CABLES AND BUS BARS

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1.0 SCOPE

This data sheet provides guidance on the protection of cables against fire hazards created by occupancy exposures, and the protection of occupancies against fire hazards created by exposure from cables. This includes, but is not limited to, communication, power, distribution, and subsea cable. This data sheet also provides loss prevention recommendations related to the inspection, testing, and maintenance of electrical cables and bus bars.

This data sheet does not cover transmission networks.

1.1 Hazard

Cables and bus bars are primarily susceptible to fire and electrical hazards. Electrical failures can typically be attributed to manufacturing and installation defects, as well as operational lifecycle. Insulation deterioration can result from mechanical damage and aging, the latter often accelerated by processes such as thermal breakdown, electrical and water treeing, and partial discharge. Cable joints and terminations tend to be the weakest points in the system due to additional mechanical, electrical, and thermal stresses present. When cables or bus bars fail, the failure can lead to ignition of nearby combustibles as well as cable jacketing and insulation.

Plastic used as the cable jacket or as insulation for conductors is combustible, and many types of cable insulations, when involved in a fire, will continue to burn beyond the area of ignition. The type of insulation and the quantity and arrangement of the cables (horizontal or vertical) determine how rapidly the fire will spread and how much smoke will be generated. Several factors can increase the size of a loss, including lack of automatic fire protection, delayed discovery, combustible accumulations in cable trays, unprotected cable penetrations, and the loss of major process equipment for extended periods of time while waiting to replace the cables.

For additional information on hazards associated with cables and bus bars, refer to the following FM publications:

- Understanding the Hazard: *Grouped Cables* (P0218)
- Understanding the Hazard: *Fire in Electrical Rooms* (P0245)

1.2 Changes

October 2021. Interim revision. The following significant changes have been made:

A. Revised the scope to clarify which hazards are covered.

B. Reorganized Sections 2.1.1, 2.1.2, and 2.3.2.

C. Added guidance for protection of cables from exposure fire due to the occupancy.

D. Added carbon dioxide as an extinguishing system option for protection of the occupancy from a cable fire.

E. Added FM Approved cable coatings tested in accordance with the 2019 Approval standard as acceptable passive protection.

F. Revised figure and table number to reflect the section they are in.

2.0 LOSS PREVENTION RECOMMENDATIONS

2.1 Construction and Location

2.1.1 General

2.1.1.1 Use FM Approved fire stops where cables, cable trays, or bus bars penetrate fire-rated floors or walls. Provide a fire resistance rating equivalent to the rating of the wall or floor. Use FM Approved fire stopping installation contractors.

2.1.1.2 Route control, signal, and power wiring to minimize exposure to fire and explosion from the surrounding occupancy.

2.1.1.3 Install power cables in cable trays separate from control, signal, and instrument wiring.

2.1.1.4 Install cables and bus bars in accordance with internationally recognized standards and best industry practices.

2.1.1.5 When the occupancy or equipment requires redundant power supplies, they should be routed independently and not exposed to a common failure or exposure.

2.1.1.6 Route underground cables to provide accessibility for future maintenance or replacement.

2.1.1.6.1 Identify underground cable routes and maintain drawings of their locations.

2.1.2 Cable Trays

2.1.2.1 Stack trays vertically in order of voltage (highest voltage on top). Locate instrument and signal wiring in the lowest tray.

2.1.2.2 Use noncombustible cable trays.

2.1.2.3 Position cable trays and runs so they are within the sprinkler spray pattern.

2.1.2.4 To eliminate fire spread between trays, space noncombustible cable trays in accordance with Table 2.1.2.4 and Figure 2.1.2.4.

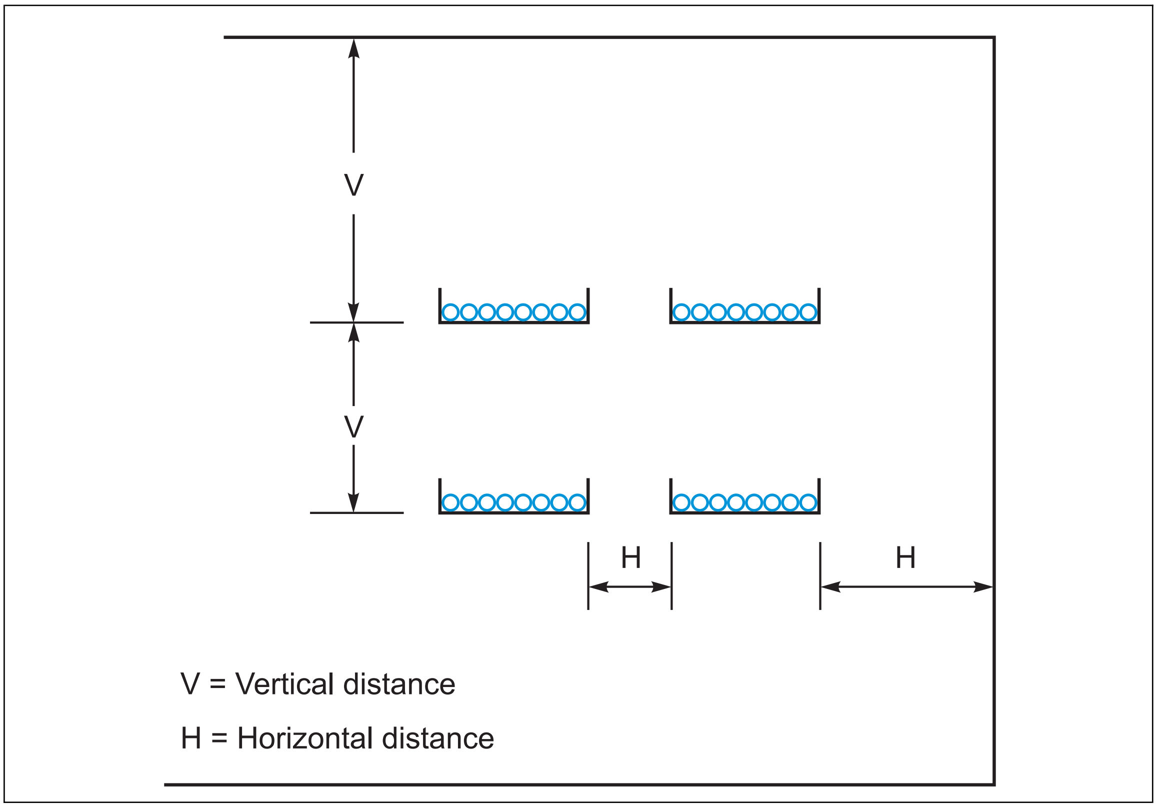

Fig. 2.1.2.4. Elevation view: uniform multilevel tray spacing

Table 2.1.2.4. Cable Tray Spacing

Tray Width (W)1 ft (m)	*Vertical Separation Distance (V)*[2]	*Horizontal Separation Distance (H)*[3]
0.5 ft (0.15 m)	4 ½ W	1 ½ W
1.0 ft (0.30 m)	3 ½ W	1 ½ W
1.5 ft (0.46 m)	3W	1W
2.0 ft (0.61 m)	3W	1W
2.5 ft (0.76 m)	2 ½ W	1W
3.0 ft (0.91 m)	2 ½ W	1W

Note 1. W is the width of the cable tray.
Note 2. Same guidelines apply for vertical separation distance from a ceiling.
Note 3. Same guidelines apply for the horizontal separation distance from a wall.

2.1.2.5 Space fiberglass reinforced (FRP) cable trays in accordance with the NFPA 70, National Electric Code, and the manufacturer's guidelines.

2.1.2.6 Provide covers or enclosures to keep debris and other combustible material out of cable trays, where needed.

2.1.2.6.1 Use covers that are made of material compatible with the tray.

2.2 Occupancy

2.2.1 Inspect and maintain cable trays free of combustible material, such as rags, paper dust, wood chips, and oily residue, by cleaning them on a regular basis.

2.2.2 Remove discontinued cable and wire when renovating existing spaces.

2.3 Protection

2.3.1 Protection of Cables from Exposure Fire

2.3.1.1 Protect cables that provide critical power or control functions using one of the following methods:

2.3.1.1.1 Route the cables so they are not exposed to a construction or occupancy fire.

2.3.1.1.2 Route the cables underground or encase them in concrete per Section 2.1.1.6.

2.3.1.1.3 Locate cables in a fire-rated enclosure designed to limit the cable exposure temperature to less than its maximum operating temperature.

A. Provide an airgap between the surface of the enclosure and the cables.

B. Design the rating of the enclosure for the expected duration of the fire or operational duration requirement of the cable.

C. Set the fire duration to either the water duration for the occupancy or in accordance with the occupancy/hazard-specific data sheet, but not less than one hour.

D. Enclose the cables for 20 ft (6.1 m) beyond the fire area.

As an example, an enclosure consisting of 2 layers of 5/8 inch (16 mm) fire-rated gypsum (e.g., Type X, EN 520 Type F, or equivalent) with staggered joints will limit the interior gypsum surface to a maximum temperature of 250°F (139°C) for 2 hours when exposed to a non-ignitable liquid exposure fire. If the enclosure will be exposed to an ignitable liquid fire, this same construction will provide approximately 1-hour of protection.

2.3.1.1.4 Provide an FM Approved cable wrap (FM 3973, Blankets for Grouped Electrical Cables) around the exposed cables rated for the expected fire duration. The fire wrap should include the flexible conduit used to route the cables. Provide the fire wrap for 20 ft (6.1 m) beyond the fire area. Verify the wrap will not result in cable de-rating.

2.3.2 Protection of Occupancy from Cable Fire

2.3.2.1 Provide one of the following methods of fire protection for areas containing combustible grouped cable:

A. Automatic Sprinklers

B. FM Approved gaseous extinguishing system

C. Passive fire protection

2.3.2.2. Install automatic sprinkler or water spray protection in accordance with Data Sheet 2-0 or Data Sheet 4-1N and the following:.

A. Arrange sprinklers or water spray nozzles so any elevated cable trays or cables will be covered by their spray pattern.

B. If cable is the only combustible material in the area, design protection to provide 0.2 gpm/ft^2 over 3,000 ft^2 (8 mm/min over 279 m^2) at ceiling level with a temperature rating of 165°F (74°C) on 130 ft^2 (12 m^2) spacing.

C. If cable is not the only combustible in the area, refer to the appropriate occupancy- or equipment-specific data sheet for guidance on sprinkler types, ratings, and spacings.

2.3.2.2.1 If ceiling-level obstructions exist, such as high-level cable trays (see Figure 2.3.2.2.1), install sprinklers in every aisle or walkway, and in accordance with Data Sheet 2-0.

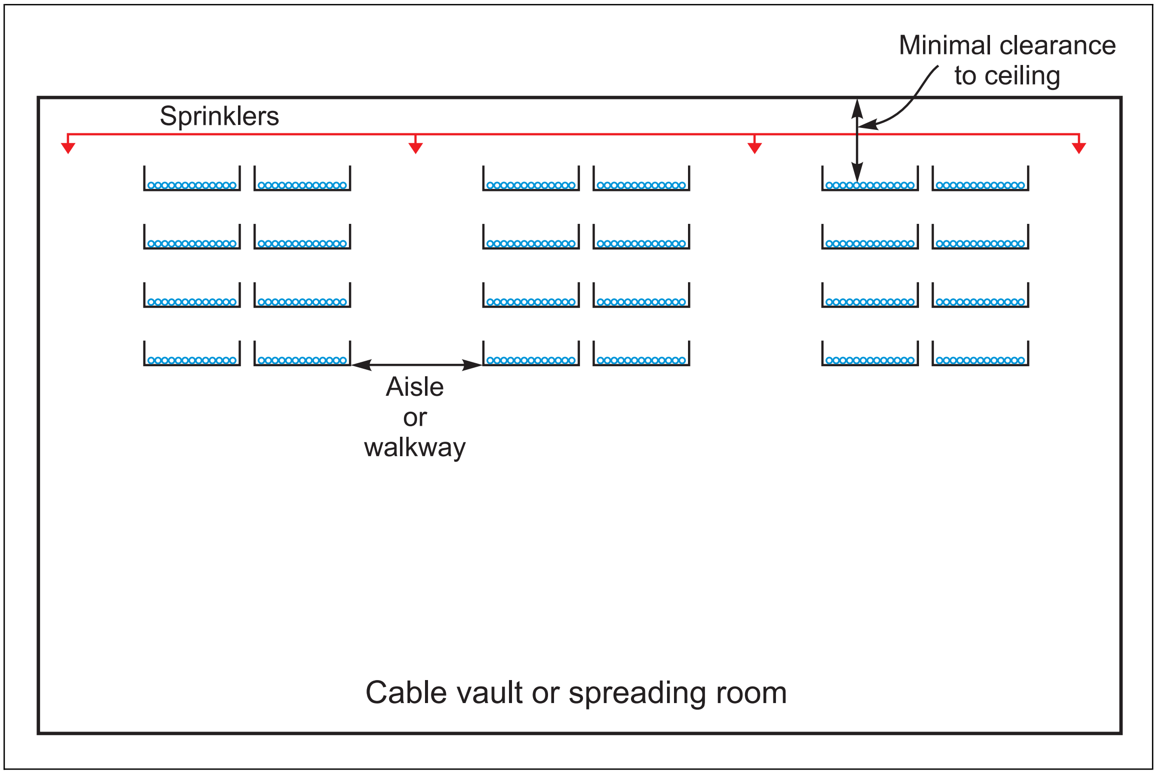

Fig. 2.3.2.2.1. Cable vault with obstructed ceilings and adequate sprinkler spacing in aisles or walkways

2.3.2.2.2 For cable tunnels or outside cable trays, design sprinkler protection using a density of 0.2 gpm/ft^2 (8.1 mm/min) over the most remote 100 linear ft (30.5 m) up to 3000 ft^2 (279 m^2).

2.3.2.3 Install a total flooding, FM Approved, gaseous fire extinguishing system in accordance with the following:

A. Cables are in rooms or enclosures only.

B. No other combustibles are in the room.

C. The room is not normally occupied.

D. If the electrical cables/equipment remain energized, use a gas concentration validated for use with energized electrical equipment.

E. If all cables within a room/enclosure are arranged to be deenergized by the fire detection system, use a gas concentration validated for a plastics fire.

F. Install a clean agent system in accordance with Data Sheet 4-9, *Halocarbon and Inert Gas (Clean Agent) Fire Extinguishing Systems*.

G. Install a carbon dioxide extinguishing system in accordance with Data Sheet 4-11N, *Carbon Dioxide Extinguishing Systems*.

2.3.2.5 Fire protection is not needed if one of the following passive means of protection is provided:

A.The cable is FM Approved with a rating of GP-1 as listed in the *Approval Guide*.

B. The cable or cable tray is wrapped with FM Approved wrap for grouped electrical cables (FM 3971, *Fire Protective Coatings and Wraps for Grouped Cables*).

C. An FM Approved cable coating (FM 3971, *Fire Protective Coatings and Wraps for Grouped Cables*) is applied in accordance with the *Approval Guide* and manufacturer's instructions.

2.3.3 Detection

2.3.3.1 Provide FM Approved smoke detection for indoor areas containing combustible grouped cable and/or combustible cable trays.

A. Arrange detection to alarm at a constantly attended location.

B. For areas with business-critical cable, consider the use of Very Early Warning Fire Detection (VEWFD). VEWFD will enable detection of an incipient fire and an opportunity to initiate manual response and possible emergency response plans.

2.3.3.2 Provide FM Approved line-type heat detection within outdoor cable trays tied to a constantly attended location.

2.4 Operation and Maintenance

2.4.1 Operation of Cables and Bus Bars

2.4.1.1 Operate cables and bus bars within their designed specifications and ratings, including operating voltage, and temperature limits, ultra violet ratings and weather resistance, direct burial and other exposures.

2.4.1.2 Include cables and bus bars in an up-to-date plant load study and provide adequate overcurrent, short circuit, and ground fault protection. Refer to DS 5-19 and DS 5-20 for electrical protection and system studies.

2.4.1.3 Keep cables and bus bars clean, cool, and dry, and all connections tightened in accordance with the relevant industry standard or to the manufacturer's recommendations.

2.4.2 Maintenance of Cables and Bus Bars

2.4.2.1 For cables and bus bars that are key to the continuity of operations, establish and implement an inspection, testing, and maintenance (ITM) program. See Data Sheet 9-0, *Asset Integrity*, for guidance on developing an asset integrity program. The program should include monitoring of the insulation system. Use this information to plan repair or replacement of compromised insulation systems prior to faulting in service. Review the ITM program when the electrical system is modified, and when events occur that require the program to be updated.

2.4.2.2 Perform an infrared survey on cable splices and connections every 1 to 3 years. Refer to DS 5-19 and DS 5-20 for general guidance on infrared surveys.

2.4.2.3 Cables and Bus Bars Operating Up to and Including 1000 V

2.4.2.3.1 Perform inspection, testing, and maintenance in accordance with Data Sheet 5-20.

2.4.2.4 Cables and Bus Bars Operating Over 1000 V

2.4.2.4.1 Visually inspect exposed sections of cables, splices, and connections on a regular basis, at minimum quarterly, depending on their age and condition. Verify the following:

A. Cable supports are intact.

B. Where possible, ground connections for cable screen, shielding, and metallic jacketing, are intact.

C. There is no physical damage, such as overheating, corona, discoloration, crazing, cracking, corrosion, contamination, or embrittlement on splice body and connector body insulation and/or the insulation along the length of a cable.

2.4.2.4.2 Perform inspection, testing, and maintenance for bus bars in accordance with Data Sheet 5-19.

2.4.2.4.3 Perform the tests identified in Table 2.4.2.4.3 every 3 to 5 years.

The frequency of testing will depend on previous results and, therefore, it is necessary to perform trending analysis (i.e., more frequent testing for cable systems with a history of defects). DC high voltage withstand testing (DC Hi-pot) can be destructive to extruded insulation systems (e.g., XLPE and EPR). A DC hi-pot test can leave high-voltage DC charges in small voids of the insulation system and cause cables to fail while in service just after having passed the DC hi-pot test. Very low frequency (VLF) testing and dampened AC (DAC) testing or rated frequency testing are suitable for extruded insulation systems. See Section 3 for additional information on Hi-pot testing.

Note: Insulation dissipation factor and partial discharge tests provide value for systems that operate over 4 kV.

Table 2.4.2.4.3 Descriptions of Electrical Tests[1, 2]

Test	*Comments*	*Acceptance Criteria*
Insulation Dissipation Factor (tan δ)	The test is typically performed at the systems phase to ground voltage level with rated power frequencies or at frequencies less than 0.1 Hz.	Trend the tan δ value over time. Cable systems that are in good condition have tan δ values that are independent of time. Thus, changes in tan δ with time can indicate that aging has occurred.
Offline Partial Discharge (PD)	PD will occur in the cable insulation and in cable accessories such as splice bodies and connector insulation. Parameters of PD detection are amplitude, pattern, decay of voltage, and extinction of voltage. This test is typically performed at voltages higher than the rated phase to ground voltage.	Compare PD parameters to historical data for that cable system or to cable systems under the same or similar conditions. Trend the recorded data for future use. The measured PD characteristics, for example phase resolved PD patterns (pulse repetition rate vs phase angle vs magnitude), can be analyzed in various ways based on experience and knowledge of the types of defects anticipated in the cable type and accessories to provide insight into the condition of the cable system.
Insulation Resistance (IR)	Perform this test between the outer-most metallic shield and earth. This test should be done at 1000 V or more depending on the cable operating voltage and the condition of the cable.	Compare the resistance to historical data for that cable or to cables under the same or similar conditions. An increase in resistance over historical readings indicates a deterioration of the outer metallic shield, over time damage to the outer shield will result in damage to the insulation.

Note 1. Testing cables at lower voltage to collect data and then working up to the rated voltage in steps is useful in understanding the total health of the insulation system.
Note 2. IEEE 400-2012 and IEEE 400.2, 400.3, and 400.4 provide detailed guidance for performing high-voltage withstand testing. There are too many scenarios of cable types and conditions to list the details for quantifying a healthy insulation system here. It is imperative that either the cable owner or the contracted third party assessing and verifying the health of the insulation system has an in-depth knowledge of these standards and the cable systems they are testing.

2.4.3 Subsea Cable

2.4.3.1 Protect newly installed subsea cable by burying it in the seabed or providing other mechanical means to protect the cable.

2.4.3.2 Perform a subsea in-service survey on the cable annually to monitor the state (such as re-exposure, free spanning) and route of the cable. The frequency of cable burial inspections depends on the seabed dynamics. In the case of sand waves or scour hole developments due to strong tidal or wave action, increase the frequency to twice per year. Compare the collected data through periodic subsea surveys with the planned data and post-installation survey data.

2.4.3.3 Provide a distributed temperature measurement system (DTS) to monitor temperatures for hot-spots, cold-spots, and other irregularities along the cable. The comparison of the temperature profile with previous measurements can detect cable exposure due to wash-away of sediment or free-span.

2.4.3.4 Provide online partial discharge (PD) monitoring of subsea power cable systems to monitor PD activities in the cable insulation system or in a cable joint due to cavity, water tree, contamination, and other flaws.

2.5 Contingency Planning

2.5.1 Equipment Contingency Planning

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

In addition, include the following elements in the contingency planning process specific to cables and bus bar:

A. Actions required to isolate damaged conductors, splice bodies and connectors to allow the rest of the system to be put back into operation.

B. Emergency replacement of custom-made or specialty cables, bus bars and splicing kits. This includes long lead-time or special-order items.

2.5.2 Subsea Cable

2.5.2.1 For subsea cable, include the following elements in the contingency planning process specific to subsea cable repair and replacement:

A. A contract to have a repair vessel available when repair is needed. In some cases, the contract might not guarantee the availability of the repair vessel. The repair plan needs to include alternatives for such a situation.

B. Appropriate electronic gear to locate the fault quickly. Time domain reflectometry pulses can be used to determine the distance down the cable at which the fault occurred. However, this technique, if it is intended to be used, must be considered in advance so the devices that can conduct such a test can be located.

C. A contract to have an experienced repair team available, including an experienced jointer, when repair is needed. If the repair team is traveling to/from different global regions to perform work, verify all local working restrictions are understood and steps are taken to address these restrictions to permit the work while the team is traveling.

D. Appropriate repair tools, such as cable jointing equipment, de-burial equipment, and burial equipment.

2.5.3 Sparing

2.5.3.1 Sparing can be a mitigation strategy to reduce the downtime caused by a subsea cable breakdown depending on the type, compatibility, availability, fitness for the intended service, and viability of the sparing. For general sparing guidance, see Data Sheet 9-0, *Asset Integrity*.

2.5.4 Equipment Breakdown Spares

2.5.4.1 Equipment breakdown spares for subsea cable are spares intended to be used in the event of an unplanned outage of subsea cable to reduce downtime and restore operations. Provide the following equipment breakdown spares for subsea cable:

A. Subsea cable with sufficient length for at least one repair operation. When the subsea cable is connected to a land-based cable, provide spare land cable with sufficient length for at least one repair operation.

B. Accessories such as armor hang-offs, subsea repair splices (joints), sea-land power transition joints, and armor anchoring devices.

2.5.4.2 Maintain the subsea cable equipment breakdown spares' viability per Data Sheet 9-0.

3.0 SUPPORT FOR RECOMMENDATIONS

3.1 Cable Fire Behavior

3.1.1 Cable Tray Spacing

Cable trays vary in width and depth and may be run horizontally or vertically. They may be constructed of aluminum, galvanized steel or stainless steel.

Tray widths vary from 6 in. (0.15 m) to 3 ft (0.91 m) with loading depths of 3 to 6 in. (7.6 to 15.2 cm). A study was completed to determine the vertical and horizontal spacing needed between horizontal cable trays to prevent fire spread from one tray to another. Calculations for non-propagating cable were based on the assumption that an area equaling the width of the cable tray would be involved. For self-propagating cable, the assumption was that a fire could involve an appreciable length of the cable tray. Exposure to adjacent cable trays was determined using heat release rates, flame heights, and critical heat flux for ignition determined using the FM Fire Propagation Apparatus.

3.1.2 Smoke Detection, Manual Response, and Nonthermal Damage Considerations

Smoke is a major factor in the ability of manual firefighting response to control a cable fire. Large-scale cable fire tests were conducted at the FM Research Campus for the Electric Power Research Institute (EPRI). A short time after the start of each test, the building filled with smoke, making it difficult to see the fire. The test center is a large building similar in size to a small aircraft hangar (2,250,000 ft3 [63,700 m3]).

Accessibility and rapid detection are needed for effective manual response.

Locations not likely to have adequate access for manual response include the following:

- Cable tunnels
- Cable spreading rooms
- Underground cable vaults
- Areas above suspended ceilings

Rapid detection is also important. Smoke and heat detection are most commonly used. Smoke detection systems in increasing order of sensitivity are: (a) photoelectric and ionization type smoke detectors, (b) beam type smoke detectors, and (c) very early warning fire detection (VEWFD) systems, such as air-sampling systems. Heat-detection systems in increasing order of sensitivity are (a) automatic sprinklers at ceiling levels, and (b) line-type heat detectors located within each tray.

When polyvinyl chloride insulation is involved in a fire, one of the products of combustion is hydrogen chloride gas, which forms aqueous hydrochloric acid with water vapor in the air. Sensitive relays, instruments, control apparatus, copper bus bars, and metals such as iron, brass, aluminum, zinc, and alloys that are exposed to the fumes are subject to corrosion and damage.

In reinforced concrete structures, chlorine contamination forms hygroscopic calcium chloride in the lime of the cement structure and attacks the reinforcing rods. Concrete may spall months or years after the fire due to corrosion of the reinforcing rods.

3.1.3 Protection of Cables from Exposure Fire

The best approach is to arrange cables so they are isolated in separate fire areas, either via independent routing of the cables or by routing them underground.

3.2 Electrical Field Tests

3.2.1 Insulation Resistance (IR) and Polarization Index (PI)

IR and PI measurements provide quantitative and relatively repeatable results. The test requires the cable to be offline, and disconnecting the cable terminations for attachment of the testing apparatus. IR is very sensitive to temperature and moisture; therefore, in addition to applied voltage, temperature and humidity at the time of the test must be recorded and the results normalized to a base temperature. IR/PI results and data trending should be considered along with the results from one or more other cable tests to assess the condition and rate of degradation of cable insulation.

3.2.2 Offline Partial Discharge

This test detects significant partial discharge sites above a specified detection level, magnitude or severity of the defect at each partial discharge site, and the location of each of the significant partial discharge sites within the insulation system. The test requires the cable to be offline, and disconnecting the cable terminations for attachment of the testing apparatus. Interpretation of the results is complex and best performed by experienced engineers.

3.2.3 Very Low Frequency (VLF) AC Withstand Voltage Test

This test involves the application of a low-frequency (0.1- 0.01 Hz) AC voltage across the cable insulation that it must withstand for a specified amount of time without breakdown. The test voltage is typically higher than operating voltage. VLF tests can be performed for diagnostics. Some diagnostic test methods are listed below:

- VLF tangent delta measurement (VLF-TD). This test measures the tangent delta of the cable insulation system at an elevated voltage.
- VLF differential tangent delta measurement (VLF-DTD). This test refers to the tangent delta tip-up between measurements at 50% and 150% rated voltage.
- VLF tangent delta temporal stability (VLF-TDTS). This test measures the variation of tangent delta with time at a particular voltage (TDTS), usually over a period of some minutes.

The measured values of VLF-TD, VLF-DTD, and temporal stability (VLF-TDTS) are primarily influenced by the condition (age, contamination, and moisture ingress) of the various cable system components (accessories, cable insulation, and metallic shield). A high value measured by any of these tests would indicate deterioration in the condition of the cable.

3.2.4 Withstand Testing

There are two approaches to withstand testing of cables and the accessories that make up the insulation system:

A. Withstand testing is performed at the working voltage of the system or starting at a lower voltage and stepping up the voltage until the working voltage is reached. Testing in this manner provides an opportunity to gather information on the health of the insulation system with less risk of damage. The health of the insulation system is gauged by performing advanced diagnostic testing and monitoring the dielectric response during the withstand tests. The data from this type of testing is studied and compared to previous results then trended to predict the health of the insulation system, and when to schedule maintenance activities. There is a higher risk that an insulation system evaluated in this manner will fail while in service causing non-scheduled outages.

B. Withstand testing is performed at voltages higher than the working voltage of the insulation system. Testing voltages can change based on the age and accessories included in the insulation system, e.g. a new system could be tested at 2 or 3 times the working voltage, where an aged system could be tested at 1.5 times the working voltage. This testing is intended to cause the weak sections of the insulation system to fail so they can be repaired during the scheduled maintenance and testing activities. Repair staff and replacement components are required. This approach is intended to ensure the cable system is suitable and reliable to operate at the working voltage, reducing the risk of in service failures.

3.2.5 Damped AC test (DAC)

DAC is used for benchmarking, maintenance testing and diagnostics testing on cable types operating from 5kv to 230kv. DAC is also used for cable operating over 230kv on a provisional basis and per IEEE for study purposes only.

DAC testing can be performed in such a way to limit damaging effects to a cable and without reducing the life expectancy of the insulation system. Typically, the DAC test consists of 50 sets of excitations to be applied to a cable under test, however, this number may change based on the purpose of the test, the historical data of the cable, and the age of the cable. The test consists of charging the cable to a predetermined voltage level, generally higher than rated voltage for Benchmarking, however, the voltage level may be lower for Maintenance and Diagnostic testing and then discharged into an inductance (see Figure 3.2.5 below).

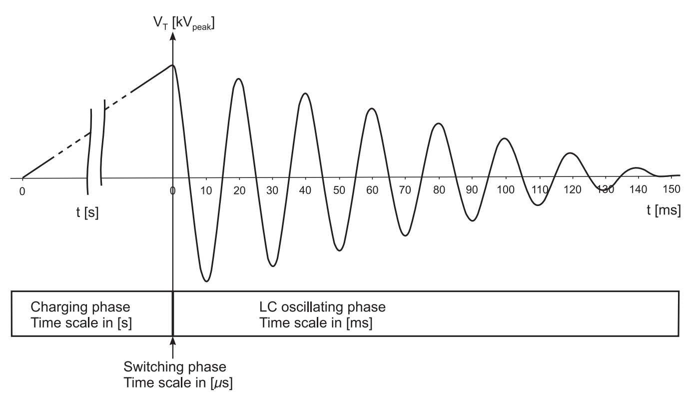

Fig. 3.2.5. Three stages of one DAC excitation; charging, switching, and discharging through inductance

3.2.6 Insulation Dissipation Factor (DF)

Insulation dissipation factor is the same as “tan δ”, the rate at which testing voltages discharge through an inductor. DF will change as an insulation system ages. Determining the condition of an insulation system is complex and will require comparison of multiple sets of data, including adjacent conductors of the same type vintage and operating conditions, and historical data for the system. There are no fixed rules for determining degradation of an insulation system, however, a common practice is to record and observe DF values over time for trending purposes. Only trained personnel can assess the health of an insulation system after careful analysis of the data generated while monitoring DF. This assessment can be valuable and influential in determining the needed for partial maintenance of a cable system.

3.3 Online Condition Monitoring

3.3.1 Infrared Thermography (IR)

IR thermography involves accurately measuring infrared radiation emitted from thermally hot electric equipment and converting infrared radiation into a visual image or thermogram. These devices can identify hotspots, which could lead to accelerated degradation of electrical cable systems, even when temperature differences are small. Additionally, several thermal images can be analyzed over a period of time and the associated temperature trended with time. IR thermography can identify faulty cables, connectors, splices, or terminations that are generating excessive heat indicative of a degraded high resistance connection due dirt, corrosion, or other contamination. Cracked or damaged insulating or jacket materials can also be identified by these techniques.

3.3.2 Time domain Reflectometry (TDR)

Time-domain reflectometry (TDR) is a measurement technique used to determine the characteristics of electrical lines by injecting a pulse down one end of the line and observing the reflected wave forms. It is used to characterize and locate faults in cables. Basic TDR displays location of impedance change, which could be a fault or water intrusion. Advanced TDRs can display the actual waveform or “signature” of the cable on a screen, which will show the pulse transmitted down the cable from the instrument and any reflections that come back to the TDR from discontinuities or impedance variations along the length of the cable. The signature TDR waveform can be trended with a baseline to evaluate impeding concerns with the cable.

3.3.3 Distributed Temperature Measurement System (DTS)

A DTS is an optical fiber-based temperature sensor incorporated into the power cable, or installed alongside the power cable. Such a system can monitor the temperature along the power cable. A land-based device evaluates the optical signals and displays a temperature profile over the cable length.

3.3.4 Strain Monitoring

Strain measurement on Subsea cables can detect in real-time physical actions on the cable such as the impact of an anchor or fishing gear, or movement in the seabed. Monitoring strain and/or impacts on Subsea cables, even if the cable has not been severely damaged at the time of impact or seabed movement, can help to identify if a degradation of the insulation system has begun.

3.4 Subsea Cable Failure Modes

The historical loss incidents involving subsea power cables indicate the following failure modes:

A. Re-exposure of the buried cable due to seabed variation conditions such as sand waves or scouring

1. Sand waves are caused by current and wave action, resulting in the formation of dune systems on the seabed that slowly travel across the seabed. They can assume heights from only a few inches (centimeters) to several feet (meters). A cable buried in a sand wave area is expected to be exposed and reburied at various sections along the cable route as time passes. If the dimensions of the sand waves are sufficiently large, extensive spanning can also result. Local or global scouring can also result in the exposure of cables, and, in case of very localized scouring, possible spanning of the cable. Exposing the cable will render it vulnerable to other hazards such as shipping anchors or dropped objects. Spanning introduces current-induced vibrations and additional tension in the cable. The added tension in combination with vibration-induced fatiguing can result in breakage of the cable.

B. External threats due to fishing activities, ship anchors, dropped objects, or dredge activities

1. Based on a CIGRE survey in 2009, 85% of subsea cable failures were due to external threats. Almost 50% of damage was known to be caused by anchors.

2. Fishing equipment can typically penetrate the seabed up to 2 ft (0.6 m), and in some cases up to 5 ft (1.5 m) depending on its type, which can damage any cable exposed on the seabed. Ship anchors can be dropped onto a cable due to mishaps or emergency anchoring. Depending on the ship size, the penetration depth of ship anchors can be up to 16 ft (4.9 m) in a muddy seabed and up to 8 ft (2.4 m) in a sandy sea bed. The cable can be easily damaged when hit by ship anchors.

3. Dropped objects are mainly due to mishaps to an offshore installation where heavy lifting or other marine operations take place. If these objects are heavy enough, the impact when they hit the seabed can result in some penetration into the seabed. If a cable is present at such location, considerable damage to the cable can result.

C. Insulation failure due to aging, fatigue cracks of lead sheath, water tree formation, partial discharge activity, and electrical trees

1. Water trees are tree-like growths consisting of water-filled micro voids that can grow in most extruded insulations when they are exposed to moisture and an electric field. The water trees that grow from water-filled voids in the insulation are called bow-tie trees. Those trees initiated at interfaces are known as vented or streamer trees. When water trees grow such that they bridge a considerable portion of the insulation, and become possible sites for inception of partial discharge (PD). Overvoltages produced by switching transients or lightning surges may increase electrical stress in a water tree to a level that will cause initiation of PD.

2. Partial discharges (PD) are the local breakdowns of the gas in voids, cuts, cracks, fillers, and contaminants, and delaminations at interfaces. Prolonged PD activity will cause pitting of the surfaces first, and then concentrate in the pits to form electrical trees, which complete the failure.

3. An electrical tree is a network of fine gas-filled channels that propagate relatively quickly through the insulation to cause failure by the action of PD. Electrical trees can be detected by PD measurements; trees have characteristic PD patterns that vary with time.

D. Failure of joints due to inadequate design, poor joint assembly work or adverse weather conditions during assembly

E. Movement of the sea bottom due to subsea landslides or earthquakes

F. Improper installation or handling of the cable

G. Missed features or inaccurate seabed characterization due to incomplete analysis of existing data or where an existing sensor was not operating correctly.

H. Improper design of J-tubes

1. J-tubes should be carefully designed to account for the characteristics of the cable, including bending radius, sufficient space for heat absorption, ensuring the that the inside path up the J-tube is free from snags, and that sufficient planning is done to ensure the appropriate power in the winches.

3.5 Subsea Cable Protection Against External Threats

Subsea cable failures due to external threats, particularly due to fishing activities or ship anchors, are the most common cause of subsea power cable failure.

The best protection against external threat is to bury the subsea cable below the depth which the threat can reach. Only a small depth (3.3 to 6.6 ft [1 to 2 m]) is required for the more frequent hazards caused by fishing activities. However, 3.3 ft to 6.6 ft (1 to 2 m) burial depth is not a truly effective measure against anchors dropped from large ships, as modern anchors can dig deep into the seabed. Selection of burial depth is a complicated task and needs to be based on the following major factors:

A. From a cable design viewpoint, the burial depth of at least 3.3 ft (1 m) (6.6 ft [2 m] for HVDC cable) is based on several requirements, but mainly from heat dissipation. Beyond this value, increased burial is not recommended because the current capacity continues to degrade with depth.

B. From a cable installation viewpoint, the burial depth of 3.3 to 6.6 ft (1 to 2 m) is customary and achievable with reasonably sized equipment without significant bottom disturbance, except in special circumstances.

C. From the navigation risk viewpoint, the industry developed the concept of a burial protection index (BPI). This BPI recognizes that different seabed soils react differently to the penetration of fishing gear and anchors (see Figure 3.5.C).

BPI = 1 is considered suitable for water depths greater than 330 ft (100 m) where anchoring of ships is unlikely or where shipping and anchoring are prohibited.

BPI = 2 would provide protection from vessels with anchors up to about 4400 lb (2,000 kg). This may be adequate for normal fishing activities, and small merchant ships, but would not be suitable for larger ships' anchors.

BPI = 3 would be sufficient to protect from anchors of all but the largest ships. It would be suitable for anchorages, at the entrances of harbors where ships have been known to accidentally deploy an anchor, and heavily trafficked shipping channels, with adjustments made to suit known ship anchor sizes.

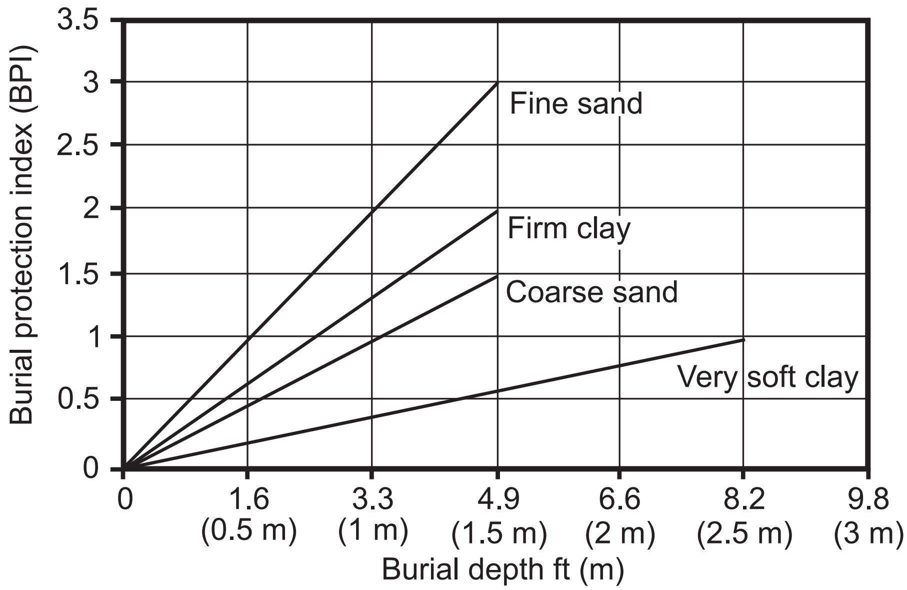

Fig. 3.5.C. Illustration of burial protection index

3.6 Repairing Subsea Cables

Repairing subsea cables can be very challenging. There are few repair vessels for subsea power cables in the world. Those may already be under contract with utilities to standby in specified locations, and as a result the ability to obtain such a vessel may involve significant delays. (see Figure 3.6).

Thus, it is a good strategy to have an equipment contingency plan to repair the subsea cable so that a vessel is available when needed. It is generally easy to find a vessel that can unbury the cable, and to re-bury it after repair, but the repairing itself may take a special arrangement that should be worked out ahead of time.

Since almost all the subsea cables are non-standard products, it is important to have equipment breakdown spare cable as part of the equipment contingency plan of the same type manufactured with the original cable and stored for potential repairs.

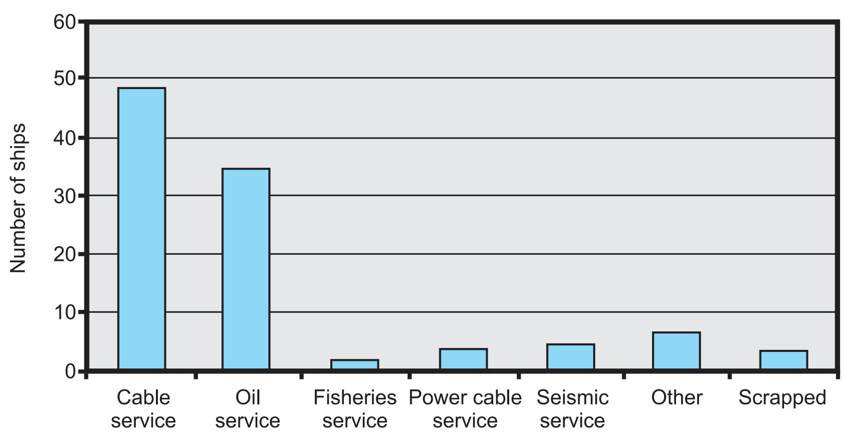

Fig. 3.6. Cable ships by market

3.7 Loss History

An analysis was conducted on grouped cable losses over a recent 10-year period. The causes of fire loss, in terms of frequency, are shown in Figure 3.7.A. The results of a similar analysis of electrical breakdown losses are included in Figure 3.7.B.

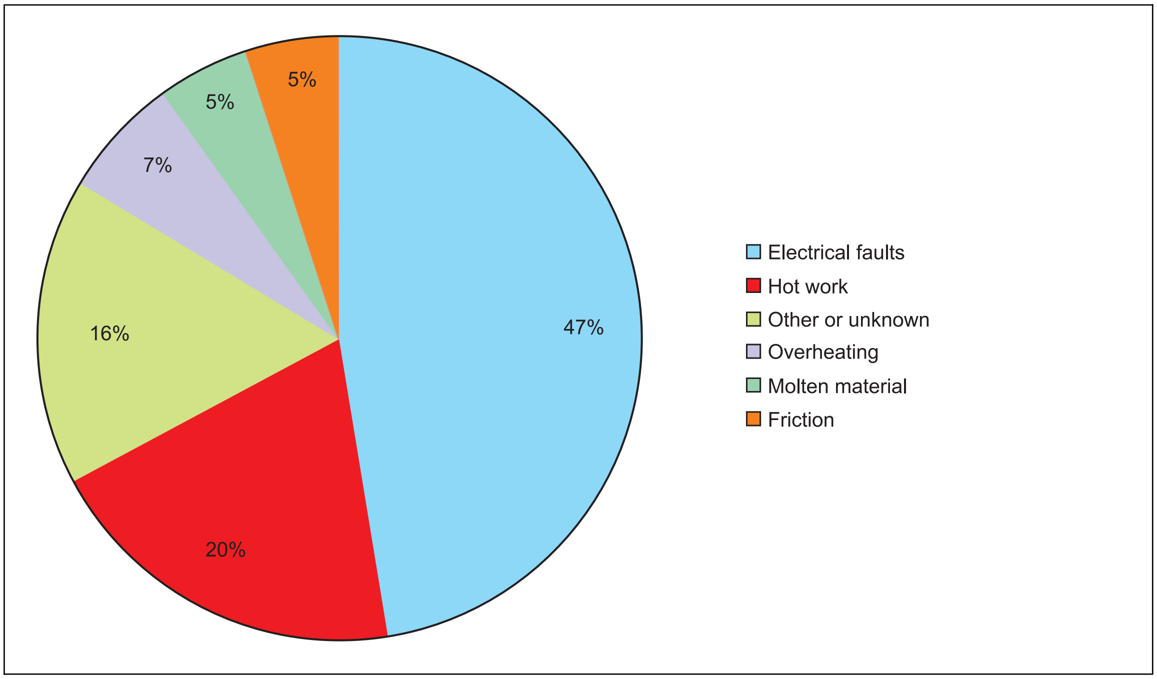

Fig. 3.7.A. Fire causes by frequency

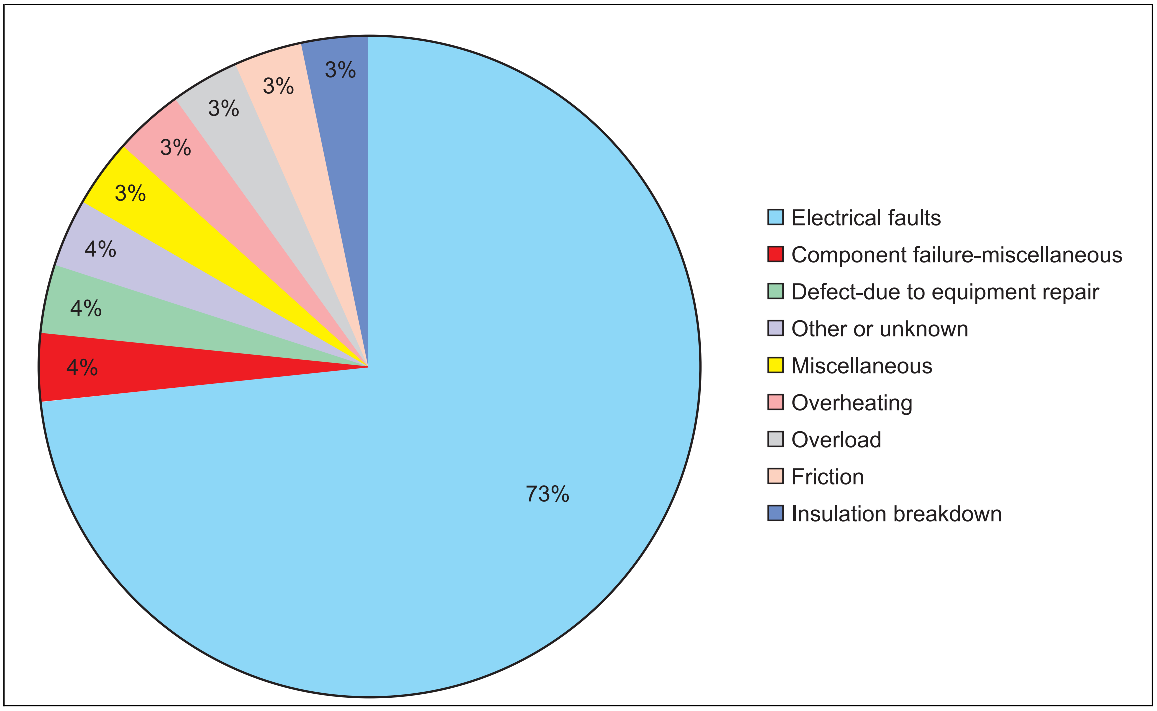

Fig. 3.7.B. Electrical breakdown by frequency

3.8 Illustrative Losses

3.8.1 Lack of Adequate Cable Fire Stopping

The main circuit breaker for a 4 kV bus failed “violently” as the ID fan speed was changed. Operators were switching ID fans from slow to fast when they heard the circuit breaker fail. This ignited a fire in the switchgear cabinet, connected bus, and nearby power and control wiring. The fire spread through unprotected cable openings into the computer room above containing boiler logic controls. The circuit breaker was a 2,000 amp air blast type that controlled one of the ID fans for a coal fired boiler powering a turbine generator. This is one of three turbine generators at an electric utility generating station. Also damaged were five other breakers, 15-20 cable trays, and a steel truss and section of metal pan floor. No cause was given for the electrical failure in the switchgear. The public fire department was not called until 15 minutes after the fire was discovered.

3.8.2 Oil-Filled Cable Fire at a Hydro-Electric Plant

A phase-to-ground fault occurred on an oil-filled cable of a turbine-generator unit. The cable, located in the upper portion of a cable shaft, ignited the oil-impregnated layers and adjacent cables in the 860 ft (260 m) vertical shaft. Two sets of three, 245-kV oil-filled cables and auxiliary equipment in and around the cable shaft were damaged. Intense heat damaged all cables in the shaft. Even though the entire 860 ft (260 m). length of cabling was not fire damaged, these cables could not be spliced, so the entire length of the six cables had to be replaced.

This incident resulted in several units being taken offline; however, within hours, only two turbine-generator units were inoperable. One of the units was restarted about four months later, with the last unit expected to be restarted seven months after that.

3.8.3 Ground Fault Shuts Down Paper Mill

A paper mill was totally shut down by a sequence of events after an electrical ground fault took place at a cable connection in a disconnect switch cabinet. The fault was apparently due to insulation failure at a stress cone (a cone shaped insulation applied over cable insulation at the connection point). The cable involved was fed from the main bus No. 1, which supplied power to the steam plant at the mill. The ground fault relay for the circuit breaker closest to the fault did not operate. Instead a breaker further upstream operated. This breaker interrupted utility power for bus No. 1. Fans for all but one of the plant boilers were shut down. A significant additional factor was that backup battery power supply for the boiler control room panel went dead. Operators were unable to see the panel and could not keep the remaining boiler on line. Loss of steam shut down the plant.

3.8.4 Cable Fire in a Paper Mill

An integrated paper mill lost all power due to a fire involving cables. The fire started in a pipe tunnel, when wood planking from scaffolding left over from maintenance was ignited by an uninsulated steam line. The pipe tunnel had large steam lines as well as power and communication cables running through it to other parts of the mill. The fire spread to the cable tray below the wood planking and through the pipe tunnel to an electrical control room.

The original smoldering fire was found by plant personnel and reportedly extinguished, without notifying the mill fire brigade or mill management. A few hours after initial notification, operators began receiving numerous process trips and alarms. It was determined that a cable fire had continued in the electrical control room. After notification of the fire brigade and mill management, the operators manually initiated the Halon fire protection system as the automatic system had been improperly impaired. The electrical systems to the affected area were sequentially disconnected resulting in a full black plant condition (entire mill was shutdown with no power).

Damage resulted in approximately 3 miles (5 km) of cables being replaced, as splicing was not considered cost effective due to the inaccessibility of the cables within the cable tunnel. Minimal heat damage was done to the mill’s buildings. Some minor damage to other equipment occurred due to the immediate shutdown of mill power. The three paper machines were shut down for over 2 days, and the sale of power from the utility was interrupted. Improper emergency communication, inadequate scaffold maintenance protocols, lack of adequate impairment handling for the automatic Halon system, and failure to fire stop wall and floor openings were all negative factors that increased the loss.

3.8.5 Cable Fire in Super Computer Manufacturing, Product Testing Lab

A fire occurred in electrical cabling under a raised floor in the product testing laboratory of a 25,000 ft^2 (2,300 m^2) super-computer manufacturing facility. The facility engaged in the assembly and testing of cluster based super-computing systems primarily for academic, governmental and commercial uses. Functional testing of all computer systems manufactured occurred in an approximately 4500 ft^2(420 m^2) specially designed testing laboratory in a separated area within the facility.

The day of the event, a smoke alarm in the testing laboratory area of the facility went off notifying plant security officials. The smoke alarm tripped the HVAC units within the test lab. Plant officials arrived to find light smoke and a strong smoke odor in the test lab, however, most computer systems under test continued to operate. Plant personnel also restarted the room HVAC systems.

Further investigation revealed fire damage to electrical cabling and a power distribution unit located under the raised tile floor near the middle of the room. Two 30 amp fuses within the power distribution unit were found to be fused. The damaged cabling and the power distribution unit were subsequently replaced. Thermal damage was limited to the electrical cabling itself however, the resulting smoke spread throughout the testing laboratory. This caused damage to five computer systems under test at the time of loss, as well as various test equipment, electrical distribution equipment and the buildings walls, ceilings, floors, etc.

Repair/replacement of the computer systems took several months to complete and caused a delay in product delivery to customers. Additionally, the inability to perform product testing while building repair and clean-up activities were underway delayed other product deliveries. This location was sprinklered, however, no sprinklers operated and no impairment existed at the time of the fire.

4.0 REFERENCES

4.1 FM

Data Sheet 2-0, *Installation Guidelines for Automatic Sprinklers*
Data Sheet 4-1N, *Fixed Water Spray System for Fire Protection*
Data Sheet 4-9, *Halocarbon and Inert Gas (Clean Agent) Fire Extinguishing Systems*
Data Sheet 5-19, *Switchgear and Circuit Breakers*
Data Sheet 5-20, *Electrical Testing*
Data Sheet 7-79, *Fire Protection for Gas Turbines and Electric Generators*
Data Sheet 7-101, *Fire Protection for Steam Turbines and Electric Generators*
Data Sheet 9-0, *Asset Integrity*

4.2 Other

CIGRE. Report 680, Implementation of long AC HV and EHV cable systems.

National Fire Protection Association (NFPA). NFPA 70/ANSI C1, *National Electrical Code (NEC)*.

National Fire Protection Association (NFPA). NFPA 262, *Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air Handling Spaces*.

APPENDIX A GLOSSARY OF TERMS

Business-critical: A piece of equipment, system, or other factor that is crucial to the operation of a business. For example, a business-critical cable may be a cable controlling safety instrumented systems (SIS), cable supplying DC power to emergency lubrication pumps, or cable with a large associated business interruption in the event of a fire.

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

Grouped cable: cable trays or cable bundles installed adjacent to each other. Cable tray systems normally consist of two or more trays either stacked or adjacent to each other. Group cable may also include cable bundles installed without confinement of a tray or tray system.

J-tube: A tube used in offshore installations to enable subsea cable to pulled up from the seabed to an offshore platform, including a wind turbine support structure or platform.

Non-propagating cable:

A. FM Approved cable with a rating of GP-1
B. Cable that has passed the NFPA 262 test

Propagating cable:

A. Cable that has not been tested by the FM Fire Propagation Apparatus
B. Cable that has been tested in the FM Fire Propagation Apparatus and has an FPI of 10 or more.

Plenum: A compartment or chamber to which one or more ducts are connected and that forms part of the air distribution system.

Re-exposure: Exposure of a buried cable. Scour and sand wave can cause the seabed to change and expose a buried cable.

Sand wave: Movement of seabed sediments due to wave action and/or water currents.

Scour: Removal or movement of seabed or lakebed soils by currents or waves caused by structural or other elements interrupting the natural flow regimen above the sea/lake floor.

APPENDIX B DOCUMENT REVISION HISTORY

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

October 2021. Interim revision. The following significant changes have been made:

A. Revised the scope to clarify which hazards are covered.

B. Reorganized Sections 2.1.1, 2.1.2, and 2.3.2.

C. Added guidance for protection of cables from exposure fire due to the occupancy.

D. Added carbon dioxide as an extinguishing system option for protection of the occupancy from a cable fire.

E. Added FM Approved cable coatings tested in accordance with the 2019 Approval standard as acceptable passive protection.

F. Revised figure and table number to reflect the section they are in.

January 2021. Interim revision. Updated contingency planning and sparing guidance.

January 2020. The following changes were made:

A. Broadened the scope to include guidance for higher voltage cables and bus bars.

B. Expanded recommendations for construction and location.

C. Added guidance on when to provide automatic fire protection for grouped cables and cable trays.

D. Updated the reference information section.

E. Added recent illustrative losses and updated loss history.

F. Improved description of FM Global Group 1 cable, and made terminology consistent throughout the document.

December 2004. The fire protection section of this standard has been revised with the following changes made:

1. The fire protection section has been reformatted. The loss experience section has been removed as this is covered by an Understanding the Hazard (UTH) publication *Grouped Cable* (P0218).

2. Cable that has been plenum rated in accordance with UL-910, or cable that has a maximum flame spread distance of 5 ft (1.5 m) or less when tested in accordance with NFPA 262, *Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air Handling Spaces,* is considered equivalent to FM Approved Group 1 (nonpropagating) cable.

3. The FM Global Fire Propagation test is compared to other cable test standards.

4. Fire protection recommendations for cable above suspended ceilings is included.

January 2001. The recommendation for smoke detection for electrical rooms was revised to provide consistency within 5-series data sheets.

September 2000. This revision of the document was reorganized to provide a consistent format.

APPENDIX C SUPPLEMENTARY INFORMATION

C.1 Insulation Failure

Insulation failure is due to many different causes, the most common of which include mechanical damage, excessive temperatures, corona, ozone, overvoltage, chemical environment, and damage from rodents and termites.

Conductors supplying power to motors and other electrical apparatus are especially subject to mechanical abuse and are exposed to many deteriorating influences, such as vibration, moisture, heat, oil, corrosive liquids and gases, and miscellaneous solvents.

Poor housekeeping is a common contributing factor to insulation failure. Oil soaked insulation breaks down easily, ground faults or short circuits result, and a severe fire may follow. Cable trays should be kept free of foreign materials that can build up and cause overheating and failure of the conductor insulation. Combustible materials such as paper dust, dried paper pulp, wood chips, oily rags, lunch papers, and similar materials should not be allowed to accumulate in the trays; these materials ignite easily, sometimes spontaneously, and aid in the propagation of flame.

C.2 Cable Flammability Tests

C.2.1 General

Full-scale fire tests are the most reliable method of determining whether a cable propagates fire. Due to the large numbers of cable and cost of testing, small scale tests have been developed to predict cable flammability. These tests attempt to duplicate, under small scale test conditions, what is likely to happen under large scale conditions.

C.2.2 FM Approved Cable

FM Approvals tests cable samples using the ASTM E2058 Fire Propagation apparatus (see Figure C.2.2), which determines two basic flammability properties of cable insulation: propensity for ignition and heat release rate. The cable sample is exposed to heat flux exposures between 10 and 65 kW/m^2, and time to ignition is measured. The square root of the inverse of the time to ignition is plotted against heat flux exposures. Thermal Response Parameter (TRP) is the slope of the line.

The heat release rate test is then performed under simulated large-scale fire exposures. A 24 in. (61 cm) long sample is placed vertically in the quartz tube. The bottom 5 in. (12.7 cm) of the cable is exposed to 50 kW/m^2. A gas concentration of 40% oxygen is used to simulate a large scale exposure fire. The heat release rate is measured by thermocouples and gas concentration is monitored in the exhaust duct.

The TRP and the chemical heat release rate are used to calculate the Fire Propagation Index (FPI) which is used to classify the cable as non-propagating or self-propagating. Cable Approved with a rating of GP-1 has an FPI of less than 10, is considered a non-propagating cable and is listed in the *Approval Guide*, an online resource of FM Approvals. Additional information on this testing is provided in FM 3972, *Examination Standard for Cable Fire Propagation*.

To validate the test, fifteen full scale cable tests were conducted at the FM Global Research Campus using the FM Fire Products Collector. Two 16 ft (4.9 m) long and 2 ft (0.61 m) wide cable trays were arranged vertically 1 ft (0.3 m) apart.

A single layer of cable with no air space between was arranged in the trays. A 210,000 Btu/hr (61 kW) propane air burner with a flame height of 2 ft (0.6 m) was used between the trays as the exposure fire. By using two trays in a parallel tray arrangement, as described above, flame radiation is increased by 50%. There is self-sustained fire propagation beyond the heat flux zone of the propane burner.

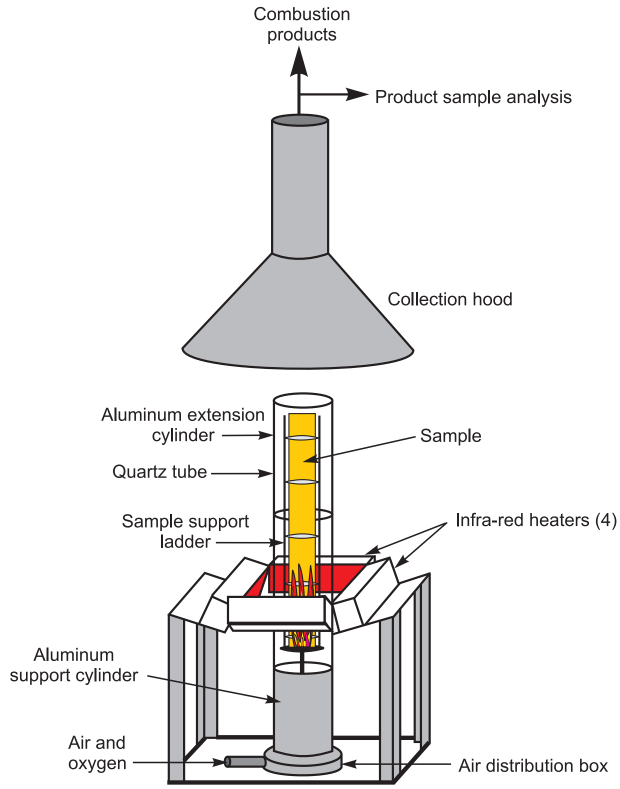

Fig. C.2.2. ASTM E-2058 Fire propagation apparatus

The fire products generated during combustion were collected in the hood and exhaust duct, and measurements of flammability properties were made. As predicted, fire spread was limited in non-propagating cable (i.e., cables with an FPI of less than 10 when tested in the ASTM E2058 apparatus). The flame extinguished when the burner was turned off after a 20-minute exposure. Conversely, self-propagating cables resulted in flame spread the full length of the tray.

C.2.3 Cable Fire Propagation and Cable Fire Resistance

There are two properties of cables that are often discussed and sometimes misunderstood: fire propagation and fire resistance. Fire propagation is the spread of flame across the surface of a cable. Fire resistance is the ability of the cable to withstand a fire and continue to operate as intended and is identified as an hourly rating. Both properties are dependent on the construction of the cable.

C.3 Subsea Cable

C.3.1 Figure C.3.1 shows a typical structure of HVAC subsea export cable. Subsea cables generally use extruded insulation such as XLPE (cross linked polyethylene) consisting of 3 layers. The first around the conductor transforms the cable into a smooth surface using a semi-conductive layer and thus produces a stress-reducing layer in case of bending of the cable. A second layer provides an insulation layer, and then a third layer provides an insulation screen.

Armor layer is used for protecting against faults due to abrasion and from vessel damage. More armor will provide more protection from external damage. However, more armor will result in a heavier cable, which will be more difficult to place, restricting the number of vessels available and making repairs more problematic. One layer of armor is common for subsea cables.

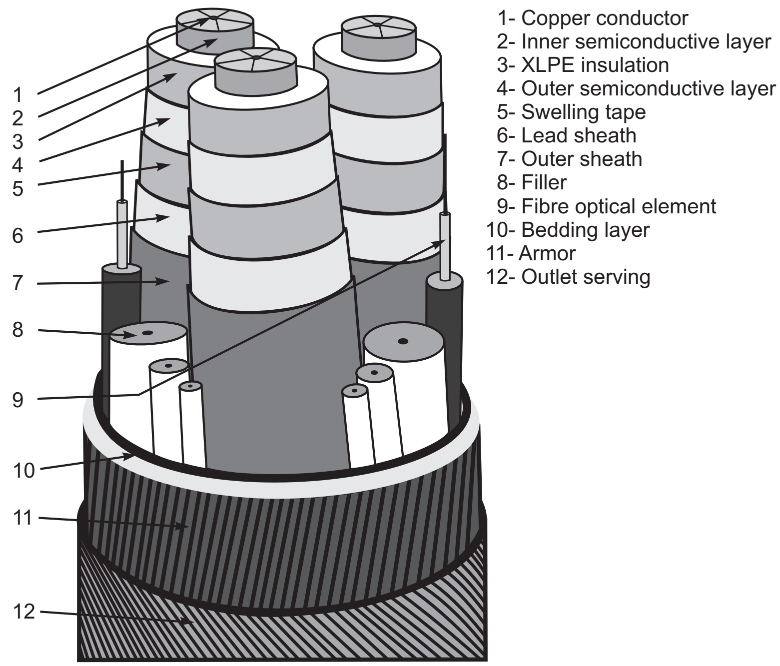

Fig. C.3.1 Typical HVAC subsea power cable: 3 phases bundled with fiber-optic elements

C.3.2 Main accessory items for subsea cable are described below:

A. Armor hang-off device (see Figure C.3.2.)

B. Armor anchoring device: used to prevent any possible cable movement at the sea-land transition location

C. Sea-land power transition joint

An armor hang-off device is used to lock a cable on top of a J-tube at off-shore platforms.

Fig. C.3.2. Accessory armor hang-off

C.4 Online PD Measurement

Partial discharge activity can be monitored on a continuous basis during the operating life of the equipment. Sensors attached to key points in the cable are required for this system. The terminations and joints of the cable system are typical PD measurement points. Online PD also helps to detect weak points in the insulation system while the cable is operating. Alternative to sensors, handheld devices can also be used to locate PD. Some acoustic devices (sniffers) make it possible to observe corona discharges along the surface of the insulator.