should reveal no visible flashover traces. The testing shall demonstrate that the gas insulated technology (SF_6 or any other gas) is well suited for commercial HVDC GIS applications. Following measurements and inspections shall be performed:

- PD plot of discharge magnitude [pC] Vs. Time [minutes]
- Bushing leakage current measurement (only for bushings containing impregnated solid insulation)
- Visual Inspections after the tests
- Contact wear and tear, state of switches, and surge arresters

5.2.3 COMPONENTS TO BE TESTED

The following components shall be tested:

- HVDC GIS busbars
- Disconnectors
- Earthing Switches
- Bushings
- Instrument transformers
- Surge Arresters

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

Failure of any one of the components during the testing shall be recorded. The complete test cycle shall be repeated following replacement of any one or more components.

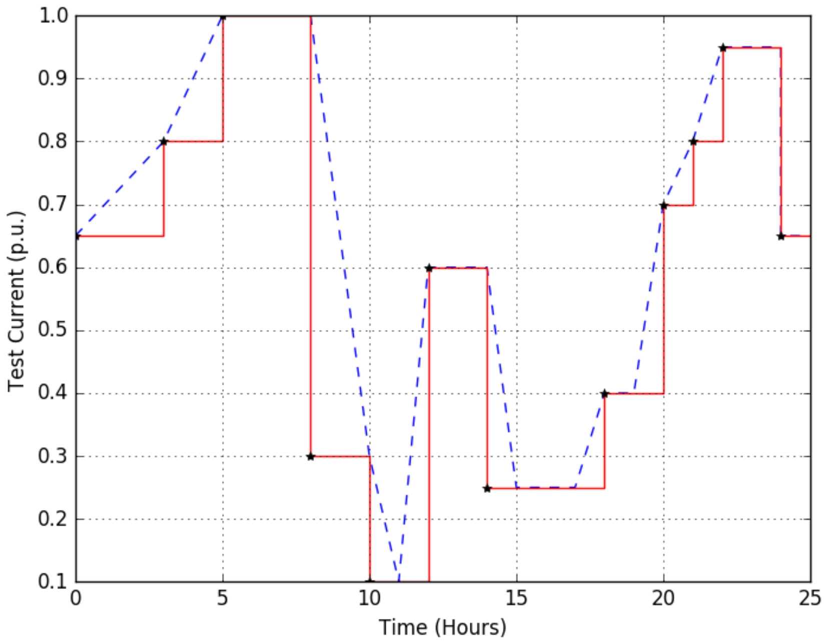
5.2.4 LOAD CYCLES

The HVDC GIS will be subjected to load cycles to mimic operation under various real-life load currents. Table 5.2 describes the load profile which will be used for testing HVDC GIS at DNV GL KEMA laboratory at Arnhem. The rated current is 4000 A for the HVDC GIS test object. Therefore, 1 p.u. in Table 5.2 corresponds to 4000 A. The table shows the load pattern over a 24-hour period. This load cycle shall be repeated to cover the duration of the test. Additional load cycle tests are performed to mimic operational cycle to increase confidence in the technology.

Figure 5.3 shows the plot of the load cycle. The dotted blue line shows the actual current variations and the red solid line shows the applied currents during the test.

Table 5.2: Load pattern for testing.

Time (hours)	0	3	5	8	10	12	14	18	20	21	22	24
Test Current (p.u.)	0.65	0.8	1	0.3	0.1	0.6	0.25	0.4	0.7	0.8	0.95	0.65



PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks

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

Figure 5.3: Load Cycle

5.3 PARTIAL DISCHARGE MEASUREMENT

In general, for detection of PD at DC voltages, same principles and test methods as at AC voltages can be applied. Either a standard PD detection system as per IEC 60270 can be chosen for PD testing of high voltage GIS or UHF / VHF system can be chosen to obtain PD pulses. It is well known that when comparing the magnitude of PD using the UHF / VHF method versus the conventional method according to IEC 60270, the actual charge transferred at the defect results in the apparent charge measured via a coupling capacitor. Therefore, for commissioning tests with GIS applications utilizing UHF / VHF technique for PD measurements, manufacturer of HVDC GIS shall verify that that the system is performing at required level of sensitivity (sensitivity verification).

5.3.1 MEASUREMENT

Dedicated sensors shall be installed for UHF frequency PD measurements. Multiple sensors shall be installed in a GIS to ensure enough coverage to allow sufficient sensitivity to detect PD defects. Because of the distortion of HF signals, the necessary number of sensors may vary according the GIS dimensions, and will need to be confirmed by the manufacturer of the GIS equipment. A sensitivity check shall be performed

5.3.2 NOISE

The signal-to-noise-ratio and therefore the sensitivity of the VHF/UHF measuring device can be improved by using suitable sensors, amplifiers and filters. The VHF/UHF method has proved to be at least as sensitive in detecting defects as the conventional method, and this is mainly due to the low external noise level. Tests in laboratories and on-site have shown that small critical defects and even non-critical defects may be detected. An accurate location of the defect may be obtained by using a broadband oscilloscope to measure the time interval between the signals arriving at adjacent sensors.

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

6 CONCLUSION

The document provides recommendations for specifying gas-insulated GIS for HVDC applications. A sample specification for 320 kV HVDC GIS switchgear and its testing requirements are also provided. This specification will be used to test the ABB supplied 320 kV HVDC GIS at DNV GL KEMA test facility at Arnhem. The test results will be recorded and reported in deliverable Task 15.3.

No disruptive discharge on non-self-restoring insulation should occur during any of the tests. Visual inspection of the spacers at various times and during final disassembly should reveal no visible flashover traces. The testing shall demonstrate that the gas insulated technology (SF_6 or any other gas) is well suited for commercial HVDC GIS applications.

Successful demonstration of performance and rating of 320 kV HVDC GIS at an independent and certified test facility, following the tests outlined in the document, will increase the TRL and provide greater confidence in commercial deployment of the technology.

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

7 REFERENCES

[1] Cigre, TB 684, Recommended voltages for HVDC grids.
[2] K. Juhre, B. Lutz, D. Imamovic, Cigre, Testing and long term performance of gas-insulated DC compact switchgear.
[3] Cigre, TB 506, Gas Insulated System for HVDC: DC Stress at DC and AC Systems.
[4] IEC 62271-1 High-voltage switchgear and controlgear: Common specifications, IEC, 2011.
[5] IEC 60060-1 High-voltage test techniques - Part 1: General definitions and test requirements, IEC, 2010.
[6] IEC 60376:2005 Specification of technical grade sulfur hexafluoride (SF6) for use in electrical equipment.
[7] CIGRE Joint Task Force 15/33.03.05: Partial Discharge Detection System for GIS: Sensitivity Verification for the UHF Method and the Acoustic Method. ELECTRA, No. 183, pp. 75 - 87, 1999.
[8] Report on DC GIS diagnostic and monitoring tools and methods. Deliverable 15.3, PROMOTioN.
[9] Report on characteristics of PD alternative gas: comparison with SF6. Deliverable 15.7, PROMOTioN.

END OF REPORT

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