HIGH VOLTAGE DIRECT CURRENT CONVERTER STATIONS

Table of Contents

List of Figures

List of Tables

1.0 SCOPE

This data sheet presents loss prevention guidelines and recommendations for high voltage direct current (HVDC) converter stations. A primary focus of this document is valve halls where the electric current is converted from AC to DC or from DC to AC including both thyristor valve and insulated-gate bipolar transistor (IGBT) based technologies. It contains loss prevention recommendations related to fire protection of valve halls. It also provides loss prevention recommendations related to electrical protection, testing, maintenance, and operation of critical systems and equipment.

This data sheet does not cover mercury arc valve based HVDC technology.

This data sheet focuses on hazards and exposure unique to HVDC stations. Apply other applicable data sheets when evaluating hazards not addressed in this data sheet; however, the guidance contained within this data sheet supersedes that present in other data sheets. Examples of other applicable data sheets include, but are not limited to, the following:

- 5-19, *Switchgear and Circuit Breakers*
- 5-4, *Transformers*
- 5-28, *DC Battery Systems*
- 5-31, *Cables and Bus Bars*

1.1 Hazards

1.1.1 Fire

The fire hazards depend on the combustibility of the components and configuration of the HVDC station. Oil-filled equipment and plastic components provide the main combustible loading.

Fire may occur due to a number of initiating events, including, but not limited to, the following:

A. Loose connections or high resistance of load current carrying devices, resulting in overheating or arcing.

B. Failure and overheating of individual valve components, including thyristors, diodes, capacitors, reactor modules, resistors, and other electronic components.

C. Loss of water cooling due to leaks or clogging, resulting in overheating.

D. Loss of air cooling (i.e., loss of fans)

E. Breakdown of electrical insulation

1.1.2 Electrical

The major electrical hazards are failure of converter transformers, valve cooling system and wall bushings which could result in further equipment damage, fire hazards, and widespread power outage. Significant power outage can be reduced by building redundancy into the systems and/or establishing viable equipment contingency planning such as sparing of convert transformers and wall bushings.

1.2 Changes

January 2023. Interim revision. Minor editorial changes were made for this revision.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 FM Approved Equipment

2.1.1 Use FM Approved equipment, materials, and services whenever they are applicable. For a list of products and services that are FM Approved, see the *Approval Guide*, an online resource of FM Approvals.

2.2 Construction and Location

2.2.1 Valve Halls

2.2.1.1 Construct valve halls using noncombustible construction.

2.2.1.2 Separate adjacent valve halls with a minimum of 1-hour fire-rated construction.

2.2.1.3 Separate valve halls from other adjacent areas (e.g., control rooms) with a minimum of 1-hour fire-rated construction.

2.2.1.4 Protect necessary openings with automatic closing fire doors. Keep all interior fire doors normally closed. Seal penetrations between the valve hall and adjacent areas with a 1-hour fire-rated, FM Approved fire stop system.

2.2.1.5 Arrange control rooms in accordance with Data Sheet 5-32, *Data Centers and Related Facilities*.

2.2.1.6 When installed, design ventilation systems to minimize potential smoke damage to the valves in the event of a fire in accordance with Data Sheet 1-45, *Air-conditioning and ventilating systems*.

2.2.2 Valve Stacks

2.2.2.1 If the facility is in FM's 50-years through 500-yearearthquake zones as defined in Data Sheet 1-2, *Earthquakes*, use suspension insulators to support the valve stacks.

2.2.2.2 Support valve stacks using noncombustible materials. Construct suspension and post insulators supporting valve stacks of high-temperature-rated materials.

2.2.2.3 Provide noncombustible materials for the converter valves.

2.2.2.4 Use dry-type (no-oil) capacitors.

2.2.2.5 Where combustible materials and/or oil-filled capacitors are used for the valves, install fire-resistant barriers between capacitors in each module, as well as between each valve module. Additionally, encase grading capacitors, snubber circuits, and power supplies within fire-resistant enclosures.

2.2.3 Converter Transformers and Smoothing Reactors

2.2.3.1 Arrange and locate transformers and smoothing reactors in accordance with Data Sheet 5-4, *Transformers*. Protect the exterior walls of the valve hall against exposure to transformer fires as recommended in Data Sheet 5-4.

2.2.3.2 Valve Hall Wall Bushings

2.2.3.2.1 Provide dry-type bushings such as resin impregnated paper (RIP) insulated or SF6 insulated bushings with polymer/silicon insulator for converter transformer valve side bushings and DC wall bushing connected to smoothing reactors.

2.2.3.2.2 If oil-insulated bushings are used, separate them from the rest of the valve hall using a minimum of 1-hour fire-rated construction.

2.2.3.2.3 If oil-insulated bushings are used, provide containment and emergency drainage to prevent fire exposure to the valve stacks, as follows:

A. Provide curbing and emergency drainage arranged to prevent the total oil contents of the bushings plus sprinkler discharge from exposing the valve stacks. Provide a minimum 3 in. (76 mm) of containment.

B. Design the containment and emergency drainage in accordance with Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*.

2.3 Fire Protection

2.3.1 Fire Detection

2.3.1.1 Provide an FM Approved Very Early Warning Fire Detection (VEWFD) system in the following areas:

A. Valve hall or valve room (as applicable)

B. Control building, rooms, or enclosures

C. Air handling systems

D. AC/DC switchyard building enclosure, as applicable

E. Reactors (if indoors)

2.3.1.2 Install and arrange the VEWFD system in accordance with Data Sheet 5-48, *Automatic Fire Detection*, and the manufacturer's recommendations.

2.3.1.3 Arrange the VEWFD system to provide multiple alarm levels as follows:

A. Initial notification – Initiate site fire emergency response plan.

B. Second notification - Deenergize electrical equipment and shut down air handling units that bring in outside air.

C. Final notification – Activate fire protection system, as applicable.

2.3.1.3.1 Transmit alarms to a constantly attended location. If the station is continuously staffed, transmit the alarm to the control room to allow operators to take necessary action. If the station is not staffed, provide video cameras to allow operators to verify the presence of a fire or other abnormal conditions and respond remotely.

2.3.2 Protection for Current Sourced Converter (CSC) (HVDC Classic or Line Commutated Converter)

2.3.2.1 Provide automatic fire protection for valve halls with oil-filled equipment or large quantities of plastic equipment. Provide one of the following fire protection systems:

A. Oxygen reduction

B. Carbon Dioxide

C. Automatic sprinkler protection

2.3.2.1.1 Where an oxygen reduction system is installed, design the system in accordance with Data Sheet 4-13, *Oxygen Reduction Systems* and provide measured oxygen concentration of no more than 12.8% by volume.

2.3.2.1.2 Where a carbon dioxide system is installed, design the system in accordance with Data Sheet 4-11N, *Carbon Dioxide Extinguishing Systems*.

2.3.2.1.3 Where automatic sprinkler protection is installed, design the system as follows:

A. For halls containing oil-filled equipment, design the sprinkler protection in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

B. For halls containing plastic equipment but no oil-filled equipment, design the sprinkler protection for HC-3 in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

C. Use preaction sprinkler systems where the primary valve activation is tied to the fire detection system to reduce the potential for accidental discharge.

2.3.2.2 Protect the control room in accordance with Data Sheet 5-32, *Data Centers and Related Facilities*.

2.3.2.3 Protect transformers and smoothing reactors in accordance with Data Sheet 5-4, *Transformers*.

2.3.2.4 Provide automatic sprinkler protection in air handling systems with combustible ductwork or filters in accordance with Data Sheet 7-78, *Industrial Exhaust Systems*.

2.3.3 Protection for Voltage Sourced Converter (VSC) (i.e. HVDC Light)

2.3.3.1 Provide automatic fire protection for valve rooms with oil-filled equipment or large quantities of plastic equipment. Provide one of the following fire protection systems:

- Oxygen reduction
- Gaseous system

2.3.3.1.1 Where an oxygen reduction system is installed, design the system in accordance with Data Sheet 4-13, *Oxygen Reduction Systems* and provide measured oxygen concentration of no more than 12.8% by volume.

2.3.3.1.2 Where a gaseous system is installed, design the system in accordance with Data Sheet 4-9, *Halocarbon and Inert Gas (Clean Agent) Fire Extinguishing Systems*.

2.3.3.2 Provide automatic sprinkler protection in the AC/DC switchyard building enclosure and design the system as follows:

A. For enclosures containing oil-filled equipment, design the sprinkler protection in accordance with Data Sheet 7-32, *Ignitable Liquid Operations*.

B. For enclosures containing plastic equipment but no oil-filled equipment, design the sprinkler protection for HC-3 in accordance with Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*.

C. Use preaction sprinkler systems where the primary valve activation is tied to the fire detection system to reduce the potential for accidental discharge.

2.3.3.3 Protect the control enclosure in accordance with Data Sheet 5-32, *Data Centers and Related Facilities*.

2.4 Equipment and Processes

2.4.1 Valve Cooling System

2.4.1.1 Provide N+1 redundancy for the entire cooling system including, but not limited to, water pumps or fans in the cooling system.

2.4.1.2 Provide a loss of total cooling system relay device to put the converter system in a safe condition in the event that all required pumps or fans are lost.

2.4.1.3 Provide the monitoring functions per Tables 2.4.1.3-1 and 2.4.1.3-2 for the cooling system that will alarm and/or trip the system at the presence of abnormal conditions. All the alarms should be individually reported to a constantly attended locations.

Table 2.4.1.3-1. Online Monitoring Recommended for Air Cooling Systems

Online monitoring function	*Purpose*	*Alarms*	*Trips*
Temperature	To monitor the cooling air temperature incoming and outgoing of the valve stack	*	*
Temperature	To monitor the cooling air temperature to and from the heater exchangers	*	
Temperature	To monitor valve hall room temperature	*	*
Differential Pressure	To monitor the air pressure difference across the valve stack	*	

Table 2.4.1.3-2. Online Monitoring Recommended for Water Cooling Systems

Online monitoring function	*Purpose*	*Alarms*	*Trips*
Temperature	To monitor the cooling water temperature incoming and outgoing of the valve stack	*	*
Temperature	To monitor the cooling water temperature to and from the heater exchangers	*	
Temperature	To monitor valve hall room temperature	*	*
Pressure	To monitor the pressure incoming and outgoing the valve hall	*	*
Water flow	To monitor the water flow to and from valve stack	*	*
Water level	To monitor the level of the water in the expansion vessel	*	*
Water conductivity	To monitor the conductivity of the de-ionized cooling water	*	

2.5 Operation and Maintenance

2.5.1 General

2.5.1.1 Provide arc detection devices interlocked to deenergize the valves upon detection.

2.5.1.2 Operate the HVDC and its support systems in accordance with approved operating instructions and within prescribed thermal and electrical limits.

2.5.1.3 Establish and implement a HVDC system inspection, testing and maintenance program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program.

2.5.2 Converter Valves

2.5.2.1 Perform annual thermographic surveys on all electrical equipment inside the valve hall.

2.5.2.2 Perform corona survey when the valve hall has any major equipment changes to verify no additional voltage stress has been introduced.

2.5.2.3 Perform the following maintenance when the HVDC station is shut down for maintenance. The interval between maintenance outages depends on the manufacturer's recommendations (usually annually or every two years) and the condition of the valves and associated equipment.

A. Visually check the valve hall, the valve stacks, and all other valve electrical equipment, such as wall bushings and surge arrestors, to ensure they are maintained in a dry, cool, and clean condition with no abnormal noise, smell, vibration, contamination, or heat.

B. Visually check the valve coolant circuit connection within the hall for tightness and any coolant leaks.

C. Clean large coolant pipes within the valve hall.

D. Clean insulator or insulation parts for all electrical equipment such as surge arrestors and wall bushings within the valve hall.

E. Visually inspect at least one representative valve module for each valve stack for contamination, fittings on the cooling circuit, grading capacitor and valve reactor, along with checks of the bus work bolts and terminations on the grading capacitor and valve reactor. Perform maintenance electrical testing of components in the representative modules if recommended by the manufacturer.

F. Check pressure gauges of gas-insulated electrical equipment, such as wall bushing, for gas leakage.

G. Check gas quality of gas insulated electrical equipment, such as wall bushing, to verify moisture, dielectric strength and contaminant levels are within manufacturer's specifications.

H. Replace any defective components, such as thyristor and electronic boards, detected by the monitoring system.

I. Lubricate cooling fans or pumps.

J. Clean outdoor coolers.

2.5.2.4 Implement a robust foreign material exclusion program during all maintenance and inspection activities. For further guidance on foreign material exclusion, see Data Sheet 9-0, *Asset Integrity*.

2.5.3 Converter Valve Cooling System

2.5.3.1 Perform visual inspections of the following valve cooling system components on a weekly basis:

A. Fans or pumps to check for any noisy operation

B. Pump mechanical seal to check for leakage

C. Conductivity level in the main line and at the output of ion exchangers (water-cooling system)

D. Pressure head before and after the main filter

E. Expansion tank level (water-cooling system)

F. Cooling motor control cubicle (MCC) front panel to check for any trouble signals such as flashing LEDs

2.5.3.2 Change the bearing of the motors at a frequency recommended by the original equipment manufacturer (OEM).

2.5.3.3 Change the resin at a frequency recommended by OEM (water-cooling system).

2.5.3.4 Perform periodic cooling water testing for water-cooled valves to ensure that the di-ionized water meets manufacturer's or chemistry consultant's specifications.

2.5.4 Converter Transformers

2.5.4.1 Refer to Data Sheet 5-4, *Transformers*, for operation, maintenance, and testing recommendations for converter transformers and wall bushings.

2.5.5 Smoothing Reactors

2.5.5.1 Refer to Data Sheet 5-4, *Transformers*, for operation, maintenance, and testing recommendations for smoothing reactors and their DC wall bushings.

2.5.6 Switchgear, Circuit Breakers and Protection Relays

2.5.6.1 Refer to Data Sheet 5-19, *Switchgear and Circuit Breakers*, for electrical testing recommendations regarding the switchgear and protection relays at the HVDC station. Refer to Data Sheet 5-28, *DC Battery Systems*, for operation, maintenance and testing recommendations for batteries.

2.5.7 Surge Arrestors and Grounding Systems

2.5.7.1 Test surge arrestors according to Data Sheet 5-19, *Switchgear and Circuit Breakers*.

2.5.7.2 Inspect and test grounding and bonding systems according to Data Sheet 5-19, *Switchgear and Circuit Breakers*.

2.6 Human Element

2.6.1 Create a training program for all employees (including operators, emergency response team members, and security personnel). Design and supervise the training program to address the complexity of the facility hazard level present. Refer to Data Sheet 10-8, *Operators*, for guidance on operator training program.

2.6.2 In addition to standard operating procedures, provide written emergency operation procedures including, but not limited to, the following scenarios, as applicable:

- Cooling water chemistry out of specification
- Cooling system related alarms such as low pressure, low water level, high temperature, etc.
- Emergency station electrical isolation procedure in response to electrical system emergencies

2.6.3 Establish a comprehensive emergency response plan to address potential fire scenarios. Refer to Data Sheet 10-2, *Emergency Response*, for general guidelines on establishing and maintaining an emergency response plan, and Data Sheet 10-1, *Pre-Incident Planning*.

2.6.3.1 Familiarize the facility's emergency response team members and the local fire service with the location of various hazards and equipment, as well as the emergency response plan. Use emergency response drills to reinforce the employee training programs and assist the fire service in pre-fire planning.

2.6.4 Arrange and prepare documented procedures to expedite safe entry and emergency response to various fire situations. Include information regarding the following items in the emergency response plan:

A. Rapid de-energization of electrical equipment. Consider all areas that might be affected by fire including control room, support areas, valve hall, etc. If control function transfer is required, include the procedure into the fire emergency response plan.

B. Controlling the extent of damage due to fire by ensuring prompt fire service notification and allowing entry for manual firefighting.

C. Ensuring the availability and function of all provided fire protection features and the ability to remotely operate fire protection systems.

D. Guidelines for recommended actions for specific incidents, such as a bushing fire, a valve fire, etc.

E. Notification of facility management and the emergency response team, including names and current contact information.

F. Organizational responsibility for managing emergency response.

The actual extent of the emergency response plan will depend on the hazards present, facility size, availability of emergency response personnel from surrounding communities (e.g., fire service), and local, state, and federal regulations.

2.7 Contingency Planning

2.7.1 Equipment Contingency Planning

When a breakdown of high voltage direct current converter station equipment would result in an unplanned outage to site processes and systems considered key to the continuity of operations, develop, and maintain a documented, viable equipment contingency plan per Data Sheet 9-0, *Asset Integrity*. See Appendix C of that data sheet for guidance on the process of developing and maintaining a viable equipment contingency plan. Also refer to sparing, rental, and redundant equipment mitigation strategy guidance in that data sheet.

2.7.2 Sparing

Sparing can be a mitigation strategy to reduce the downtime caused by equipment specific to high voltage direct current converter stations, depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.7.2.1 Routine Spares

Routine spares are spares that are consumables. These spares are expected to be put into service under normal operating conditions over the course of the life of the equipment, but not reduce equipment downtime in the event of a breakdown. This can include sparing recommended by the original equipment manufacturer. See Section 3.4 for routine spare guidance.

2.7.2.2 Equipment Breakdown Spares

Equipment breakdown spares for high voltage direct current converter stations are spares intended to be used in the event of an unplanned outage to reduce downtime and restore operations. Provide the following equipment breakdown spares for high voltage direct current converter station equipment, which is based on long lead times to obtain replacements and/or criticality of this equipment to station operation:

A. Smoothing reactor

B. DC bushing

C. Converter transformer(s)including its bushing for each type:

1. One converter spare if the transformer used is three phase three windings.

2. Two converter spares if the transformers used are three phase two windings: One for Y/Δ transformer and the other for Y/Y transformer.

3. One converter spare if the transformer used is single phase, two or three windings.

D. Valve module

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Failure Modes

3.1.1 Converter Transformers and Smoothing Reactors

The detailed failure mechanism of converter transformers/smoothing reactors can be found in FM Datasheet 5-4, *Transformers*. Failure of converter transformers and their wall bushings have occurred in HVDC converter stations. Their failure can result in loss of full transmission power of one pole or less, depending on whether there are series-connected converter units in one pole. Significant long outage can occur when there is no equipment breakdown spare available. According to public literature, converter transformer failures have occurred in the majority of HVDC systems. The following information was collected by a Cigre task force on converter transformer failures at various HVDC stations in 2002.

- Hokkaido Honshu (1 failure)
- Itaipu (3 failures)
- Pacific Inter-tie expansion (3 failures)
- Fino-Skan (3 failure)
- Hydro Quebec to New England (3 failure)
- Kontek (1 failure)
- Konti-Skan (3 failures)
- Nelson River (3 failures)
- Nelson River (2 failures)
- Skagarak (2 failures)
- Gesha (2 failures)
- Chandrapur Padge (1 failure)
- Chateauguay (2 failure)
- Hatenam (3 failures)
- Rihand to Dadri (4 failures)
- Vyborg (1 failure)
- Highgate (2 failures)
- Virginia Smith (1 failure)
- Madawaska (1 failure)
- Square Butte (1 failure)
- Eel River (1 failure)
- Welsch (1 failure)
- Inter Mountain (1 failure)
- Swedepol (1 failure)

3.1.2 Equipment Within Valve Halls

3.1.2.1 Insulation Breakdown Failure

Breakdown of electrical insulation within a valve or across other equipment in the valve hall such as voltage dividers can occur due to insulation failure and lead to electrical equipment damage and arcing, which could ignite combustible material. Insulation failure could be internal degradation of the dielectric material, or external due to corona or contamination of insulating surfaces (e.g., because of a coolant leak). Smoke or other ionized by-products arising from an overheated electrical component can reduce the withstand level of the air insulation within the valve.

3.1.2.2 Contamination and Condensation

The equipment inside the valve hall is subjected to high voltage that contains a large DC component. This creates an electric field that tends to attract airborne particles that are naturally present in the valve hall air. As a result, equipment surfaces may become covered with deposits of foreign material. Buildup of contaminants increases the risk of flashover. The electrical creepage distances and electrical clearances inside the valve are based on a reasonably clean environment.

The size and density of dust particles inside the valve hall depend upon the efficiency of the ventilation and filtering system. Also, if the inside of the building (walls, roof, floor, structure, etc.) is not properly treated with a maintenance-free coating, it can lead to generation of dust that may eventually be deposited on the various surfaces of the valve.

Condensation inside the valve hall is possible on any cooled surface, such as water pipes and connections if their temperature is allowed to fall below the dew point in the valve hall. The contaminants deposited on valve hall equipment surfaces, together with high humidity conditions or water leaks, further increase the risk of a major flashover.

3.1.2.3 Loose Connections or High-Resistance Joints

An overheated connection can arise from improper connection between different sections of the valve, with the series reactor, with the thyristor or IGBT, or any other connector that forms the path of the load current. Any loose connection or high-resistance joint will overheat. In the case of an open circuited connection, arcing will develop. In either case, the heat generated may cause damage to adjacent components, especially insulating material. If high temperatures are reached, a fire may result.

3.1.2.4 Valve Module Component Failures

The failure of some valve components, such as snubber capacitors, valve reactors, and electronic circuits, can lead to arcing or fire.

Snubber capacitors are oil- or gas-insulated. These capacitors can fail due to production defects, electrical short-circuit inside the capacitor, or sparking at a broken internal connection. For oil-insulated snubber capacitors, the failure can cause a buildup of pressure inside the capacitor, resulting in rupture of the can, and an ensuing fire. Failure of gas-insulated snubber capacitors will not lead to can rupture.

The valve reactors can be oil- or air-cooled. The major failure modes of valve reactors are overheating, turn-to-turn failure, turn-to-core failure, or failure of banding straps used to secure the reactor and its core. Failure of the oil-insulated reactor may cause a fire within the valve module.

The electronic circuits for the control, protection, and monitoring of the thyristors are normally of low power. The failure of individual components may, however, pose a fire hazard as well.

3.1.2.5 Valve Water Cooling System Failure

The failure modes of the valve cooling circuit are corrosion, leakage, and clogging due to erosion or foreign objects.

If cooling water flow is blocked to the valve, overheating may damage valve components, leading to an internal fault or to releasing debris onto other electrically live parts. This may result in the release of smoke or ionized air that may develop into a partial flashover. Complete loss of cooling could result in damaging temperatures being reached within seconds that, in a worst-case scenario, can destroy all valves in the stack.

Cooling water leaks can occur at any of the joints due to the failure of gaskets or O-rings. The cracking of plastic pipes caused by premature aging could also lead to leakage. In addition, mechanical vibrations (e.g., from reactors) may cause loosening of joints or cracking of pipes that could lead to a leak. The leakage of water can lead to flashover, which could also cause a fire. Failure of the cooling system is normally sensed by external monitoring of flow, temperature, pressure, etc.

3.1.2.6 Failure of Surge Arresters

Because of the absence of combustible material inside arresters, their failure should not directly lead to a fire. However, ionized plasma from the arcing due to operation of the surge arrester has the possibility to initiate a flashover (although proper design should minimize this potential).

3.1.4.7 Failure of Valve Hall Bushings

Failure of valve hall bushings, including smoothing reactor bushings and transformer valve side bushings, could be due to external flashover or internal short circuit caused by insulation failure. The wall bushings are either oil-insulated or dry type. Failure of oil-insulated bushings can result in an explosion and ensuing fire inside valve hall building as well as indoor and outdoor oil contamination. Therefore, modern wall bushing designs are insulated with SF6 gas or resin impregnated paper insulated, i.e., oil free. Since a severe internal fault in a porcelain-housed bushing may cause an explosion resulting in consequential damage to other equipment, composite polymer insulators are used in modern design. Composite bushings may rupture, but that will not result in flying debris that could cause damage to other equipment.

3.2 Valve Hall Fire Protection

The design of fire protection systems for valve halls presents several difficulties, including the presence of sensitive and high-voltage electrical equipment, the potential for oil and plastic fire hazards, and the large volumes associated with the halls. Occupancies with electrical equipment can be effectively protected using gaseous extinguishing systems, carbon dioxide systems, and oxygen reduction systems. Local application gaseous protection systems have also been proposed for individual valve modules. However, the effectiveness of these systems in preventing vertical fire spread throughout a valve stack is unknown.

The use of water-based fire protection systems for valve halls is not widespread due to concerns with equipment damage from water discharge. Some valve halls are provided with a manually activated water deluge system to avoid inadvertent discharge of water on very high-voltage equipment. However, valve operators have been reluctant to initiate water discharge due to fears of damaging the high-voltage equipment, rendering the protection system ineffective.

If the electrical equipment is deenergized prior to water discharge, these concerns may be alleviated. This can be achieved through the use of a preaction system, where the electrical equipment is shut down prior to sprinkler discharge.

With these safeguards in place, water is an effective agent. The sprinkler discharge will wet the deenergized valve modules, and it may be necessary to unstack the valve(s), clean all components, and reassemble the stacks, including electrical tests. However, the ceiling sprinkler protection will limit a fire to the stack of origin, and will protect the building structure, cool the valve stack support structure, and prevent fire growth to other valve stacks.

Some HVDC facilities have even used water to directly protect the valve. For example, a converter station in the United States installed deluge-type water spray nozzles within the valve stack, in addition to an automatic sprinkler system at ceiling level, to extinguish a fire within the valve itself. This data sheet does not recommend fire protection at this local level, but this is a business decision due to client concerns with potential water damage.

The sprinkler protection recommended in this data sheet will not extinguish a fire in the valve but will provide cooling at the ceiling and limit thermal damage to one valve stack.

3.3 Fire Tests

3.3.1 Valve Stack Construction and Fire Barriers

Given the fire hazard associated with HVDC converter valves, methods to limit fire spread should be pursued. One method is to use noncombustible materials. Where this is not possible, fire barriers may be located below each capacitor bank, and vertical barriers placed within the capacitor banks. This will reduce the number of capacitors involved in a fire and prevent propagation of the fire up through the modules (see Figures 3.3.1-1 and 3.3.1-2).

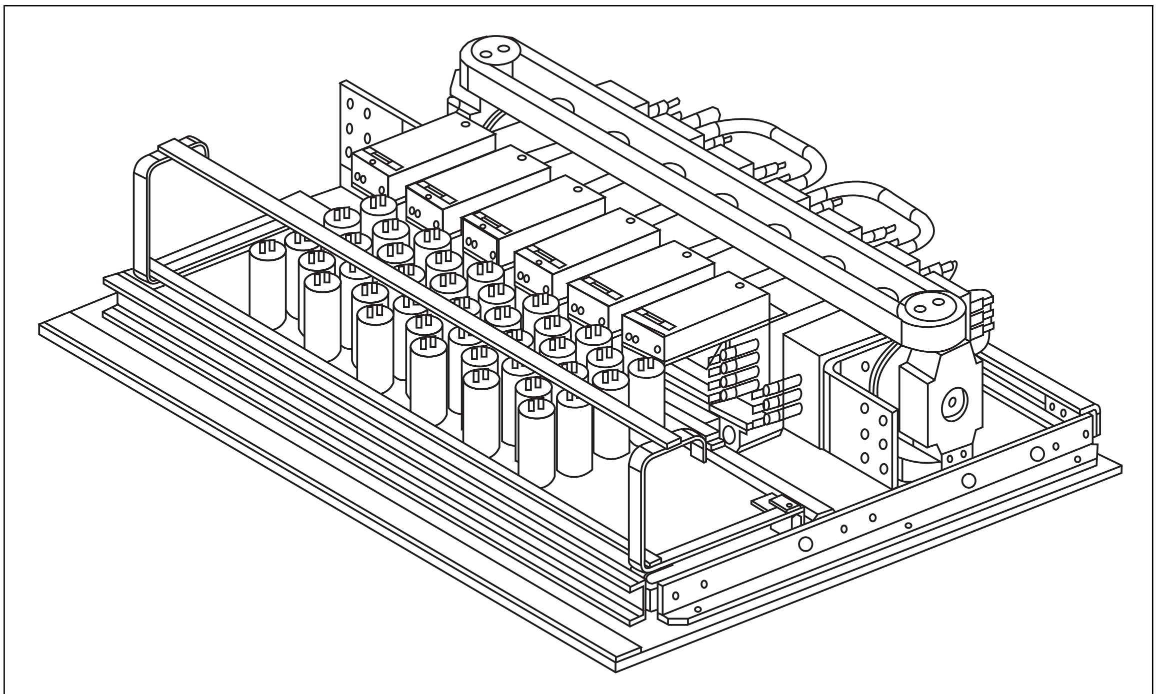

Fig. 3.3.1-1. Module containing a circuit board mounted on an aluminum tray (note the location of the power supply and control, thyristers, resistors, capacitors, and the cooling system)

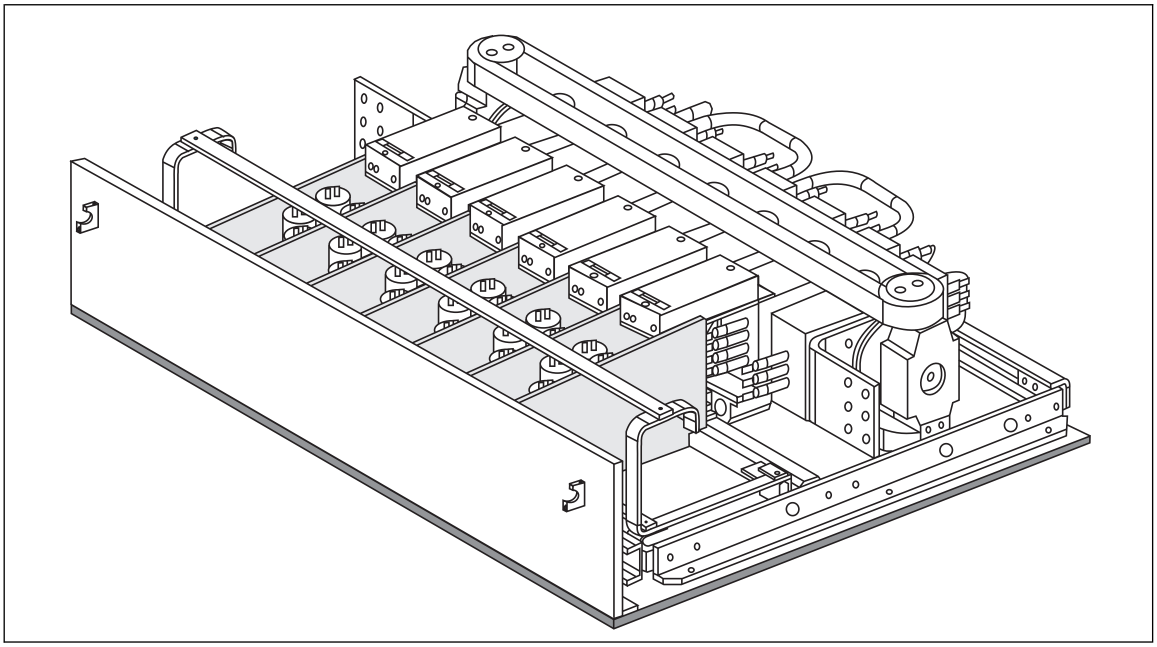

Fig. 3.3.1-2. Module with vertical fire barriers between capacitors and sides to prevent the release of liquid onto modules below (note: aluminum tray has been replaced by fire-resistant material; circuit boards for power supply, gate control power, and thyristor control are individually enclosed with metal enclosures)

3.4 Routine Spares

The following are common routine spares for high-voltage direct current converter station equipment. Store and maintain the routine spares per the original equipment manufacturer's recommendations to maintain viability. Refer to Data Sheet 9-0, *Asset Integrity*, for additional guidance.

- Cooling pumps and fans

4.0 REFERENCES

4.1 FM

Data Sheet 2-0, *Installation Guidelines for Automatic Sprinkler Systems*
Data Sheet 3-26, *Fire Protection for Nonstorage Occupancies*
Data Sheet 4-9, *Halocarbon and Inert Gas (Clean Agent) Fire Extinguishing Systems*
Data Sheet 4-11N, *Carbon Dioxide Extinguishing Systems*
Data Sheet 4-12, *Foam-Water Sprinkler Systems*
Data Sheet 4-13, *Oxygen Reduction Systems*
Data Sheet 5-4, *Transformers*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-28, *DC Battery Systems*
Data Sheet 5-32, *Data Centers and Related Facilities*
Data Sheet 5-48, *Automatic Fire Detection*
Data Sheet 7-32, *Ignitable Liquid Operations*
Data Sheet 7-78, *Industrial Exhaust Systems*
Data Sheet 7-83, *Drainage and Containment Systems for Ignitable Liquids*
Data Sheet 9-0, *Asset Integrity*
Data Sheet 10-0, *The Human Factors of Property Conservation*
Data Sheet 10-1, *Pre-Incident Planning*
Data Sheet 10-2, *Emergency Response*

4.2 Other

ASTM International. ASTM E119, *Standard Test Methods for Fire Tests of Building Construction and Materials*.

Underwriters Laboratories (UL). UL 94, *Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances Testing*.

APPENDIX A GLOSSARY OF TERMS

Dry-type wall bushing: A wall bushing that does not contain oil. Examples include gas insulated (e.g., SF6) bushings and resin impregnated paper (RIP) bushings.

FM Approved: Products and services that have satisfied the criteria for FM Approval. Refer to the *Approval Guide*, an online resource of FM Approvals, for a complete listing of products and services that are FM Approved.

HVDC classic: Current sourced converter (CSC), line commutated converter (LCC). Line-commutated converters are made with thyristor electronic switches that can only be turned on.

HVDC light: Voltage sourced converter (VSC). Voltage-sourced converters are made with IGB switching devices that can be turned both on and off.

Ignitable liquid: Any liquid or liquid mixture that has a measurable flash point. The hazard of a liquid depends on its ability to sustain combustion or create a flammable vapor-air mixture above its surface. Flash point is one way of understanding if a liquid can create that flammable vapor-air mixture. For a liquid to burn in a pool, it must have a fire point as well as a flash point. Ignitable liquids include flammable liquids, combustible liquids, inflammable liquids, or any other term for a liquid that will burn. N+1 redundancy: Excess capacity to ensure the availability of a component or system in the event of a failure. At least one more component will be installed than is required (e.g., if two pumps are required, three will be made available).

Valve: A device which has the property of conducting in the forward direction and blocking in the reverse direction used for HVDC converters. Examples include thyristors, insulated-gate bipolar transistors (IGBTs) or mercury arc valves. Mercury arc valves are old technology and not used in new designs anymore.

Valve module: An assembly compromising a number of thyristors or insulated-gate bipolar transistors (IGBTs) and their immediate auxiliaries for firing and protection, voltage dividing components, distributed valve reactors, from which the valve is built up and which exhibit similar electrical properties as the complete valve.

APPENDIX B DOCUMENT REVISION HISTORY

The purpose of this appendix is to capture the changes that were made to this document each time it was published. Please note that section numbers refer specifically to those in the version published on the date shown (i.e., the section numbers are not always the same from version to version).

January 2023. Interim revision. Minor editorial changes were made for this revision.

January 2022. This is the first publication of this data sheet.

APPENDIX C HVDC CONVERTER STATION BACKGROUND INFORMATION

The fundamental process that occurs in an HVDC system is the conversion of electrical current from AC to DC (rectifier) at the transmitting end, and from DC to AC (inverter) at the receiving end. A typical HVDC system is shown in simplified form in Figure C.1. The converter stations at each end are replicas of each other and therefore consist of all the needed equipment for going from AC to DC or vice versa. The connection between the converters may be by overhead line, cable, or both. Power electronic valves (essentially high-powered, electronic switches) within the converters allow the power flow to be controlled. The HVDC system is usually designed so the converter at either terminal can be operated as a rectifier or an inverter and therefore the direction of the power flow can be reversed as required.

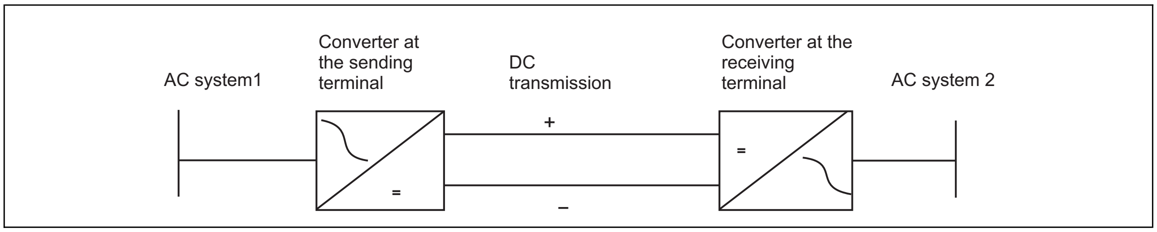

Fig. C.1 Typical HVDC system

HVDC facilities are used for both long-range transmission of electricity and connecting grids. Electricity can be transmitted by high-voltage DC with lower line losses than with AC current. HVDC facilities are also used over short distances to connect two AC grids that are at different voltages or different phases. An example of the former is the transmission of electricity from Quebec hydro plants to the electric grid in the northeast United States. An example of the latter is the transmission of power into Texas where the electric grid was originally designed to be independent from the rest of the country.

C.1 HVDC Converter Technologies

The first HVDC facility was constructed in 1954 and used a mercury arc converter. Since then, almost all mercury arc valves have been de-commissioned or converted to thyristor valves. Currently there are two main technologies used in the industry to achieve the conversion between AC and DC: line commutated converters using thyristors and voltage source converters using IGBT.

C.1.1 Line Commutated Converters (LCC)

Line commutated converters, also known as current commutated converters (CCC), are the most prevalent technology currently used in HVDC systems. The component that enables this conversion process is the thyristor valve, which is a controllable semi-conductive device that can carry very high currents and is able to block high voltage. Thyristor valves only have turn-on ability, so their commutation is dependent on AC system current. Almost all LCC-based converters use 12-pulse circuits (termed “quadra-valve”). This is a series connection of two fully controlled 6-pulse converter bridges (see Figure C.1.1-1). It requires two 3-phase systems spaced apart by 30 electrical degrees, which is achieved by utilizing converter transformers with valve side winding connections of Y and Delta.

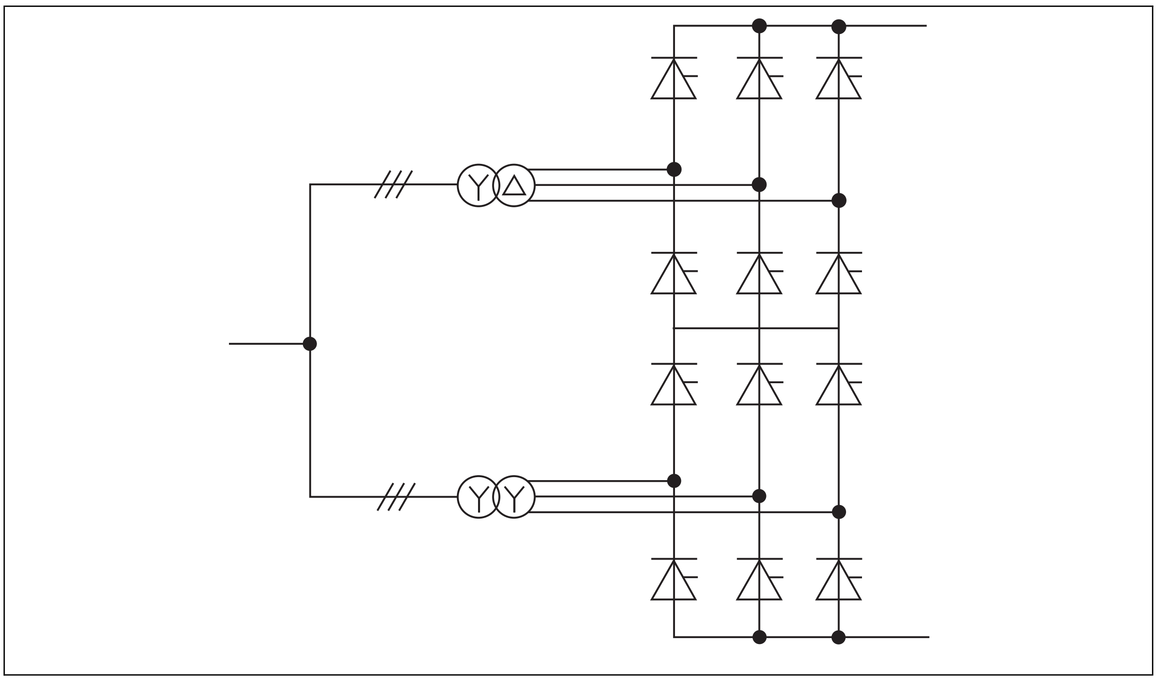

Fig. C.1.1-1. Example of a 12 pulse converter bridge connected to two 2-winding converter transformers

An LCC-based HVDC converter generates many harmonics on its AC side. Therefore, AC harmonic filters are installed to limit AC harmonic currents to the level required by the network. The conversion process of LCC also consumes reactive power that is compensated in part by the AC harmonic filter banks, and the rest by capacitor banks. On the DC side of the converter, a reactor is provided to smooth the DC current. The reactor also reduces the peak current in the event of a fault on the DC connection. DC filters may also be required to reduce harmonic voltages on the DC circuit, particularly when the circuit includes overhead lines. A typical LCC converter station electrical diagram is shown in Figure C.1.1-2.

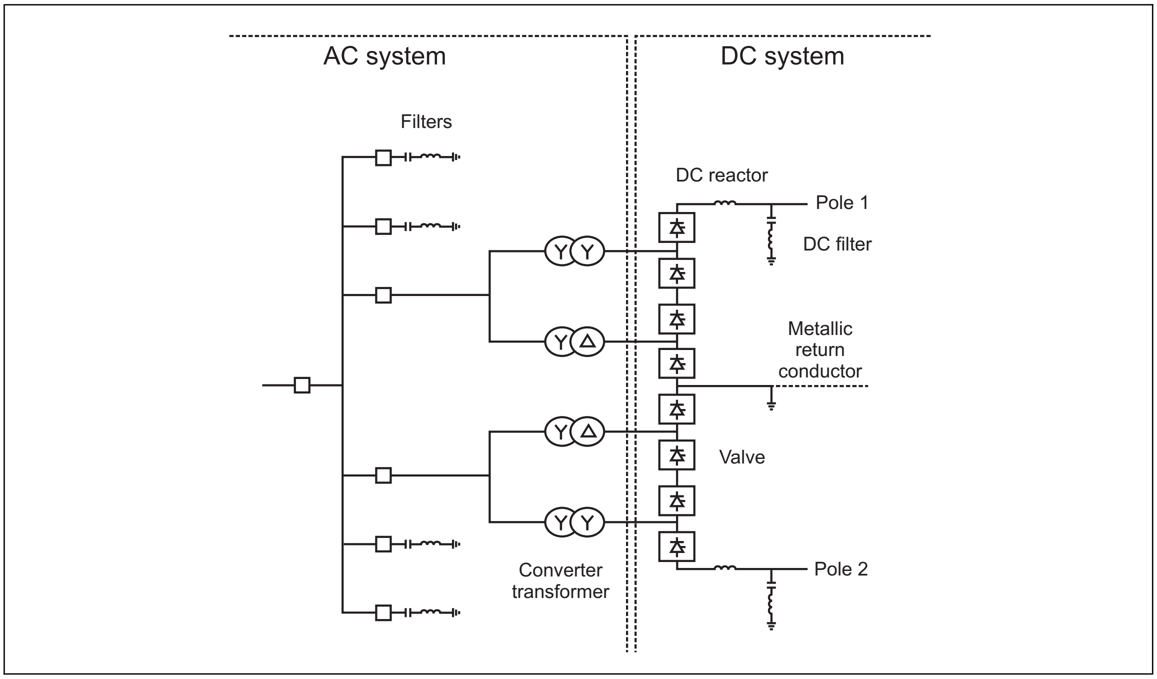

Fig. C.1.1-2. Typical LCC converter station electrical diagram for a bipolar HVDC station

C.1.2 Voltage Source Converter (VSC)

The valves of these converters are built up with semiconductors with the ability to self-commutate (i.e., the ability to not only turn on but also to turn off). Therefore, there is no need for converter transformers. Two types of semiconductors are normally used in voltage source converters: the gate turn-off thyristor (GTO) and the insulated gate bipolar transistor (IGBT). The IGBT is most frequently used in this application. In comparison with LCC technology, VSC offers the possibility to control both active and reactive power independently. VSC has no need to compensate any reactive power consumed by the converter itself. In addition, there is much less harmonics on the AC side. The number of filters in this type of converter is reduced dramatically compared with LCC-based converters, leading to a much smaller footprint (see Figure C.1-2. for a typical electrical diagram for a VSC HVDC converter station). Due to this feature, the wind-power industry tends to use VSC technology for off-shore HVDC stations.

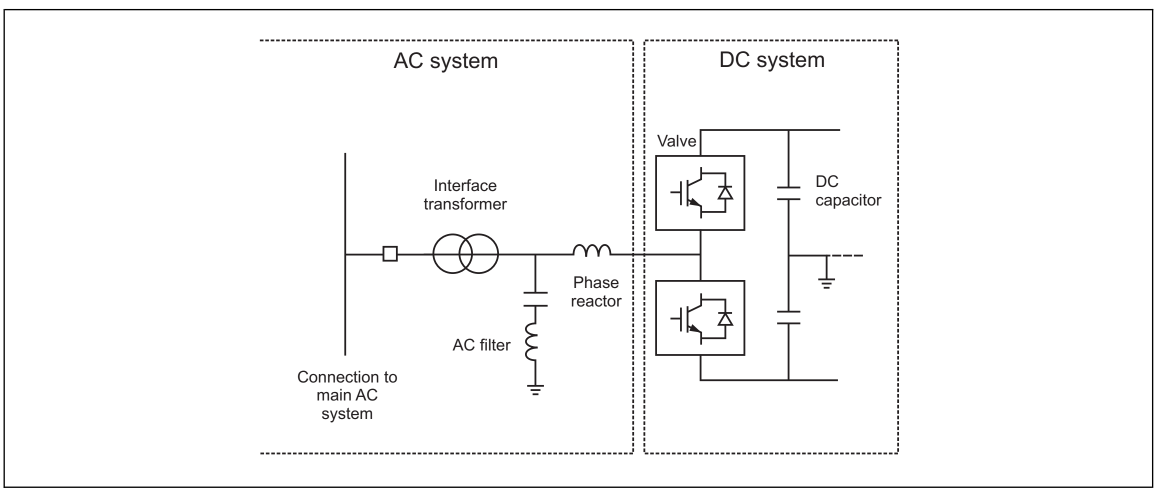

Fig. C.1-2. Electrical diagram of two-level VSC converter station

The VSC HVDC converter station is relatively new technology but is getting more and more attention. ABB produced its first VSC HVDC station (named HVDC light) in 2000. The application so far has been limited to lower voltages and power ratings than LCC systems. However, with the advancement of this technology, the power rating of VSC is increasing. Until recently, the IGBT valve bridge for HVDC applications has been based on two (used in ABB HVDC light technology) or multi-levels (used in Siemens HVDC plus technology), meaning there are two or more valves in each phase.

C.2 HVDC System Configurations

The configuration of HVDC systems can be mono-polar or bipolar. A mono-polar HVDC system has either ground return or metallic return. A mono-polar HVDC system with ground return consists of one or more converter units in series or parallel at each end, and a single conductor and return through the earth or sea, as shown in Figure C.2-1. It can be a cost-effective solution for an HVDC cable transmission and/or the first stage of a bipolar scheme. At each end of the line, it requires an electrode line and a ground or sea electrode built for continuous operation.

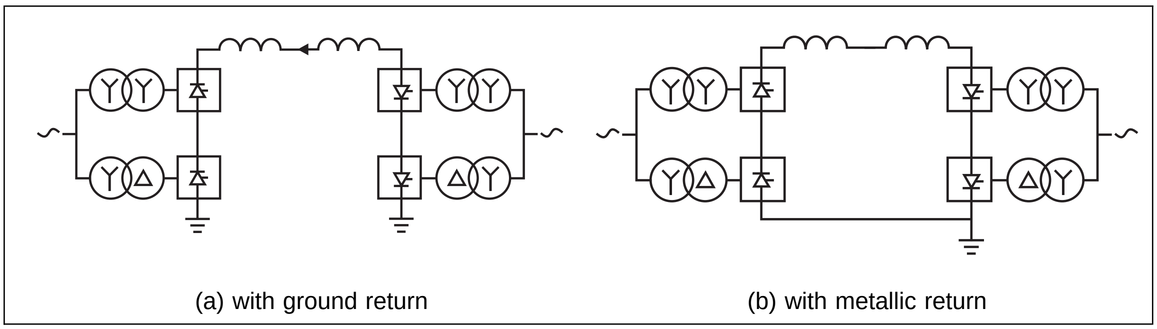

Fig. C.2-1. Examples of mono-polar HVDC systems

A bipolar HVDC system consists of two poles, each of which includes one or more converter units, in series or parallel. There are two conductors, one with positive and the other with negative polarity to ground for power flow in one direction. For power flow in the other direction, the two conductors reverse their polarities. A bipolar system is a combination of two mono-polar schemes with ground return, as shown in Figure C.2-2. During an outage of one pole, the other could be operated continuously with ground return. This is a very common arrangement.

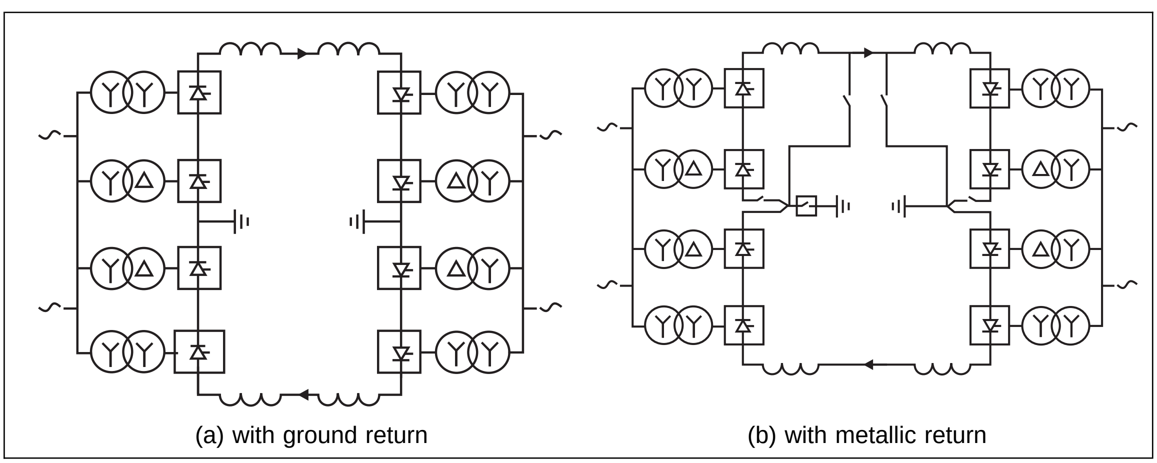

Fig. C.2-2. Examples of bipolar HVDC systems

C.3 Major HVDC Converter Station Equipment

Converter stations have four major components:

A. HVDC switchyard

B. Converter building

C. Converter transformer area

D. AC switchyard

The converter building houses the valve hall(s), control room, valve electronics room(s), mechanical and electrical service facilities, and maintenance facilities. Conversion from AC to DC or DC to AC occurs in the valve hall(s). The major equipment in the valve hall(s) consists of valves or valve stacks, bushings, and valve electronics rooms.

C.3.1 Converter Valves

Converter valves are an integral part of an HVDC converter station. The most common valves are thyristor valves used for LCC and IGBT valves for VSC. Both technologies consist of a certain number of series connected valve modules.

C.3.1.1 Thyristor Valves

Nearly all HVDC converters with thyristor valves are assembled in a converter bridge of twelve pulse configuration with three groups of four valves (known as a quadra-valve). To minimize the space requirement in the valve hall, the quadra-valves are often vertically stacked to take advantage of the graded insulation level. The necessary creepage and electrical clearances between and within the valves are achieved by the use of porcelain and/or composite insulators. Either support insulators mounted on the floor or suspension insulators mounted from the ceiling structural steel may be used for the valve stack (see Figures C.3.1.1-1 and C.3.1.1-2). The latter design evolved as a means of preventing damage due to earthquakes.

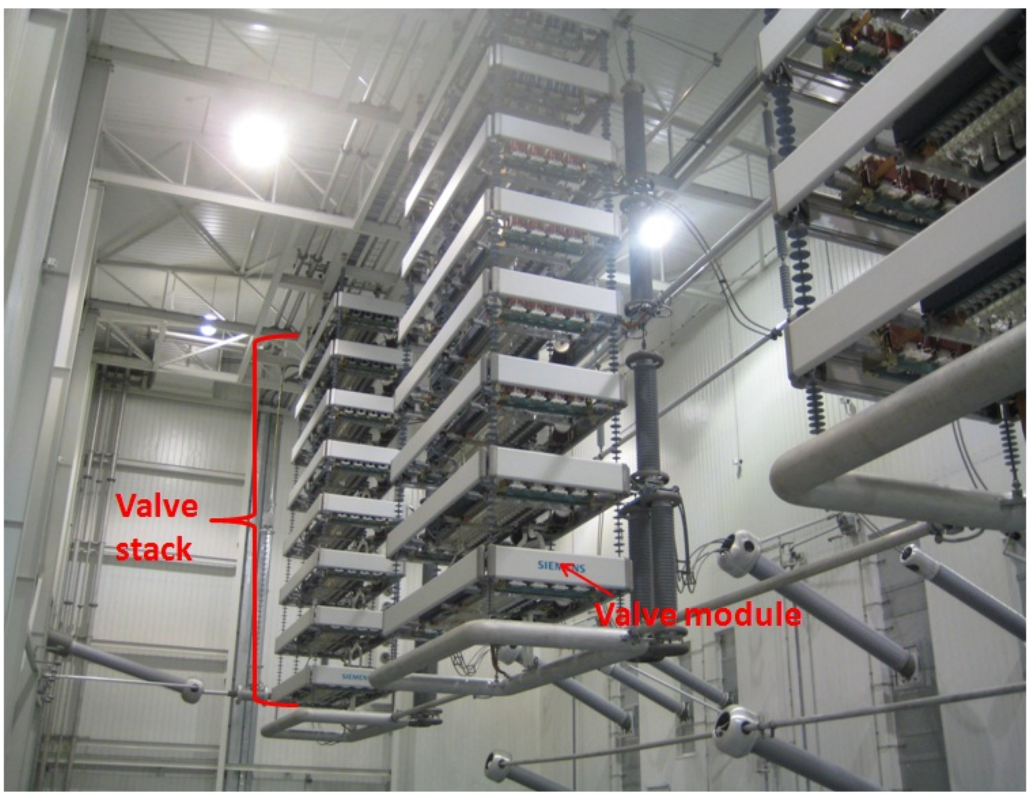

Fig. C.3.1.1-1. Example of suspended thyristor valve stack in an LCC valve hall

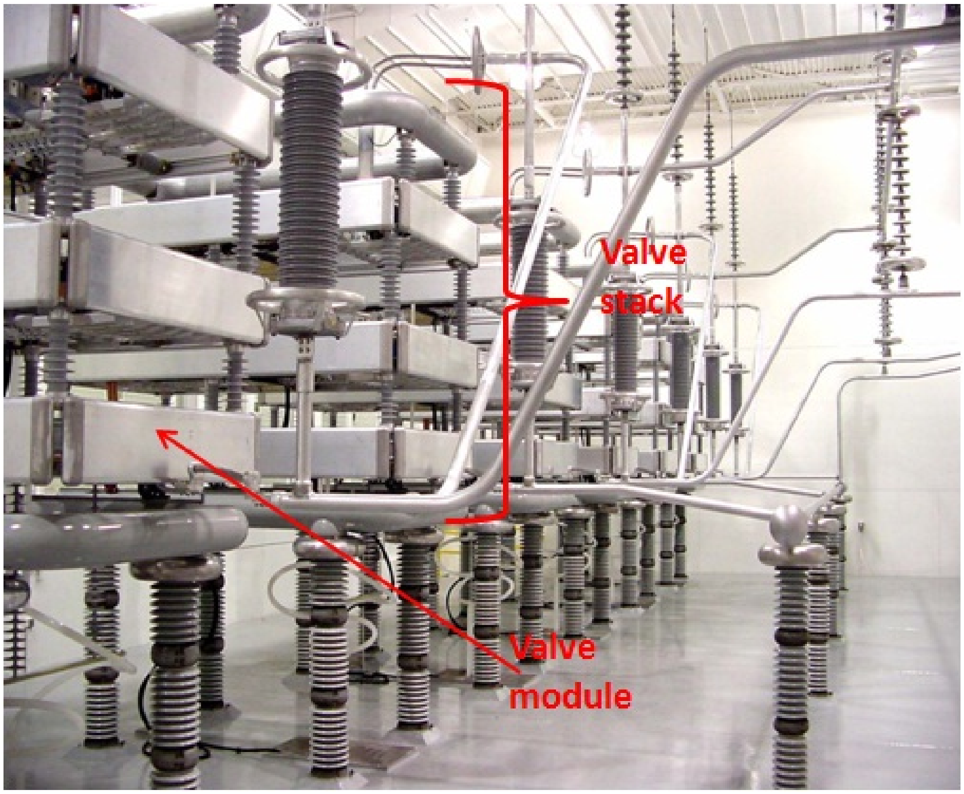

Fig. C.3.1.1-2. Example of bottom-supported thyristor valve structure in an LCC valve hall

A typical converter building for LCC-based technology has a separate valve hall for each pole, which contains a minimum of three valve stacks. Each single thyristor valve in a valve stack consists of a certain number of series connected valve modules, also known as valve trays or valve tiers. A valve module is composed of series connected thyristor with auxiliary components such as snubber capacitors and resistors (also called damping capacitors and resistors), valve reactors, and thyristor voltage monitoring cards (TVM). Figure C.3.1.1-3 shows examples of thyristor valve modules from different manufacturers during assembly.

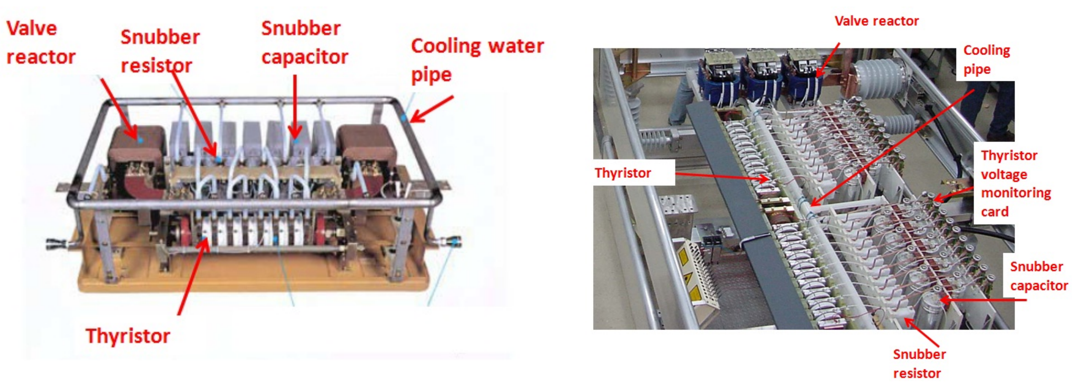

Fig. C.3.1.1-3. Examples of thyristor valve modules from different manufacturers

Depending on the design, snubber capacitors and reactors can be either gas- or oil-insulated. Their purpose is to limit the electrical voltage stresses that thyristors are subjected to during valve firing. The voltage of each thyristor is monitored online through TVM, which sends the monitored signal back to the control center though fiber optics. All other communication between each thyristor and the control equipment at earth potential is performed with fiber optics. The thyristor valve can be turned on electrically or with light signals. The electrically triggered thyristor (ETT) has a specific control unit at high potential to generate the gate pulse for turning on the thyristor, With light triggered thyristor (LTT) technology, the gating light pulse is transmitted via a fiberoptic cable through the thyristor housing directly to the thyristor wafer. Therefore, no elaborate electronic circuits and auxiliary power supplies are needed at high potential.

When overstressed, thyristors fail to an approximate short circuit. Provided they remain properly clamped and cooled, short-circuited thyristors can safely conduct normal load current. A valve can be kept in service for long periods in the presence of a small number of short-circuited thyristors due to the redundancy incorporated in the design.

C.3.1.2 IGBT Valves

The IGBT valves can be two or more levels, meaning there are two or multiple IGBT valves in each phase (sometimes called a bridge). Each single valve in the converter bridge is built up with a higher number of series-connected IGBTs together with their auxiliary components, such as a heat sink, gate unit (switching element), capacitor, and cooling pipe. All IGBTs and coolers in a valve stack are mounted tightly together under high pressure in order to minimize contact resistance and to increase cooling capacity. Circular aluminum shields are mounted around the IGBT stacks to smooth the electrical field around the high-voltage equipment. The stacks are suspended on an insulator from the ceiling of the valve enclosure to prevent damage due to earthquake or other movements. For some VSC converter stations, IGBT valves, control equipment, and cooling equipment are in steel aluminum enclosures to help improve the electromagnetic compatibility. These valve containers might be within one valve hall or there could be a separate valve hall for each pole.

IGBTs are currently manufactured mainly as single side cooled encapsulated assemblies, although press-pack assemblies are available. The press-pack assemblies should fail to short-circuit, but the encapsulated assemblies can fail to either short circuit or open circuit. The mode of failure is not fully controlled. The mode of failure can lead to rupture, or even a more explosive effect. To protect against this uncertainty, a component such as a fast-acting switch is usually included in the design.

C.3.2 Auxiliary Equipment for Valve Operation

C.3.2.1 Valve Base Electronics (VBE), Control and Protection

The valve base electronics (VBE) contains equipment necessary for valve firing and monitoring. The room(s) housing these devices may be located between the valve halls at floor or ceiling level, or may be directly below each valve. The control and support area is usually located at the end of the valve hall and contains control and computer equipment needed to operate the HVDC facility and coordinate it with the grid and the DC transmission lines.

C.3.2.2 Converter Valve Cooling System

C.3.2.2.1 Air-Cooling System

An air-cooling system is usually used for older designs of thyristor valves. These air-cooled valves are located in plastic cabinets that are open at the top and bottom. Fans in the basement draw cooled air through openings in the top of the cabinet. Air removes heat from the power modules in the cabinet and exits through openings in the base of the cabinet. The air is then forced through air conditioning systems and back up into the valve hall.

C.3.2.2.2 Water-Cooling System

Almost all modern designs of thyristor valves and IGBT valves use de-ionized water to remove the heat. The water-cooled design is usually an open structure. The water coolant is distributed in parallel to every valve module in the valve via insulating plastic pipes, and the waste heat is moved to outdoor-mounted coolers. Even though the water conductivity in an HVDC valve is normally extremely low, it is never zero. As a consequence, any water pipe spanning two points at different electrical potentials will inevitably carry a small leakage current. Metal electrodes may be used at strategic locations to distribute cooling water electrical potential throughout, avoiding leakage current between the water-cooled components of a valve stack. The water-cooling system is typically a closed system.

C.3.2.3 Insulator Supports

Failure of insulators has been a contributing factor in large fire losses. The necessary insulator length depends on the voltage of the valve. Insulators are typically not made longer than 5 ft (1.5 m), and are attached to each other to obtain the length needed to electrically isolate the valve from the building.

Insulators are typically either porcelain or fiber-reinforced plastic. Porcelain is the most widely used material for valve stack support structures. The method of attachment may be by sulphur compound cement, which can fail at temperatures of 250°F (121°C). Insulators using other compounds, such as Portland cement, can withstand temperatures of over 1000°F (538°C).

C.3.2.4 Converter Transformers

Converter transformers are only used in LCC-based HVDC converter stations. They are the interface between the AC system and the thyristor valves. The converter transformer has a star-star-delta three-winding configuration, or a combination of transformers with two windings in star-star and star-delta connections to provide 30 degree shift for the 12-pulses operation. The converter transformer is subjected to a DC voltage insulation stress as well as the AC voltage stress normally experienced by a power transformer. The distribution of the DC voltage stress is predominantly defined by the resistivity of the insulating materials and thus more DC stress is concentrated in the winding insulation than in the insulating oil. Therefore, converter transformers have more insulation compared to power transformers.

Converter transformers are mounted outdoors, adjacent to the valve hall. They are connected to valves through wall bushings (also called valve-side bushings). The wall bushings are either oil-insulated or dry type. Failure of oil-insulated bushings can result in an explosion and ensuing fire, leading to building and equipment damage, as well as indoor and outdoor oil contamination. Therefore, modern wall bushing designs are insulated with SF6 gas instead of oil to minimize the fire exposure in the valve hall. Since a severe internal fault in a porcelain-housed bushing may cause an explosion resulting in consequential damage to other equipment, composite bushings are used in modern design.

C.3.2.5 DC Smoothing Reactors

DC smoothing reactors are principally used to do the following:

A. Reduce the DC current ripple on the overhead transmission line or cable.

B. Reduce the maximum potential fault current that could flow from the DC transmission circuit into a converter fault.

C. Modify the DC side resonances of the scheme to frequencies that are not multiples of the fundamental AC frequency.

D. Protect the thyristor valve from fast front transients originating on the DC transmission line (for example, a lightning strike).

The DC smoothing reactor is normally a large, air-cored reactor and is principally located at the high-voltage terminal of the HVDC converter for schemes rated at, or below, 500 kV. Above 500 kV, the DC smoothing reactor is commonly split between the high-voltage and neutral terminals. There are few oil-filled reactors in service on HVDC converter stations. Oil-filled reactors were used in mercury arc systems and in some of the early 1970s thyristor-based HVDC systems.

C.3.2.6 AC and DC Harmonic Filters

Converter operations generate harmonic currents and voltages on the AC and DC sides, respectively. AC filters are installed to absorb those harmonic components and to reduce voltage distortion below a required threshold. Tuned filters and high pass filters are used as AC filters. On the DC side, DC filters, along with DC reactors, reduce the harmonics flowing out into the DC line. DC filters are not required in cable transmission or back-to-back schemes. The filters needed to take care of the harmonics generated on the DC end are usually considerably smaller and less expensive than the filters on the AC side. Modern DC filters are active DC filters. In these filters, the passive part is reduced to a minimum and modern power electronics is used to measure, invert, and re-inject the harmonics, thus rendering the filtering very effective.