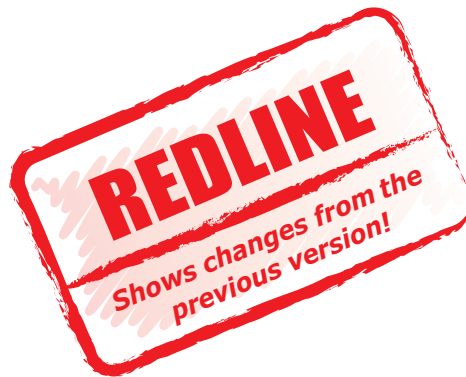


IEEE Guide for Substation Fire Protection

IEEE Power and Energy Society

Sponsored by the
Substations Committee



IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 979™-2012
(Revision of
IEEE Std 979-1994)

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IEEE Guide for Substation Fire Protection

Sponsor

Substations Committee
of the
IEEE Power and Energy Society

Approved 30 August 2012

IEEE-SA Standards Board

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Abstract: Guidance is provided to substation engineers in determining the design, equipment, and practices deemed necessary for the fire protection of substations.

Keywords: fire, fire protection, hazard, IEEE 979™, risk, safety, substation design, substations

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Introduction

This introduction is not part of IEEE Std 979-2012, IEEE Guide for Substation Fire Protection.

Since the original edition of IEEE Std 979 (issued in 1994 and reaffirmed in 2004) was prepared, the body of knowledge on fire protection has increased significantly. This revision captures much of this knowledge and presents it for use by both the substation designer and the fire protection professional.

Contents

1. Overview	1
1.1 Scope	1
1.2 Purpose	1
1.3 General	1
2. Normative references.....	3
3. Definitions	3
3.1 General terms.....	4
3.2 Fire-suppression system terms.....	4
3.3 Fire detection system terms	5
4. Fire hazards	6
4.1 General	6
4.2 Combustible oil hazards	6
4.3 Flammable and combustible liquid and gas hazards.....	7
4.4 Fire exposure hazards	7
4.5 Indoor substation hazards	8
4.6 Critical loss assets.....	8
4.7 Maintenance and construction	9
5. Fire protection considerations for substation sites.....	9
5.1 General	9
5.2 External exposures.....	9
5.3 Site grading.....	10
5.4 Prevailing winds	11
5.5 Fire emergency response capability.....	11
5.6 Available firefighting water supplies.....	11
5.7 Emergency access to the substation.....	11
6. Fire protection for substation buildings.....	12
6.1 General	12
6.2 Use and occupancy	12
6.3 Underground substations	13
6.4 High-rise substations	13
6.5 Indoor substations.....	14
6.6 Construction	14
6.7 Fire alarm and detection systems.....	18
6.8 Fire suppression.....	18
6.9 Life safety	19
6.10 Combustible materials	20
7. Fire protection for substations	20
7.1 Spatial separation of outdoor mineral-oil-insulated equipment	20
7.2 Prescriptive separation requirements	21
7.3 Calculated separation requirements	23
7.4 Ground surface material	23
7.5 Cable raceway systems	23
7.6 Water supply.....	25
7.7 Fire extinguishers	25

8. Fire protection for equipment	25
8.1 Oil-spill-containment systems	25
8.2 Stone flame suppression	26
8.3 Fire barriers	27
8.4 Fire-suppression systems	27
8.5 Explosion suppression	28
8.6 Equipment design	29
9. Fire protection measures selection	29
9.1 General	29
9.2 Fire protection objectives	29
9.3 Performance factors	29
9.4 Life cycle factors	30
9.5 Risk-based economic analysis	30
9.6 Benefit/cost analysis	30
Annex A (normative) Additional information to main body clauses.....	32
Annex B (informative) Quantitative methods for analysis of hazards.....	47
Annex C (informative) Selection of fire protection systems and substation design	56
Annex D (informative) Fire emergency plan, incident management, and recovery	65
Annex E (informative) Examples	69
Annex F (informative) Bibliography	84

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1. ~~General~~ Overview

1.1 Scope

~~This~~ The original guide (1994) was developed to identify substation fire protection practices that generally have been accepted by industry.

This revision includes changes in industry practices for substation fire protection. New clauses on fire hazard assessment and pre-fire planning have been added.

1.2 Purpose

The purpose of ~~this document is the original guide (1994) was~~ to give design guidance, fire hazard assessment, and pre-fire planning in the area of fire protection to substation engineers. Existing fire protection standards, guides, ~~etc., and so on~~ that may aid in the design of specific substations or substation components, are listed in ~~the annex~~ Annex F. This revision updates that guidance.

~~NOTE — No recommendation listed in this document should be followed if it is less restrictive than that specified in any local code or ordinance.~~

~~2. Control and relay buildings~~

~~2.1.3~~ General

~~This clause contains recommendations for fire protection practices that should be used as a guide in designing substation control and relay buildings~~

The guide outlines substation fire protection practices based on industry standards and good practices. It incorporates lessons learned from substation fires, substation fire protection research and testing, advancements in fire protection engineering practices, and changes in fire protection due to risk and environmental concerns. The guide provides design guidance in the area of fire protection for substation engineers and others involved in substation fire safety and protection.

The predominant dielectric insulating fluid for transformers is mineral oil, and mineral oil constitutes one of the primary fire hazards in the substation. Consequently, much of this guide addresses hazards and protection measures based on mineral oil fires. There are several alternative fluids with improved fire safety properties (higher flash and fire points), known as “less-flammable” dielectric fluids, which have been introduced. Many of these fluids have been recognized as reducing the hazard and the risk of a fire occurring relative to mineral oil. Use of a “less flammable” fluid is one means to reduce the risk of fire at a substation. See 8.4.2 and A.21 for additional information on these fluids.

It is the intent of this guide that the analysis and decisions made may require the use of a team approach comprising various specialists. These specialists will be able to provide specific guidance on their areas of expertise; provide interpretation of the related codes, standards, and practices; and help formulate fire protection solutions. The following are some of the specialists that could be involved:

- Substation design engineers (civil, electrical, mechanical, and structural)
- Substation operation and maintenance staff

- [— Fire protection engineers and specialists](#)
- [— The local fire department](#)
- [— The authority having jurisdiction over the substation](#)
- [— Architects and code consultants](#)

[This guide provides fire protection guidance for the following types of substations that have the principal power delivery functions accomplished with alternating current \(ac\) or direct current \(dc\) power and are operated at voltages of 1 kV and above:](#)

- [— Generating plant switchyards](#)
- [— Customer substations](#)
- [— Switching substations](#)
- [— Transmission substations](#)
- [— Distribution substations](#)
- [— Capacitor substations](#)
- [— Converter station switchyards](#)

[The types of substations listed can be designed in a number of different configurations and layouts as follows:](#)

- [— Outdoor substations](#)
- [— Indoor substations](#)
- [— Multistory above-grade substations](#)

- Multistory below-grade substations
- Substations in mixed-use buildings including high-rise (>22.9 m) buildings

- Substations in conjunction with other related operations (e.g., offices, maintenance facilities, and control centers)

This guide provides electric power engineers and fire protection professionals with fire protection and safety guidelines for application in the planning, design, and operation of substations. Guidelines are outlined in the following critical areas of application:

- The identification of substation fire hazards

- The fire protection aspects for substation sites, buildings, and switchyards

- Issues to be considered when selecting the various types and levels of fire protection

- Recommended typical fire protection applications

- Fire planning and incident management

This guide is not intended to be the primary standard for the minimum levels of fire protection required for new and existing substations. The minimum required level of substation fire safety and protection is based on the minimum requirements of governing authorities and on the level of risk the asset owner is willing to accept. This guide provides design options and strategies for the mitigation of substation fire hazards once the minimum required level of substation fire safety and protection is determined.

The application of this guide is not meant to take precedence over local building, fire, safety, and electrical codes. It is intended to be used in conjunction with these governing codes and standards for the purpose of providing specialized substation fire protection guidance for asset protection and customer service reliability. This document does not necessarily cover aspects of life safety covered by local building, fire, safety, and electrical codes.

[Refer to A.1 for additional information.](#)

2.2 Cable

~~Cable installed either in trays, below the floor (raised floor), or in trenches cast into the floor could spread a fire from one area or piece of equipment to another. Therefore, the following precautions are suggested: Removable covers for trenches should be made of metal or fire-retardant material. If the floor is raised, use of a fire protection system beneath the floor should be considered. When cables are installed in either covered trays, under raised floors, or in trenches cast into floors, consideration should be given to the installation of cable fire breaks. Cable fire breaks should be repaired and maintained to correct damage that may occur when cables are removed or installed. The cable used in substation control houses should be of a material that does not readily propagate a fire. The cables used should be qualified by the flame test parameters specified in IEEE Std 383-1974 [B46].¹ Consideration should be given to adding either a fire protective coating or covering, or sprinkler protection, to any cable installation that does not meet the flame requirements of IEEE Std 383-1974 [B46].~~

2.3 Exits

~~Most control houses should have a minimum of two exits. These exits should be located at opposite ends of the building to prevent the possibility of personnel being trapped by a fire. These doors should open outward and be equipped with illuminated exit signs. Panel and equipment arrangements should be designed so personnel can exit the equipment area from both ends. Additional guidance can be found in ANSI/NFPA 70-1993 [B22], ANSI/NFPA 101-1994 [B26], and ANSI/NFPA 101A-1995 [B27].~~

2.4 Door locks

~~Panic hardware on all doors should override any exterior lock or padlock to allow egress from the building. This feature is recommended because personnel may enter the building without first unlocking all of the exterior doors.~~

¹The numbers in brackets preceded by the letter B correspond to those of the bibliography in the annex.

2.5 Fire extinguishers

2.5.1 Portable extinguishers

Portable fire extinguishers should be located in accordance with ANSI/NFPA 10-1994 [B2]. Locations adjacent to normal entrance/exit doors are suggested. See clause 7 for guidance in selection of the type of extinguishing agent.

2.5.2 Fixed extinguishing systems

Local fire codes may require fixed fire extinguishing systems, or their installation may be necessary due to the critical location or type of substation. Guidance in selection of this type of system may be found in clause 7.

2.6 Alarms

It may be desirable to equip unattended substations with smoke or heat detectors to sense a fire. Duct smoke detectors, installed in the return ducts of heating and cooling equipment, provide an effective means of detecting fire. The detectors should activate an audible/visual fire alarm at the substation site, the master station (if the substation is equipped with supervisory control equipment), and, if desired, the local fire station. Attended should be equipped with similar devices that should actuate a local alarm. See clause 6 for guidance in the selection of the detection system.

2.7 Combustible materials

The use of combustible materials with flame spread, fuel contributed, and smoke developed ratings greater than 25 should be avoided in the selection of desks, chairs, filing cabinets, storage boxes, display boards, building insulation, interior wall panels, mounting boards, etc. The flame spread is calculated utilizing ANSI/NFPA 255-1990 [B29].

2.7.1 Housekeeping

Good housekeeping practices should be followed to eliminate the accumulation of combustible materials, e.g., discarded papers, prints, cups, newspapers, etc. Waste cans should be fire approved and self-closing.

2.7.2 Storage

The storage of paper products, cleaning fluids, and other combustible materials in a control building should be minimized. If stored in the control building, they should be kept in a separate area having a minimum 1-h rating to prevent a fire from spreading to the main control and relay areas. Flammable liquids should be stored only in safety cans approved by Underwriters Laboratories. Guidance for the storage of flammable liquids can be found in ANSI/NFPA 30-1993 [B18].

2.8 Ventilation

Since most fires produce extremely heavy smoke that inhibits manual fire fighting, special portable or fixed exhaust and ventilating systems that bring in outside air should be utilized to remove or reduce the smoke. This is especially important in confined areas where manual fire fighting is the only practical method of fire extinguishment. Fixed exhaust and ventilating systems should shut down automatically during a fire and be equipped with an override device to allow for smoke removal when fire fighters deem it necessary. The fan override switch should be located outside the fire hazard area, clearly marked, and easily accessible to fire fighters. For additional guidance, see ANSI/NFPA 204M-1991 [B28] and SMACNA [B53].

2.9 Lighting

Exit lights and emergency lighting sufficient to provide egress from the building should be considered. These lights should be supplied per ANSI/NFPA 101-1994 [B26] and ANSI/NFPA 101A-1995 [B27].

2.10 Construction

The control and relay building should be constructed of fire resistive or noncombustible materials. The building should be located and designed so that the largest credible fire (e.g., of an oil-filled transformer, a circuit breaker, or neighboring plants or storage facilities) will not involve or affect the operation of the equipment within the building or vice versa.

2.10.1 Fire ratings

All fire walls, doors, floors, and ceilings should have a fire rating commensurate with the largest credible fire they could encounter. All fire doors should be equipped with self-closing devices to maintain the fire rating of the wall.

2.10.2 Floor and wall openings

In multistory structures and fire-rated rooms, all floor and wall openings should be sealed in a manner that will not reduce the fire rating of the floor or wall. Guidance for installations of cable penetrations can be found in IEEE Std 634-1978 [B50].

2.10.3 Conduits

Conduits should be sealed at ceiling, floor, and wall penetration(s) to prevent the transfer of liquid fires, smoke, flammable gases, or vapors from one area to another. Consideration should be given to using conduits made of fire-retardant materials.

2.10.4 Heating equipment

Portable heating equipment should not be used in control buildings unless their design, installation, electrical supplies, etc., are deemed suitable by the fire protection engineer or another responsible individual. Clearances for heat-producing appliances should be adequate to minimize the risk of igniting adjacent combustible material. Guidance for air conditioning systems can be found in ANSI/NFPA 90A-1993 [B25].

2.11 Uses

Substation control and relay buildings should not be used for any other purpose. If welding, repair, storage of spare clothing, storage of crated spare parts, oil testing, etc., is unavoidable, a separate fire-rated area should be provided.

2.12 Telephones

A list of emergency telephone numbers, in the order in which they should be called in a fire emergency, should be located by the telephone in a conspicuous place in the operator's area. This list should be preceded by the substation name, address, and telephone number. These numbers and a telephone should be located outside of the building.

2.13 Batteries

~~The level of hydrogen gas given off from batteries should be calculated using manufacturer's guidelines. If this gas level is large enough to cause an explosion, the guidance found in 8.2 should be followed.~~

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 980TM, IEEE Guide for Containment and Control of Oil Spills in Substations.^{1, 2}

NFPA 850, Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.³

NFPA 851, Recommended Practice for Fire Protection for Hydroelectric Generating Plants.

When exploring the additional information in NFPA 850 and NFPA 851, keep in mind that these documents were developed for generating facilities that have different hazards and risks than transmission and distribution substations.

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3. Transformers

3.1 General

Transformers generally contain the largest quantity of combustible substance located in a substation. Therefore, special attention should be given to their location, relay protection, and fire protection. Fires in oil-insulated transformers result principally from the breakdown of insulation. This may be caused by overloads, switching or lightning surges, gradual insulation deterioration, low oil level, moisture or acid in the oil, or failure of an insulating bushing. Arcing that follows an electrical breakdown can burn through the tank or vaporize the oil, thereby creating pressure sufficient to force off the cover or rupture the tank. A considerable amount of burning oil may be expelled over a large area, and an intense fire may follow. The flexible connection joints often used in transformer oil conservator systems can fail because of damage resulting from arcing, fire, or some other cause, contributing further to fire propagation. Special attention should be given to protecting these joints from fire and damage. Another possible source of fires from power transformers is combustible gas accumulation within the transformer tank. These gases are generated by a variety of causes and can reach sufficient concentration to pose a possible explosive hazard. These gases can be detected by performing periodic combustible gas-in-oil analysis on oil samples taken from each power transformer.

3.2 Fixed fire-extinguishing systems

Consideration should be given to the installation of fixed fire-extinguishing systems in substations where transformers are located near substation buildings, other transformers or other major equipment, residences, etc. Clauses 6 and 7 offer additional guidance in selecting extinguishing agents and in designing fixed extinguishing systems and fire detection systems.

3.2.1 Fixed water extinguishing systems

The most common type of extinguishing agent employed to protect transformers is water. A water system is a special fixed pipe system connected to a reliable source of water and equipped with discharge nozzles to provide a specific water discharge pattern and distribution over the transformer. The piping system is connected to the water supply through an automatically actuated valve that initiates flow of water to the nozzles. The automatic valve is actuated by heat-sensing devices located around the perimeter of the transformer. The system should be designed

~~so that the water discharge will not cause a flashover. This is recommended to avoid spurious tripping caused by false operation of the water extinguishing system. Consideration should be given to the automatic tripping of the transformer and the deenergization of its pumps and fans upon the activation of the water system. Sometimes, because of low ambient temperatures or high wind, spot type heat sensing devices located around the perimeter of outdoor transformers can operate too slowly to activate the fire extinguishing systems. This delay could allow the transformer sufficient time to fail catastrophically and possibly render the fire extinguishing system inoperative. For general design and guidance, see ANSI/NFPA 15-1990 [B11].~~

3.2.1.1 Water pressure

~~Substations often must be located in areas where the local community's water mains may not be of sufficient size to supply the fixed water extinguishing system or where water mains may not exist. At sites such as these, alternate methods may have to be utilized. A series system of nitrogen bottles or an engine driven pump can be utilized to supply the pressure to drive the water from a holding tank. The holding tank may be filled from low pressure mains, a private well, or a tank truck. Another method is to use a pressurized tank designed to meet NFPA standards. For general guidance, see ANSI/NFPA 20-1993 [B14], ANSI/NFPA 22-1993 [B15], and ANSI/NFPA 24-1992 [B16].~~

3.2.1.2 Water systems freeze protection

~~In areas that are subject to freezing temperatures, consideration should be given to the installation of freeze protection (heat tracing) or to providing a "dry system."~~

3.2.1.3 Water capacity

~~The water system should be capable of supplying $0.25 \text{ gal/min/ft}^2$ (0.17 L/s/m^2) of transformer area, including the tank and radiators, for a minimum of 30 min for each transformer protected.~~

3.2.1.4 Cable buses

~~The water spray system should also be installed to protect any enclosed transformer cable bus systems that could be exposed to a transformer fire.~~

3.2.2 Foam systems

Occasionally, foam systems are installed to extinguish transformer fires. These systems are activated similarly to fixed water systems. The advantage of this system is that it forms a blanket of foam over the engulfed area and provides a smothering effect, thus reducing the spread of fire. The disadvantage of a foam system is that all foams are electrically conductive and could cause flashover problems. For special design features, see ANSI/NFPA 16-1995 [B12].

3.3 Actuation of fire-extinguishing systems

The earlier a fire is detected, the higher the degree of fire-extinguishing system effectiveness is achieved. This minimizes fire damage, and could prevent transformer catastrophic failure. Many of the transformer built-in detection sensors could be used to actuate the fire-extinguishing system (for example, hot spot temperature sensor, high oil temperature sensor, sudden pressure surge sensor, combustible gas detection sensor, etc.). These sensors have the advantage of being in place and readily available. However, because of possible spurious operation of some transformer sensor devices, a double-contingency arrangement requiring the operation of two sensors concurrently is recommended in order to initiate fire-extinguishing system operation.

3.4 Oil containment

Transformer fires are almost always associated with a rupture of the exterior tank of the transformer. This rupture, depending on its location on the tank and the size of the transformer, could allow a large amount of flaming liquid to be spread over a large portion of the substation yard. Also, even after the fire is extinguished, the transformer may still leak a sizable amount of combustible and environmentally damaging liquid over the yard. Therefore, special precautions should be taken to collect and contain the oil. For general guidance, see ANSI/NFPA 30-1993 [B18] and IEEE Std 980-1987 [B52].

3.4.1 Yardstone

The voids obtained with the use of yardstone in combination with the substation grading can be used to retain or spread out a given amount of oil. The objections to this system are that oil can be absorbed into the ground, and if the site is graded to hold oil, it will also hold rain water.

3.4.2 Berms

Oil can be contained in a specified area by constructing a berm or curb around a transformer. The berm should be constructed of a material, such as asphalt, concrete, etc., to form a liquid-tight container. The berm should enclose an area large enough to hold the largest amount of oil that is expected to leak from the transformer plus rainfall and, if applicable, the total quantity of water from a fixed water extinguishing system. It should also be able to withstand the expected hydraulic head and provide adequate fire rating. The objections to this system are that rain water can be trapped or that a pool of burning oil could be formed outside of the transformer fixed fire protection system. Also, the berm could present a problem during testing and in bringing oil handling equipment, laboratory trucks, etc., close to the transformer. However, berms offer a positive means of assuring that oil spills or oil fires are contained in the area surrounding the leaking transformer and do not spread to expose other equipment or buildings. For additional guidance, see ANSI/NFPA 30-1993 [B18] and IEEE Std 980-1987 [B52].

3.4.3 Pits

Various types of holding pit designs are presently being utilized in substations. The grade surrounding oil filled equipment is contoured so that oil is collected in the pit. Concrete, clay, or lined pits are sometimes filled with crushed stone, gravel, or shells. Pits should be designed so that collected oil and water will not weaken equipment foundations. A limitation to pit containment is that oil may not penetrate fill which may become frozen in cold climates. The most common designs include those listed in the following sub-clauses.

3.4.3.1 Sump pumps

Pits may utilize a sump pump to remove collected water. The pump is manually operated in attended substations or automatically operated in unattended substations. Automatic drainage should be equipped with oil detecting controls. A high water level generally activates an alarm. Automatic operation of the pump is normally de-activated when a fixed extinguishing system is activated to avoid oil discharge.

3.4.3.2 Holding tanks

Water and oil may be piped from a pit to a holding tank or pond. The oil is then removed with a skimmer.

3.4.3.3 Drainage pipes

Drainage pipes from pits should be provided with a specific gravity valve that opens to allow water to pass, but closes when oil attempts to pass.

3.4.3.4 Fire quenching or oil retention pits

These pits are filled with fairly uniform sized material, such as crushed stone, of sufficient volume to provide the necessary holding capacity. This type of pit is usually surrounded by a berm or curb to prevent the entrance of runoff rain water. This type of construction will usually prevent an oil pool fire but will usually require the installation of some form of drainage facilities. Before selecting this containment method, consideration should be given to the local water table, freezing temperatures and, in some locations, the possibilities of sand or dust storms.

3.4.3.5 Shallow pits

Shallow pits have lined or unlined covered ditches or piping that allows the oil and water to be diverted to another location in the substation for removal.

NOTE — All materials used in the construction of pits, drainage pipes, drainage ditches, holding tanks, etc., should be of noncombustible materials that are capable of withstanding the thermal shock of the oil fire followed by the cooling effect of the water. Also they should have adequate mechanical strength to withstand any traffic or equipment handling weights to which they may be subjected. The holding tanks, ponds, berms, piping, etc., should be sized to handle the maximum amount of oil available, the quantity of water that may be used in fighting the fire, and any collected rainfall.

3.4.3.6 Oil separation

Water and oil may be piped to an oil separator that will retain oil but allow water to pass through after separation. For details of traps, oil stop valves, etc., refer to IEEE Std 980-1987 [B52].

3.4.4 Grading

The substation grading, depending on the topography of the site, may be contoured to permit the oil to flow to an area of the substation that will not endanger other pieces of equipment. The possible problem with this system is that during an oil fire a larger portion of the substation will be involved in the fire. This could make extinguishment and cleanup more expensive and

~~difficult. Also, even though the oil is directed to an area normally unoccupied by equipment, this area could be used for temporary storage and pose an unnecessary danger.~~

3.5 Surge arresters

~~Surge arresters should be located to minimize the possibility of a missile from an exploding arrester striking porcelain bushings or rupturing transformer radiators and causing an oil leak. Arresters should be rigidly supported and properly grounded. If separate conductors are utilized to ground arresters mounted on transformers, they should not contact the radiators.~~

3. Definitions

For the purposes of this document, the following terms and definitions apply. The IEEE Standards Dictionary Online should be consulted for terms not defined in this clause.⁴

3.1 General terms

control building: A building or structure in a substation that contains protection, control, system control and data acquisition (SCADA), and telecommunications equipment, electrical panels, battery banks, and other auxiliary equipment. In this guide, this term may be used interchangeably with other commonly used terms such as control house or control enclosure.

fire protection: The study and application of measures to prevent, detect, extinguish, control, or deal with fires, and the subsequent impact on people, assets, business activities, or the environment.

hazard: Any source of potential damage, harm, or adverse health effects on something or someone under certain conditions at work.

risk: The chance or probability that a person will be harmed or experience an adverse health effect if exposed to a hazard. It may also apply to situations with property or equipment loss.

⁴ The IEEE Standards Dictionary Online subscription is available at http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

switchyard: The outdoor portion of a substation with only a single voltage level. In multivoltage substations, the switchyards are typically connected by one or more power transformers.

3.2 Fire-suppression system terms

clean agent gas fire extinguishing systems: A fire protection system that uses clean gaseous agents that are (1) electrically nonconducting, (2) volatile or gaseous, and (3) do not leave a residue on evaporation. The system discharges the agent for the purpose of achieving a specified minimum agent concentration throughout a hazard volume. A clean agent complies with restrictions on the production of certain Halon fire extinguishing agents under the Montreal Protocol signed September 16, 1987.

deluge sprinkler system: A sprinkler system employing open sprinklers that are attached to a piping system that is connected to a water supply through a valve that is opened by the operation of a detection system installed in the same areas as the sprinklers. When this valve opens, water flows into the piping system and discharges from all sprinklers attached thereto.

double interlock preaction sprinkler system: A Preaction system that admits water to sprinkler piping on operation of both detection devices and automatic sprinklers and only discharges from opened sprinklers. This type of arrangement provides the most redundancy to reduce the probability of accidental sprinkler discharge by requiring both detection devices and sprinklers to activate independently prior to water being admitted to the piping network. This type of arrangement also allows for pressure monitoring to detect leaks in the piping network or open sprinklers prior to water being admitted to the system.

dry pipe sprinkler system: A system employing automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure, the release of which (as from the opening of a sprinkler) permits the water pressure to open a valve known as a dry pipe valve, and the water then flows into the piping system and out the opened sprinklers.

foam-water system: A sprinkler system that generates a foam-water solution and discharges it onto the hazard to be protected utilizing air-aspirating foam-water sprinklers or nozzles or non—air-aspirating standard sprinklers.

overhead sprinkler system: The installation includes at least one automatic water supply that supplies one or more systems. The portion of the sprinkler system above ground is a network of specially sized or hydraulically designed piping installed in a building, structure, or area, generally overhead, and to which sprinklers are attached in a systematic pattern. Each system has a control valve located in the system riser or its supply piping. Each sprinkler system includes a device for actuating an alarm when the system is in operation. The installation includes at least one automatic water supply that supplies one or more systems. The system is usually activated by heat from a fire and discharges water over the fire area.

single interlock preaction sprinkler system: A single interlock system is a Preaction system that admits water-to-sprinkler piping upon operation of detection devices and discharges out only the opened sprinklers. This type of arrangement reduces the probability of accidental sprinkler discharge by requiring the activation of a detection device prior to admitting water to the sprinkler piping and then requiring a sprinkler head to open prior to water flow.

water mist system: A distribution system connected to a water supply or water and atomizing media supplies that is equipped with one or more nozzles capable of delivering water mist intended to control, suppress, or extinguish fires. Water mist systems must only be used for applications that they are listed for or where specific research and testing has validated the application.

water-oscillating monitor: Typically a supplement to an overhead sprinkler or foam system, they provide additional delivery of the liquid suppression agent to areas shadowed from the overhead sprinkler system.

wet pipe sprinkler system: A sprinkler system utilizing automatic sprinklers attached to a piping system containing water and connected to a water supply so that water discharges immediately from sprinklers opened by heat from a fire.

video image detection: The principle of using automatic analysis of real-time video images to detect the presence of smoke or flame.

3.3 Fire detection system terms

beam detector: A type of photoelectric light obscuration smoke detector where the beam spans the protected area.

dry-pilot line detector: A system of heat detection employing automatic sprinklers on a pressurized dry pipe network. The activation of a sprinkler causes a loss in system pressure, which is annunciated as an alarm signal.

electronic heat detector: A fire detector that detects either an abnormally high temperature or a rate of temperature rise or both.

linear heat detector: A heat-sensitive cable that has a fixed alarm temperature rating or a heat-sensitive cable in which the impedance with changes in temperature can be adjusted to specific resistance levels to establish alarm temperature thresholds.

optical flame detector (1R3): A flame detection device sensitive to various portions of the infrared spectrum commonly emitted from flaming fires. This type of fire detection is not sensitive to smoldering fires, and detection is limited to each sensor's field of view.

pneumatic rate-of-rise heat detector: A line-type detector comprising small-diameter tubing, usually copper, which is installed throughout the protected area. The tubing is terminated in a detector unit containing diaphragms and associated contacts set to actuate at a predetermined pressure. The system is sealed except for calibrated vents that compensate for normal changes in temperature.

smoke aspirating system: The principle of using an air sample drawn from the protected area into a high- humidity chamber combined with a lowering of chamber pressure to create an environment in which the resultant moisture in the air condenses on any smoke particles

present, forming a cloud. The cloud density is measured by a photoelectric principle. The density signal is processed and used to convey an alarm condition when it meets preset criteria.

spot-type ionization detector: The principle of using a small amount of radioactive material to ionize the air between two differentially charged electrodes to sense the presence of smoke particles. Smoke particles entering the ionization volume decrease the conductance of the air by reducing ion mobility. The reduced conductance signal is processed and used to convey an alarm condition when it meets preset criteria. This type of smoke detection is best applied to flaming or incipient fires in which small particulate matter is produced.

spot-type photoelectric detector: The principle of using a light source and a photosensitive sensor onto which the principal portion of the source emissions is focused. When smoke particles enter the light path, some of the light is scattered and some is absorbed, thereby reducing the light reaching the receiving sensor. The light reduction signal is processed and used to convey an alarm condition when it meets preset criteria. This type of smoke detection is best applied to fires in which larger particulate matter is produced.

wet-pilot line detector: A system of heat detection employing automatic sprinklers on a pressurized wet pipe network. The activation of a sprinkler causes a loss in system pressure, which is annunciated as an alarm signal.

4. Separation and general information

4.1 General

~~This clause contains guidelines for separating oil filled equipment from other equipment, buildings, etc., and general information for use in locating oil filled equipment. Some factors to consider in the decision making process in determining protection needs are~~

- ~~a) — Fire insurance implications~~
- ~~b) — Probability of public rebuke from an environmental contamination standpoint as a result of an unchecked fire~~
- ~~c) — Possible reduction in outage time that fixed protection would afford~~
- ~~d) — Potential for an unchecked fire to damage any structures, lines, or related exposures that could impair operation of backup neighboring units~~

4.2 Insulating oil

Flash point is the minimum temperature at which a liquid will give off vapor in sufficient amount to form a flammable air vapor mixture that can be ignited. Liquids with a flash point above 200 F (93 C) are classified as a Class IIIB combustible liquid according to ANSI/NFPA 30-1993 [B18]. Insulating oil has a flash point temperature of approximately 295 F (146 C) and is therefore a Class IIIB combustible liquid. Therefore, based on its high flash point temperature, the oil can be handled and stored in a safe manner. But, when installed in electrical equipment, this oil does possess the qualities to be considered a fire hazard. This is due to the high temperatures that can be produced during an electrical fault or an external fire that engulfs an oil filled piece of equipment. Furthermore, when oil is subjected to intense heat, as from an electrical arc, it is possible to crack the oil into dangerous gases, such as hydrogen, methane, acetylene, and ethane, which greatly contribute to the hazard. Therefore, the placement in substations of transformers or other pieces of oil filled equipment should be of concern to the designer and engineer. Every attempt possible should be made to locate oil filled equipment away from other equipment, substation buildings, fire hazards present in neighboring properties, etc. Actual tests by Ontario Hydro in 1967 have shown that when large oil fires develop in transformers, the temperature above the transformer can reach 1800–2000 F (982–1093 C). With a wind velocity of 15 mi/h (24 km/h) to 25 mi/h (40 km/h), temperatures up to 1500 F (816 C), 30 ft (9.1 m) to 40 ft (12.2 m) from the fire source, can be produced.

4.3 Fire barriers

The amount of oil contained in power transformers and circuit breakers varies with the manufacturer, voltage ratings, and MVA ratings. Some typical values are given in table 1. The magnitude of the possible fire area and the hazard resulting from the rupture of large oil filled equipment tanks can be emphasized by the fact that 1000 gal (3785 L) of oil will cover an unrestricted area (e.g., an epoxy painted concrete floor) of slightly over 1600 ft² (149 m²) to a depth of 1 in (2.5 cm). When the design and size of the containment facilities utilized are inadequate, it may be necessary to install some form of fire barrier to protect other substation equipment or neighboring properties. These barriers should be totally constructed of noncombustible materials such as concrete block, brick, sheet steel, reinforced concrete, etc. They

should be designed to withstand the largest credible fire to which they may be subjected. Removable fire barriers should be considered when space is needed for equipment maintenance or replacement.

Table 1— Typical oil quantities in equipment			
Three-phase transformers		Circuit breakers	
Gallons of oil Typical MVA ratings		Gallons of oil per tank of three-tank breaker kV ratings	
12 000 and above	100 MVA and above	1000 and above	230 kV
10 000–11 999	50–99 MVA	500–999	138 kV
8000–9999	30–49 MVA	499 and below	69 kV
2000–7999	5–29 MVA		
1999 and below	5 MVA		

(Deleted)

4.4 Transformer outdoor installations

Sub-clauses 4.4.1–4.4.5 give recommendations for separation, barrier installations, and extinguishing systems for the installation of outdoor

4.4.1 Separation of large transformers from buildings

Transformers containing 2000 gal (7571 L) or more of insulating oil should be at least 20 ft (6.1 m) from any building. If these large oil filled transformers are located between 20 and 50 ft (6.1–15.2 m) of a building, the exposed walls of the building should constitute, or be protected by, at least a 2-h fire-rated barrier. The barrier should extend in the vertical and horizontal directions such that any point of the transformer is a minimum of 50 ft (15.2 m) from any point on the wall not protected by the barrier. Should it be necessary to encroach on the above minimums, the installation of a transformer fire protection system should be considered. Some jurisdictions require a combination of barriers and fire protection systems.

4.4.2 Separation of small transformers from buildings

Transformers containing less than 2000 gal (7571 L) of insulating oil should be separated from buildings by the minimum distances shown in table 2.

Table 2— Separation of small transformers from buildings

Transformer rating	Recommended minimum distance from building [*]
75 kVA or less	10 ft (3.0 m)
76–333 kVA	20 ft (6.1 m)
More than 333 kVA	30 ft (9.1 m)

^{*}Guidance for recommended minimum distances from buildings in electric generating plants are given in ANSI/NFPA 850-1992 [B31] and ANSI/NFPA 851-1992 [B32].

(Deleted)

Where a transformer is installed less than the minimum distance, the building should have fire-resistive wall construction. Guidance can be found in NFPA 255-1990 [B29].

4.4.3 Separation between large transformers

Large oil-filled transformers should be separated by at least 30 ft (9.1 m) of clear space and/or a minimum 1 h fire-rated barrier.

4.4.4 Fire barrier size

The height of a fire barrier should be at least 1 ft (0.30 m) above the height of the oil-filled circuit breaker tank, transformer tank and its oil conservator (if applicable), transformer bushings, pressure-relief vents, etc. The fire barrier should extend at least 2 ft (0.61 m) horizontally beyond the line of sight between all points on adjacent transformers. The height of the fire barrier should be not less than that required to break the line of sight from any point on the top of the transformer tank and its oil conservator (if applicable) to any adjacent transformer bushing and surge arrester mounted on the transformer. Consideration should be given to the rating factors of the transformers when barriers are used.

4.4.5 Extinguishing systems

Automatic extinguishing systems should be considered for all liquid-cooled transformers, except those that are adequately separated in accordance with 4.4.1, 4.4.2, 4.4.3, and 4.4.4, or that qualify as

- ~~a) Spare transformers not intended to be used in place, or~~
- ~~b) Transformers containing less than 500 gal (1893 L) of combustible transformer liquid.~~

4. Fire hazards

4.1 General

The impact of fire hazards on health, safety, continuity of operations, and asset preservation is a reason to provide fire prevention, fire protection, and other fire safety measures. Fire hazards are the conditions that create the potential for a fire. Fire hazards have at least the following attributes:

- The magnitude of a possible fire
- The consequence of the potential loss
- The probability of an occurrence over a period of time (i.e., risk)

Sub clauses 4.2 through 4.7 present recognized fire hazards found in substations.

Refer to A.2 for additional information.

4.2 Combustible oil hazards

Based on mass and potential for energy release, mineral-oil-insulated equipment is normally the largest fuel source present in most substations. Mineral-oil-insulated equipment includes the following:

a) Transformers and reactors

1) Main tanks

2) Bushings

[3\) Radiators](#)

[4\) Conservator tanks](#)

[5\) Tap changers](#)

[6\) Cooling pumps](#)

[b\) Instrument transformers](#)

[c\) Voltage regulators](#)

[d\) Circuit breakers](#)

[e\) Cables](#)

[1\) Oil insulated](#)

[2\) Pipe type](#)

[3\) Potheads](#)

[4\) Transition joints](#)

[f\) Capacitors](#)

[g\) Lubricating oil systems \(e.g., for synchronous condensers\)](#)

h) Oil pump houses

i) Oil processing plants

4.3 Flammable and combustible liquid and gas hazards

Other equipment-related fuel sources that may be found at substations include the following:

a) Hydrogen-cooled synchronous condensers

b) Oxy-acetylene used for maintenance and construction purposes

c) Battery rooms

1) Heat from short circuits or thermal runaway

2) Hydrogen gas generated by battery charging

d) Diesel- or propane-fueled generators and fuel cells for backup power

e) Propane heating fuels

f) Flammable and combustible liquid storage, handling, and dispensing

4.4 Fire exposure hazards

Critical substation equipment and other assets can be compromised due to external fire exposures in addition to internal failure modes. Some example of exposure hazards include the following:

a) Auxiliary structures

1) Office areas

2) Warehouse areas

3) Oil storage areas

4) Shop areas

5) Stand-by diesel generator buildings

6) Hazardous materials storage areas

b) Any building, room, or support structure that is of combustible construction

c) Miscellaneous combustible storage

d) Vegetation (nearby forests, hedges, and shrubs).

4.5 Indoor substation hazards

Indoor substations present a unique set of hazards requiring a higher level of fire protection for the following reasons:

— Any smoke and other products of combustion contained in the building can create an exposure hazard to building occupants, emergency personnel, and possibly a corrosive exposure to critical substation equipment.

— Heat (flame impingement, radiative and convective exposures) and the blast pressures from fires and explosions contained within the structure can expose the structure and/or equipment to damage.

— The egress of building occupants and access by emergency personnel for manual firefighting and rescue operations can be complicated by the smoke, heat, structural damage, and travel distances.

4.5 Waterways

~~When substations are located where an oil spill could contaminate ground water, streams, rivers, or other water systems, special attention should be paid to prevent insulating oil from being released. For Federal Regulations regarding oil spills, see CFR, Title 40, Part 300 [B34]. Also, flaming oil on top of the water could endanger nearby docks or other facilities, although this situation is unlikely except in the case of a large spill.~~

4.6 Critical loss assets

The following are critical elements of a substation that if destroyed or damaged can impact the substation's ability to function:

a) Control, computer, protection, switchgear rooms, and equipment

1) System protection equipment

2) Communication equipment

3) SCADA equipment

4) Computers

b) Cable spreading areas, cable trenches, cable tunnels, and cable vaults

c) Batteries and charger systems

d) Station service transformers (dry or liquid filled)

e) Power transformers

f) Circuit breakers

g) Bus structures

[h\) Auxiliary equipment](#)

[The annexes provide more information on fire hazards and their potential impacts.](#)

4.6 Pressure reliefs

~~The discharge from any oil pressure relief device should be directed away from any nearby equipment to prevent damage from flaming oil.~~

4.7 Maintenance and construction

[Maintenance and construction activities can create high-risk conditions within substations. The following equipment and activities could present hazardous conditions:](#)

[a\) Oil-processing equipment](#)

[b\) Mobile transformers](#)

[c\) Painting](#)

[d\) Hot work \(cutting, grinding, and welding\)](#)

[e\) Maintenance activities](#)

[f\) Increased fire exposure and fuel load associated with](#)

[1\) Temporary or permanent construction](#)

[2\) Combustibles and flammable transient fire loads \(e.g., fuel cans, rags, and wood\)](#)

[3\) Material and equipment storage](#)

[4\) Office trailers](#)

[5\) Parked vehicles](#)

4.7 Explosion venting

To minimize the structural and mechanical damage from an explosion of indoor oil-filled equipment, such as transformers, circuit breakers, or regulators, explosion relief and venting devices should be installed. Guidance can be found in ANSI/NFPA 68-1994 [B21].

4.8 Supports

Structures supporting disconnect switches, etc., should be kept as low as possible when they are placed near oil-filled equipment to avoid the extreme high temperatures at the upper levels of a fire. Any essential structure or support that may be subjected to an oil fire should be constructed of steel rather than aluminum. Steel can withstand temperatures of 1000 F (538 C) without structural damage (see 4.2), while aluminum can only withstand 350 F (177 C). The placement of any supports directly over a transformer should be avoided.

4.9 Miscellaneous hazards

Trash storage, decorative fences made of combustible materials, dry grass and weeds, etc., are all fire hazards that should be kept at a sufficient distance from equipment to minimize their possible damage. Vandalism that can result in a fire should be a concern in the substation design and security study.

5. Cable installation practices

5.1 General

Guidance for selection of cable may be found in clause 2.

5.2 Outdoor installations

The most common type of outdoor cable installations found in substations are listed in 5.2.1 through 5.2.4.

5.2.1 Direct burial

Direct burial of cables is a method whereby cables are laid in an excavation in the earth with cables branching off to various pieces of equipment. The excavation is then backfilled. Care should be taken to prevent the accumulation of combustible materials during the period of time when the cables are lying in the trench prior to backfilling.

5.2.2 Tunnels (gallery)

Walk-through cable tunnels may be used where there will be a large number of cables. The cable trays in this system should be separated by a distance sufficient to ensure that a fire in one tray will not propagate to an adjacent tray. If flame retardant cables are utilized, recommended separation distances are given in IEEE Std 384-1992 [B47] and IEEE Std 525-1992 [B49]. If cables are not flame retardant or the proper separation cannot be achieved, a fire resistive barrier or shield can be used between the trays or a fire retardant coating may be applied to the cables. Fire hazards can also be minimized by utilizing fire breaks. Consideration should also be given to the installation of a fire detection system, a fixed extinguishing system, locating fire fighting equipment at the tunnel entrances, and keeping air flows through the tunnels to a minimum.

5.2.3 Permanent trenches

Trench systems consist of main runs that bring large groups of cables through the centers of equipment groups, with smaller trenches, short runs of conduit, or direct burial cable branching off to individual pieces of equipment. These trenches may also feed directly into the control and relay building. The trenches may be made of treated wood, cast in place concrete, large bituminized fiber pipes, or precast materials. Note that fire barriers around cable systems can interfere with cable maintenance work. The fire barriers should be designed with consideration for future cable maintenance crew operations, inspected periodically, and restored after cable maintenance work is performed. Consideration should be given to the installation of fire stops between the main trench and the smaller branch trenches and where they enter the control and relay buildings or other equipment. The use of combustible materials in the construction of these trenches and their covers should be avoided. Consideration should be given to ventilating the trench system to prevent the buildup of combustible gases from either natural or other sources. Trenches should be located in a manner that will prevent any combustible liquids, such as insulating oil, from entering the trench and possibly igniting the cables. Guidance for the installation of cable penetration fire stops can be found in IEEE Std 634-1978 [B50]. All of these considerations would also be applicable to tunnels listed in 5.2.2.

5.2.4 Underground conduit

Conduit systems may be made of various materials, with manholes or pull boxes located at reasonable pulling lengths. These manholes and pull boxes should be located and constructed in a

~~manner to prevent any flammable liquids from entering and possibly igniting the cables. Consideration should be given to the installation of fire stops where the cables enter and leave manholes and pull boxes, and where the cables leave the conduit system.~~

~~5.3 Vertical cable runs~~

~~Fire stops or fire breaks, should be installed in vertical cable runs since fire will more readily propagate vertically than horizontally. For additional guidance, see FM Data Sheet 5-31 [B42].~~

5.Fire protection considerations for substation sites

5.1 General

The following should be considered during new site selection or existing site analysis:

- External exposures
- Site grades
- Available firefighting water supplies
- Emergency access to the substation
- Fire emergency response capability
- Prevailing winds
- Environmental consideration

Refer to A.3 for additional information.

5.2 External exposures

External exposures are fire hazards external to the substation. A fire involving these external hazards has the potential to impact substation operations adversely and may spread into the substation with more significant consequences. A review of site fire exposures should consider all of the following:

- Type of exposure and possible spread mechanisms
- Level of existing protection present in the external exposure
- Risks involved
- Additional fire protection features required to create an acceptable level of risk

Sub clauses 5.2.1 through 5.2.3 discuss some typical external hazards. ANSI/NFPA 80A-2012 [B30]⁵ provides a method for the analysis and mitigation of external radiant heat threats from these types of exposures.

5.2.1 Forested or grassland areas

Forest and grass fires can expose the substation to conductive smoke, fire plumes, radiant heat, and soot. Generally, unplanned landscaping, trees, and vegetation should be removed for a minimum of 9.1 m (30 ft) beyond critical buildings, structures, and equipment. In addition, vertical vegetation (i.e., trees) heights should be analyzed to minimize fall potentials that exist within 9.1 m (30 ft) of operational critical buildings and equipment.

Refer to A.4 for additional information.

5.2.2 Hazardous industries or operations

Chemical plants, petroleum refineries, liquefied natural gas plants, and compressed gas tank farms are examples of neighboring facilities that could pose an external threat to substation operations should an emergency or fire occur at the neighboring site. Spatial separation or other fire protection methods should be used to protect the substation from these types of external threats.

⁵ The numbers in brackets correspond to those of the bibliography in Annex F.

5.2.3 Combustible buildings

Nearby combustible buildings and warehouses often represent substantial fuel loads that can expose the substation to conductive smoke, fire plumes, radiant heat, and soot. Spatial separation or other fire protection methods should be used to protect the substation from these types of external threats. Refer to 7.2.4 for additional information and other reference documents such as ANSI/NFPA 80A-2012 [B30].

Temporary enclosures made of combustible materials and temporary heating for construction activities require special considerations for fire prevention. Issues include providing safe heating sources and isolation of combustible materials from hot work.

Wherever possible, buildings used to support the operation of a substation (e.g., offices and warehouses) should be located outside the substation fence.

5.3 Site grading

Mineral oil spill fires can spread long distances over a wide area, potentially exposing critical elements of the substation to fire. In addition, oil can cause environmental impacts if it reaches nearby environmentally sensitive areas such as streams and rivers or is absorbed into the ground.

One of the most critical factors that can impact the fire protection of substation equipment and buildings is the site grading. Special attention should be paid to site grading conditions, spatial separation, and overall substation layout to minimize the degree and direction of oil spread.

5.4 Prevailing winds

The prevailing wind direction should be taken into consideration when determining mineral-oil-insulated equipment locations. The prevailing winds can create an increase in the hazard from fires involving mineral-oil-insulated equipment and combustible structures. In a fire situation, the wind can cause the flame and fire plume to tilt. This can result in higher heat fluxes, smoke concentrations, and soot levels at downwind buildings or equipment. Additional fire protection measures may be considered when the wind is found to increase the fire hazard.

Refer to A.5 for additional information.

5.5 Fire emergency response capability

The fire response time and resources of either internal fire brigades or local fire departments are important factors in determining the required level of fire protection. The substation designer should consider these factors in the selection of fire protection mitigating measures in the substation design.

Refer to A.6 for additional information.

5.6 Available firefighting water supplies

In the event of a fire in the substation buildings or mineral-oil-insulated equipment, water is the most commonly used fire-extinguishing agent. As part of the design process, the available firefighting water supplies should be reviewed. Available water supply is an important design attribute for both automatic suppression systems that may be considered as well as for responding fire departments or fire brigades.

Refer to A.7 for additional information.

5.7 Emergency access to the substation

Access roads should be designed to accommodate emergency response vehicles. Provisions for emergency access at two locations should be considered around the station yard. Where feasible, vehicle entry gates should conform to the following:

- Not be located beneath overhead power lines
- Not be adjacent to fire hazards (such as mineral-oil-insulated transformers) that could cause them to be blocked during an incident
- Be located as far apart as practical (a minimum of one half the overall station diagonal is recommended)

Refer to A.8 for additional information.

6. Fire protection for substation buildings

6.1 General

Substation buildings should be designed in accordance with applicable local building codes. In the absence of applicable building code requirements, the following recommendations may be followed for the design and construction of substation buildings.

Fire protection may be applied to substation buildings that meet one or more of the following criteria or where fire protection is required by local codes:

- The building area is greater than 1000 m² (10 000 ft²).
- The building is multistory.
- The building contains mineral-oil-insulated equipment.

As a minimum, all new substation buildings should be of noncombustible construction and should include the life safety recommendations in 6.9.

6.2 Use and occupancy

In the absence of explicit local building code classification criteria, electrical equipment buildings and battery buildings should be classified as special-purpose industrial occupancies. Warehouse buildings should be classified as storage occupancies. Maintenance shop areas should be considered as industrial occupancies. Office areas separate from control building spaces should be considered business occupancies.

Refer to A.9 for additional information.

6.2.1 Control buildings and rooms

Control buildings and rooms should be reserved for control equipment, metering equipment, SCADA equipment, telemetry and communications equipment, low-voltage (<1 kV) station service distribution equipment, metal-enclosed (non-oil-filled) switchgear cubicles and associated relays, and minimal work and office areas necessary to facilitate these operations. Uses for other purposes should be discouraged.

Storage of paper products (drawings, test reports, and instruction books), cleaning fluids, and other combustible supplies in a control building are discouraged. If stored in the control building, then they should be stored in separated areas with a 1 h or 2 h fire separation rating based on the hazard or in cabinets to preclude a fire from spreading to the main control and relay areas (see A.11). Flammable liquids should only be stored in approved containers and/or cabinets. Welding and other flammable gases should never be stored in control buildings.

6.2.2 Battery rooms and areas

Battery main terminals and connections between the main battery terminals and the battery over current protection should be designed with insulation or separation to minimize short circuits during maintenance and normal activities in the area of the battery. Battery rooms or areas in control buildings need adequate ventilation. The flash arresting vents on battery cells should be maintained to provide adequate diffusion of hydrogen and oxygen gases that evolve on battery charging. The maintenance should be to clean and/or replace the flash arresters so the dissipation of gases can be accomplished without an appreciable pressure buildup inside the battery cell jar. Battery rooms and areas should be designed based on the requirements of the applicable safety and electrical codes. Further guidance may be obtained from IEEE Std 484TM-2002 [B67].

6.2.3 Support buildings and separated areas

Office facilities for functions not directly related to substation control should be housed in buildings separate from the substation control building or in areas separated by fire-rated construction provided in accordance with the separation provisions of A.11. Maintenance buildings may incorporate indoor storage of substation equipment and supplies.

6.3 Underground substations

Underground substations create high fire safety and fire protection risks that require a high level of fire protection. Generally, underground substations are special structures and can create the following challenges:

— Egress

— Firefighting access