IEC TR 62757

Edition 1.0 2015-07

TECHNICAL REPORT

Fire prevention measures on converters for high-voltage direct current (HVDC) systems, static var compensators (SVC) and flexible ac transmission systems (FACTS) and their valve halls

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FIRE PREVENTION MEASURES ON CONVERTERS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS, STATIC VAR COMPENSATORS (SVC) AND FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS) AND THEIR VALVE HALLS

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IEC/TR 62757, which is a technical report, has been prepared by subcommittee 22F: Power electronics for electrical transmission and distribution systems, of IEC technical committee 22: Power electronic systems and equipment.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
22F/347/DTR	22F/353A/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

FIRE PREVENTION MEASURES ON CONVERTERS FOR HIGH-VOLTAGE DIRECT CURRENT (HVDC) SYSTEMS, STATIC VAR COMPENSATORS (SVC) AND FLEXIBLE AC TRANSMISSION SYSTEMS (FACTS) AND THEIR VALVE HALLS

1 Scope

IEC TR 62757, which is a technical report, deals with fire prevention measures on converters and their valve halls for high voltage direct current (HVDC) systems, static VAR compensators (SVC) and flexible AC transmission systems (FACTS). It is intended to be primarily for the use of the utilities and consultants who are responsible for issuing technical specifications for new converter valves and valve halls. It concerns fire incidents in HVDC projects using line commutated converters (LCC) or voltage sourced converter (VSC) technology and it is from these projects that most examples of fires and fire incidents are taken. This technical report also addresses converter valves and valve halls for SVC and FACTS.

This technical report provides general recommendations to be considered while preparing specifications for these systems. Specific requirements for a particular project need to be clearly specified and mutually agreed upon between the supplier and the purchaser.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Void.

3 Terms and definitions

For the purpose of this document the following terms and definitions apply.

3.1
alarm system
installation for initiating a fire alarm

3.2
automatic fire detector
device that detects abnormally high temperature, rate of temperature rise, visible or invisible particles, infra-red or visible radiation, or gases produced by a fire

3.3
automatic fire extinguishing system
any system designed and installed to detect a fire and subsequently discharge an extinguishing agent without the necessity of human intervention

3.4
burn, intransitive verb
undergo combustion

[SOURCE: ISO 13943:2008, 4.28]

3.5
burn, transitive verb
cause combustion

[SOURCE: ISO 13943:2008, 4.29]

3.6
ignite, intransitive verb
catch fire with or without the application of an external heat source

[SOURCE: ISO 13943:2008, 4.184]

3.7
ignite, transitive verb
initiate combustion

[SOURCE: ISO 13943:2008, 4.185]

3.8
char, noun
carbonaceous residue resulting from pyrolysis or incomplete combustion

[SOURCE: ISO 13943:2008, 4.38]

3.9
char, verb
form char

[SOURCE: ISO 13943:2008, 4.39]

3.10
combustion
exothermic reaction of a substance with an oxidizing agent

Note 1 to entry: Combustion generally emits fire effluent (4.105) accompanied by flames (4.133) and/or glowing (4.168).

[SOURCE: ISO 13943:2008, 4.46]

3.11
exit
designated point of departure from a building

[SOURCE: ISO 13943:2008, 4.86]

3.12
explosion
abrupt expansion of gas that can result from a rapid oxidation (see 4.245 of ISO 13943:2008), decomposition reaction or other means, with or without an increase in temperature

[SOURCE: ISO 13943:2008, 4.87]

3.13
extinguishing medium¨
extinguishing agent
solid, liquid or gaseous substance especially suited to the extinction of fires

3.14
fire
process of combustion characterized by the emission of heat accompanied by smoke and/or flame

3.15
fire alarm
alarm
alarm signal for alerting the fire service or people endangered by fire

3.16
fire alarm box
call box
pull station
part of a fire alarm system from which a fire call is made, either by hand or automatically

3.17
fire barrier
fire separation
separating element which provides, for a stated period of time, simultaneous integrity and thermal insulation under specified test conditions

[SOURCE: ISO 13943:2008, 4.99]

3.18
fire control system
system which provides integrated control of fire detection, fire alarm, fire suppression, smoke management and other services as part of a total fire protection scheme

3.19
fire damper
smoke damper
mechanical plate or shutter which is closed to restrict the passage of fire/smoke in a flue or duct

3.20
fire department connection
connection through which the fire department can pump supplemental water into the sprinkler system, standpipe, or other system furnishing water for fire extinguishment to supplement existing water supplies

3.21
fire door
door of at least 30 min fire resistance which is prescribed for fire safety reasons and which has to be kept closed in accordance with the authorities instructions

3.22
fire hazard
physical object or condition with a potential for an undesirable consequence from fire

[SOURCE: ISO 13943:2008, 4.112]

3.23
fire load
quantity of heat which can be released by the complete combustion of all the combustible materials in a volume, including the facings of all bounding surfaces

[SOURCE: ISO 13943:2008, 4.114, modified – The notes have been deleted.]

3.24
fire suppression system
any system provided for the extinguishing of a fire

3.25
fire wall
partition wall of specified fire resistance rating

3.26
fire-fighting
all measures involved in the combat against fire

3.27
flame, noun
rapid, self-sustaining, sub-sonic propagation of combustion in a gaseous medium, usually with emission of light

[SOURCE: ISO 13943:2008, 4.133]

3.28
flame, verb
produce flame

[SOURCE: ISO 13943:2008, 4.134]

3.29
flammable
capable of flaming combustion (see 4.148 of ISO 13943:2008) under specified conditions

[SOURCE: ISO 13943:2008, 4.153]

3.30
foam
emulsive extinguishing agent, consisting of water, bubbles of gas or air, and a foam stabilizer (foam compound which is used to extinguish burning liquids)

3.31
heat release rate
burning rate (deprecated)
rate of burning (deprecated)
rate of thermal energy production generated by combustion

Note 1 to entry: The typical units are watts (W).

[SOURCE: ISO 13943:2008, 4.177]

3.32
ignite, intransitive verb
catch fire with or without the application of an external heat source

[SOURCE: ISO 13943:2008, 4.184]

3.33
ignite, transitive verb
initiate combustion, light

[SOURCE: ISO 13943:2008, 4.185]

3.34
ignition
sustained ignition (deprecated)
general: initiation of combustion

[SOURCE: ISO 13943:2008, 4.187]

3.35
ignitability, ease of ignition
measure of the ease with which a test specimen can be ignited, under specified conditions; ignition time, conditions; ignition time

[SOURCE: ISO 13943:2008, 4.182]

3.36
ignition source
source of energy that initiates combustion

[SOURCE: ISO 13943:2008, 4.189]

3.37
incipient fire
initial fire

3.38
means of egress
continuous and unobstructed way of exit travel from any point in a building or structure to a public way and consists of three separate and distinct parts: a) the exit access, b) the exit and c) the exit discharge

Note 1 to entry: A means of egress comprises the vertical and horizontal travel and should include intervening room spaces, doorways, hallways, corridors, passageways, balconies, ramps, stairs, enclosures, lobbies, escalators, horizontal exits, courts, and yards.

3.39
non-combustible
not capable of undergoing combustion (under specified conditions)

Note 1 to entry: In some regulations a material is classified as being non-combustible even if it is capable of combustion, provided that its heat of combustion (4.174) is less than defined amount.

[SOURCE: ISO 13943:2008, 4.239]

3.40
non-flammable
not capable of burning with a flame (3.27 and 3.28) under specified conditions

[SOURCE: ISO 13943:2008, 4.240]

3.41
overheating
excessive rise in temperature of a material or body

3.42
quick response sprinkler
type of sprinkler that is both a fast response and a spray sprinkler

3.43
flame spread
propagation of a flame front

[SOURCE: ISO 13943:2008, 4.142]

3.44
self-extinguish, verb
auto-extinguish, verb
cease combustion without being affected by any external agent

[SOURCE: ISO 13943:2008, 4.284]

3.45
self-extinguishing
the characteristic of a material ceasing to burn, under specified test conditions, after the igniting source has been removed

Note 1 to entry: Although in common usage (including this report), this term is deprecated in international standards because it may convey a false sense of security and lead to misunderstanding. The properties of materials after removal of an ignition source are better described by the afterflame time, the afterglow time, the extent of combustion and the damaged area (length) under specified test conditions (compiled from various sources).

3.46
semiconductor device
one of the series connected devices used in valves such as thyristors, diodes or insulated gate bipolar transistors (IGBTs)

3.47
smoke
visible part of fire effluent

[SOURCE: ISO 13943:2008, 4.293]

3.48
smoke detector
fire detector which initiates an alarm on the presence of a certain quantity of smoke

3.49
smoke development rating
smoke development rating means an index or classification indicating the smoke development characteristics of a material or an assembly of a material as determined in a standard fire test

3.50
smoke management system
any system designed and installed to control the accumulation and spread of smoke in a building

3.51
water spray deluge system
special fixed pipe system connected to a reliable source of fire protection water supply and equipped with water spray nozzles for specific water discharge and distribution over the surface or area to be protected

Note 1 to entry: The piping system is connected to the water supply through an automatically or manually actuated valve that initiates the flow of water. An automatic valve is actuated by operation of automatic detection equipment installed in the same areas as the water spray nozzles. (in special cases the automatic detection equipment may also be located in another area).

4 Fire hazards in valves and valve halls

4.1 General

Converter valve halls house the converter valves, wall bushings or converter transformer bushings, valve and group arresters as well as, in certain designs, other high voltage components such as high voltage capacitors or voltage dividers.

The valve equipment is subjected to various mechanical and electrical stresses during operation. They are designed and constructed from many series and parallel connected components such as thyristors, diodes, IGBTs (and similar packages), capacitors, resistors and saturable reactors.

To minimize the space requirement in the valve hall, the 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 insulators and/or composite insulators. Extensive use of composite materials is made in the structural components of the valves.

Several years ago, following the spate of fires that culminated in the generation of CIGRÉ Technical Brochure 136, several purchasers demanded that no oil-filled components be in the valve hall and that valve components be generally fire retardant. Today also, the valve structure comprises various materials such as plastics, composites, and rubbers, the non-metallic materials being fire retardant, self-extinguishing, generally to UL94V-0 or equivalent.

There is essentially minimal combustible material in the converter valve equipment, however, materials will burn if there is sufficient heat input from the ignition source. The possible sources of fire in a valve hall are discussed in detail in the following clauses, and cover HVDC and FACTS equipment (thyristor valves, SVCs, STATCOMs, VSC, etc.).

4.2 Possible causes

4.2.1 Valve insulation failure

Breakdown of electrical insulation within or between parts of the valve which are common to more than one semiconductor device level can lead to arcing which could ignite flammable materials.

Insulation failure could be internal, for example due to partial discharges in a dielectric material, or external due to corona or contamination of insulating surfaces (e.g. as a result of a coolant leak). Smoke or other ionised by-products arising from, for example, an overheated electrical component can reduce the withstand voltage of the air insulation within the valve.

The consequences of insulation failure will strongly depend on the location, materials and energy associated with the event. It should be noted that it is not necessary for total breakdown of an insulation system to occur before hazardous conditions can arise. High surface leakage currents, for example on a contaminated insulating surface can, depending on the materials, present a direct risk of combustion.

4.2.2 Loose connections or high resistance joints in the power circuit

An overheated connection or series arc can arise from improper connection of bus bars used for carrying the load current. These could be connections between different sections of the valve, with the series reactor, with the semiconductor device or any other connector which forms the path of the load current. Any loose connection or high resistance joint will overheat. In the case of an open circuited connection, a series arc will develop. In either case the heat generated will depend on the level of the current and may cause damage to adjacent components, especially insulating material. If the temperatures reached are high enough then it may lead to a fire.

4.2.3 Valve component failures

4.2.3.1 General

Breakdown of electrical insulation within or between parts of the valve which are common to more than one thyristor level can lead to arcing which could cause charring of components or ignition in certain circumstances if the source is sufficiently intense.

4.2.3.2 Thyristors and diodes

When overstressed, thyristors and diodes fail to an approximate short circuit. Provided that they remain properly clamped and cooled, short circuited thyristors can safely conduct normal load current and overcurrents. By providing series redundant levels, a valve can be kept in service for long periods in the presence of a small number of short circuited thyristors.

4.2.3.3 IGBT and similar semiconductor devices

These devices are, at the time of writing, 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 in parallel with the semiconductor device needs to be included.

The thyristors and diodes themselves are non-flammable and, because failure relieves other components from significant voltage stress, it is often arranged that other component faults lead directly or indirectly to thyristor short circuit, thereby avoiding a hazardous condition elsewhere.

4.2.3.4 Capacitors

To obtain long life and high reliability at the operating voltage of one semiconductor device level, capacitors which experience this voltage should employ an impregnated dielectric construction.

Non-flammable impregnating fluids based on polychlorinated bi-phenyls (PCB) exist, but are prohibited on environmental grounds.

Today, many capacitors contain (usually small) quantities of an impregnating medium in the form of a resin which, if exposed to air and an ignition source can burn. Capacitors may also be impregnated with special dielectric fluids, all of which are flammable material. Virtually all high voltage capacitors today use polypropylene as the dielectric which also may burn if exposed to air and ignition. The failure modes of these capacitors are therefore of particular interest.

In all cases, rupture of the capacitor can is an essential pre-requisite for exposing the dielectric material and impregnating medium to air. This could arise from mechanical damage caused by abuse or resulting from a production defect, or from an electrical fault inside the capacitor. Internal faults for example short circuit of one or more capacitor elements, sparking at a broken internal connection, etc. can cause decomposition of the dielectric material and/or of the impregnating medium, leading to a build-up of pressure inside the capacitor. Unless the process can be arrested (e.g. the capacitor is rendered open circuit by operation of an over-pressure protection device) or the pressure is relieved in a controlled and safe manner, then the over-pressure may lead to rupture of the can. Electrical arcing/overheating of the now disrupted capacitor provides a likely source of ignition. Recent experiences demonstrate that the risk for fire of contained polypropylene capacitors is low.

Capacitors that are dry type, normally contain polyurethane or silicone gel, as filling material does not burn itself even though it is exposed to air.

4.2.3.5 Reactors

The reactors within a valve equipment may be liquid cooled. A mode of failure of valve reactors is overheating due to total or partial blockage of the cooling pipes within the reactors. If such a condition goes undetected, failure of the reactor is possible and this may cause a fire within the valve equipment.

Other modes of failure could be turn-to-turn or turn-to-core insulation failure or for example failure of the banding straps used to secure the reactor cores.

The consequences of such failures will depend on the particular valve design.

4.2.3.6 Resistors

The resistors used in damping circuits are generally wire wound, although thick-film devices are frequently used. The failure of resistors could be due to overheating of the element caused by inadequate cooling or corrosion of resistor elements which are in direct contact with the coolant. If the resistors are indirectly cooled, i.e. heatsink mounted, the breakdown of the resistor to the heatsink could result in localised arcing. This may result in open circuit, insulation or housing failure. If the insulation provided is flammable, then it may ignite.

Another scenario would be that the arcing inside the resistor persists and the resistor may fail explosively, damaging other adjacent components. This can lead to arcing and flashover.

4.2.3.7 Electronic circuits

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. Two situations could be:

a) The semiconductor device firing electronics provides gate trigger pulses to more than one series-connected semiconductor device via insulated output pulse transformers. Failure of the insulation of a pulse transformer could result in load current flowing in low current wiring.
b) The electronic circuits require a source of power which, for HVDC valves, is normally extracted from one of the voltage grading networks at the respective semiconductor device level. The power supply must provide sufficient energy to meet performance requirements under the worst operating conditions, therefore, under other conditions, more energy than is needed is available. The technique adopted to control this surplus energy could influence the consequences of a component failure in this part of the circuit.

4.2.3.8 Light guides

Light guides, either individually or in bundles involve a risk of fire ignition, if exposed to conductive surface contamination. Certain types of light guide jacket material may sustain combustion and transfer fire within the valve structure.

4.2.4 Semiconductor device level connections

When the semiconductor devices are electrically connected to damping circuits, grading resistors and/or other circuitry, this requires auxiliary wiring of low current carrying capacity.

The semiconductor device control and protection circuitry, including network grading and detection components, involves a large number of low current connections. If a connection inadvertently becomes open-circuited, arcing can result which could ignite flammable material.

4.2.5 Coolant system problems

4.2.5.1 Water based systems

In liquid cooled valves the heat is removed from the semiconductor device, resistors and reactors by deionized water or a mixture of deionized water and glycol. The flow, temperature and conductivity of the coolant delivered to the valve are continously monitored externally to the valve. Internally to the valve, the cooling water and plastic pipes are required to withstand voltage stresses.

The failure modes of components of the valve cooling circuit are corrosion, leakage and clogging. Failures can be caused by electrical, chemical or mechanical phenomena either acting alone or in combination.

Unless the materials in contact with the coolant are carefully selected and applied, electro-chemical processes within the cooling circuit may cause corrosion of metallic couplings and other components of the coolant system. In the presence of leakage currents there is the possibility of erosion and deposition of material in some parts of cooling water circuit. This process, if continued for a period of time, can result in leaking or clogging at some critical parts of the water circuit.

The presence of foreign material inside the cooling circuit can also cause clogging if proper care is not taken.

When series connection of cooling water pipes is used, all components in the series path (perhaps from more than one semiconductor device level) can be damaged due to over-heating as a consequence of restriction of cooling water flow.

If cooling water flow is blocked to the valve reactor, overheating may damage the reactor insulation leading to an internal fault or to releasing debris on to other electrically live parts causing smoke or ionized air which may develop into a partial flashover. If the temperature of the reactor is increased further, ignition of the reactor insulation materials may occur.

Cooling water leaks can occur at any of the joints due to the failure of gaskets or O-rings used in the joints. The cracking of plastic pipes caused by premature aging could also lead to leakage. In addition, mechanical vibrations, for example, from reactors may cause loosening of joints or cracking of pipes which could lead to a leak.

If the insulating surfaces of the valve are polluted, the leakage of water can give rise to tracking and eventually flashover.

4.2.5.2 Contamination and condensation

The equipment inside the valve hall is subjected to high voltage which contains a large d.c. component. This creates an electric field which has a tendency to attract airborne particles which are naturally present in the valve hall air. As a result, the equipment surfaces may become covered with deposits of foreign material. Build-up 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 depends 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 which may eventually be deposited on the various surfaces of the valve.

Condensation inside the valve hall is possible on any cooled surfaces 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.

For example, contaminants collected by electrostatic effects in the presence of moisture or even high humidity may form conducting electrolytes on the surfaces. In the presence of electrical stress, small leakage currents may form and create tracking paths. In time, these currents can increase and may damage the insulation, ionize the surrounding air and could precipitate a high current flashover.

Electrostatically attracted contaminants in high potential gaps may create corona which could also cause flashover.

Flashover arising from any of the above phenomena may create a fire as a function of the materials involved in or adjacent to the event.

4.2.6 Failure of valve hall bushings

Failure of bushings could be due to external flashover or internal discharges. An external flashover may puncture the porcelain and expose the flammable materials (paper/oil). For the case where transformer bushings or oil insulated smoothing reactor bushings project into the valve hall the possibility exists for some quantity of oil to enter the valve hall. Due to purchaser requirements today, and for many years now, in HVDC plants there are no oil insulated or oil-filled equipment in the valve hall, the possibility should not exist for any quantity of oil to enter the valve hall.

A severe internal fault in a porcelain bushing may cause an explosion, resulting in the complete destruction of the bushing and consequential damage to other equipment. Composite bushings may rupture but not cause debris being thrown apart.

4.2.7 Failure of surge arresters

Because of the absence of flammable material inside arresters their failure should not directly lead to a fire, however, ionized plasma from the arc chutes due to operation of the surge arrester, has the possibility to initiate a flashover (although good design should minimize this), but the complete failure and destruction of the surge arrester could initiate a flashover or cause consequential damage leading to a flashover.

4.2.8 False operation of deluge system

Though not common, if a deluge system is used in the valve hall then, in the event of operation, the whole protected area will be flooded with water. False operation of the water deluge system could result in a flashover in the valve hall. Even if water of high resistive quality is used the surfaces already contaminated with pollutants can experience a flashover.

4.2.9 Other valve hall equipment

Other valve hall equipment such as voltage dividers, current transformers or other equipment may cause fire due to flashover or consequential damage if they fail. Current HVDC practice is to only use oil free equipment inside the valve hall.

4.2.10 Work in and around valve hall

Due to the large number of electrical and mechanical connections in a valve there is potential for human error during either commissioning or maintenance. If connections are left loose or foreign objects left behind it could lead to a fault that may cause a fire.

4.3 Assessment of possible consequences

For a fire to start, three components are involved: heat (i.e. a source of ignition), a supply of oxygen and a quantity of combustible material.

In the simplest analysis, the severity of a worst case fire can be assessed from the "fire load".

The concept of fire load is, however, a conservative way of assessing the worst conceivable fire since it presumes total consumption of all combustible materials within a defined area. No account is taken of the availability of the various materials for combustion, their ignitability or the rate at which they may burn. Fire retarding or self-extinguishing characteristics, if provided, are ignored. As a result, the concept of fire load is of limited usefulness in determining the likely consequences of a real fire.

Although a valve hall contains an identifiable quantity of combustible material, the assessment of the consequences arising from any of the possible causes of fire identified in 4.2 and the comparison of one design with another, cannot be dependably made on the basis of the fire load that this quantity of material represents. For example, the introduction of barriers of fire retardant material in valves will actually increase the valve hall fire load, while it should decrease the risk for a fire to propagate. The assessment of possible consequences must therefore consider the totality of measures taken to limit the effects of any fire incident.

It is not foreseen that valve hall equipment will ever be constructed entirely from non-combustible materials. Therefore, since combustible materials will be employed, it should be determined what the likely consequences of any of the possible causes, given in 4.2, might be. Consideration should be given to:

a) The probability of the initiating event occuring;
b) The quantity of combustible material directly involved in any initiating incident;
c) The flammability characteristics of the materials involved;
d) The method of detecting the presence of a fire and the action taken thereon;
e) The protection measures incorporated in the design to contain and/or limit the spread of any resulting fire to adjacent materials or equipment;
f) The risk of the protection measures failing;
g) The possible impact of elevated temperature arising from any fire incident on the mechanical integrity of the valve hall equipment or the valve hall building;
h) The likely degree and impact of cross-contamination of other equipment by combustion products;
i) The likely need for and consequences arising from the use of a fire extinguishing agent to put out a fire.

5 Valve hall layout and access

5.1 Physical arrangements

5.1.1 General

The physical arrangement of valve halls and service facilities is based on a number of factors (e.g. valve type, building costs, seismic conditions, etc.) which may not relate to fire protection and safety. If a facility layout was reviewed only from the fire protection perspective, the valve hall would be physically separated from other service facilities such as: control rooms, auxiliary power rooms, converter transformers, oil-filled smoothing reactors and maintenance areas. While the physical separation of valve halls and service facilities may be desirable from the fire protection perspective, it may create operational and economic concerns that override the fire protection considerations. If the valve hall and service facilities must be constructed within a single facility, fire compartments able to confine a fire to its area of origin, should be considered.

Walls in fire compartments only resist the spread of fire for their specified rating if their constructional integrity is not compromised by unprotected openings, such as doors, ducts, grilles, viewing windows and cable penetrations. Care must be taken in sealing these openings to ensure the integrity of the fire walls. Protection of these openings can be in the form of fire doors, fire and smoke dampers, fire-rated window assemblies and fire stopped cable penetrations.

5.1.2 Present practices

In the majority of facilities, the valve halls and service spaces are located in a single facility for logistic and operational reasons. One other practice is to have the valve hall located in a separate building from the service spaces. When the valve halls and service spaces are in the same building, the usual practice is to use fire walls to separate the valve halls from the main building. The fire separation needs to be taken into consideration when designing the valve hall installations and what measures are to be taken to mitigate the chance of fire spreading.

5.1.3 Specific provisions

5.1.3.1 Facilities in physically separate buildings

In terms of physical separation, there are four major areas of an HVDC substation that should be considered: the valve halls, service and maintenance areas, control/relay and auxiliary power rooms, and adjacent oil-filled equipment areas.

The installation of oil-filled electrical apparatus, such as converter transformers, can also be looked at from the physical separation perspective. The basic guidelines of NFPA 850 and IEEE 979 include a number of criteria for the spacing of oil-filled equipment away from adjacent buildings.

5.1.3.2 Facilities separated by fire walls or fire barriers

When equipment is housed in a common building, the valve halls, service and maintenance areas, control/relay room and auxiliary power facilities should be separated from each other by fire walls of a suitable rating (e.g. 2 h). Apertures in fire walls should have the same rating as the wall.

Where oil-filled electrical apparatus must be installed closer to the main building than the physical separation distances noted in NFPA 850 and IEEE 979 fire separation measures will need to be considered.

5.2 HVDC valve hall construction

5.2.1 General

The basic valve hall structure shields the equipment from the weather, and provides a controlled environment for the operation of the valves consisting of semiconductor devices. The valve hall also reduces the radio-frequency radiation from the valves. The normal components of valve hall construction would be the floor, walls, roof and interior finishes. From the fire perspective, the valve hall enclosure will contain the heat and toxic corrosive smoke which will subsequently affect the equipment.

In order to avoid the normal fire related problems in a building, the following concepts should be considered:

a) The use of non-combustible construction and finish wherever possible. Where it is not possible, control measures should be incorporated;
b) The use of fire resistant construction materials for the valve hall to increase endurance against fire exposure and possible subsequent collapse. Not only should non-combustible material be looked at, but also the fire resistance characteristics of the materials of construction are important;

c) The incorporation of design measures in the construction of the building to lessen other fire and operational problems such as roof leaks, oil spill containment and water drainage.

5.2.2 Valve hall construction

5.2.2.1 General

The following is a review of hazards, practices and recommendations for the construction of roofs, walls, floors and finishes in a valve hall.

5.2.2.2 Floors

The floors of a valve hall should be of non-combustible construction and provide a clean, stable surface on which to carry out maintenance on the valve and valve hall equipment.

5.2.2.3 Walls

The walls of valve hall not only function as an enclosure, but also generally support the roof and, in some cases, the actual valve structure.

Walls should be non-combustible, fire resistant, and form a fire separation from other areas of the building. The rating of the walls depends on the configuration and material used in the structure, and the fire load of the valve and other equipment within the valve hall. Where steel construction is used for the wall or roof support members, special care should be taken to ensure that these exposed surfaces are protected for example approved spray-on cementitious coatings, intumescent paint, fire-rated enclosures.

5.2.2.4 Roofs

The construction of valve hall roof components is a fire concern, since the roof structure may be exposed to hot gases and flame during a fire. This exposure could lead to the collapse of the roof structure and subsequent major damage to the valve structure. The use of exposed steel and combustible materials for a roof should be avoided.

The construction of the roof is particularly critical in those applications where the roof structure is actually the supporting assembly for the valve. The type of roof construction should be based on an analysis of the arrangement and configuration of the valve, and the construction and flammability of the valve structure and its components. The effect of fire protection measures and smoke management system to be incorporated in the valve hall should also be considered.

5.2.2.5 Finishes

Materials with low flame spread and smoke development ratings should be used for valve hall interior finishes.

5.3 Means of egress

The only expected time in which most valve halls will be occupied would be during maintenance and, for some designs, short operational inspections. Means of egress from the valve hall should be in accordance with local regulations and operational requirements.

6 Supervision of valve components and other valve hall equipment

6.1 General

The monitoring or the supervision of the valve hall equipment is intended to detect failures, some of which may lead to major damage. Two types of monitoring are available:

a) On-line monitoring;

b) Off-line checks and inspection.

6.2 Supervision of valve components

6.2.1 General

In order to establish an appropriate monitoring practice for the valve components, a definition of valve components must be established. The valve components typically include the following parts (depending on the converter technology):

a) Thyristors, IGBTs, free-wheeling diodes or other semiconductors;

b) Gate electronics or monitoring electronics;

c) Damping circuits (capacitors and resistors) (if applicable);

d) Voltage source capacitance or level capacitance (if applicable);

e) DC grading resistors (if applicable);

f) (Saturable) reactors (if applicable);

g) Grading capacitors (if applicable);

h) Light guides between the valve and the valve base electronics;

i) Coolant pipes within the valve;

j) Support insulators between tiers;

k) IGBT level short-circuiting devices (if applicable);

l) Load current carrying connections;

m) Any electrical connections between the level components.

It is evident from this list that there are a large number of different component types within the valve structure and, when it is taken into account that there may be in excess of 1000 examples of most of the above listed items in a single valve hall, it will be difficult to devise a common monitoring system for all these components.

6.2.2 On-line monitoring

Generally, semiconductors like thyristors or IGBTs are directly monitored and locations and numbers of defective elements are reported. Alarm and trip signals are usually generated if the number of redundant levels in a valve is reduced respectively exhausted. While defective thyristors fail short circuit and safely protect the affected level against damage, defective IGBTs may fail open circuit. To avoid the risk of arcing, which might cause ignition, such levels should be shorted by other means. The proper functioning of these means should also be monitored and reported.

Other valve components, like resistors, capacitors or (saturable) reactors, are usually not directly monitored. Failure of such components may create a higher risk of ignition than failure of semiconductors, especially when the failure of those components does not directly lead to a short-circuit failure of the semiconductor.

Interconnections within a valve level (wiring) as well as busbar connections inside the valve are difficult to monitor electrically during operation. Periodic infrared heat scans or observation of the valves using a video camera system may be a good means, however, both techniques require a direct line-of-sight to the joints to be monitored and therefore provide only restricted applicability. A video system could be used for permanent monitoring if automatic image evaluation is available.

Air sampling systems could also be effective in detecting over-heated joints or components.

When a water-cooling system is used it is usually monitored for leakages within and/or outside the valve structure. There are different methods depending on the design that are utilized to monitor water leakage within the valve structure. In the majority of cases an alarm or a trip is generated. Even small cooling water leaks must be detected as soon as possible as water leakage is a major risk for ignition when spread on insulating surfaces.

It is important that any type of on-line monitoring should not complicate the design or reduce converter reliability.

6.2.3 Off-line checks and inspection

The philosophy for off-line checking will depend on the manufacturer's maintenance recommendations and the user's maintenance practices, such as the interval between maintenance outages and the duration of the outage. The following activities are typical examples of off-line work for semiconductor valves:

a) Replacing any defective components such as semiconductor devices, electronics boards or complete valve sub-modules;
b) Checking for coolant circuit connection tightness and any minor coolant leaks;
c) Cleaning of insulators or insulating parts and possibly large coolant pipes;
d) Checking for tightness (torques) of the bus bar connections as well as for discoloration;
e) Checking for integrity of the wiring between components at individual valve levels;
f) Visual inspection of coolant pipes and cooling water connections for any deterioration;
g) Testing of components in individual valve levels using special test sets if recommended;
h) Pressure testing of the water valve cooling circuit if recommended.

6.3 Supervision of other valve hall equipment

The other equipment within the valve hall will, depending on the design, include wall bushings or transformer bushings, arresters, valve capacitors and voltage dividers and earthing switches.

In modern HVDC valve hall designs, bushings and voltage dividers are oil-free and pressurized gas filling is used to provide the necessary electrical insulation. Arresters contain non-combustible metal-oxide ceramic blocks mostly enclosed in composite housings.

Bushings or voltage dividers filled with pressurized gas are usually equipped with pressure gauges. These devices may include electrical contacts which allow online monitoring for low gas pressure. Warnings and trip signals can be derived by evaluating different pressure levels. During maintenance bushings and dividers are checked for correct gas pressure.

In recent years foam and gas insulated bushings are increasingly used where the gas/air is kept under atmospheric pressure. No monitoring is applied for these kinds of bushings.

The load current carrying connections to the bushing may be monitored by infrared scanning on load.

In the case of arresters, on-line monitoring is either through surge counters or through the monitoring of the arrester current or energy. This information can be transmitted to earth potential via light guides. Off-line monitoring is either by recording counter readings or periodic off-line testing. It should be noted that arrester failures, in the majority of situations, will not lead to a valve hall fire.

No monitoring is performed for valve hall grounding switches, however, they do not impose any fire risk.

7 Fire detection systems

7.1 General

Since the consequences of a major fire in a valve hall can be significant, suppression of incipient fire is critical. For this purpose, fire detection at a very early stage is important to alert the operating personnel and to take appropriate actions to limit the consequences. Since the most important action is de-energization of the equipment to stop the electrical energy infeed, the fire detection scheme must be capable of accurate and reliable detection of the fire to allow for prompt intervention and to avoid false alarms.

A practical approach for existing HVDC systems is to combine the most up-to-date proven technology in the fire detection and security surveillance industries to reliably detect a fire at the earliest possible stage. There are several highly sensitive fire detection methods that are suitable.

7.2 Detection and operating principles

7.2.1 General

Generally, the method of detection makes use of one or more of the following principles:

– smoke: detect smoke, gases, and particulates before fire spreads;
– heat: detect overheating before ignition;
– light: detect light spectrum associated with arcs, sparks, corona and flames;
– visual: detect actual fire via surveillance camera/video system inside the valve hall or via viewing windows.

Fire detection/alarm systems that should be considered for detecting valve hall fires are described below; these are:

- Air sampling systems;
- Infra-red beam smoke detectors;
- Arc detector systems;
- Infra-red flame detectors;
- Ultra violet flame detectors;
- Imaging video camera systems.

It is recognized that all above may not be feasible due to large area to be covered and location to be selected, especially in UHVDC application involving very large valve structures and valve halls. It must be noted that location should not compromise the required electrical clearance. For UHVDC, some of above may be impractical.

7.2.2 Air sampling systems

There are several such systems on the market. These systems draw air samples through sampling heads continuously to detect sub-micron particles generated during the incipient stage of a fire. To detect the presence of such particles, these systems use either the cloud chamber method or the light scattering method.

7.2.3 Infra-red beam smoke detectors

These are optical devices which utilize infra-red beams projected between a transmitter and a receiver. The power output of the transmitter units are adjustable depending on the beam range. The detection of the smoke is based on the principle of beam obscuration caused by heat or smoke. An alarm is given if the light beam detection level falls below a preset level.

7.2.4 Arc detector systems

Commercially available flame detectors, whose operating principle depends on the detection of infra-red or ultra violet light, are widely in use as arc detectors.

7.2.5 Infra-red flame detectors

These detectors work by monitoring the varying infrared energy emitted by flames and gases from a fire. The detector reacts rapidly to all flaming fires in which carbonaceous materials are burned. The unit can be equipped as single wavelength operation or multiple operating based on slightly different wavelengths and the signals from the detectors are correlated to enable a clear differentiation between flame radiation and other sources of radiation.

7.2.6 Ultraviolet (UV) flame detectors

UV flame detectors are capable of detecting flaming fires emitting light in the ultraviolet spectrum and arcs. Typically, UV flame detectors can respond to a flame or arc in less than 10 ms and are used, but to reduce false alarm frequency a time delay of 2 s to 3 s is often applied.

7.2.7 Imaging video camera systems

Standard high resolution cameras can be installed at different places on the valve hall walls to provide coverage of the protected areas.

7.3 Guidelines for valve hall fire detection

The air sampling systems are the most effective systems for smoke and incipient fire detection available today. Test and operating experience show that the air sampling systems can provide accurate and reliable detection of incipient fires. Typical response times of a few minutes appear to be adequate for most situations. However, it should be noted that a major arcing fault may produce a large amount of energy in a very short time. Power arcs associated with major insulation failure are usually detected very rapidly with conventional electronic protection. However, series arcs may not be detected and therefore these can be sustained until a more substantial fault develops. An arc detection system that can detect such an event quickly, for example an ultraviolet detector, may be used.

8 Fire suppression systems

8.1 General

Due to past experiences with fires in HVDC valve halls CIGRÉ Technical Brochure 136 was produced. From this experience the HVDC industry took efforts to mitigate the risks of fires in the valve hall. This was achieved by two measures, removing combustible materials from the valve hall, and introducing self extinguishing materials into the valve design itself. This combined with the introduction of sensitive fire detection systems that allows an incipient fire to be detected and the energy source to be effectively removed before damage can become extensive has allowed recent valve hall designs to greatly reduce the need for a fire suppression system.

Fire suppression arrangement and complexity depends on a number of factors such as:

– valve and valve hall construction;
– valve hall layout;
– proximity of oil-filled converter transformers and smoothing reactors;
– proximity of adjacent converters in a bipole;
– requirements of local fire codes;
– advice from and proximity to fire brigade;

– insurance company requirements;
– consequences of lost capacity;
– manned or unmanned converter HVDC substation.

The review of the above factors will lead to one of the following two options:

a) There is a low risk of a valve hall fire and any fires that do occur will self-extinguish or be safely contained without the need for any intervention, if the energy source is removed.
b) There is a major risk of fire incident that may not self-extinguish or be contained after the equipment is de-energized and/or could develop rapidly within the time scale needed to obtain safe personnel access for the purpose of attacking the fire.

In alternative a), no valve hall fire suppression system is recommended.

In alternative b) a fully integrated, permanently installed valve hall fire suppression system is recommended.

The design goal should always be fire prevention according to alternative a). In cases of uncertainty about which alternative the installation complies with, it is recommended to protect the valve hall by measures described in alternative b).

8.2 Design considerations for an installed fire suppression system

When considered feasible, installed fire suppression systems should be designed to completely engulf the volume of the area or zone to be extinguished and protected. It should have sufficient projection to reach or surround all parts. It is not recommended to use fire suppression systems leaving deposits on the valve hall equipment due to consequential damage.

The fire extinguishing agent should be non-toxic to personnel during and after a fire.

If oxygen level is reduced to a dangerous level proper warnings and protective equipment should be furnished.

Design of fire suppression system, installation, testing, training, maintenance, refilling and resetting work after triggered system affect the operation of the facility and should be considered.

The fire suppression system should not require extensive installation that complicates the station design or adversely affects the operation of the electrical equipment.

Manually initiated operation with electrical and mechanical interlocking, is desirable to reduce false operation.

The fire extinguishing agent should have a long shelf life and equipment should be provided to monitor its condition periodically.

Environmental considerations should be taken into consideration when choosing extinguishing agents.

The operation of the fire suppression system should be clearly marked as to operational sequences, the zone(s) to be activated, indications that the proper safety procedures have been followed and that detection has been verified and equipment de-energized. Early detection of fire on self-extinguishing materials followed by de-energization very likely makes it unnecessary to activate additional suppression. The procedure should allow an appropriate delay after de-energization to determine whether the fire self-extinguishes.

8.3 Types of fire extinguishing agents

8.3.1 List of agents

Table 1 gives examples of fire extinguishing agents.

Table 1 – Fire extinguishing agents

Type	Agent	Suitable for use in confined spaces
Inert Gases	IG-01	Y
	IG-100	Y
	IG-541	Y
	IG-55	Y
Carbon Dioxide	CO_2	N
Hydro fluorocarbons	HFC-125	Y
	HFC-23	Y
	HF-227ea	Y
	HFC-236fa	Y
	HFC Blend B	Y
Perfluoroketone	FK-5-1-12	Y
Iodofluorocarbon	FIC-13I1	N
	FIC-217I1	N
Hydro chlorofluorocarbons	HCFC-124	N
	HCFC Blend A	Y
C6-fluoroketone	$C_6F_{12}O$	Y

8.3.2 Carbon dioxide

Carbon dioxide (CO_2) is a gas, commonly compressed to the liquid state for storage. When released, it affects fires by crystallizing water in the air and displaces oxygen. Carbon dioxide can cause thermal shock and large pressure changes in an enclosed volume, which can potentially damage the building structure. Pressure dampers usually are needed. CO_2 is hazardous to life as suffocation is a possibility. Precautions should be taken to avoid accidental operation of the system during maintenance.

8.3.3 Inert gases

Inert gases are a blend of inert atmospheric gases which affects fires by lowering the concentration of oxygen to a point that cannot support combustion, but still safe for humans. Inert gases are stored in high pressure vessels and, similarly to carbon dioxide, can cause large pressure changes in an enclosed volume. Pressure dampers are usually needed. Inert gases systems are relatively expensive and require large quantities sufficient to maintain a 35 % to 50 % concentration in the valve hall volume.

8.3.4 Hydro fluorocarbons

Hydro fluorocarbons affects fire by chemically disrupting combustion. One well known Hydro fluorocarbon is the liquefied gas HF-227ea, commonly called FM200®[1]. FM200® is popular because it is effective without leaving residue. Due to high pressure storage it can cause

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1 FM200® is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product

large pressure changes in an enclosed volume. Pressure dampers usually are needed. Quantities sufficient to maintain a 6,25 % to 9 % concentration in the valve hall volume is needed.

8.3.5 Other gases

Another gas that should be mentioned is the C6-fluoroketone named Novec™ 1230[2]. Compared to other gases it is stored at lower pressure and therefore needs no pressure dampers.

8.4 Installation requirements

The electrical environment in a valve hall must be considered. The electrical clearances are usually large and should not be diminished. Fire extinguishing systems must be able to project the extinguishing agents across these clearances.

Electrical interlocks and manual initiation of operation after verification of a fire by redundant means should be considered. Remote manual activation is desired to provide adequate separation between the operator and possible heat and smoke of the fire.

The fire suppression installation should be arranged to be compatible with the fire detection system.

Redundant electrical supply systems should be considered such as redundant electrical service or self-contained diesel pumps and generators. Specific safety consideration should be given to the possible need to de-energize certain areas and equipment during fires (see Clause 11).

On-site storage of chemicals, water supply and fire pump fuels is desirable.

Re-supply of materials required for extinguishing a fire in a valve hall should be made via standard type fittings located at a safe distance from the valve hall.

On-site drainage, storage and containment equipment should be considered to collect fire residue and to protect the environment from contamination. Where possible, oil-water separators should be furnished to contain these materials.

Electrical and mechanical interlocks and signalling devices should be provided to avoid inadvertent operation inside energized valve halls or misoperation inside the wrong zone if zonal operation is provided. Measures should also be taken to prevent unintended discharge of extinguishing systems into the valve hall while maintenance is taking place, because of the risk of asphyxiation of the maintenance personnel.

Since it is not practical to test fire suppression system installations in an actual valve hall, it is desirable to provide means to test the system periodically without operation. Auxiliary control valves and piping for limited testing or temporary connections should be restored to the proper arrangement and carefully checked after testing. Monitoring or mimic panels or both may be furnished to assure a proper arrangement.

8.5 Guidelines for fire extinguishing agents

Water or powder based fire suppression systems should not be used as fixed installations in valve halls because of the harm the extinguishing medium will cause to the electrical components. For the same reason it should be avoided, if feasible, during manual fire fighting.

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2 Novec™ 1230 is an example of a suitable product available commercially. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of this product

Gaseous suppression systems are considered to be the most effective fire suppression system for valve halls that still meets electrical, environmental and human safety demands. However, due to the large volume of valve halls, large quantities of gas should be used. This means numbers of canisters and complex piping which can risk leakages and other problem that may force unplanned stoppage. The advantages and disadvantages of such an approach should be carefully weighed up by the purchaser before finalizing the technical specification. Modern agents in gas suppression systems all meet the demands of fire suppression. The main difference between agents is the amount of gas that is needed. By using environmentally neutral hydro fluorocarbons the amount of gas can be reduced compared to inert gases. The agents are under constant development and other gases that fulfill the suppression demands without leaving residue may be considered.

The demands for a potential fire suppression system may be one or more as below:

a) Contain and/or extinguish a fire in a valve or valve section.
b) Protect the valve and other valve hall equipment structural components and their supporting arrangements from heat in the event of a fire, unless the valve and valve hall design limits the maximum expected fire temperature to acceptable limits.
c) Provide means to extinguish an oil fire resulting from a rupture or leak of a wall or transformer bushing in the valve hall, if applicable.
d) Provide means to extinguish any other fire inside the valve hall.

9 Vent management

9.1 General

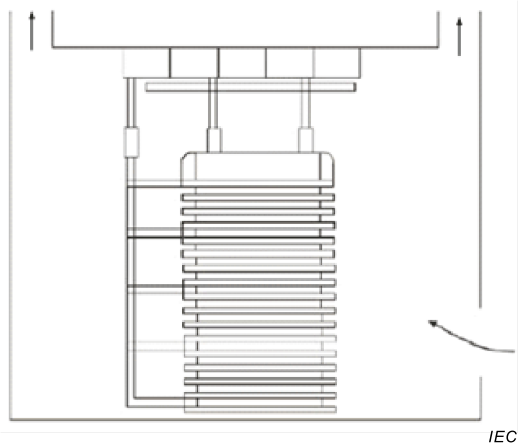
The products from combustion can both be hot, toxic and also reduce the visibility to zero. Good ventilation design reduces damage to valve hall components by lowering the temperature and reducing the contamination. It also keeps smoke/gases out of other areas and makes it possible for fire fighters (equipped with breathing apparatus) to suppress the fire. This will reduce the outage time following a fire.

A further advantage of vent management is the reduction of pressure inside the valve hall. Natural ventilation of the valve hall will lower the pressure which leads to less structural stress and reduces the risk of transfer of smoke to other parts of the building. Forced ventilation systems may be used to improve this effect by drawing negative pressure in the valve hall to keep smoke and toxic fumes from other parts of the building.

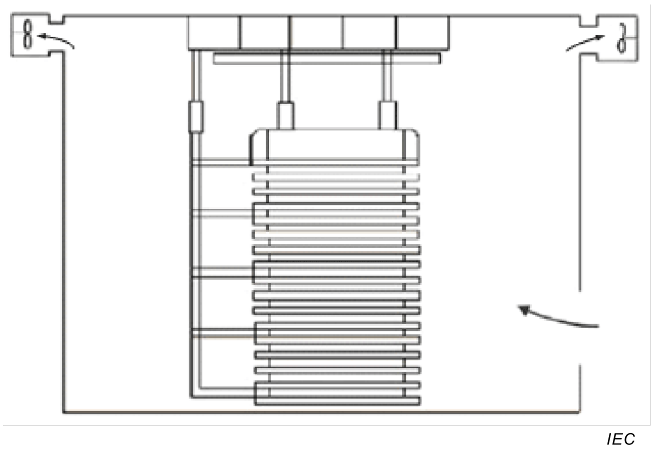
An HVDC valve hall is considered a "simple building" from the standpoint of designing a venting management system. During a fire, hot smoke/gases will rise from the burning object and draw in cooler ambient air as they rise towards the ceiling. When the plume of smoke/gas reaches the ceiling and spreads across it, it forms a distinct layer of smoke/gases near the ceiling. As long as the fire expands, so does the smoke/gas layer near the ceiling and the temperature increases. If roof or wall mounted fire dampers are provided to give natural ventilation, the smoke/gas layer will develop a pressure to drive the smoke/gas out and at some stage an equilibrium will be reached when the mass of smoke and hot gases leaving the enclosure is equal to the mass of air sucked into the enclosure and drawn in the fire-plume. This is the basis for the design of roof and/or wall mounted venting systems, which requires adequate air to be drawn into the building through openings at the lower levels of the enclosure to replace the hot gases flowing out. Forced mechanical ventilation can achieve the same effect as shown in Figure 1.

Proper ventilation will decrease the temperature near the ceiling and can provide a layer of clear air near the floor. The degree of cross-contamination will be reduced the higher the smoke layer can be maintained. This also allows the fire fighters to enter the valve hall to fight the fire at its source. Venting management works as a pressure relief system to reduce overpressure in the building and the concentration of vaporized hydrocarbons.

If a fire occurs in a nearly closed building without ventilation, the internal pressure and temperature may rise to such an extent that the building components fail. Further, due to the consumption of oxygen, unburned smoke/gases may gather in the hot air on the ceiling and may at some point exceed the flammability limit. When a door or equivalent at the floor level is opened, oxygen enters the building and increases the risk of an explosion. Since it is difficult to clear a building once it has become smoke filled, the venting management system should be activated at an early stage of a fire but must be coordinated with the chosen fire suppression method. If suppression by a gaseous agent is employed, the building must remain sealed until the fire is extinguished, but pressure relief dampers are usually active to release excessive overpressure.



a) Roof natural ventilation



b) Forced ventilation

Figure 1 – Types of ventilation

9.2 Design considerations

9.2.1 General

Factors to be considered when selecting naturally or forced ventilated systems are given below.

9.2.2 Natural ventilation

Natural ventilation depends on the basic physical property of hot gases to be more buoyant than the surrounding air. This makes it automatically self-compensating according to the intensity of the fire; the more intense the fire the more efficient the ventilation process. The negative side of this is that a low intensity, but very smoky fire may not be effectively vented.

Natural ventilation can only reduce the overpressure in the valve hall. This is usually adequate from the perspective of reducing the stresses on the building structure but can still leave a positive internal pressure which could force smoke products through openings into adjacent areas. This may not be a problem if the base of the smoke/gas layer is above the level of adjacent rooms (e.g. as in high voltage applications) but this can be more problematic for low voltage applications where valve hall and service building heights can be similar.

Efficient operation requires that the fire dampers be fitted in the roof or high on the walls. Roof mounted dampers may impair the integrity of the roof and therefore represent potential sites for water leakage. The design, taking into account wind, rain, snow and ice loadings, can be complex. The dampers should not be opened except for under fire or for maintenance checks.

Activation of the dampers should be simple and be made independent of external sources. It can be made "fail safe", i.e. automatically open if supply is lost. Redundant supplies should be considered if motor operated dampers are used.

Operation can be manual or via precharged mechanical/gas spring systems with heat activated release. It should be possible to close the dampers after they have served their primary purpose in order to prevent adverse weather conditions contributing to the valve hall contamination.

9.2.3 Forced ventilation

Forced ventilation depends on active aspiration of the valve hall by large capacity fans. The dimensioning of the fans should be carefully addressed since the capacity is inversely proportional to the intensity of the fire: the more intense the fire the lower the mass flow rate of the fans. Therefore, the design requires a degree of conservatism.

Forced ventilation can actively produce negative pressure in the valve hall, which reduces the risk for smoke migration into other areas of the building.

Efficient operation can be achieved by locating fans on the outside wall of the valve hall, at high level, thereby preserving the waterproof integrity of the roof deck and providing a high level of security against external environmental conditions.

Activation of the dampers and the fans are dependent on the availability of auxiliary supplies which should therefore be secure. The routing and supervision of the auxiliary supplies should be protected from the consequences of a developing fire. Local fire codes should be taken into account when designing auxiliary supplies. The fan motors should be rated for operation at the maximum temperature of the smoke/gas layer.

Automatic closure of fire/smoke dampers in air conditioning ducts, if any, should precede activation of the vent management system, which could be either a natural or a forced ventilation system.

9.2.4 Design

The actual design of a venting management system should be undertaken with the assistance of experienced fire professionals and available software for simulating the smoke/gas filling process. Great care is needed to ensure that the system will operate properly and not only vent the valve hall but all the rooms of the HVDC substation building.

10 Control and integration of fire detection, fire protection and converter control systems

10.1 General

Fire detection and active fire extinguishing systems of the size necessary for HVDC and FACTS substations are available. These systems combine a number of new detection and fire extinguishing technologies, with a goal of providing comprehensive fire protection. These systems should be designed to be a complementary arrangement with the control and protection system of the HVDC and FACTS converter. The integration of these systems into an overall fire control system is recommended to ensure a proper coordination of actions to effectively detect the fire, locate the area, trip the HVDC and FACTS converter, manage the heating, ventilation and air conditioning (HVAC) system, and manage the removal of smoke. However, it is accepted that some clients may not wish to incorporate the fire detection signal into a trip sequence for the converter.

Many factors need to be considered in the selection of major items of each of the fire control system. These factors include:

– Detection system method and zone arrangements;
– Speed of detection, with cross zoning or backup of different detection methods;

- Visual verification system including video cameras, viewing windows/ports, valve hall access arrangements and annunciation systems;
- HVDC and FACTS converter arrangements such as standard valve protections, coolant leak detection, HVDC and FACTS converter protection arrangements;
- Local and remote (e.g. fire brigade) alarm annunciation requirements;
- Grid control system requirements, including SCADA;
- Fire management and emergency control measures;
- Availability of trained personnel.

10.2 Fire alarm classification

10.2.1 General

The functions and properties to be provided by the fire control system should include the following with respect to fire alarm classification:

- Identification of the specific/zone location of a fire, so that the actions for prevention of fire propagation and its suppression can be effectively implemented;
- Capability of promptly and accurately detecting the fire is necessary, so that any delay in initiation of counteraction is avoided;
- High accuracy and reliability so that the system responds when required but does not cause tripping of the converter system or operation of the fire suppression system due to false operation.

The fire control systems which are used in HVDC and FACTS substations can be classified according to their fire detection principle, detection objective, degree of importance and their functions. Figure 2 shows the typical interconnections between the various fire extinguishing, alarm and control systems. It may be noted that all boxes shown in Figure 2 may not be applicable in every case.

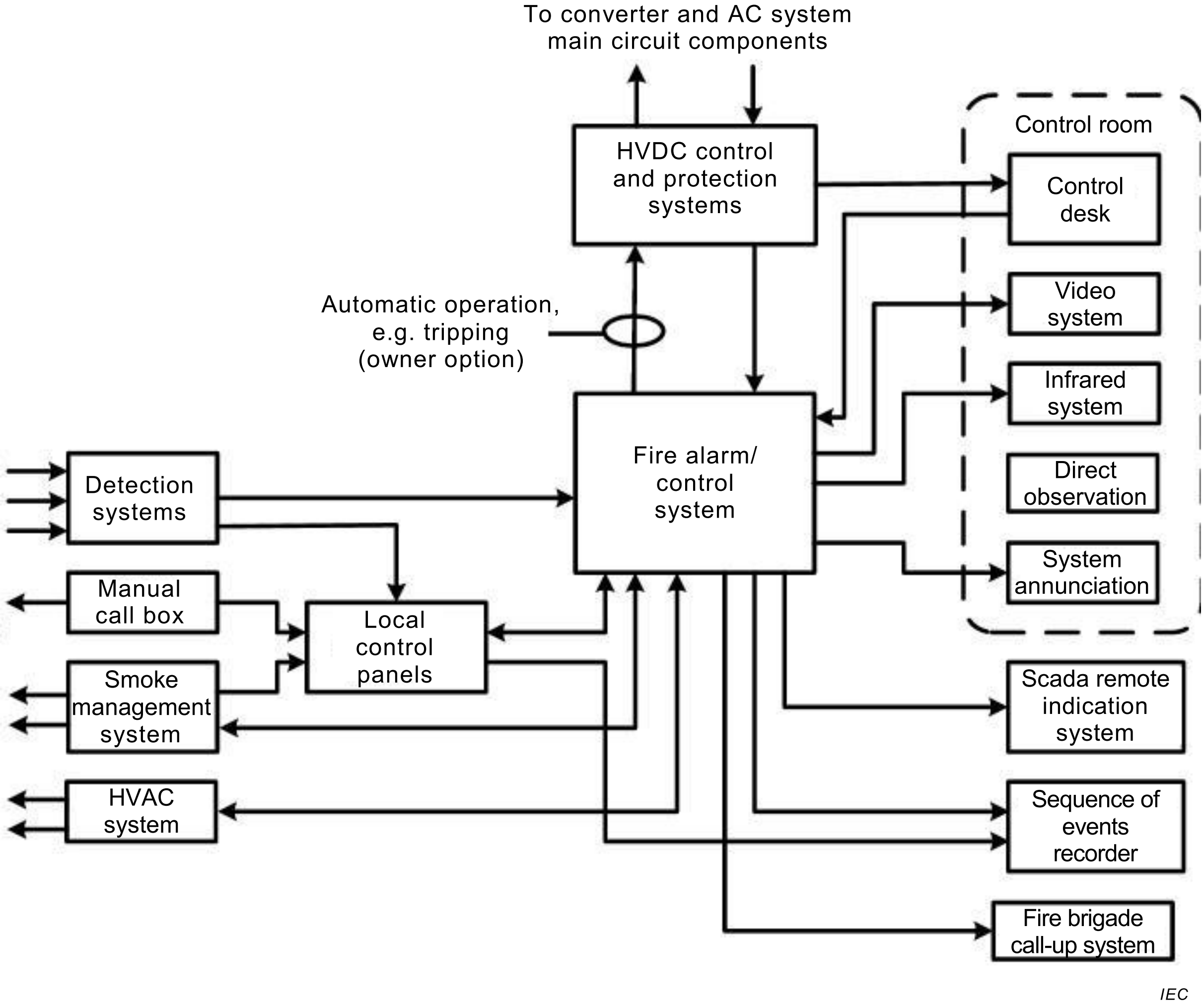


Figure 2 – Possible arrangements and interconnections of an integrated fire detection and control system

10.2.2 Classification by detection principle

The detection systems can be classified into those which detect heat, smoke and electrical phenomena such as electric arcs and are capable of sensing combustion products, those that detect fire visually by means of monitoring television systems, and those employing combinations of the above means (see Clause 7).

The combination and cross zone arrangement of each detection system will provide the maximum sensitivity of detection assuring the reduction of false alarms. In manned HVDC and FACTS substations visual inspection could contribute to fire detection.

Given the availability of network based controls and operator display equipment, consideration should be given to equipping the operator's control desk with annunciation, monitoring and visual monitors. This will ensure that a quick response and coordinated action can be taken to safely manage both fire suppression and HVDC and FACTS transmission operations.

10.2.3 Classification by detection objective

Fire alarm systems can be classified according to the objective of detection into:

– Those designed to automatically trip the converter;

– Those for which the objective is to alert the operator.

If the conditions leading to fire can be detected at a very early stage, it may be possible to avoid fire by tripping the converter and thereby cutting off the energy source. An example of an alarm system for early detection before a fire develops is one which is designed to detect the existence of an arc by means of electromagnetic radiation, see 7.2.4 to 7.2.6.

10.2.4 Detection system reliability

If desired, redundancy for valve hall applications can be achieved by providing multiple detectors for each valve hall.

False fire signals, leading to tripping of the converter or activation of automatic fire suppression systems, will seriously aggravate the reliability of HVDC and FACTS systems. The following provisions could prevent such situations:

– Setting the sensors with appropriate sensitivity;
– Providing supervision of the fire alarm system;
– Providing redundant fire detection systems using the same sensing principles;
– Providing multiple detection alarm systems having different fire sensing principles.

One approach to the reliability issue is to use the system only to alert the operators who will take action only after they have confirmed the situation visually. For systems installed to detect major arcing faults, automatic blocking of the converter will be essential. Reliability is then dependent on the other provisions listed above.

Serious consequences can arise from false activation of a fire suppression system. In most cases, fire action should only be taken manually after visual confirmation that a fire exists, that the affected zone has been properly identified and that, following de-energization, the fire has not self-extinguished or remained contained within limits allowed for in the design.

10.3 Fire control system

10.3.1 General

The fire control system may consist of some or all of following, which are shown in Figure 2:

– Fire detection, arc detection, and monitoring system;
– Fire alarm annunciation system (local and remote);
– Vent management system;
– Fire suppression systems;
– Heating ventilation and air conditioning system emergency control;
– Control desk display;
– Video surveillance system;
– Redundant auxiliary power;
– Sequence of events recorder.

It is important to note that the annunciation and interfaces with local fire brigades are usually subject to country codes and some specific customising may be necessary. Design of displays for the HVDC and FACTS system operator need to be straightforward and uncomplicated so that in the event of an alarm, unambiguous and decisive actions can be taken without having to consult instruction books or supplier documentation.

10.3.2 Basic system functions

The basic functions in a typical time sequence of the fire control system are:

– The detection of a fire event;
– Location indication alarm;
– Annunciation;
– Alarm verification (cross zone);
– Visual verification.
– Notify Grid control and if necessary emergency services (e.g. fire brigade);
– If converter not already tripped, alert operators for converter tripping action;
– Prime fire extinguishing systems;
– Trip, isolate and earth involved equipment;
– Shut down valve hall air handling units;
– Initiate the vent management system;
– Provide monitoring and control of the fire extinguishing actions.

It is recommended to have the status of operation of fire protection facilities and operating status of major equipment displayed, as well as the display of the occurrence of the fire and the location of fire, on the main control desk or nearby panel. For remotely controlled stations, it is desirable to provide means of monitoring the station conditions at a manned controlling station.

Any fire suppression systems may be controlled manually or automatically. A manual control scheme is usually adopted at manned stations. In unmanned stations, the overall control of fire suppression facilities may be performed automatically. The prevention of faulty actuation of a fire suppression system is a requirement of the automatic scheme. In addition, fire control systems should be equipped for the following functions:

– Recording functions by which the information related to the sequence of occurrence of fire, extinction of fire, operation of fire suppression systems, and occurrence of faults on system components can be logged.
– Functions to monitor the system components and detect faults of the fire control components including the condition of the fire extinguishing agents.

10.3.3 Other system components

Other system components include the following items:

– Fire alarm manual call boxes/pull stations.
– Fire alarm horns, buzzers, strobes and annunciators.
– Fire door control.
– Fire shutters for windows.
– System fault alarms.

These systems need to be integrated in accordance with applicable codes and country regulations.

10.3.4 Outline of system design

The fire control system can have a variety of designs depending on the size of the HVDC and FACTS converter, related AC substation, its importance in the power system, equipment layout inside the valve hall, the economic consideration and the overall HVDC and FACTS design approach. Actual requirements for a specific substation must be evaluated first and then final requirements must be clearly specified for every substation before making the purchase. These typical elements are shown interconnected in Figure 2. Power supplies for the fire control system must not be affected by the fire event.

10.4 Guidelines for integrated fire control systems

Since each country has its own relevant fire protection codes, and the design of the fire control system for valve halls must comply to these national codes, this document should facilitate the recognition and adoption of reasonable applications of these codes.

In addition, special conditions may be imposed by local codes and owner specifications for the design of fire detection/protection systems for valve halls.

In HVDC and FACTS substations there can be either automatic or manual control arrangements. These arrangements require prudent review to minimize the damage from maloperation by automatic action.

Since unnecessary tripping of a converter or the actuation of a fire suppression system by a false alarm could substantially degrade the HVDC and FACTS system reliability, as well as result in lost revenue, fire suppression systems are usually manually operated.

The selection between an automatic or manual converter tripping system must be based on a judgment which takes into account: the specific interconnected a.c. system impacts caused by a monopolar or bipolar emergency tripping of the HVDC system, the relative damage to the converters caused by the fire extinguishing agents and the skill of the operating staff.

Since continued technology development is expected for the detection systems and the components that make up a valve hall fire control system, it is recommended that the HVDC system specifier should consult the HVDC and FACTS system suppliers, fire suppression system suppliers, and recognized technical experts in the fire protection field and clearly specifies different requirements without ambiguity for a substation before purchase.

11 Fire fighting and maintenance

11.1 General

The main rule regarding fire fighting is that regulations from local fire departments must be followed. Techniques used in fighting a fire in an HVDC installation depend upon the type of fire suppression system available, the available personnel and local practice. For example, if a carbon dioxide gas system were installed, evacuation of the affected area would be a prime requisite since suffocation of personnel can occur.

11.2 Role of station and fire fighting personnel

11.2.1 General

HVDC substations without permanently based personnel should not be designed for involvement of personnel in the initial action in case of fire. Unless the user is prepared to maintain a fire fighting training programme, the role of station personnel will normally be limited to detecting the fire, notifying appropriate authorities, isolating the affected areas, initiating installed fire suppression systems and evacuating personnel. If the valve equipment has been constructed using self-extinguishing fire materials as far as possible and if non-self-extinguishing materials have been segregated by fire resistant barriers, actual fire fighting may not be required. When required, fighting a fire in a valve hall can be extremely hazardous as a result of the heat, toxic fumes and the possibility of valve collapse. The owner should consider the extent to which his personnel should be trained to intervene in fire fighting.

11.2.2 Actions in case of a fire

Local and remote station personnel will need to be familiar with the correct actions/procedures associated with the following typical sequence of events.

a) Detection: by means of fire alarm system, visual observation, electrical monitoring or other means.
b) Verification: by visual means through the viewing windows, cameras if available, alarms from more than one detector in the fire system or operational abnormalities.
c) De-energisation: if not already de-energised by protective action, block and trip the affected converter.
d) Isolation: isolate and earth the affected valve hall.
e) Evacuation of personnel (if applicable).
f) Notify the grid control and if necessary the emergency service (e.g. fire brigade).
g) Shut down of valve hall HVAC system.
h) Initiation of vent management system.
i) Initiation of fire suppression system.
j) Coordination with local fire authorities.
k) Other actions in accordance with the contingency plans for dealing with a fire.

11.2.3 Fire fighting

Unless the user has trained the station personnel in fire fighting techniques, fire fighting will be carried out by the local fire brigade.

Specific instructions and precautions should be provided where applicable for:

– Use of hand held equipment;
– Vent management.

12 Guidance for purchaser specifications

12.1 General

Purchaser specifications should require measures to minimize the risk of a fire in a valve hall, to prevent it from spreading, and to achieve this the material should be self-extinguishing.

Consideration of fire hazards should be included at all of the following phases of the project:

– preparation of purchaser specification;
– project design and engineering;
– selection of materials and components;
– manufacturing, assembly and testing;
– operation and maintenance.

12.2 Purchaser specification

12.2.1 General

In this report, only general guidelines are given. These guidelines will have to be interpreted in the context of each application.

The following general aspects should be considered in the specification:

– Site and environmental conditions;
– National and local safety codes;
– Applicable fire standards and guides;
– Insurance companies terms and conditions;

– Local fire department safety rules and practices;
– Operation and maintenance practices

12.2.2 Semiconductor valves

The specification should emphasize the need for the valves to be designed to minimize the risk of a fire developing and to limit the consequences.

Fire risks should be minimized by:

– Rating components for normal and abnormal operating conditions including electrical, thermal and mechanical stresses which occur throughout the operating life. Adequate margins for aging and degradation of electrical, thermal and mechanical properties should be provided;
– Considering possible failure modes and fire risk consequences. This should guide the selection and positioning of materials and components consistent with their required function in the design. The aim should be to minimize failure probabilities or ensure that any resulting fires are contained;
– Applying appropriate quality control, inspection and test procedures at all stages of the design, manufacture, installation and commissioning to ensure conformity with the requirements and consistency in performance;
– Having comprehensive repair/maintenance instructions in the operation and maintenance manual to alert the user to potential fire hazards and provide guidelines on how to deal with them;
– Including supervision/monitoring systems to detect problems at an early stage.

Consequences should be minimized by:

a) Reducing the energy infeed during and after a fault. This has two components:
   1) Electrical: the electrical energy released will depend on the nature of the fault and the time taken to detect and de-energize the equipment. Rapid detection and de-energization should be mandatory.
   2) Chemical: energy released by combustion should be minimized by using non combustible or self-extinguishing materials wherever possible: UL94-V0 or equivalent is a target for self-extinguishing capability. Where this is not achievable, due to other technical considerations, then the quantities of such material should be minimized. Selection of materials with low heat release rate is helpful, however comparison of materials must always include consideration of self-extinguishing properties due to flame-retardant additives or properties.
b) Providing fire separation barriers (or other features), if materials, which are not self-extinguishing are used to a noticeable extent,

At the tender stage, the purchaser could request a report describing the design approach used to deal with the fire hazards discussed in Clause 4, which could include details of the types and quantities of materials used in the valve, with special attention to those items which do not meet UL94-V0 rating or equivalent. The report should address the consequences of and precautions against:

– faults in electrical components such as: damping resistors, damping capacitors, valve reactors, valve electronics, etc.;
– series arcs due to an open circuit in auxiliary circuit wiring or in the main current path;
– shunt arcs due, for example, to insulation failure between tiers caused by pollution or a coolant leak;
– component overheating due to coolant leakage or blockage arising from a damaged cooling water pipe or connection, corrosion, or debris circulating in the cooling system, etc.

At the contract stage the purchaser could request that the suitability of the fire prevention measures is demonstrated by actual tests except where appropriate tests have already been performed. Purchaser and supplier should agree on suitable test setup and test procedures. The test should be applied to a sufficient representation of a portion of a valve to demonstrate that the objectives have been met. If applicable, structural components of the valve assembly (e.g. support/suspension insulators, valve section structural frames, etc.) should be shown to retain their mechanical integrity when subjected to the elevated temperatures and exposure times associated with the worst case fire scenario allowed for in the design.

12.2.3 Other valve hall equipment

Other valve hall equipment includes transformer bushings, DC-wall bushings, voltage dividers, capacitors, current transformers, arresters, suspension- and post-insulators, earthing switches and bus work. The purchaser specification for these items should require the supplier to minimize fire hazards using only non-flammable or self-extinguishing material according to UL 94-V0 wherever possible. Particularly, the use of oil-filled equipment should not be permitted. The impact of equipment failure on other adjacent equipment should be considered in the design.

12.2.4 Valve hall construction

In addition to the fire aspect of valve hall equipment, the specification should address more specifically the valve hall construction.

The fire risks and consequences should be minimized by:

– Valve hall isolation against the spread of fire by suitably rated fire walls, floors and ceilings;
– All openings in walls, floors and ceilings should be sealed with the fire rating of the seals corresponding to the same level as the wall, floor or ceiling penetrated;
– Ensuring that any viewing windows or video cameras are arranged so that the maximum practical area of the valve hall is within line of vision;
– Including fire rated doors and windows between the service block and valve hall. The doors should be adequately air tight.

All the systems and equipment should be designed to meet the requirements of the National and Local Fire Codes. Systems and equipment that are not covered by local rules and regulations should be designed in accordance with applicable standards. Even though valve halls may not be specifically covered by these standards, valve hall construction should ensure that equivalent fire protection measures are included.

Suitable fire segregation and compartmentation should be used for all valve hall services (e.g. cables, fibre optics, cooling pipes, ducts, etc).

12.2.5 Fire detection systems

The purchaser specification should include a requirement for a fast acting fire detection system (e.g. air sampling system) capable of early detection of incipient fire and smoke. For fast response there should be a sufficient number and distribution of air sampling points for each valve structure. The detector and control unit should be located outside the valve hall for ease of verification and maintenance.

The air sampling system could be reinforced by the use of a sufficient number of arc detectors (e.g. UV-sensors) to achieve quick de-energization of the converter in case of flashover. In addition, conventional systems could be specified to conform to local fire regulations and insurance company requirements.

For unmanned substations and for HVDC substations where it is not possible to view all parts of the valves when energized, a camera system is useful.

12.2.6 Fire suppression systems

The specification of the HVDC substation fire protection should address the special requirements for protection of the valves and valve hall equipment. The recommendation is that the valves should not be exposed to any fire-fighting agents, but should exhibit self-extinguishing properties. Therefore, an installed fire suppression system for the valves is not recommended.

If a fire suppression system is to be installed, only systems using gases as extinguishing medium should be considered as water or powder based systems will very probably cause more damage to the valves than a fire itself, provided the valves are properly designed. Manually operated systems are preferred to prevent false operation which would cause unnecessary outage.

When provided, a valve hall gaseous fire suppression system should include all equipment required for directing the gas discharge at a fire. Gaseous systems include fixed systems, wheeled carriages loaded with cylinders and hand held extinguishers. The effective reach of gas jets from portable extinguishers should enable the suppression of small fires that could develop anywhere in a valve or valve hall. It may be noted that for some valve halls, it may not be feasible to provide such portable systems, due to large sizes and distance involved. Fixed systems may be considered to cover dedicated areas to complement portable systems.

12.2.7 Vent management system

Each valve hall would normally have an independent air-handling system. In addition, a vent management system could be specified.

12.2.8 Fire alarm and control systems

Each valve hall should have an alarm and control system which reports to the main HVDC substation fire control system.

Operation of any single fire detection system should cause initiation of visible and/or audible fire alarms indicating the location of the alarm origin. In this case the HVDC substation operator should decide how to proceed.

The confirmation of a fire (e.g. via operation of two independent detectors or by visual verification by the operator) should cause the following:

a) Blocking and de-energizing of the converter (if not already implemented by protective action).

b) Activation of the vent management system.

Annexe A
(informative)

Valve hall fire hazards and survey of fire incidents

A.1 General

From a survey of thyristor valve and valve hall fire incidents conducted in 1993, together with other incidents reported subsequent to this, utilities operating 27 HVDC links have reported a total of 29 incidents, three of which were catastrophic. Investigations of the three major incidents concluded that each of them started at first as a minor event and developed into a major incident. For further information on these incidents, see CIGRÉ Technical Brochure 136.

In 2012 an additional survey was made for any fires or fire Incidents in HVDC plants in operation from February 1997 to October 2012. Of a total of 40 utilities approached 22 utilities with 48 HVDC substations in operation answered reporting 66 fire incidents demonstrating the continued need for the fire prevention measures recommended in this report. The approached utilities are listed in Table A.1. The statistics demonstrate that older installations, where all recommended fire prevention measures had not been adopted, have a much higher fire incident rate.

A.2 Hazard categories

The following valve hall fire hazards are considered:

1) Overheating of valve components due to reduced cooling.
2) Valve component failures.
3) Loose or high resistance connections in the load current carrying circuit.
4) Failure of auxiliary circuit electrical connections.
5) Insulation failures.
6) Failure of equipment associated with the valve hall
7) False alarms.
8) Unknown causes.

A.3 Reports from HVDC users

Table A.1 – HVDC converters owners/suppliers reference list (May 2012)

Owner(s)	Project/ Name of converters	Answer received	Any incident	Comment
APA	Direct Link	No		
APA	Murray Link	No		
50 Hz Transmission	Kontek / Rostok	Yes	No	
Baltic Cable AB	Baltic Cable / Herrenwyk, Kruseberg	Yes	Yes	False alarm at Herrenwyk HVDC substation.
BC Hydro	Vancouver island/ Arnott, VAT	Yes	Yes	
BP	Valhall	No		
BPA	Pacific Intertie/ Celilo	Yes	Yes	
Chubu	Minami-Fukumitsu	Yes	No	
Chubu	Higashi-Shimizu	Yes	No	
CIEN	Garabi 1 and 2	Yes	No	
CSG	Gezouba-Shanghai, Tian-Guang	No		Only verbally informed and therefore not included.
EdF	Cross Channel/ Les Mandarins	No		
Energinet DK	Skagerrak 1 /Tjele	Yes	Yes	
Energinet DK	Skagerrak 2 /Tjele	Yes	Yes	
Energinet DK	Skagerrak 3 /Tjele	Yes	Yes	
Energinet DK	Storebaelt / Fraugde, …	Yes	Yes	
EPDC	Hokkaido-Honshu	Yes	No	
EPDC	Sakuma	Yes	No	
EPDC, Kansai, Shikoku	Kii Channel	Yes	No	
ESKOM	Cabora Bassa/ Apollo	No		
Fingrid	Fenno-Skan/Rauma	Yes	No	
Fingrid	Estlink/Esbo	Yes	No	
FURNAS	Itaipu HVDC link/ Ibiuna	Yes	No	
Great River Energy	CU Coal Creek , Dickinson	No		
Hydro-Quebec	HQ_NEH/ Nicolet, Quebec	Yes	No	
KEPCO	Cheju Island/ Haenam, Cheju	No		
LADWP	Pacific Intertie/Sylmar	No		
LADWP	IPP/Adelanto	No		
Manitoba Hydro	Nelson River 1/ Dorsey, Radisson	Yes	Yes	
Manitoba Hydro	Nelson River 2/ Dorsey, Hensey	Yes	Yes	
Moyle Interconnection Co	Moyle Interconnection/	No		
MSEB	Chandrapur-Padghe/ Chandrapur	Yes	Yes	
Nampower	Caprivi Link	Yes	Yes	
National Grid / UK	Cross Channel/ Sellindge	No		
New England Hydro	HQ_NEH/Sandy Pond	No		
New South Wales	Broken Hill	No		

Owner(s)	Project/ Name of converters	Answer received	Any incident	Comment
/Australia				
Power Grid India	Rihand-Delhi/Rihand	Yes	Yes	
Power Grid India	Vizac	Yes	No	
Power Grid India	Vindhyachal	Yes	No	
FSK EES	Vyborg B-to-B	Yes	Yes	
Saudi	SGCIA	No		
SGCC	3 Gorges- Changzhou, 3 Gorges-Guandong, 3 Gorges-Shanghai	No		Only verbally informed and therefore not included.
SNEL	Inga-Kolwezi/ Inga, Kolwezi	No		
STATOIL	Troll 1 and 2	Yes	No	
STATNET	Skagerrak 1/ Kristianssand	Yes	No	
STATNET	Skagerrak 2/ Kristiansand	Yes	No	
STATNET	Skagerrak 3/ Kristiansand	Yes	No	
Svenska Kraftnät	Konti-Skan/ Lindome	Yes	No	
Svenska Kraftnät	Fenno-Skan 1/ Dannebo	Yes	Yes	
SwePol link operator	SwePol link/ Stärno, Slupsk	Yes	No	
Terna	Italy-Greece/ Galatina Sapei	Yes	Yes	False alarm.
Terna	Sacoi	Yes	No	
Terna	Sapei/ Latina, Fiume Santo	Yes	No	
Transpower / NZ	DC Hybride link/ Benmore, Hayward	Yes	No	
VELCO	Highgate	No		

A.4 Reported incidents

A.4.1 Overheating of valve components due to reduced cooling

Failure of the cooling system for a complete converter is normally sensed by external monitoring of flow, temperature, conductivity, etc. However, localized overheating of some valve components can occur as a result of the total or partial loss of cooling to part of a valve. The loss of cooling may be due to a coolant leak or partial blocking of an individual cooling pipe or duct within a valve.

4 incidents were reported under this category:

a) Scheme: Nelson River Bipole 1, Dorsey HVDC substation

Date	2004-06-15
Transmission capacity	1800 MW
HVDC substation	Dorsey
Capacity forced out	300 MW
Cooling medium	Deionized water
Outage duration	5,2 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	Saturable reactor overheated due to partial blocking of the cooling tubes within the reactor. The event was discovered by a burning smell, the converter was tripped manually. No damage to other components.

b) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2009-01-14
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	94,5 h
Fire detection (Aspiration system, etc.)	Group protection trip
Description	De-ionized water module supply line broke and sprayed coolant onto thyristor module, causing a flashover and fire. Fiber optics channels were damaged.

c) Scheme: Pacific Intertie, Celilo HVDC substation

Date	2011-07
Transmission capacity	3100
HVDC substation	Celilo
Capacity forced out	2000
Cooling medium	Deionized water
Outage duration	12 h
Fire detection (Aspiration system, etc.)	No information
Description	Snubber resistor overheated due to blocked cooling water inlet pipe and developed a coolant leak which was not detected. Leak water caused a line to earth fault within the valve. No fire, but extensive damage to various valve components.

d) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2011-12-18
Transmission capacity	2000
HVDC substation	Henday
Capacity forced out	500
Cooling medium	Deionized water
Outage duration	315,3 h
Fire detection (Aspiration system, etc.)	Group protection trip
Description	DIW module supply line broke and sprayed coolant onto thyristor module, causing a flashover and explosion. 50% of the fiber optics channels including the fibers and 36 thyristors were destroyed.

A.4.2 Valve component failures

Converter valves are constructed from a number of components, namely semiconductor devices (thyristors or IGBTs), capacitors, resistors, reactors and gate electronics circuit boards. The failure modes of these components are different and each represents a different level of fire hazard. On the other hand capacitors usually contain flammable dielectric material and therefore are a specific hazard. Reactors and resistors, depending on the mode of failure, may cause a fire either in the failed component itself or by consequential overheating of an adjacent component. The gate electronics circuit boards may cause a fire similar to other valve component failures.

There were 44 events attributed to this category of failures.

a) Scheme: Skagerrak 1, Tjele HVDC substation

Date	1997-02-12
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	250 MW
Cooling medium	Air
Outage duration	4 h
Fire detection (Aspiration system, etc.)	Pre-warning
Description	Burnt power resistor

b) Scheme: Nelson River Bipole 2, Dorsey HVDC substation

Date	1997-09-21
Transmission capacity	2000 MW
HVDC substation	Dorsey
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,9 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics printed circuit board (PCB) partially burnt

c) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	1997-10-18
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	4,9 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

d) Scheme: Skagerrak 1, Tjele HVDC substation

Date	1998-09-18
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	3 burnt power resistors. Found during scheduled outage.

e) Scheme: Skagerrak 2, Tjele HVDC substation

	1999-09-17
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	2 burnt power resistors. Found during scheduled outage.

f) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	1999-10-31
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,9 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

g) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2000-06-30
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	2,2 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

h) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2000-09-11
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt power resistor. Found during scheduled outage.

i) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2001-05-04
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt capacitor.

j) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2001-12-17
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	5,1 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

k) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2002-02-08
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt power resistor.

l) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2002-02-19
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	2,1 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

m) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2002-09-19
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt capacitor.

n) Scheme: Rihand-Delhi, Rihand HVDC substation

Date	2003-04-06
Transmission capacity	750 MW
Pole	2
Capacity forced out	750 MW
Item designation	P2.R.V1.V4.A9.V1.C11/C12/C13
Cooling medium	Water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	VESDA
Description	Fire occurred in the R-phase of pole 2 at position V1.V4.A9.V1 capacitors C11, C12 and C13.
Action	11 pieces of capacitors and 12 optical fibres were replaced.
Observation	On receipt of VESDA alarm, the operator initiated “Emergency stop” of the pole and the fire extinguished. Fire barriers in the module had prevented the fire from spreading to other modules.

o) Scheme: Nelson River Bipole 2, Dorsey HVDC substation

Date	2004-05-03
Transmission capacity	2000 MW
HVDC substation	Dorsey
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	5,0 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

p) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2005-07-01
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,4 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

q) Scheme: Thailand-Malaysia: Khlong Ngae Thailand HVDC substation

Date	2005-07-22
Transmission capacity	30 MW
HVDC substation	Khlong Ngae Thailand
Capacity forced out	30 MW
Cooling medium	De-ionized water
Outage duration	0,5 h
Fire detection (Aspiration system, etc.)	Pre-warning
Description	UV detector operated due to burnt thyristor electronics.

r) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2005-08-10
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	4,3 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

s) Scheme: Nelson River Bipole 2, Dorsey HVDC substation

Date	2005-09-23
Transmission capacity	2000 MW
Converter station	Dorsey
Capacity forced out	500 MW
Cooling medium	Deionized water
Outage duration	2,5 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

t) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2006-03-01
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0 MW
Cooling medium	Air
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt capacitor and power resistor.

u) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2006-03-29
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,9 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

v) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2006-03-30
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,9 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

w) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2006-10-06
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	3,4 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

x) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2007-05-15
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.VY.V2.A15.T2
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst.
Action	Replaced with a new one.

y) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-02-29
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.B.V4.A12.T4
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst.
Action	Capacitor rack, thyristor electronics PCB, thyristor and optical fibre replaced.

z) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-02-29
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.R.V4.A3.T5
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst.
Action	Capacitor rack and optical fibre replaced.

aa) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-02-29
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.R.V4.A5.T5
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst.
Action	Capacitor rack and optical fibre replaced.

bb) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-05-10
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.VY.V2.A15.T2
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst..
Action	Capacitor rack, thyristor electronics PCB, thyristor and optical fibre replaced.

cc) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-05-10
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.VY.V2.A15.T6
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst.
Action	Capacitor rack, thyristor electronics PCB, thyristor and optical fibre replaced.

dd) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2008-05-25
Transmission capacity	750 MW
Pole	-
Capacity forced out	0 MW
Item designation	VY.V2.A6.T4 & VY.V2.A14.T3
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst and optical fibers damaged.
Action	Capacitors and optical fibers replaced.

ee) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2008-08-05
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	Deionized water
Outage duration	3 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

ff) Scheme: Thailand-Malaysia, Khlong Ngae Thailand HVDC substation

Date	2008-08-18
Transmission capacity	300 MW
Capacity forced out	30 MW
Position	Phase B valve, tier 1R, valve No 12.
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	Pre-warning
Description	UV detector operated due to burnt thyristor electronics.

gg) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-01-12
Transmission capacity	750 MW
Pole	2
Capacity forced out	0 MW
Item designation	P2.VR.V2.A6.T3
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor burst and optical fibres damaged.
Action	Capacitor and optical fibre replaced.

hh) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-02-07
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.VB.V1.M16.T6
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor C3 and C15 burst, thyristor electronics PCB and optical fibers damaged.
Action	Capacitors, thyristor electronics PCB and optical fibers replaced.

ii) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-02-07
Transmission capacity	750 MW
Pole	2
Capacity forced out	0 MW
Item designation	P2.VB.V1.A10.T6.C11
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	IP and FP optical fibres found damaged due to capacitor C11 burst.
Action	Capacitors, thyristor electronics PCB and optical fibres replaced.

jj) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2009-02-13
Transmission capacity	500 MW
HVDC substation	Tjele
Capacity forced out	500 MW
Cooling medium	Glycol
Outage duration	7 h
Fire detection (Aspiration system, etc.)	Pre-warning
Description	Burnt capacitor and fiber optic cable.

kk) Scheme: Thailand-Malaysia, Khlong Ngae Thailand HVDC substation

Date	2009-03-26
Transmission capacity	300 MW
Capacity forced out	30 MW
Cooling medium	Water
Outage duration	3 h
Fire detection (Aspiration system, etc.)	Pre-warning
Description	UV detector operated due to burnt thyristor electronics.

ll) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-04-10
Transmission capacity	750 MW
Pole	1
Capacity forced out	0 MW
Item designation	P1.VY.V2.M15.T5, P1.VY.V2.M15.T6, P1.VB.V1.M1.T1, P1.VB.V1.M1.T2/T3/T4/T5/T6
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	IP and FP optical fibres found damaged due to capacitor C11 burst.
Action	Capacitors, thyristor electronics PCB and optical fibers replaced.

mm) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-04-10
Transmission capacity	750 MW
Pole	2
Capacity forced out	0
Item designation	P2.R.V1.M14.T3
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor C3 and C14 found burst.
Action	Capacitors replaced.

nn) Scheme: Chandrapur-Padghe, Padghe HVDC substation

Date	2009-05-29
Transmission capacity	750 MW
Pole	2
Capacity forced out	0 MW
Item designation	P2.R.V1.M14.T3
Cooling medium	Water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Capacitor C3 and C14 found burst.
Action	Capacitors replaced.

oo) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2010-04-17
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	5,7 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

pp) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2010-04-19
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	2,4 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	One thyristor electronics PCB partially burnt

qq) Scheme: Skagerrak 1, Tjele HVDC substation

Date	2010-04-26
Transmission capacity	500 MW
HVDC substation	TJE
Capacity forced out	0 MW
Cooling medium	Glycol
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Burnt capacitor.

rr) Scheme: Caprivi Link, Gerus HVDC substation

Date	2011-07
Transmission capacity	300 MW
HVDC substation	Zambesi
Capacity forced out	5 MW
Cooling medium	De-ionized water
Outage duration	Not reported.
Fire detection (Aspiration system, etc.)	Detected by VESDA
Description	Cascading failure of IGBTs leading to flashovers and some additional damages to the valve.

A.4.3 Loose or high resistance connections in the load current carrying circuit

Loose load current bus bar connections within a valve or inside the valve hall may lead to overheating. In extreme cases a joint may become open circuited and a series arc will develop. Whether it is an overheated connection or a series arc it can damage adjacent components which can lead to a fire.

There were 2 events reported for this type of failure:

a) Scheme: Murray Link, Berri HVDC substation

Date	2005-10-16 00:20
Transmission capacity	220 MW
Capacity forced out	Failure occurred during start up.
Item designation	Phase C Valve 4 stack 4
Cooling medium	Water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	The VESDA (fire detection) system detected smoke in enclosure housing for phase C.
Description	The stack position 15 was heavily burned and other damages could be seen as result from the arcing on position 15. The failed reported IGBT were Phase C Valve 4, Stack 4, Position 11, 12, 13, 14, 15 and 17. Fire barriers in the module had prevented the fire from spreading to other modules.
Action	The failed IGBTs were replaced and the owner was instructed how to exchange the IGBT without cracking it.
Observation	The cause for the failure was a cracked hybrid and the reason for the failure is most probably that the hybrid was cracked during replacement of the IGBT position and not detected during final testing.

b) Scheme: Storebaelt, Fraugde HVDC substation

Date	2011-10-19
Transmission capacity	600 MW
HVDC substation	Fraugde
Capacity forced out	0 MW
Cooling medium	De-ionized water
Outage duration	NA
Fire detection (Aspiration system, etc.)	No alarms
Description	Overheated flexible connection between valve module and busbar. Found during scheduled outage.

A.4.4 Failure of auxiliary circuit electrical connections

Loose connections within the auxiliary circuits at a thyristor level may produce either arcing or overheating at that connection. This type of failure, if undetected for a period of time, may ignite adjacent materials leading to a fire.

There was 1 event reported due to this type of failure.

Scheme: Caprivi Link, Zambesi HVDC substation

Date	2011-06
Transmission capacity	300 MW
HVDC substation	Zambesi
Capacity forced out	50 MW
Cooling medium	De-ionized water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	Pre-warning
Description	Bad potential contact to corona shields resulted in burnt corona shield connection

A.4.5 Insulation failures

Insulation failures can be either within a valve or within or across other equipment in the valve hall, such as bushings or voltage dividers. In both cases it involves a shunt electrical arc that may lead to a fire. Insulation failures within a valve can be the result of contamination, increased humidity or coolant leak in a liquid cooled valve. Insulation failure of other equipment such as bushings can be due to either external or internal flashover of the equipment. The failure of oil-filled equipment represents a major risk of fire, especially if it leads to its puncture.

There were 9 events reported that involved shunt electrical arcs due to insulation failure:

a) Scheme: Nelson River Bipole 2, Dorsey HVDC substation

Date	1997-10-14
Transmission capacity	2000 MW
HVDC substation	Dorsey
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	17,6 h
Fire detection (Aspiration system, etc.)	No information
Description	Rubber bumper moved into contact with electrical circuit and started burning, creating smoke and soot. The valve group had to be cleaned.

b) Scheme: Nelson River Bipole 1, Radisson HVDC substation

Date	2001-10-18
Transmission capacity	1800 MW
HVDC substation	Radisson
Capacity forced out	300 MW
Cooling medium	De-ionized water
Outage duration	4,4 h
Fire detection (Aspiration system, etc.)	No information
Description	Valve berth piping caught fire. Cause unknown

c) Scheme: Nelson River Bipole 1, Radisson HVDC substation

Date	2005-01-21
Transmission capacity	1800 MW
HVDC substation	Radisson
Capacity forced out	300 MW
Cooling medium	Deionized water
Outage duration	40,5 h
Fire detection (Aspiration system, etc.)	No information
Description	Failure of an oil-filled wall bushing caused rupture of the outside porcelain and a small fire. No internal leakage or fire.

d) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2005-11-08
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	Deionized water
Outage duration	5,8 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	Reactor module isolating rod and equipotential copper braid both burnt open. No further damage

e) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2005-11-13
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	7,5 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	Reactor module isolating rod and equipotential copper braid both burnt open. No further damage

f) Scheme: Nelson River Bipole 2, Henday HVDC substation

Date	2005-11-22
Transmission capacity	2000 MW
HVDC substation	Henday
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	5,3 h
Fire detection (Aspiration system, etc.)	“Manually” (burning smell)
Description	Reactor module isolating rod and equipotential copper braid both burnt open. No further damage

g) Scheme: Nelson River Bipole 2, Dorsey HVDC substation

Date	2009-01-20
Transmission capacity	2000 MW
HVDC substation	Dorsey
Capacity forced out	500 MW
Cooling medium	De-ionized water
Outage duration	16,4 h
Fire detection (Aspiration system, etc.)	Valve protection trip
Description	A rubber bumper got loose, fell across the electrical circuit of a thyristor module and started burning, creating smoke and soot within the valve. Cleaning and replacement of one thyristor module was required.

h) Scheme: Fenno-Skan 1, Dannebo HVDC substation

Date	2012-10-06
Transmission capacity	0 MW
HVDC substation	Dannebo
Capacity forced out	0 MW
Cooling medium	De-ionized water
Outage duration	Not reported.
Fire detection (Aspiration system, etc.)	Detected by VESDA
Description	Valve hall optical fiber channel caught fire during preparation for open line test, due to too high humidity in valve hall.

i) Scheme: Vyborg back-to-back HVDC substation

Date	2004-06-10
Transmission capacity	300 MW
Converter Back-to-Back Unit	KVPU 4
Capacity forced out	300 MW
Cooling medium	De-ionized water
Outage duration	48 h
Fire detection (Aspiration system, etc.)	No information.
Description	The leak of de-ionized water from a welded seam of the cooler case. Electric arc and water vapour resulted in numerous flashovers between adjacent thyristor modules inside the valve and the grounding contour which caused the protection operation.
Action	Three thyristor valve modules were replaced.
Observation	The considerable number of valve faults was caused by “burning out” plug-and-sockets of thyristor electronics resulting in failures of thyristor levels and in valve protection operation. As a rule the greatest damage took place due to a drop leak on the upper levels of the valve causing failures of lower valve modules. 40 thyristor modules were replaced due to such failures at all four complete converter back-to-back units (KVPU) of the Vyborg Back-to-Back HVDC substation during 2000-2012. The outage duration was from 2 h to 48 h.

A.4.6 Failures of equipment associated with the valve hall

There was 1 event reported due to this type of failure.

Scheme: Skaggerrak 2 Tjele HVDC substation

Date	2006-01-30
Transmission capacity	250 MW
HVDC substation	Tjele
Capacity forced out	0 MW
Cooling medium	Air
Outage duration	0 MW
Fire detection (Aspiration system, etc.)	Pre-warning
Description	Defect motor bearings in valve hall ventilation.

A.4.7 False alarms

There were 4 false alarm events reported.

a) Scheme: Italy-Greece: Galatina HVDC substation

Date	2001
Transmission capacity	Not reported
HVDC substation	Galatina
Capacity forced out	Not reported
Cooling medium	De-ionized water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	Pre-warning
Description	False alarm due to fire in the neighbourhood.

b) Scheme: Thailand-Malaysia: Khlong Ngae Thailand HVDC substation

Date	2005-08-18
Transmission capacity	30 MW
HVDC substation	Khlong Ngae Thailand
Capacity forced out	30 MW
Cooling medium	De-ionized water
Outage duration	6,5 h
Fire detection (Aspiration system, etc.)	Pre-warning
Description	UV detector inside valve hall operated. No fire occurred/detected.

c) Scheme: Baltic Cable: Herrenwyk HVDC substation

Date	2006-01-30
Transmission capacity	Not reported
HVDC substation	Herrenwyk
Capacity forced out	Not reported
Cooling medium	De-ionized water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	Pre-warning
Description	False alarm due to fire in the neighbourhood.

d) Scheme: Vancouver Island: VIT HVDC substation

Date	2010-12-01
Transmission capacity	270 MW
HVDC substation	VIT
Pole	2
Capacity forced out	270 MW
Cooling medium	De-ionized water
Outage duration	Not reported
Fire detection (Aspiration system, etc.)	Pre-warning
Description	On 2010-12-01, there reported some smoke in Pole 2 valve hall at VIT prior to valve blocking. So far, we have not been able to confirm the root causes of the smoke. After an extensive examination of all the components involved, we found no burned components or materials.
Action	A subsequent experimentation suggested that dust settling on a snubber resistor's surface can be a source of combustion material resulted in smoke when this element heated up. Also, we found the fire detection system worked quite well, though on the extreme sensitive side.

A.4.8 Unknown causes

There was 1 fire incident with unknown cause reported.

Scheme: Sino-Russia Back-to-Back

Date	2011-12
Transmission capacity	750 MW
HVDC substation	Heihe
Commissioning year	2012
Capacity forced out	75 MW
Cooling medium	Water/Glycol
Outage duration	Not reported
Description	During commissioning, several modules of one phase were badly damaged due to a fire that started in the region of the damping capacitors. The affected damping capacitors, any structural components, and minor assorted components, were replaced. Remaining components were cleaned, and the thyristor valve equipment reassembled. .
Description 2	During repeat commissioning, a second fire started in the region of the damping capacitor, but was quickly spotted and extinguished.
Action	In both instances, the fire is believed to have started due to a poor connection.

A.5 Conclusion and recommendations

The amount of recently reported fire incidents within HVDC converter valves and valve halls shows that fire prevention in valve halls for HVDC is still very much needed. Examination of the events reported shows that no event had occurred due to overload or operation of the converter outside the design limits. After installation of air sampling systems and/or UV detectors all recent events were detected before developing into a critical situation. Before this all incidents either were discovered by the operating personnel and manual intervention was necessary or the converter was tripped by a converter protection. Still on many HVDC schemes the alarm settings may be too coarse for early intervention leaving many fire incidents to the detection and manual intervention of operational personnel. This highlights the importance of a sensitive fire detection system and its careful setting up during its commissioning. For converter valves of older design, where valve material does not self-extinguish, fire barriers may still be valuable to avoid spread of fire.

The potential and actual fire incidents described in Annex A clearly demonstrate that fire can occur within valves and valve halls. Although 65 fire incidents were reported between 1999 to 2012 roughly only 60% of utilities answered the request to present information on fire events.

From the number of incidents reported it is concluded that the recommended actions are required to make HVDC converter valve halls secure against the consequences of fire damage. Most reported fire incidents relate to valve designs that were made before the publication of CIGRÉ Technical Brochure 136, suggesting that the recommendations within this report have substantially reduced the risk of fire within converter valves and valve halls. Another conclusion that can be drawn from the statistics of reported fire incidents is that the air sampling systems and/or UV detection systems, etc. have considerably contributed to avoiding major valve hall fires, although the statistics demonstrate that the fire alarm and trip levels must be more carefully adjusted during commissioning in order to detect any incipient fire as early as possible.

The following recommendations can be made:

1) Semiconductor valves should use materials and design practices that minimize the risk of fire and aim to prevent a fire from spreading within the valve.
2) Oil-filled equipment should be excluded from the valve halls.

In order to reliably detect fires and de-energise the equipment, a fully integrated fire detection and equipment supervision system should be installed to provide two or more (preferably independent) means of verifying that a fire exists, together with visual confirmation.

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