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IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories

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Switchgear Committee
of the
IEEE Power Engineering Society

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National Electrical Manufacturers Association (NEMA)

Abstract: Information on the application, operation, and maintenance of high-voltage fuses (above 1000 V), distribution enclosed single-pole air switches, fuse disconnecting switches, and accessories for use on ac distribution systems is provided. This guide is one of a series of complementary standards covering various types of high-voltage fuses and switches, so arranged that two of the standards apply to all devices while each of the other standards provides additional specifications for a particular device. For each device, IEEE Std C37.40-1993, IEEE Std C37.41-1994, plus the standard covering that device, constitute a complete set of standards for each device. In addition, IEEE Std C37.48-1997 is an application, operation, and maintenance guide for all the devices.
Keywords: current-limiting fuses, distribution class fuses, expulsion type fuses, fuse enclosure packages, fuses, power class fuses

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Introduction

(This introduction is not part of IEEE Std C37.48-1997, IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.)

This guide is a revision of ANSI/IEEE Std C37.48-1987 to bring it up to date and in line with present day requirements for high-voltage fuses and switches. The addition of guidelines for full-range current-limiting fuses, expulsion fuses in enclosures, and external fuses for shunt capacitors broadens its applicability. Information formerly included on the testing of current-limiting fuses in enclosures now appears in IEEE Std C37.41-1994.

This guide was prepared by the IEEE Subcommittee on High-Voltage Fuses with cooperation from the National Electrical Manufacturers Association (NEMA). Liaison was maintained with the Edison Electric Institute (EEI) and the International Electrotechnical Commission (IEC) during the development in order to incorporate the latest thinking up to the time of publication.

This guide is one of a series of complementary standards covering various types of high-voltage fuses and switches, so arranged that two of the standards apply to all devices while each of the other standards provides additional specifications for a particular device. For each device, IEEE Std C37.40-1993, IEEE Std C37.41-1994, plus the standard covering that device, constitute a complete set of standards for each device. In addition, IEEE Std C37.48-1997 is an application, operation, and maintenance guide for all the devices.

The following standards comprise this series:

ANSI C37.42-1995, American National Standard Specifications for Distribution Cutouts and Fuse Links.

ANSI C37.44-1981 (R1992), American National Standard Specifications for Distribution Oil Cutouts and Fuse Links.

ANSI C37.45-1981 (R1992), American National Standard Specifications for Distribution Enclosed Single-Pole Air Switches.

ANSI C37.46-1981 (R1992), American National Standard Specifications for Power Fuses and Fuse Disconnecting Switches.

ANSI C37.47-1981 (R1992), American National Standard Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.

IEEE Std C37.40-1993, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.41-1994, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.48-1997, IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

Work on the added material on external capacitor fuses began in 1981 to fill a void in fuse standards and is being published for the first time in this revision of IEEE Std C37.48.

At the time this guide was completed, the Capacitor Fuse Working Group had the following membership:

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The final conditions for approval of this guide were met on 18 July 1997. This guide was conditionally approved by the IEEE Standards Board on 26 June 1997, with the following membership:

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Contents

IEEE Guide for the Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories

1. Overview

This guide presents information on the application, operation, and maintenance of high-voltage fuses (above 1000 V), distribution enclosed single-pole air switches, fuse disconnecting switches, and accessories for use on ac distribution systems.

1.1 Scope

These guidelines apply to the following specific types of equipment:

a) Distribution and power class expulsion type fuses;
b) Distribution and power class current-limiting type fuses;
c) Distribution and power class fuse disconnecting switches;
d) Items a) through c) used in fuse-enclosure packages (see types listed in 1.2 and 1.3);
e) Fuse supports, fuse mountings, and fuse hooks, of the type intended for use with distribution and power class fuses, and fuse disconnecting switches;
f) Removable switch blades of the type used exclusively with distribution class oil cutouts, power class fuses, and distribution class fuse disconnecting switches;
g) Fuse links of the type used exclusively with distribution class oil cutouts, power class fuses, and distribution class fuse disconnecting switches;
h) Distribution class oil cutouts;
i) Distribution class enclosed single-pole air switches; and
j) Distribution and power classes of expulsion, current-limiting and combination external capacitor fuses used with a capacitor unit, groups of units, or capacitor banks.

NOTE—The distribution and power class expulsion type fuses listed above are the same as those covered in IEC 60282-2[1]. The distribution class fuses are the same as class "A" fuses in that document and the power class fuses are the same as the class "B" fuses. At present IEEE standards do not cover the class "C" fuses. Some of the power and distribution class current-limiting fuses listed above are the same as those covered in IEC 60282-1.

[1]For information on references, see Clause 2.

1.2 Description of fuse-enclosure packages (FEPs) using expulsion type indoor power class fuses

— *Type 1E:* A fuse mounted in an enclosure with relatively free air circulation within the enclosure (for example, an expulsion fuse mounted in an enclosure or in a vault)
— *Type 2E:* A fuse mounted in a container with restricted air flow surrounding the fuse, but relatively free air circulation within the enclosure on the outside of the container (for example, an expulsion fuse in an enclosure with insulating barriers that form a container that restricts the airflow)
— *Type 3E:* A fuse mounted in an enclosure, directly immersed in liquid, with relatively free liquid circulating around the fuse (for example, an expulsion fuse in a switchgear enclosure)

1.3 Description of FEPs using current-limiting type indoor distribution and power class fuses

— *Type 1C:* A fuse mounted in an enclosure with relatively free air circulation within the enclosure (for example, a fuse mounted in a live front pad mounted transformer or in a vault)
— *Type 2C:* A fuse mounted in a container with restricted air flow surrounding the fuse, but with relatively free air circulation within the enclosure on the outside surfaces of the container (for example, a fuse inside a canister in a vault)
— *Type 3C:* A fuse mounted in a container with restricted air flow surrounding the fuse, but relatively free liquid circulating within the enclosure on the outside surfaces of the container (for example, a fuse inside a canister immersed in transformer oil)
— *Type 4C:* A combination of types 2C and 3C, where the container is partially in air and partially in liquid (for example, a fuse inside a transformer bushing)
— *Type 5C:* A fuse mounted in an enclosure, directly immersed in liquid, with relatively free liquid circulation around the fuse (for example, an oil immersed fuse in a transformer or switchgear enclosure)

2. References

2.1 American National Standards

When the following standards are superseded by an approved revision, the revision may not apply.

ANSI C37.42-1995, American National Standard Specifications for Distribution Cutouts and Fuse Links.[2]

ANSI C37.44-1981 (R1992), American National Standard Specifications for Distribution Oil Cutouts and Fuse Links.

ANSI C37.45-1981 (R1992), American National Standard Specifications for Distribution Enclosed Single-Pole Air Switches.

ANSI C37.46-1981 (R1992), American National Standard Specifications for Power Fuses and Fuse Disconnecting Switches.

ANSI C37.47-1981 (R1992), American National Standard Specifications for Distribution Fuse Disconnecting Switches, Fuse Supports, and Current-Limiting Fuses.

IEEE Std 18-1992, IEEE Standard for Shunt Power Capacitors.[3]

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[2]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

IEEE Std 1036-1992, IEEE Guide for Application of Shunt Power Capacitors (ANSI).

IEEE Std C37.40-1993, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.41-1994, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories (ANSI).

IEEE Std C37.99-1990 (Reaff 1994), IEEE Guide for the Protection of Shunt Capacitor Banks (ANSI).

IEEE Std C37.100-1992, IEEE Standard Definitions for Power Switchgear (ANSI).

NEMA CP1-1988 (R1992), Shunt Capacitors.[4]

2.2 Other standards

IEC 60282-1 (1994-12), High-voltage fuses—Part 1: Current-limiting fuses.[5]

IEC 60282-2 (1995-09), High-voltage fuses—Part 2: Expulsion fuses.

3. General application guidelines for all fuse types

3.1 Introduction

The application, operation, and maintenance of equipment covered by this guide is the responsibility of the user, who is expected to take into account his or her own particular requirements. As an aid in obtaining satisfactory performance of equipment, this guide provides information on some of the more important features of the above functions for normal conditions of service; unusual conditions may require special measures.

Although fuses are single-phase devices, they can be applied with single- or three-phase equipment or lines, or a combination of these. However, characteristics of the power system should be considered when selecting all fuses.

A fuse, when applied in an electric circuit within the limits of its ratings, protects the circuit. Its primary function is to isolate faulty equipment from the system. When applied with other equipment in a coordinated overcurrent protection scheme, it may also limit service interruptions to only a predetermined section of a power system. In many applications it is possible that the equipment connected to the system can be protected from excessive damage. In this latter application, the primary function is to remove the faulted equipment from the system, and the secondary function is to minimize the damage to the connected equipment as much as possible, considering the varying fault or overload circumstances that can occur.

Fuse performance depends upon the integrity with which the fuse was manufactured, the correctness of its application, and the attention it receives after it is installed. If not properly applied and maintained, it might not perform properly when required, which might result in considerable damage to costly equipment or extensive interruptions in service.

[4]A 1995 revision of CP1 has ben published and may be referred to for general information. The 1988 edition is used for normative references in this guide. NEMA publications are available from the National Electrical Manufacturers Association, 1300 N. 17th St., Ste. 1847, Rosslyn, VA 22209, USA.

[5]IEC publications are available from IEC Sales Department, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse. IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

It cannot be stressed too strongly that prescribed safety rules and manufacturers' recommendations and instructions should be adhered to at all times when operating or maintaining these devices near energized equipment or conductors. This is especially true for devices where air-insulated blades, insulating barriers or liners, or fuses are removed or replaced while mating contacts are energized.

3.2 Service conditions

3.2.1 Usual

Usual service conditions conforming to this guide are defined in IEEE Std C37.40-1993, subclause 2.1. These conditions specify limits in altitude and ambient temperature.

3.2.2 Unusual

Unusual service conditions are defined in IEEE Std C37.40-1993, subclause 2.2, which gives examples of such conditions. IEEE Std C37.40-1993, Table 1, lists altitude correction factors for dielectric strength, and rated continuous current, or ambient temperature for altitudes above 1000 m (3300 ft).

If, during service, the fuse will be subjected to mechanical vibratory stress that may damage the fuse element, the manufacturer should be consulted to verify that it can withstand these conditions.

3.3 Selection of class and type of fuse

There are no generalizations that can be made about selecting the class and type of fuse to use at a particular location. In selection of the class of fuse, factors such as power being supplied, dielectric properties of the equipment being protected, X/R ratios, fault currents available, and transient recovery voltage (TRV) severity require consideration. The major classes of fuses are power class and distribution class.

3.3.1 Fuse class

3.3.1.1 Power class fuses

Power class fuses are

a) Generally used in three-phase applications.
b) Generally used in substations, cabinets, or vaults where a large amount of electrical power is being supplied to a distribution system or some facility that requires large quantities of energy.
c) Generally used in that part of a system where high dielectric properties are required for all equipment.
d) Normally placed in a position on the system where fault currents are high, X/R ratios are high, and TRV characteristics are more severe than those found in the applications where distribution fuses are used.
e) Used in single-phase applications where severe faults, high X/R, or severe TRV is anticipated in an area where distribution fuses would normally be used.

3.3.1.2 Distribution class fuses

Distribution class fuses are

a) Generally used in single-phase applications.
b) Generally used in the distribution line on single-phase taps for sectionalizing purposes or for protecting single-phase transformers supplying residential or small business energy requirements.
c) Generally used in that part of a system where the requirements of the system can be accommodated by the distribution fuse's rated interrupting capabilities, and dielectric properties.

d) Suitable for use in three-phase applications where the high capabilities of the power fuse are not required and other application requirements are met.

3.3.2 Fuse types

3.3.2.1 Expulsion type fuses

An expulsion fuse is a vented device in which the expulsion effect of the gases produced by the interaction of the arc with other parts of the fuse results in the current interruption in the circuit. A consideration in their application is the criteria that the gases expelled are properly directed, and that the noise and pressure created are acceptable. Some power class expulsion fuses can be provided with an exhaust-control device to virtually eliminate the effect of these gases. Manufacturers' recommendations for the use of expulsion type fuses should be followed. In most cases expulsion fuses do not appreciably limit the circuit's prospective fault current.

3.3.2.2 Nonexpulsion type fuses

Nonexpulsion type fuses may be current-limiting or non-current-limiting. The major uses for nonexpulsion type fuses are in applications where the clearances to grounded parts are limited or the current-limiting properties of current-limiting fuses are required.

3.3.2.2.1 Backup current-limiting fuse

This is a current-limiting fuse that provides only fault current interrupting duty from its maximum interrupting rating down to its minimum interrupting rating. Some auxiliary device is used to interrupt any lower faults or overcurrents.

3.3.2.2.2 General-purpose current-limiting fuse

This is a current-limiting fuse that can satisfactorily interrupt high and low fault currents and overcurrents as low as those that cause fuse operation in not less than one hour.

3.3.2.2.3 Full-range current-limiting fuse

This is a current-limiting fuse that can satisfactorily interrupt high and low fault currents, as well as any overcurrent that causes fuse operation, with the fuse applied at its rated maximum application temperature specified.

3.3.2.2.4 Non-current-limiting types of nonexpulsion type fuses

There are other types of nonexpulsion type fuses such as liquid fuses, vacuum fuses, or SF_6 fuses. However, their application is very special. In all cases the manufacturer's recommendations should be followed. These types of nonexpulsion fuses do not appreciably limit the circuit's prospective fault current.

3.4 Clearances and spacing

Minimum electrical spacings and clearances for power fuse and disconnecting switch installations shall be in accordance with ANSI C37.46-1981, Tables 7, 8, and 9. The application should recognize the conditions prevalent during design testing (per IEEE Std C37.41-1994) and generally conform to the test clearances and conditions as a minimum, unless the manufacturer recommends the minimum clearances to be observed.

Expulsion fuses should be applied with adequate clearance in the direction or directions in which they are vented, and facilities should be provided to ensure that operators are not exposed to fuse discharges either during replacement or when working in the area. When this is not possible, the circuit should be de-energized.

Clearances for distribution oil cutouts are generally dictated by type of cable connection and should be in accordance with the manufacturer's recommendations.

3.5 Fuse position

The positioning of the fuses on a pole or crossarm should be such that their operation is facilitated. Fuses that are far out on a crossarm should open in a plane that is inclined toward the pole, rather than in a plane that is perpendicular to the crossarm.

3.6 Noise level

Expulsion fuses may produce intense short-term noise levels during fault interruption. The height, location, and exhaust control of expulsion fuses should be such as to minimize the noise level at any location normally occupied by personnel. Some power class expulsion fuses can be provided with an exhaust-control device to virtually eliminate the noise produced during an interruption.

3.7 Selection of fuse voltage rating (see 4.4.2.2 and 4.4.3.2 for specific guidelines for voltage rating selection for capacitor fuses)

The selection of the proper voltage rating for fuses is based on consideration of the following system parameters:

a) Maximum system line-to-line or line-to-ground power frequency recovery voltage,
b) System neutral grounding, and
c) Single- or three-phase circuits.

The rated voltage of expulsion fuses may exceed the system voltage by any desired amount. Care should be taken in applying current-limiting fuses with higher voltage ratings than the system voltage. Current-limiting fuses can produce peak arc voltages higher than the fuse voltage rating. These overvoltages should not exceed system and equipment insulation levels. The sparkover voltage of source-side-connected surge arresters should be considered. The fuse manufacturer's recommendations should be followed in this regard.

3.7.1 Power class fuses

The fuse should have a maximum voltage rating equal to or exceeding the maximum system line-to-line voltage.

NOTE—Most power fuses are used on three-phase applications. When used on single-phase line-to-ground circuits, the fuse should have a maximum voltage rating of at least 1.15 times the maximum line-to-ground voltage of the system. If the fuse has been tested for rated interrupting current at rated maximum voltage, or the fault current where the fuse is to be applied does not exceed 87% of the fuse rated interrupting current, then the fuse need only have a maximum voltage rating equal to or greater than the maximum line-to-ground voltage of the system when applied on single-phase line-to-ground circuits.

3.7.2 Distribution class fuses

3.7.2.1 Fuses for ungrounded-neutral systems or systems having higher resistance grounding than effectively grounded neutral (multigrounded) systems

A single-voltage rated distribution fuse should have a maximum voltage rating equal to or exceeding the maximum system line-to-line voltage. A slant-voltage-rated (multiple-voltage-rated) cutout (e.g., 15/27 kV) should have a maximum voltage rating to the left of the slant equal to or exceeding the maximum system line-to-line voltage.

3.7.2.2 Fuses for effectively grounded-neutral (multigrounded) systems

3.7.2.2.1 Single-voltage-rated distribution fuses

a) In single-phase, line-to-neutral circuits, the fuse should have a maximum voltage rating equal to or exceeding the maximum system line-to-ground voltage, and a basic insulation level (BIL) coordinated with the line-to-ground insulation of other connected apparatus.
b) In three-phase circuits where multiphase faults not involving ground can occur, the fuse should have a maximum voltage rating equal to or exceeding the maximum system line-to-line voltage.
c) In three-phase circuits where multiphase faults not involving ground cannot occur or are unlikely (for example, where phase isolation is employed as in underground or cubicle construction), and the fuse is not required to protect transformers against secondary faults of the types that would impose greater than line-to-ground recovery voltage, the fuse may have a maximum voltage rating equal to or exceeding the maximum system line-to-ground voltage, and should have a BIL coordinated with the line-to-ground insulation of other connected apparatus. Another device may be required to clear such faults, should they occur.

3.7.2.2.2 Slant-voltage-rated (multiple-voltage-rated) distribution cutouts

a) In single-phase, line-to-neutral circuits, the cutout should have a maximum voltage rating to the left of the slant equal to or exceeding the maximum system line-to-ground voltage.
b) In three-phase circuits, the cutout should have a maximum voltage rating to the right of the slant equal to or exceeding the maximum system line-to-line voltage. Some of the criteria for using slant-voltage-rated cutouts in three-phase circuits as herein set forth are:
    1) Three-phase faults not involving ground, which impose 87% of line-to-line voltage across the first cutout to clear, seldom occur. Operation of another device may be required to clear such faults, but experience indicates such cases are rare.
    2) Phase-to-phase faults not involving ground generally cause two cutouts to operate in series to clear the fault. Even with differences in fuse-link melting time, both cutouts work together to clear high-current faults. On medium-current faults, the possibility exists of load current continuing to flow through one of the cutouts, after fault clearing by series operation of the two cutouts. Operation of another device may be required if the cutout does not clear the continuing load current, but experience indicates that such cases are extremely rare.
    3) The maximum current to be cleared by one cutout operating alone at line-to-line voltage is limited to approximately the one-cycle melting current of the fuse link in the second cutout involved. Slant-voltage-rated cutouts will generally clear such relatively low currents at full line-to-line recovery voltage.
    4) The BIL of a slant-voltage-rated cutout should be coordinated with the line-to-ground insulation of other connected apparatus. Consideration should also be given to service conditions listed in IEEE Std C37.40-1993, Clause 2, as they apply to dielectric strength.
    5) Manufacturer's recommendations should be followed on the suitability of particular slant-voltage-rated cutouts for three-phase application.

3.8 Selection of continuous-current rating (all applications except capacitor fuses and fuses used in enclosures—see 4.2, 4.3 and 4.4)

There are no generalizations to be made about the selection of a current rating for a high-voltage fuse since there are radically different objectives for using a fuse as an overcurrent protective device, such as the type and rating of the equipment being protected, the nature of the loads imposed by the equipment or circuits, special operating practices of the user such as loading of transformers, special operating requirements of the user such as the ability to withstand cold load pickup after extended outages, and coordination with other series protective devices.

This guide, therefore, will present a listing of the most commonly used applications for high-voltage fuses together with the objectives that are required and can be achieved with proper fuse ampere rating and time-current characteristics (TCC) selection. The effect of ambient temperature on the current rating of the fuse is also presented.

3.8.1 Fuse applications on primary distribution systems

3.8.1.1 Fuses for distribution transformers—residential, industrial, institutional, and commercial

Some desirable functions of fuses for these applications are as follows:

a) To protect the distribution system from faults at or within the transformer, and coordinate with the next upstream overcurrent protective device up to the maximum fault current available at the transformer fuse.
b) To provide maximum protection to the transformer from through-faults, with the degree of transformer protection determined by comparing the appropriate time-current curve for the fuse selected with the appropriate transformer short-time loading curve; both curves need to be properly adjusted to reflect differences between primary- and secondary-phase currents and winding currents associated with the specific transformer connection involved and the types of possible faults in the secondary circuit.
c) To provide earliest possible detection and clearing of internal transformer faults.
d) To permit loading of the transformer to the maximum loading practice of the user.
e) To withstand combined transformer magnetizing inrush and load pickup current after short-time (up to 1 min) service interruption, and combined transformer magnetizing inrush and load pickup current after extended (30 min and longer) outages.
f) To properly coordinate with overcurrent protection devices on the secondary of the transformer.
g) For small residential transformers (25 kVA and lower), to withstand surge discharge through a grounded primary winding whose magnetic circuit has become saturated by a long-time lightning-induced surge.
h) For residential transformers with a fuse located ahead of a surge arrester at the transformer, to withstand the potential surge current that may be discharged through the arrester.

3.8.1.2 Fuses for reclosers or circuit-breaker bypass switches

Some desirable functions of fuses in these applications are as follows:

a) To protect the substation transformer from feeder faults in the zone from the bypassed device to the next main circuit downstream overcurrent protective device, and coordinate with the next upstream overcurrent protective device up to the maximum through-fault current available at the bypass fuse.
b) To permit loading of the feeder to the maximum loading practice of the user.
c) To properly coordinate with main circuit downstream overcurrent protective devices.

3.8.1.3 Fuses for sectionalizing

Some desirable functions of fuses for these applications are as follows:

a) To protect conductors from burn-down or extreme heating in the zone from the sectionalizing fuse to the next main circuit downstream overcurrent protective device, and coordinate with the next upstream overcurrent protective device up to the maximum fault current available at the sectionalizing fuse.
b) To permit loading of the circuit to the maximum loading practice of the user.
c) To properly coordinate with main circuit downstream overcurrent protective devices.

3.8.2 Fuse applications on subtransmission systems

Some desirable functions of fuses for these applications are as follows:

a) To protect the substation bus from faults at or within the distribution substation transformer, and coordinate with all upstream overcurrent protective devices up to the maximum fault current available on the substation bus.
b) To provide maximum protection to the transformer from through-faults, with the degree of transformer protection determined by comparing the appropriate time-current curve for the fuse selected with the appropriate transformer short-time loading curve; both curves need to be properly adjusted to reflect differences between primary- and secondary-phase currents and winding currents associated with the specific transformer connection involved and the types of possible faults in the secondary circuit.
c) To provide earliest possible detection and clearing of internal transformer faults.
d) To permit loading of the transformer to the maximum loading practice of the user.
e) To withstand combined transformer magnetizing inrush and load pickup current after short-time (up to 1 min) voltage interruption on the substation bus.
f) To properly coordinate with overcurrent protective devices on the secondary of transformer.

3.8.3 Fuses for motor protection

Some desirable functions of fuses for these applications are as follows:

a) To protect the supply system from faults at or within the motor and from cable faults between the motor and the motor starter, that are above the "takeover" point from the associated device that provides low overcurrent protection.
b) To coordinate with upstream protective devices up to the maximum available fault current at the motor starter location.
c) To permit maximum loading of the motor under continuous loading, emergency overloading, and frequent motor start conditions, within the ratings of the motor and the loading practice of the user.

3.9 Selection of interrupting rating

In many applications the available fault current is within the interrupting capability of a single fuse. In some applications the available fault current is higher than the interrupting rating of the fuse desired and another device is used in series. For such applications, an expulsion fuse is generally used for clearing the low fault currents and a backup current-limiting fuse is used for clearing the high fault currents. Coordination of these two devices is covered in 4.1.

The interrupting rating of a fuse, when used alone, should be equal to or greater than the maximum fault current available at the fuse. When used in conjunction with a backup fuse having a higher interrupting rating, the maximum interrupting rating of the first fuse should be greater than the minimum interrupting rating of the backup fuse. The interrupting rating of the combination of the first fuse and backup fuse is then equal to that of the backup fuse rating and should be equal to or greater than the maximum fault current available at the combination. The backup fuse should be chosen to have an I^2t let-through that is less than the I^2t-withstand capability of the first fuse.

Fuses are normally rated for their interrupting capability in symmetrical amperes. However, the test also checks their capability to interrupt asymmetrical fault currents associated with specified X/R ratios. These X/R ratios are generally more severe than those experienced on actual power systems. For the rare cases where system X/R is greater than that specified in the testing of the fuse, reduction of the interrupting rating may be necessary. The fuse manufacturer should be consulted.

3.10 Fuse coordination procedure

For the fuses on an electric system to operate properly and provide the desired system protection, consideration of voltage, continuous current, and interrupting ratings is not sufficient to select the proper fuse for a particular application. One must also ensure that the fuse being selected will operate correctly relative to the other series-connected fuses being used in the system. The procedure by which this is accomplished is called the fuse-to-fuse coordination procedure.

The information required to select fuses that coordinate with one another is usually provided in the form of two curves that represent the melting and clearing characteristics of the fuses. The minimum melting time-current curve shows the minimum time, expressed in seconds, required to melt the fusible element(s) for a particular value of symmetrical power-frequency current. The total clearing time-current curve shows the maximum time, expressed in seconds, to complete current interruption at a particular value of symmetrical current. Both curves take into account variations resulting from manufacturing tolerances and represent performance under specific conditions (see IEEE Std C37.41-1994).

On both the minimum melting and total clearing time-current curves for current-limiting fuses, currents can usually be determined for times as short as 0.01 s. However, since expulsion and other types of non-current-limiting fuses do not clear in less than one loop of current, the total clearing curves for these fuses show a constant value of time for all currents that produce melting in less than one loop (that is, approximately 0.8 of a cycle, 0.013 s for 60 Hz, for a typical X/R value).

Characteristic information for current-limiting fuses for times less than 0.01 s is often provided in terms of I^2t (strictly $\int i^2 dt$). Data on the minimum melting I^2t and total clearing I^2t can be presented either in tabular form or as curves showing I^2t as a function of the available fault current. As melting time decreases, melting I^2t approaches a fixed value, which is a function of the fusible element material and geometry.

Properly coordinating expulsion and other types of non-current-limiting fuses is basically a matter of keeping the minimum melting curve of the source-side fuse above and to the right of the total clearing curve of any load-side fuse within the range of fault current available at the load-side fuse. To allow for variables such as preloading and ambient temperature variations, the manufacturer should be consulted for proper adjustment factors. In the absence of manufacturer's data, one of the following commonly used techniques may be used. The first technique is to allow a 10% safety margin in current for any value of time. The second utilizes a 25% margin in time for any value of current.

When load-side current-limiting fuses are used, coordination can be done in a similar fashion, for times as short as 0.01 s. Additionally for load-side current-limiting fuses, coordination can be achieved for melting and clearing times at less than 0.01 s if the minimum melting I^2t of the source-side fuse is greater than the maximum let-through I^2t of a load-side current-limiting fuse. Consult the fuse manufacturer for appropriate safety margins in this regard.

Coordination of current-limiting fuses in the low current region is dependent on which of the three types of current-limiting fuses is being considered; general-purpose, full-range, or backup type current-limiting fuse. Refer to 4.1 for information on coordination procedures for the three types of current-limiting fuses.

3.11 Coordination for motor starter fuses (motor protection)

These fuses are normally selected on the basis of the assigned "R" value, which specifies the melting current in the 15 s to 35 s region of the time-current characteristic curve (see ANSI C37.46-1981). This coordinates with the contactor relay settings to give full protection to the motor circuit. However, it is necessary to ensure that the full load current of the motor, or any sustained motor overload conditions, are within the continuous-current capability of the fuse, at the application ambient temperature.

4. Additional application guidelines for specific devices

4.1 Current-limiting fuses

4.1.1 General

Different types of current-limiting fuses have different capabilities of interrupting low currents. For this reason, numerous techniques have been developed to enable current-limiting fuses to interrupt these low currents. As a result, three different types of current-limiting fuses, backup, general-purpose, and full-range have been defined and are recognized in industry standards. Each type has unique operation and application characteristics.

Many of these fuses have a similar external appearance. However, each type of fuse has different internal structures that allow them to function correctly, according to the requirements for each type of fuse. Since backup current-limiting fuses are not designed to interrupt low currents, another means, such as a series-connected device, is necessary to interrupt during overload or low fault current conditions. General-purpose and full-range fuses incorporate low current interrupting capability into the fuse design to different degrees.

4.1.2 Descriptions of the three types of current-limiting fuses

The description of the various types of current-limiting fuse is as follows:

a) A backup current-limiting fuse is capable of interrupting all continuous currents from its rated interrupting current, down to its rated minimum interrupting current. It is normally applied in conjunction with a second interrupting device that can interrupt currents below the minimum interrupting current of the backup fuse.
b) A general-purpose current-limiting fuse is defined as being capable of interrupting all currents from its rated interrupting current down to the current that causes melting of the fusible element(s) in no less than one hour.
c) A full-range current-limiting fuse is capable of interrupting all continuous currents from its rated interrupting current down to the minimum continuous current that causes melting of the fusible element(s) with the fuse applied at the maximum ambient temperature specified by the fuse manufacturer.

4.1.3 Selection guidelines for current-limiting fuses

Several factors must be considered in the selection of different types of current-limiting fuses. One important factor, not to be overlooked, is the fuse's ability to interrupt low current conditions. Principles guiding the selection of current-limiting fuses are summarized below.

4.1.3.1 Backup current-limiting fuses

A backup fuse can interrupt any current between its rated minimum interrupting current and its rated maximum interrupting current. If a backup fuse is melted open at a current less than its minimum interrupting rating, the fuse may not interrupt the circuit. Because of this, a backup fuse should not be used in applications where it will be required to interrupt currents less than its rated minimum interrupting current. The backup fuse is always applied in series with another interrupting device that will interrupt currents below the rated minimum interrupting current of the backup fuse. The series device may be another fuse or a breaker. In other cases, these currents may be interrupted by a device that is tripped when the backup fuse's element(s) melt open and is coordinated to protect the backup fuse. More commonly, expulsion fuses are used with backup fuses to achieve the low end interrupting capability.

A backup fuse used out-of-doors in series with a fuse cutout presents a special case of coordination. Typically backup fuses used in this application are rated by the largest expulsion fuse link that they may be used with while still meeting coordination rules. For instance, one type of backup fuse that can be used with a 12 A type K expulsion fuse link is designated as being a 12K coordinating fuse.

For all types of backup fuses, manufacturers' recommendations for application should be followed. If manufacturers' recommendations are not available, one of the following coordination methods may apply.

4.1.3.1.1 Backup current-limiting fuse coordination

Two methods for establishing coordination between backup current-limiting fuses and the series-connected low current interrupting device are as follows:

a) *Matched melt coordination:*

   This coordination principle ensures that the series-connected device will operate under any fault current condition. With matched melt coordination, when the series device is an expulsion fuse, the minimum I^2t (ampere squared seconds) let-through of the current-limiting fuse must be equal to or greater than the maximum melt I^2t of the expulsion fuse. One conservative approach ensuring that the current-limiting fuse will let through sufficient energy to melt open the expulsion fuse is to choose a current-limiting fuse having a minimum melting I^2t greater than the maximum melting I^2t of the expulsion fuse.

   A more practical approach is to take into account the fact that the current-limiting fuse will, under almost all practical circumstances, let through more I^2t than its minimum melting I^2t. Not only will the I^2t that causes melting likely be higher than the minimum melting I^2t, additional I^2t will be let through as a result of the arcing that occurs after melting and which continues until the fuse has cleared. Experience has shown that excellent coordination can be realized as long as the maximum melting I^2t of the expulsion fuse does not exceed approximately twice the minimum melting I^2t of the current-limiting fuse.

   In order to use the matched-melt method of coordination, one must know the values of the maximum melting I^2t for the expulsion fuse and the minimum melting I^2t for the current-limiting fuse. Although the latter is usually included in the performance data published by the current-limiting fuse manufacturer, the former is not normally published by expulsion fuse manufacturers. However, it can be readily calculated from the expulsion fuse's minimum melting time-current characteristic curve.

   One method of calculation involves first determining the current corresponding to the value of time representing the fewest whole number of quarter-cycles shown on the time-current curve. For many published curves, this would be the current corresponding to three quarter-cycles (.0125 s). Once the current has been determined from the expulsion fuse's minimum melting curve, it should be increased by an appropriate factor to take into account variations resulting from manufacturing tolerances.

In the case of expulsion fuses having silver elements, this factor is 10%. For fuses with elements made from other materials, this factor is normally 20%. After the current has been corrected to allow for manufacturing tolerances, the maximum melting I^2t of the expulsion fuse can be calculated by first squaring this current and then multiplying that value by the time (expressed in seconds) that was the basis for determining the current. If the expulsion fuse manufacturer publishes a value for the fuse's maximum melting I^2t, that value should be used rather than the value that one would obtain from the previously described procedure.

The principal advantage of the matched-melt method is that the expulsion fuse will melt open even if the current-limiting fuse does the actual clearing. This is the approach that should be used with those backup current-limiting fuses that may not have a long-term voltage withstand capability. When applied in series with a fuse cutout, the melting open of the cutout link ensures that the fuseholder will always drop open. Having the cutout drop open provides a visual indication as to the location of the fault that caused the fuses to operate and also serves to remove the voltage stress from the current-limiting fuse that has operated. The latter function is also accomplished by any other type of expulsion fuse that would be used in series with the current-limiting fuse. Therefore, when the current-limiting fuse is properly coordinated with any series-connected expulsion fuse using the matched-melt method, the current-limiting fuse is not likely to have the system's voltage impressed across it after it has operated.

Another advantage of this coordination method is that in three-phase applications the voltage rating of the backup current-limiting fuse usually need only be equal to the system's line-to-neutral voltage as long as the voltage rating of the expulsion fuse is equal to the system's line-to-line voltage. This is the main reason why this coordination method is sometimes used with the under-oil backup current-limiting fuse.

The above comparison checks the coordination at the high current, short-time region of the curves. To ensure complete coordination, the time-current curves of the two devices should be checked to be sure the total clearing curve of the protecting device does not cross the minimum melting curve of the current-limiting fuse in a low current, long duration region.

b) *Time-current curve-crossover coordination:*

The second method for coordinating backup current-limiting fuses is referred to as time-current curve-crossover coordination. This method of coordination is frequently used with under-oil backup current-limiting fuses. Time-current curve-crossover coordination is rarely used in applying the outdoor backup current-limiting fuses, because there is no assurance that a series cutout would drop open using this method, since the current-limiting fuse may melt and clear without letting through enough energy to melt the expulsion fuse under fault conditions. If the cutout does not open, full voltage can be impressed on a weathered outdoor fuse that may no longer have full voltage withstand capability.

One need not be concerned with the melt I^2t values of the two fuses when using the crossover method of coordination. The principal criterion to be satisfied is that the intersection (crossover point) of the expulsion fuse's total clearing curve and the current-limiting fuse's minimum melting curve in the high current, short duration region must correspond to a current that is greater than the minimum interrupting rating of the current-limiting fuse, but less than the maximum interrupting rating of the expulsion fuse. The manufacturers of the expulsion fuse and the current-limiting fuse should publish values for these performance characteristics.

For applications of backup current-limiting fuses on the primaries of transformers, another important selection criterion, from the standpoint of serviceability and operability, is the current associated with a bolted-fault at the secondary terminals of the transformer. A current-limiting fuse should be chosen such that this current is less than the current corresponding to the crossover point of the maximum clearing curve of the protecting device and the minimum melting curve of the current-limiting fuse.

More specifically, one needs to first locate the point in time on the expulsion fuse's total clearing curve that corresponds to the bolted-fault current. After this point has been located, next determine the current on the minimum melting curve of the current-limiting fuse that corresponds to this time. If that current equals at least 125% of the bolted-fault current, the current-limiting fuse should only melt in the case of an internal transformer fault.

As is the case with matched-melt coordination, it is important that the expulsion fuse's total clearing curve not recross the current-limiting fuse's minimum melting curve in the low-current, long-time region. This would allow the current-limiting fuse to respond to a current below its rated minimum interrupting current.

A suitable safety margin is considered to exist if, in the long-time region of the curves, the current-limiting fuse's minimum melting current at any given time equals at least 125% of the current determined from the expulsion fuse's total clearing curve at that same time. Preloading should not affect this as any shifting to the left of the characteristic curves due to I^2R heating of the fuse element(s) or ambient oil temperature rise will be as much or more for the expulsion fuse as for the current-limiting fuse.

The principal advantage of the time-current curve crossover method is that it normally permits the use of a lower current-rated current-limiting fuse than does the matched-melt method. This can be significant in several regards.

First, the lower the current-limiting fuse's current rating is, the less energy the fuse will let through under fault conditions. Obviously, the lower the energy that is let through by the current-limiting fuse, the better the protection will be against eventful failure anywhere on the system that is protected by the current-limiting fuse. In addition, the fault will have less effect on the rest of the distribution system, as voltage drops are minimized.

Second, the lower the current rating of the current-limiting fuse, the smaller it usually is apt to be and the less space it will require for installation.

Third, this method of coordination allows extension of current-limiting fuse protection to larger kVA transformers.

4.1.3.1.2 Presentation of backup fuse operating characteristics

For backup fuses, currents that are less than the minimum rated interrupting current but will still melt the element(s) are often shown as a dashed or broken line on the minimum melting TCC curve. Currents less than the minimum current the fuse can interrupt are usually not shown on the total clearing curve since the fuse cannot reliably interrupt those currents.

The fuse manufacturer also provides the maximum interrupting rating of the fuse. This rating should not be exceeded. Other characteristics such as minimum-melt I^2t, maximum let-through I^2t, and peak let-through current vs. available current charts are also published and generally available. This data provides needed information to properly apply and coordinate these fuses.

Caution should be exercised when replacing a backup fuse. Coordination between the backup fuse and the low current interrupting device in series with it, is critical to preventing damage to the backup fuse and associated equipment. Therefore, replacement of either protective device with one of a different rating or supplied by a different manufacturer should be done only after a careful review of the total protection scheme to be sure that coordination is maintained.

4.1.3.2 General-purpose current-limiting fuses

A general-purpose fuse is defined by standards as a device that can interrupt any fault current between a current that will cause the fuse to melt in not less than one hour and its rated maximum interrupting current. Typically, these fuses are used for transformer through-fault protection (for melting times less than about one hour), or to protect the system from the effects of a high-current, low-impedance fault.

General-purpose CL fuses may not require any series device to be used with them. However, care should be taken so that the fuse is not called upon to interrupt overload currents that are below its one-hour melt current. In addition, general-purpose fuses should not be subjected to currents between their rated continuous current and their one-hour melt current, even if such a current does not result in melting. Operating a fuse in this zone can lead to fuse deterioration, which might later prevent the fuse from performing successfully at currents it could otherwise interrupt.

One method of ensuring that the general-purpose fuse is not overloaded, or required to interrupt overload conditions, is to apply the fuse in conjunction with load or temperature sensing devices, such as a secondary or primary breaker in oil-filled distribution transformers. This prevents the fuse from melting open as a result of overloads or very long duration low current transformer through-faults. Breakers must be selected so that they will interrupt the current going through the transformer before the general-purpose fuse, mounted to the primary of the transformer, is damaged. A secondary breaker will not protect the transformer fuse from being damaged by a high-impedance primary fault.

When this type of fuse is used, care must be exercised to be sure that any derating of the fuse, caused by elevated temperature around the fuse or restricted air flow, is included in the selection process. When using some types of general-purpose fuses in drywell canisters, for instance, the continuous-current rating may require derating, as a result of the restricted air flow around the fuse. If this fuse is used in a very warm environment, say 100 °C, in an overloaded transformer, an additional derating is usually required. After derating is factored in, the load current may be at or above the rated continuous current of the fuse. In this case, the manufacturer should be consulted for advice concerning the temperature and environment that the fuse was tested in to be sure there is adequate margin for the application.

Although not required by standards, some fuse manufacturers can provide the one-hour capability of each general-purpose fuse (this is sometimes known as the minimum current required for successful interruption and is sometimes expressed as a percentage of the fuse's continuous-current rating) and the maximum temperature in which the fuse may be used. This may be done in table form or taken from time-current curves, which are extended beyond the normal 1000 s point on the time axis, the upper limit on most TCC curves. Other application data sometimes supplied in charts and curves includes minimum melt I^2t, maximum let-through I^2t, and peak let-through current vs. available current.

4.1.3.3 Full-range current-limiting fuses

A full-range current-limiting fuse, as defined by standards, can interrupt any continuous current between the minimum current that can cause melting of its elements, with the fuse applied at the maximum temperature specified by the manufacturer, and its rated interrupting current.

A full-range current-limiting fuse does not require any other associated device to protect it from overloads or high-impedance faults, as long as the ambient temperature surrounding the fuse does not exceed its maximum application ambient temperature. Full-range fuses can be used to protect against both faults and overloads.

A common application parameter for full-range fuses is the continuous-current rating at the typical service temperature (25 °C typically, with a range from 10 °C to 40 °C specified as typical in the standards). This rating is based on the temperature rise of the fuse, compared with limitations detailed in standards. TCC curves, minimum melt I^2t, maximum let-through I^2t, and peak let-through current vs. available current charts and tables are also often supplied.

Other criteria, such as voltage ranges, must also be used in selecting a fuse for a given application. Normal current-limiting fuse application guides must be followed with full-range fuses. These fuses can also experience difficulty if exposed to transient overcurrent conditions. Factors such as magnetizing inrush current levels need to be considered, as do coordination rules with other protecting and protected devices.

4.2 Current-limiting fuses used in FEPs

4.2.1 General

Many applications require the use of current-limiting fuses in enclosures where the fuse and the associated contacts may be subjected to air temperatures above 40 °C. Other applications may require the fuse to be immersed in a liquid such as transformer oil. Current-limiting fuses intended for such service shall comply with the applicable design tests specified in accordance with IEEE Std C37.41-1994, ANSI C37.46-1981, and ANSI C37.47-1981.

When current-limiting fuses are applied in enclosures of any type, the performance characteristics of the total system should be evaluated.

4.2.2 Applicable devices

See 1.3 for fuse container and enclosure package (FEP) types covered by this clause.

4.2.3 Clearances and spacing

The use of adequate insulating barriers may permit reduced separations when verified by proper tests.

4.2.4 Considerations for ambient temperature

The FEP application should take into consideration any higher operating temperatures caused by fuse confinement or elevated ambient temperatures. The supplier of the FEP specifies the maximum reference ambient temperature, in degrees Celsius, preferably selected from the 20 series of preferred numbers (typically 56, 63, 71, 80, 90, 100, 112, 125, or 140).

The modification of the thermal environment for the fuse due to an enclosure, and the higher than normal ambient temperatures of the FEP, will cause some shift of the fuse TCC. The largest shift occurs at the long-time end.

NOTE—Use of the general rule of thumb coordinating factor, that is, maximum clearing time of the load-side protective device, should not exceed 75% of the minimum melt time of the source-side device, generally provides sufficient allowance for TCC shift in the 0.01 s–1000 s region. Consult the manufacturer for specific adjustment information.

Application of general-purpose and full-range current-limiting fuses in enclosures, subject to, or producing high ambient temperatures may result in a reduction of the current required to produce element melting. Because the fuse and enclosure have interacting effects that determine the thermal environment of the fuse, the supplier of the FEP provides the long-time minimum melting current for each fuse size applied as described in 1.3. This current will be determined at the reference ambient temperature of 25 °C ± 5 °C. Any derating factor so determined will be due to the application of the fuse in the container.

A second derating factor may be published by the FEP supplier. This factor gives the percentage reduction of the long-time minimum melting current as related to the reference ambient temperature above the standard 25 °C. When no specific derating factor is provided, the following derating factors for the FEP long-time minimum melt current may be used as a guide.

Type (1C) 0.4%/°C of air temperature above 25 °C
Type (2C) 0.4%/°C of air temperature above 25 °C
Type (3C) 0.2%/°C of top oil temperature above 25 °C
Type (4C) 0.1%/°C of top oil temperature above 25 °C
Type (5C) 0.2%/°C of top oil temperature above 25 °C

Backup-type current-limiting fuses that are coordinated with other fuses (or overload sensing devices) intended to operate at low overload currents require no derating factors.

Backup current-limiting fuses that trip an interrupter switch after the fuse element melts may require a derating factor.

4.3 Expulsion fuses in enclosures

4.3.1 General

When expulsion fuses are applied in enclosures of any type, the performance characteristics of the total system should be evaluated.

The fuse, fuse container (if present), and the enclosure produce a system with interacting effects. Each component may be supplied by a different manufacturer. Data should be available from the component manufacturers to permit proper application. Suitability of a specific application of a fuse inside a container (F/C) should be the responsibility of the manufacturer of the F/C. Suitability of a specific application of a fuse or F/C in an enclosure should be the responsibility of the switchgear manufacturer. Proper application of the switchgear, based on the recommendations of the switchgear manufacturer, should be the responsibility of the user.

Application guidelines in this clause are in addition to those shown in Clause 3.

4.3.2 Applicable devices

a) Many applications require the use of expulsion fuses in air-insulated fuse-enclosure packages, where the fuse and associated contacts may be subjected to air temperatures above 40 °C. This section applies to the use of fuses that are in conformance with applicable sections of ANSI C37.46-1981 and IEEE Std C37.41-1994.
b) Some applications require expulsion fuses to be immersed in a liquid.

This subclause also applies to expulsion fuses that are immersed in liquid and used in switchgear (not directly associated with transformers). It is not intended to apply to distribution oil cutouts, which are devices covered by ANSI C37.44-1981 and by other clauses of this guide.

4.3.3 Clearances and spacing

Expulsion fuses generate high-pressure gases that are expelled during the interruption process. These gases should not be directed in a manner that reduces the dielectric withstand between phases and from phases to ground to a level that will result in dielectric breakdown.

Three-phase assemblies should be capable of withstanding the transient and power-frequency recovery voltages associated with the simultaneous operation of fuses in all three phases.

Clearances between fuses of adjacent phases and from each fuse to ground should be sufficient to maintain adequate dielectric withstand at all times. Manufacturer's recommendations for proper clearances and spacing should be followed.

The use of adequate insulating barriers may permit reduced separations when verified by proper tests.

4.3.4 Reduction of allowable continuous-current capability

Application that subjects the fuse to high ambient temperatures may result in a reduction of the allowable continuous current that the fuse or fuse container (F/C) is capable of carrying, since the capabilities are usually related to a lower ambient temperature.

Allowable continuous current is the highest current that the fuse is capable of carrying in a specified ambient without exceeding the maximum total temperature limits permitted by the device design.

The manufacturer of the fuse or F/C should provide the allowable continuous current for each fuse applied. Usually, these capabilities are available based upon a 25 °C ± 5 °C reference ambient. Factors normally published by the fuse manufacturer give the percent reduction of the allowable continuous-current capability for ambient temperatures above 25 °C.

An additional factor will be needed if a fuse normally intended to be used alone is placed in a close-fitting container, thus producing an F/C. This factor adjusts for the condition that the temperature of air surrounding the fuse inside the container will be higher than the reference ambient temperature of the air surrounding the F/C.

4.3.5 Operating forces

The manufacturer of the fuse or F/C should be consulted for the direction and magnitude of the force exerted by the assembly when it operates at its maximum interrupting rating.

4.4 External fuses for shunt capacitors

Fuses that are to be used for overcurrent protection of shunt capacitor banks have some operating and application requirements that differ from the requirements of fuses used for overcurrent protection in other applications. This subclause provides application guidelines for fuses that are mounted external to the capacitor(s), that are intended for the overcurrent protection of the capacitor(s) and that comply with applicable design tests of IEEE Std C37.41-1994. This document supplements information shown in IEEE Std C37.99-1990 regarding fuse application.

4.4.1 General application information for external fuses for shunt capacitor banks

An external fuse used for shunt capacitor bank protection, within the limits of its ratings, minimizes damage to the system and to the capacitor bank or capacitor unit resulting from a fault. Proper fuse performance will depend upon the correctness of the application and the attention the fuse receives before, during, and after its installation.

There are two kinds of external capacitor fuses: capacitor line fuses and capacitor unit fuses. Capacitor line fuses are used for the protection of the entire capacitor bank installation, whereas capacitor unit fuses are used for the protection of individual capacitor units. Some installations incorporate both capacitor line fuses and capacitor unit fuses. Small distribution capacitor banks are often protected only by capacitor line fuses.

Typically, the melting of the fuse is initiated by power-frequency overcurrent and/or, for capacitor unit fuses, from stored capacitor energy that is discharged through the fuse.

Power-frequency current and stored energy factors that should be considered when determining the proper protection for a capacitor bank are the system fault current available at the capacitor bank location, the type of capacitor bank connection (such as delta or wye, neutral grounded or ungrounded), the kvar rating of the capacitor unit or capacitor bank, and the number of capacitor units in parallel.

For applications where capacitor line or capacitor unit fuses are used in enclosures or vaults, expulsion fuses that have controlled venting or current-limiting fuses should be considered.

4.4.2 Guide for capacitor line (group) fuse application

Typically, when small wye-connected or single series group delta-connected distribution capacitor banks are protected by fuses, only capacitor line fuses are employed. For larger banks a line fuse may be used to protect the bank along with unit fuses for protection of each capacitor unit.

4.4.2.1 Application characteristics of capacitor line fuses

Some desirable characteristics for capacitor line fuses may include the following:

a) To protect the distribution system or substation bus from major faults at, or within, the capacitor bank, and coordinate with the next upstream overcurrent protective device up to the maximum fault current available at the capacitor bank.
b) To provide earliest possible isolation of one or more phases of a capacitor bank having a faulted capacitor unit, if no capacitor unit fuses are used.
c) To permit higher current loading associated with plus-side tolerance of capacitance in capacitor units, operating voltage in excess of nameplate rating, and the presence of harmonic currents.
d) To operate, when one phase of an ungrounded-wye bank becomes faulted to neutral, within a time span that will minimize the probability of damaging the capacitor units in the unfaulted phases due to overvoltage.
e) To withstand the transient energizing current from the system and from other nearby energized capacitor banks.
f) To withstand or operate (user's choice) on discharge current from the capacitor bank into a fault on the system near the capacitor bank.

Some considerations where only capacitor line fuses are used include the following:

— It is important that the fuse have a time-current total clearing characteristic consistent with the degree of risk associated with capacitor unit rupture that is acceptable for the type of installation and location contemplated for the capacitor bank.
— Where line fuses are used on an ungrounded wye-connected bank, the capacitor units on the unfaulted phases are subjected to overvoltages up to 1.73 per unit until the fault is cleared by the line fuse.
— Where line fuses are connected outside of the delta on a delta-connected bank, a faulted capacitor unit is not disconnected from the circuit if only one fuse operates.

4.4.2.2 Selection of rated maximum voltage for capacitor line fuses

The rated voltage V_f of the fuse is its rated maximum voltage, i.e., the maximum power-frequency rms voltage (including any system overvoltage) at which it is intended to be applied.

The rated maximum voltage of the fuse selected for capacitor line fuse applications should be equal to or greater than the maximum expected system operating voltage. This basis for rating selection does not necessarily ensure proper fuse operation during transient or short-time overvoltages associated with restriking circuit breakers, system faults, etc.

The rated voltage of expulsion fuses may exceed that required by the application by any desired amount.

Current-limiting fuses may produce peak arc voltages that are substantially higher than normal system peak power-frequency voltage. Selection of current-limiting fuses having a rated maximum voltage that is considerably higher than system power-frequency voltage may result in arc voltages that may cause insulation damage or surge arrester failure. The lowest available voltage rated current-limiting fuse that meets the application voltage requirement is recommended. If higher voltage rated current-limiting fuses are to be used, consult the manufacturer.

For ungrounded-wye- or delta-connected capacitor banks applied on ungrounded systems (including unigrounded systems), a single-voltage-rated expulsion fuse or a current-limiting fuse should have a maximum rated voltage equal to, or exceeding, the maximum system line-to-line voltage. A slant-voltage-rated (multiple-voltage-rated) cutout should have a maximum rated voltage to the left of the slant equal to, or exceeding, the maximum system line-to-line voltage. (For example, a 15/27 kV slant-voltage-rated cutout can be used on these systems when the system's line-to-line voltage does not exceed 15 kV.)

For ungrounded-wye- or delta-connected capacitor banks applied on effectively grounded systems, a single-voltage-rated expulsion or current-limiting fuse should have a rated maximum voltage equal to, or exceeding, the maximum system line-to-line voltage. A slant-voltage-rated (multiple-voltage-rated) cutout should have a rated maximum voltage to the left of the slant equal to, or exceeding, the maximum system line-to-ground voltage. (For example, a 15/27 kV slant-voltage-rated cutout can be used for this application when the system's line-to-ground voltage does not exceed 15 kV.)

For grounded-neutral wye-connected capacitor banks applied on effectively grounded (multigrounded four-wire) systems, a distribution class single-voltage-rated expulsion fuse or current-limiting fuse should have a maximum rated voltage equal to, or exceeding, the maximum system line-to-ground voltage. Power class single-voltage-rated expulsion fuses or power class current-limiting fuses should have a maximum rated voltage equal to, or exceeding, 1.15 times the maximum system line-to-ground voltage unless the fuse has been tested for rated interrupting current at rated maximum voltage or the available fault current at the capacitor bank location does not exceed 87% of the fuse's rated interrupting current. A slant-voltage-rated (multiple-voltage-rated) cutout should have a maximum rated voltage to the left of the slant equal to, or exceeding, the maximum system line-to-ground voltage. (For example, a 15/27 kV slant-voltage-rated cutout can be used for this application when the system's line-to-ground voltage does not exceed 15 kV.)

The application guidelines of the two previous paragraphs are based on the usual application where the fuse cutouts are located close to the capacitor bank and a three-phase fault not involving ground is not likely to occur. For applications where the fuses are located remote from the capacitor bank, or the capacitor bank construction is such that a three-phase fault not involving ground needs to be considered, the recovery conditions for this fault should be used to select the appropriate fuse. For these applications a single-voltage-rated expulsion fuse or current-limiting fuse should have a maximum rated voltage equal to, or exceeding, the maximum system line-to-line voltage. Likewise, a slant-voltage-rated (multiple-voltage-rated) cutout should have a maximum rated voltage to the left of the slant equal to, or exceeding, the maximum system line-to-line voltage. (For example, a 15/27 kV slant-voltage-rated cutout should be used for this application when the system's line-to-line voltage does not exceed 15 kV.)

NOTE—In the event of a three-phase ungrounded fault, the first capacitor line fuse to clear would see a recovery voltage of 1.5 times the line-to-ground voltage after clearing the fault current in its phase. The probability of the occurrence of such faults will have an effect, as indicated above, on the determination of the fuse voltage rating selected for the application. See 3.7 for further information on fuse voltage rating selection for three-phase applications.

The insulation withstand voltage level (BIL, power frequency voltages, and creepage) of the mounting used for the line fuse should be consistent with the system insulation level.

4.4.2.3 Selection of current rating for capacitor line fuses

4.4.2.3.1 Allowance factor

In general, the capacitor bank fuse should be selected based on the highest anticipated capacitor bank current. Specifically, the fuse selected should have an allowable maximum continuous-current-carrying capability, as differentiated from its nominal ampere rating, that is greater than this highest anticipated capacitor bank current level.

It follows, then, that this maximum capacitor bank current should be accurately known. This maximum current can be estimated by first calculating the nominal capacitor bank current and then applying correction factors.

The nominal capacitor line fuse current is equal to the nominal capacitor bank phase current. This nominal phase current ($I_{nominal}$) for three-phase capacitor banks can be calculated using Equation (1):

$$I_{nominal} = \frac{kvar_{3\phi}}{\sqrt{3}\ kV_{\phi-\phi}}\ A \tag{1}$$

where

$kvar_{3\phi}$ is the nominal three-phase kvar rating of the capacitor bank, and
$kV_{\phi-\phi}$ is the nominal phase-to-phase voltage rating of the capacitor bank in kilovolts.

For single-phase capacitor banks, this nominal phase current can be calculated using Equation (2):

$$I_{nominal} = \frac{kvar}{kV}\ A \tag{2}$$

where

kvar is the nominal single-phase kvar rating of the capacitor bank, and
kV is the nominal single-phase voltage (kV) rating of the capacitor bank.

NOTE—Equations (1) and (2) provide a method for calculating the nominal phase current for single- or three-phase capacitor banks wherein the nominal system voltage is equal to the nominal voltage rating of the capacitor bank. When fusing the individual legs of a delta-connected capacitor bank, the current in each leg (i.e., the current seen by the capacitor line fuse) may be determined by multiplying the nominal capacitor bank phase current by 0.58.

For systems operating at a nominal system voltage below the nominal voltage rating of the capacitor bank, the adjusted bank phase current ($I'_{nominal}$) can be determined by using Equation (3):

$$I'_{nominal} = I_{nominal} \cdot \frac{kV_{system}}{kV_{nominal}}\ A \tag{3}$$

where

$I_{nominal}$ is the nominal capacitor bank phase current,
kV_{system} is the nominal system voltage in kilovolts, and
$kV_{nominal}$ is the nominal voltage rating of the capacitor bank in kilovolts.

The same base reference is used for all voltage parameters (e.g., either a phase-to-phase or phase-to-ground voltage reference).

Once the nominal capacitor bank current has been calculated from the system voltage, capacitor bank voltage, and capacitor bank kvar rating, the highest anticipated capacitor bank current is then determined in the following manner. The maximum system operating voltage can be as much as 6% higher than the nominal system operating voltage. The capacitor units themselves are permitted by IEEE Std 18-1992 and NEMA CP1-1988 to have manufacturing tolerances of plus 15% in capacitance. Additionally, the presence of harmonics can add as much as 10% to the rms value of current. These factors, taken together, would require that the nominal capacitor bank current, calculated based on rated voltage and kvar, be increased by an allowance as high as 34% ($1.06 \times 1.15 \times 1.1 = 1.34$). However, an allowance of 35% is commonly used when conservatively selecting a capacitor line fuse.

In practice, the operating variables described above rarely attain the maximum values listed, and it is even less likely that they will all be at their maximum value at the same time. Consequently, some presently used allowances are as low as 17% for ungrounded banks and 25% for grounded banks. When applying expulsion type fuses, use of such allowances will typically result in the selection of a fuse ampere rating that can withstand inrush currents that result during switching of the capacitor bank even when other energized banks are nearby.

For small current rated expulsion fuses (less than 25 A), or for current-limiting type fuses, a slower speed ratio and/or a larger current rating may be required because of system transients caused by lightning, nearby faults, or switching of back-to-back banks.

When applying current-limiting type fuses, greater allowances may be required even with larger current rated fuses so the fuse can withstand these transient currents. For these types of applications it is recommended that the manufacturer of the selected capacitor line fuse be consulted.

Also, capacitor banks for certain types of industrial users may have currents of high harmonic content. Sufficient allowance must be made for these cases.

4.4.2.3.2 Adjustment for ambient temperature

Some manufacturers publish a maximum allowable continuous current for each fuse ampere rating when it is operating in a 25 °C or 30 °C ambient temperature. Peak load capabilities should be reduced according to manufacturers' recommendations to reflect operation in ambient temperatures as high as 40 °C (higher, if the installation warrants). Correction for a higher ambient recognizes that power-factor correction and voltage regulation provided by shunt capacitor banks is most crucial on those days when the load is highest. This condition may be coincident with summer peak loads and/or heat storms.

4.4.2.3.3 Maximum size fuse

The above considerations guide the selection of the minimum size fuse. The maximum size fuse for the application is determined by case rupture considerations. (See 4.4.2.5.)

For ungrounded wye-connected banks, the ability of the capacitor units in the unfaulted phases to withstand the overvoltage described in 4.4.2.1 until the fault is cleared should be considered.

The smallest size fuse that meets the guidelines in 4.4.2.3.1 and 4.4.2.3.2 is usually preferred for case rupture considerations and to minimize the time that the capacitors in the unfaulted phases of an ungrounded neutral capacitor bank are exposed to overvoltage.

4.4.2.4 Selection of rated interrupting current for capacitor line fuses

Generally capacitor line fuses used for the protection of small capacitor banks must be capable of interrupting both capacitive type fault currents and inductive type fault currents. The capacitive and inductive fault current interrupting ratings for capacitor line fuses should be equal to or greater than the maximum fault current of each type that is available at the bank's location. Both types of fault current interrupting ratings are specified in symmetrical amperes and are directly comparable to calculated fault current values of each type that are available at the capacitor bank location.

Capacitive current faults occur when there is some amount of capacitance that remains in series with the fuse as it is interrupting the circuit. A typical minimum capacitive type current the fuse may be required to interrupt can occur when there are progressive pack failures within the capacitor unit and the fuse is sized to respond prior to complete capacitor unit failure. A typical maximum capacitive type current the fuse may be required to interrupt can occur with a capacitor bank that has an ungrounded-neutral and only one series group of capacitors per phase. This current is three times the normal bank current and occurs if one phase is fully faulted.

For some larger capacitor banks, a line fuse may be used to protect the bank along with capacitor unit fuses for protection of each individual capacitor unit. Depending on the application and capacitor bank configuration, the line fuse may not need to meet the capacitive current interrupting requirements associated with a capacitor line fuse. For example, in a grounded-wye bank with a single series group, the individual capacitor unit fuses will normally respond to failures within a capacitor unit, thereby preventing the operation of the line fuse. As each individual capacitor unit is removed by its capacitor unit fuse, the line fuse sees decreasing current, and should only operate in the event of a catastrophic failure or fault external to the bank. In this case, the line fuse will see the full available inductive-type fault current. Another example where a line fuse may not need to meet the capacitive current interrupting requirements for a capacitor line fuse is a grounded-wye capacitor bank with multiple series groups protected by a switch/fuse combination. As successive individual capacitor units in a series group are isolated from the bank by their respective fuses, the surviving units are protected against overvoltage stress by the capacitor unbalance protection. In this selective coordination scheme, the line fuse will only respond in cases where a line-to-ground, line-to-line, or three-phase inductive-type fault occurs. Other examples, including delta-connected banks with a single series group, illustrate this point. A capacitor line fuse, rated for capacitive current interruption, must be used for the protection of banks where the configuration of the bank is such that interruption of capacitive currents by the line fuse cannot be ruled out.

Inductive fault currents are always possible in capacitor banks protected by capacitor line fuses since inductive fault currents can occur in the leads to the capacitor bank, in equipment between the fuses and the capacitor bank (switches, arresters, etc.), for some types of capacitor unit failure, or in the case of a major fault within the bank.

If the prospective inductive fault current at the capacitor bank exceeds the interrupting rating of an expulsion type capacitor line fuse, or the capability of the connected equipment, a current-limiting fuse may be used. This can be a general-purpose or full-range fuse to replace the expulsion fuse or the addition of a backup current-limiting fuse in series with the expulsion fuse. The let-through current of the current-limiting line fuse should be less than the withstand capability of the associated switch(es), expulsion fuse(s), and capacitor unit(s).

For applications where capacitor line fuses are used in enclosures or vaults, expulsion fuses that have controlled venting or current-limiting fuses should be used.

4.4.2.5 Capacitor unit rupture protection for banks protected by line fuses only

In addition to consideration for the fuse's rated maximum interrupting current, proper capacitor line fuse selection will also consider the maximum fault current that the capacitor unit can withstand without rupturing.

Capacitor units consist of series and parallel packs within a metal case that is filled with a dielectric fluid. These packs usually consist of a metal foil electrode and a film dielectric. Capacitor unit failure typically begins with the failure of a single pack. When this pack fails and shorts out, the voltage across and the current through the remaining packs increases. This increased stress causes additional packs to fail and, if the failure process is allowed to continue, it will result in all of the capacitor unit series packs shorted. Other capacitor unit failures may be caused by improper internal connections or dielectric failure to the case. Capacitor failure may lead to case rupture.

To determine case rupture protection, the total clearing curve for the fuse or fuse link is compared to the capacitor unit's case rupture curve. The currents for both of these curves are expressed in symmetrical values. The degree of case rupture protection will be dependent on the fuse's current rating and the shape of its TCC curve. Protection is obtained if the total clearing curve of the fuse is to the left of and below the capacitor unit's case rupture curve.

For expulsion or other types of non-current-limiting fuses, the lower part of the total clearing curve turns and becomes asymptotic with the 0.8 cycle (0.013 s for 60 Hz) line. Therefore, a fuse curve that is otherwise to the left of the capacitor case rupture curve will always intersect with the case rupture curve at this time. This intersection delineates the highest equivalent available symmetric fault current for which the fuse will protect the capacitor unit from case rupture. To avoid case rupture when using these types of fuses, the capacitive current or inductive current available at the bank location should be less than this value.

For inductive fault currents, the symmetrical current available at the bank should be used instead of the asymmetrical current available. This is an acceptable practice for rupture protection comparisons since capacitors usually will degenerate into a total unit failure at or near a peak voltage, thereby producing a symmetrical current fault.

If the prospective inductive fault current at the bank location exceeds the capacitor unit's withstand level, the system fault current may be limited by the use of general-purpose, full-range or backup type current-limiting fuses. When an expulsion fuse/backup current-limiting fuse combination is used as a capacitor line fuse, the series expulsion fuse should coordinate with the current-limiting fuse such that all currents below the rated minimum interrupting current of the backup fuse are cleared by the expulsion fuse before the backup fuse melts open.

On these systems with high inductive faults, the use of a current-limiting fuse will reduce the probability of case rupture. Protection in the area where the clearing time of the current-limiting fuse is greater than 0.010 s is determined by comparing the total clearing curve of the fuse to the capacitor unit's case rupture curve. Protection is obtained in this area if the total clearing curve of the fuse is to the left of and below the capacitor unit's case rupture curve. Generally when a current-limiting fuse is properly selected for capacitor case rupture protection for current levels below the current-limiting fuses 0.010 s total clearing current, the current limiting action of the current-limiting fuse will also provide adequate case rupture protection at higher currents. In the event that extrapolation of the curves up to the maximum short-circuit current available at the capacitor bank location indicates possible intersection, the capacitor and fuse manufacturers should be consulted. An example of capacitor case rupture curve characteristics is shown in Figure 1.

As capacitor bank size is increased by the use of multiple parallel capacitor units, the size of the capacitor line fuse will also increase. As the fuse size increases, its total clearing curve will move toward the right while the rupture curve remains constant. As a result, the bank size that can be protected with a line fuse is limited. If the system requires that amount of capacitance in that location, one solution is to use larger kvar capacitor units in the bank since larger units may have greater withstand capabilities. Another solution may be to use multiple smaller banks in the same basic location, spacing them some number of poles apart.

Capacitor manufacturers should be able to provide the case rupture curves mentioned above and/or provide additional information or assistance regarding the protection of their capacitor units. The total clearing curves are available from the fuse manufacturer.

4.4.3 Guide for capacitor unit fuse application

Typically, capacitor unit fuses are used to protect individual capacitor units in a large capacitor bank. For single-series group grounded wye- or delta-connected banks, a line fuse may be used to protect the bank along with a capacitor unit fuse for protection of the capacitor unit. For other station banks the capacitor unit fuse is used for the protection of the capacitor unit and an unbalance protection scheme is used for bank protection.

4.4.3.1 Application characteristics of capacitor unit fuses

Some desirable characteristics for capacitor unit fuses may include the following:

a) To provide earliest possible isolation of a faulted capacitor unit.
b) To permit maximum normal loading associated with
    1) Capacitance of the capacitor unit larger than nominal.
    2) Voltage across the capacitor unit higher than nominal, due to system operating voltage above nominal and/or increased voltage across the remaining capacitor units in a group resulting when parallel capacitor units are isolated.
    3) The presence of harmonics in the capacitor current.
c) To withstand the discharge transient outrush current from an individual capacitor unit into a faulted capacitor unit within the same series group.

4.4.3.2 Selection of rated maximum voltage for capacitor unit fuses

The rated voltage V_f of the fuse is its rated maximum voltage, i.e., the maximum power frequency rms voltage (including any system overvoltage and capacitor voltage unbalance) at which it is intended to be applied.

The selection of the unit fuse voltage rating is based on achieving proper fuse operation at the maximum continuous system operating voltage. This basis for voltage rating selection does not include provision for operation during transient or short-time overvoltages associated with restriking circuit breakers, system faults, etc.

An expulsion fuse or a current-limiting fuse should have a rated maximum voltage equal to or exceeding the maximum power frequency voltage that will appear across the fuse following its operation. Higher than nominal capacitor bank voltages can result from higher than nominal system voltages or from voltage unbalance within the bank. Formulae are available in IEEE Std C37.99-1990 for calculating the voltage across a capacitor group as a function of the number of isolated capacitor units, the number of series groups, and the capacitor bank connection. For example, for a small bank operating at rated voltage, the operation of the first fuse may result in 109% voltage across the affected series group (with an alarm), the operation of the second fuse may result in 120% voltage across the affected series group until the unbalance voltage protection trips and operates. In this case the fuse rating should be at least 1.2 times nameplate rating of the capacitor unit. If the capacitor bank will be operated at above rated voltage, the fuse rating may need to be even higher.

An expulsion fuse can have a rated maximum voltage that exceeds the power frequency system voltage by any amount. If the bank is fused with current-limiting fuses and a fuse could be subjected to an inductive current fault, care should be taken in applying fuses with voltage ratings much greater than the maximum system voltage. The fuse manufacturer should be consulted in this regard.

4.4.3.3 Selection of current rating for capacitor unit fuses

4.4.3.3.1 Allowance factors

In general, the capacitor unit fuse should be selected based on the highest anticipated capacitor unit current. Specifically, the fuse selected should have an allowable maximum continuous-current-carrying capability, as differentiated from its nominal ampere rating, which is greater than this highest anticipated capacitor unit current level.

It follows, then, that this maximum capacitor unit current should be accurately known. This maximum current can be estimated by first calculating the nominal capacitor unit current and then applying correction factors.

The nominal capacitor unit current ($I_{nominal}$) for single-phase capacitor units can be calculated using Equation (4):

$$I_{nominal} = \frac{\text{kvar}}{\text{kV}}\ \text{A} \tag{4}$$

where

kvar is the nominal single-phase kvar rating of the capacitor unit, and
kV is the nominal single-phase voltage rating (in kilovolts) of the capacitor unit.

For three-phase capacitor units, this nominal capacitor unit current ($I_{nominal}$) can be calculated using Equation (5):

$$I_{nominal} = \frac{\text{kvar}_{3\phi}}{\sqrt{3}\ \text{kV}_{\phi-\phi}}\ \text{A} \tag{5}$$

where

$\text{kvar}_{3\phi}$ is the nominal three-phase kvar rating of the capacitor unit, and
$\text{kV}_{\phi-\phi}$ is the nominal phase-to-phase voltage rating of the capacitor unit in kilovolts.

NOTE—Equations (4) and (5) provide a method for calculating the nominal current for the capacitor unit where its expected operating voltage is equal to the nominal voltage rating of the capacitor unit. For capacitor units operating at an expected voltage below their nominal rated voltage, the adjusted capacitor unit current ($I'_{nominal}$) can be determined by using Equation (6):

$$I'_{nominal} = I_{nominal} \cdot \frac{\text{kV}_{operating}}{\text{kV}_{nominal}}\ \text{A} \tag{6}$$

where

$I_{nominal}$ is the nominal capacitor unit current,
$\text{kV}_{operating}$ is the expected operating voltage of the capacitor unit in kilovolts, and
$\text{kV}_{nominal}$ is the nominal rated voltage of the capacitor unit in kilovolts.

However, the highest anticipated capacitor unit current is not simply derived from the capacitor unit voltage and var ratings. The capacitor unit may operate for some extended time at a voltage 10% higher than its nominal voltage rating. Further, the capacitor unit is permitted by the standards to have a manufacturing tolerance of plus 15% in capacitance. The presence of harmonics can add as much as 10% to the rms value of current. These factors, taken together, would require that the nominal capacitor unit current, calculated based on rated voltage and kvar, be increased by an allowance as high as 39%: $1.1 \times 1.15 \times 1.1 = 1.39$.

In practice, however, the operating variables described above rarely attain the maximum values listed, and it is even less likely that they will all be at their maximum values at the same time. Consequently, some presently used allowances are as low as 22% for ungrounded banks and 31% for grounded banks. Capacitor banks for certain types of industrial users, on the other hand, may have currents of high harmonic content. Sufficient allowance must be factored in for these cases.

A further factor needs to be considered while selecting the current rating of a capacitor unit fuse. When capacitor units are paralleled within a capacitor bank and a full-fault occurs in one of the capacitor units, there is an energy discharge out of the other parallel-connected capacitor unit into the faulted capacitor unit. The discharge consists of a damped high-frequency current whose characteristics depend upon such factors as capacitor bank construction (number, rating, and spacing of capacitor units) and the location of the faulted capacitor unit. The capacitor unit fuses of capacitor units connected in parallel with the faulted capacitor should be capable of withstanding this outrush current without melting and without damage that would alter their TCC. Some manufacturers may limit the application of certain fuses to avoid this type of damage.

For some current-limiting fuses, the current rating may be dictated by the level of inrush and outrush currents occurring during operation of the capacitor bank, and to how frequently the capacitor bank is switched. The application data of the fuse manufacturer should be consulted for the selection of fuses for frequently switched back-to-back capacitor bank applications, or capacitor bank applications where a large number of nearby faults are expected.

4.4.3.3.2 Adjustment for ambient temperature

Some fuse manufacturers publish a maximum allowable continuous-current-carrying capability for each ampere rating based on a 25 °C or 30 °C ambient temperature. Continuous-current-carrying capabilities of these fuses should be reduced to reflect operation in ambient temperatures as high as 40 °C (the recommended maximum operating temperature for capacitors).

4.4.3.4 Selection of rated interrupting current for capacitor unit fuses

Capacitor unit fuses may be required to interrupt capacitive type fault currents. With some bank configurations and some fault conditions, they may also be required to interrupt inductive type fault currents. The capacitive and inductive fault current interrupting ratings for capacitor unit fuses should be equal to or greater than the maximum fault current of each type that is available at the fuse location. Both types of fault current interrupting ratings are specified in symmetrical amperes and are directly comparable to the calculated values of each type that are available at the capacitor fuse location.

Capacitive current faults occur when there is some amount of capacitance that remains in series with the fuse as it is interrupting the circuit. A typical minimum capacitive type current the fuse may be required to interrupt can occur when there are progressive pack failures within the capacitor unit and the fuse is sized to respond prior to complete capacitor unit failure. A typical maximum capacitive type current the fuse may be required to interrupt can occur with a capacitor bank that has an ungrounded-neutral and only one series group of many parallel connected capacitors per phase. This current is three times the normal bank current and occurs if the failing capacitor unit is fully faulted. This maximum capacitive current to be interrupted could be as high as 50 times the normal capacitor unit current if it is a large bank with many parallel capacitor units.

On systems where inductive fault currents can occur (such as wye-connected single series group capacitor banks with a grounded neutral and/or a grounded capacitor bank frame, or single series group delta-connected banks), the maximum inductive fault current available at the bank location requires consideration. For the wye-connected banks listed above the fault current will be the available phase-to-neutral fault current and for the delta bank it will be the available phase-to-phase fault current. Fuses are rated for their interrupting capability in symmetrical amperes.

If the available inductive-fault current at the capacitor fuse location exceeds the interrupting rating of an expulsion type unit fuse, a current-limiting unit fuse may be used.

For applications where capacitor units are used in enclosures or vaults, and capacitor unit fuses are required, current-limiting fuses should be used.

4.4.3.5 Capacitor unit rupture protection for capacitor banks protected by capacitor unit fuses

In addition to consideration of the fuse rated maximum interrupting current, proper capacitor unit fuse selection will also consider the maximum fault current that the capacitor unit can withstand without rupturing.

Capacitor units consist of series and parallel packs within a metal case that is filled with a dielectric fluid. The packs usually consist of metal foil electrodes and a film dielectric. Capacitor unit failure typically begins with the failure of a single pack. When this pack fails and shorts out, the voltage across and the current through the remaining packs increases. The increased stress causes additional packs to fail. If the failure process is allowed to continue, it will result in all of the capacitor unit series packs shorted. Other capacitor unit failures may be caused by improper internal connections or dielectric failure to the case. Capacitor unit failure may lead to case rupture.

When the capacitor unit is completely shorted, the power-frequency current through it depends upon various factors. For example, in a single series group grounded wye bank applied on an effectively grounded system or a single series group delta bank, this will be the system inductive fault current that is available at the bank location. With multiple series group capacitor banks or ungrounded wye-connected banks, the power-frequency current will be the available capacitive current that is allowed by the capacitors that remain in the circuit.

To determine case rupture protection, the total clearing curve for the fuse or fuse link is compared to the capacitor unit's case rupture curve. The currents for both of these curves are expressed in symmetrical values. The degree of case rupture protection will be dependent on the fuse's current rating and the shape of its TCC curve. Protection is obtained if the total clearing curve of the fuse is to the left of and below the capacitor unit's case rupture curve.

For expulsion or other types of non-current-limiting fuses the lower part of the total clearing curve turns and becomes asymptotic with the 0.8 cycle (0.013 s for 60 Hz) line. Therefore, a fuse curve that is otherwise to the left of the capacitor case rupture curve will always intersect with the case rupture curve at this time. This intersection delineates the highest available symmetric fault current for which the fuse will protect the capacitor unit from case rupture. To avoid case rupture when using these types of fuses, the capacitive current or inductive current available at the fuse location should be less than this value.

For inductive fault currents, the symmetrical current available at the bank should be used instead of the asymmetrical current available. This is an acceptable practice for rupture protection comparisons since capacitors usually will degenerate into a total unit failure at or near a peak voltage, thereby producing a symmetrical current fault.

If the bank can be subjected to inductive type fault currents and these fault currents exceed the capacitor unit withstand level, the system fault current can be limited by the use of current-limiting fuses. Protection in the area where the clearing time of the current-limiting fuse is greater than 0.010 s is determined by comparing the total clearing curve of the fuse to the capacitor unit's case rupture curve. Protection is obtained in this area if the total clearing curve of the fuse is to the left of and below the capacitor unit's case rupture curve. Generally when a current-limiting fuse is properly selected for capacitor case rupture protection for current levels below the current-limiting fuses 0.010 s total clearing current, the current-limiting action of the current-limiting fuse will also provide adequate case rupture protection at higher currents. In the event that extrapolation of the curves up to the maximum short-circuit current available at the capacitor bank location indicates possible intersection, the capacitor and fuse manufacturers should be consulted. An example of capacitor case rupture curve characteristics is shown in Figure 1.

Many station banks have multiple series groups or other configurations such that capacitance remains in the circuit when a single capacitor unit fails. Since these fault currents are relatively small as compared to inductive system faults, a current-limiting fuse is not normally required to limit available fault current.

The use of current-limiting fuses as a capacitor unit fuse is normally limited to

a) Wye-connected single series group capacitor banks with a grounded neutral and/or a grounded capacitor bank frame, or a single series group delta-connected bank;
b) Metal-enclosed banks because of their nongassing operation; and
c) Applications where the discharge from many parallel units has enough energy that it exceeds the discharge interrupting capacity of expulsion fuses or the withstand ability of the capacitor unit cases.

Capacitor manufacturers should be able to provide the case rupture curves (tank rupture curves) mentioned above and/or provide additional information or assistance regarding the protection of their capacitor units. The fuse total clearing curves are available from the fuse manufacturer.

4.4.3.6 Selection of the capacitor unit fuse for discharge-energy withstand

If a capacitor unit failure occurs in a capacitor bank, where the capacitor units are protected by unit fuses, the energy stored in the parallel connected unfaulted capacitors will discharge through the unit fuses on these units and into the failed capacitor unit and its fuse.

The capacitor unit fuse of a fully-faulted capacitor unit that is part of a parallel-group of other capacitors units must be able to operate and withstand, without bursting during operation, the outrush current from the healthy parallel capacitors as they discharge into the faulted capacitor unit. The energy stored in the parallel connected capacitor units is available to be absorbed by the fuse and the faulted capacitor unit. While the fuse itself may absorb only a portion of the total energy available in the parallel-connected capacitor units, the withstand requirement for the fuse is determined by the total energy that is available for this discharge.

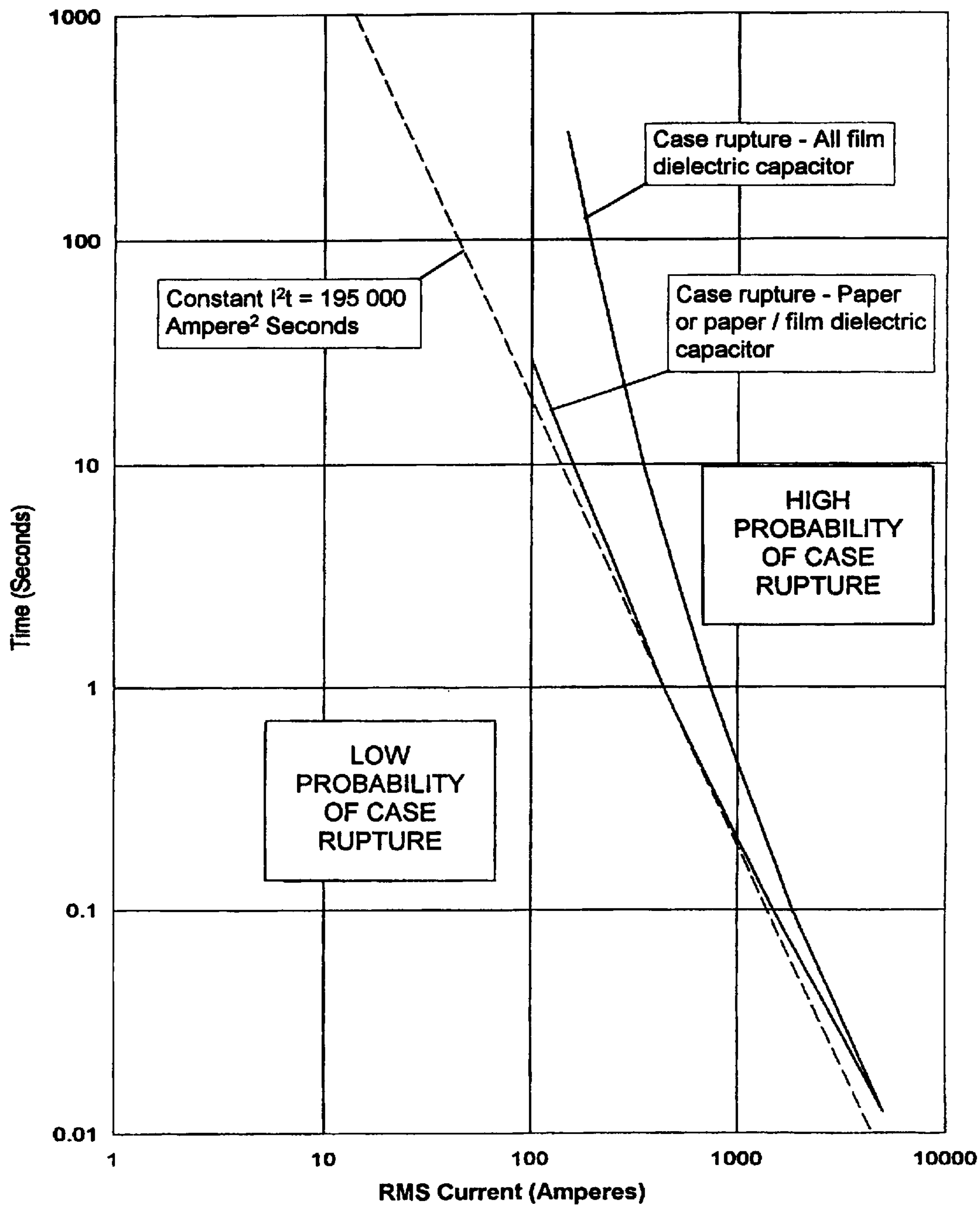
Capacitor units also have a discharge-energy withstand capability that is related to their construction. If the capacitor bank design can produce a total discharge-energy that is equal to or less than the withstand capability of the capacitor units, then the fuse is not required to limit the discharge. A fuse with a discharge-energy rating equal to or exceeding this total discharge-energy should be selected without regard to current limitation.

If a capacitor bank design has the capability to discharge more energy than the capacitor units can withstand, then the use of current-limiting fuses should be considered. Current-limiting fuses are capable of limiting the discharge energy from adjacent parallel connected capacitor units into the faulted capacitor unit. For proper protection of the capacitor unit from the discharge energy of the parallel capacitor units, the maximum let-through I^2t of the fuse should be less than the withstand I^2t of the capacitor unit. For specific guidelines in this area, the capacitor and fuse manufacturers should be consulted.

Other methods that can be used to eliminate excessive discharge energy are

a) To use more series groups and less parallel units, or
b) To use two smaller parallel capacitor banks.

The discharge-energy rating for a capacitor unit fuse is the maximum stored energy at rated voltage with which the fuse will be required to operate and successfully interrupt the circuit. Discharge-energy ratings for expulsion type capacitor unit fuses range from 10 kJ to 30 kJ. The application of these fuses may be limited to less than the maximum discharge energy rating of the fuse by the withstand capability of the capacitor unit. The rating for current-limiting capacitor unit fuses is usually 40 kJ or higher.



NOTE—Typical case rupture characteristics for two types of capacitors. Curves vary by manufacturer and unit construction; refer to manufacturer for actual curves.

Figure 1—An example of capacitor case rupture curve characteristics

5. Operation guidelines for various fuse types

5.1 Use of nonexpendable cap on expendable-cap cutouts

Installation of a nonexpendable cap on an expendable-cap cutout results in a reduction of the expendable-cap cutout interrupting capability.

Refer to manufacturers' instructions as to the reduction in the rating.

5.2 Operating speed

Any of the devices that are designed to disconnect or close an energized circuit should be operated in a rapid, positive manner since the success of this function may be dependent upon the use of proper procedure and technique as established by the manufacturer.

5.3 Locking or latching of fuses, blades, or links in closed position

Special care should be taken to see that the fuse, blade, or link is securely locked, latched, or held fast in the closed position as recommended by the manufacturer. The fuse carrier assembly of distribution oil fuse cutouts or other devices applied in sealed enclosures should be locked and sealed; therefore, the sealing gaskets must be maintained in good condition for satisfactory operation.

5.4 Fuseholder position

Certain types of outdoor fuses should not be left hanging in the open position as a means of isolating the equipment from the system since rain water may collect in the fuse tube and cause swelling or other damage, thus impairing the interrupting capability of the fuse. If an equipment installation or a circuit is to be left out of service the fuseholders may be hung upright from a pin or hook on the pole.

5.5 Voltage withstand of blown fuses

Many fuse cutouts and other "drop-open" fuses are designed to incorporate a drop-open action following an interrupting operation. This action quickly removes all voltage stress across the fuse holder.

Many applications of non-drop-open fuses, such as the backup current-limiting type, utilize a series expulsion fuse, or other device coordinated to provide isolation means to prevent possible dielectric breakdown of a contaminated non-drop-open fuse if subjected to long-time voltage stress. Also, many capacitor unit fuses have a disconnector that removes any long-term voltage stress from a blown fuse.

For those applications where long-time voltage stress can occur across a blown fuse, and dielectric breakdown would permit resumption of current flow, the fuse manufacturer should be consulted as to the adequacy of the proposed fuse for this application.

5.6 Replacement and handling of fuses

Replacement fuses should be those recommended by the manufacturer.

5.6.1 Replacement of fuses

When fuses are to be replaced, this should be done with the circuit de-energized unless the fuse manufacturer's recommendations or the user's operating practices permit otherwise. However, expulsion fuses should never be replaced from within the venting area with the circuit energized.

5.6.2 Handling of current-limiting fuses

Careless handling of current-limiting fuses may result in damage. When damage is suspected, the fuse should not be installed.

5.6.3 Fuses subject to partial melting or deterioration

There are fuse constructions that are subject to partial melting or damage by current that is not of sufficient magnitude and time to cause total melting of the fuse. For such fuses it is important that the following precautions be observed:

a) In two- or three-phase applications it is advisable to replace the fuse units (or fuse links) in all phases when the fuses in one or more phases are found to have blown unless
   1) The manufacturer's instructions are followed for determining the suitability of the fuse(s) for continued service.
   2) There is proof that no damaging current occurred in the remaining phases(s).
b) In applications where these fuses are used in series with other fuses or interrupting devices in the same phase in such a manner that their melting or clearing curves cross one another, or both, it is advisable after an operation to follow carefully the manufacturer's instructions for determining the suitability of the fuse(s) for continued service.

5.6.4 Re-energization after fuses have blown

It is advisable to locate and correct the situation that caused the fuse to operate before re-energizing. The operator should be aware that a potential hazard may exist if the circuit is re-energized with the fault condition still present.

5.7 Replacement of exhaust control device

The exhaust-control device on the fuse is usually suitable for reuse after a fuse operation. This is dependent upon the fault magnitudes, and numbers of fault-current interruptions it has experienced. It is advisable, after the operation of a fuse, to inspect the exhaust-control device and follow carefully the manufacturer's instructions for determining the suitability of the device for further service.

5.8 Operation of energized fuses

A fuse or piece of fused equipment not equipped with a means of breaking load should not be opened unless the fuse has blown or the circuit has been de-energized.

When a fuse or piece of fused equipment equipped with a means of breaking load is used, it should not be opened immediately after the circuit has been energized. The time delay before opening will vary considerably, depending upon the continuous-current rating of the fuse, but should be adequate to allow the fuse to interrupt any existing fault current that might exceed the load-break rating of the device. For large-sized fuse links above 100 A, this time delay could be as long as 10 min.

5.9 Storing spare fuse units and replaceable parts

Spare fuse units and replaceable parts of fuse units should be stored in such a manner that they will not be damaged, and will be available when needed. If several types and ratings of fuses are used in a given location, the spare parts should be suitably marked, coded, or indexed to show the mountings, circuits, or equipment with which they are to be used. This will minimize the possibility of improper use.

6. Additional operation guidelines for specific devices

The following operational guidelines are in addition to those in Clause 5.

6.1 Capacitor fuses

6.1.1 General operating requirements for capacitor fuses

The fuse should be capable of carrying normal capacitive currents including currents above capacitor rated current that results from system overvoltage, system harmonics, or higher than rated capacitance.

The fuse should also be capable of carrying transient currents that can normally occur in capacitor banks.

Care should be taken to discharge the capacitors after de-energization, and to ground the entire capacitor bank before any maintenance is performed. Refer to 4.4 for complete capacitor fuse application guidelines.

6.1.2 Capacitor fuse replacement

Fuses used on capacitor units should not be handled, removed, or replaced unless due precautions are taken beforehand to de-energize, discharge, and ground the capacitor units. The entire capacitor bank should be de-energized and grounded while replacing capacitor-unit fuses. Capacitor-line fuses may be handled using live-line tools.

Capacitor units used in power applications usually have a discharge resistor to reduce the capacitor-unit voltage to a specified value in a specified time after being de-energized. This internal-discharge device should not be considered as a substitute for the recommended safety practice of manually discharging the residual stored energy before working on capacitor units. Capacitor units may be damaged if discharged too soon after being de-energized. It is recommended that at least 5 min be allowed for adequate discharge through the discharge resistor, and then the capacitor terminals should be shorted together and connected to ground. Refer to IEEE Std 18-1992 or NEMA CP1-1988 for complete information in regard to discharging of capacitor units.

When installing or removing capacitor unit fuses the fuse link leader should first be disconnected from the capacitor bushing to avoid twisting of the fusible element.

When replacing a capacitor unit fuse it may be desirable to check the continuity and the condition of the fuses or fuse links on adjacent parallel capacitor units.

6.2 Liquid-submerged expulsion fuses in enclosures

6.2.1 Liquid in which the fuse is submerged

The liquid is an integral part of the equipment design and the fuse performance, and manufacturer's recommendations should be followed.

The operation of the fuse may cause carbon to form in the liquid. The degree to which this will affect the equipment characteristics depends upon the number of operations as well as their magnitude and duration. Operating experience will usually be the best basis for establishing a maintenance schedule. See Clauses 7 and 8 for additional information.

6.2.2 Removal and replacement of fuses

A sealed tank may have a pressure greater than atmospheric. This internal pressure should be returned to atmospheric pressure prior to removing fuses.

7. Maintenance for all fuse types

7.1 Safety precautions

Examination and maintenance of equipment that is connected to an energized circuit should be done at a safe distance from any exposed energized parts of equipment or conductors, or the circuit and equipment should be de-energized. In the case of equipment on capacitor installations, precautions should be taken to discharge the capacitors after de-energization. Alternatively, live-line techniques may be employed if they are adequate to ensure safety to personnel.

7.2 Frequency of maintenance

All fuses should be maintained in accordance with the manufacturer's recommendations.

7.3 Inspection of fuse or switching device

Equipment within the scope of this guide usually consists of several parts, some current-carrying and some non-current-carrying, all subject to atmospheric and other environmental conditions. The equipment is also subject to the normal and abnormal operating conditions of the system in which it is connected. The frequency and completeness of inspection will necessarily be a function of the service reliability required and the conditions at the specific equipment location and must be determined by the user. Some of the items that should be considered are as follows:

a) The equipment should be given a general examination for obvious defects and to ensure that bolts, nuts, washers, pins, and terminal connectors are securely in place and in good condition.
b) Insulators and other porcelain or plastic parts should be inspected for breaks, cracks, burns, or contamination. Insulators and other insulating surfaces should be cleaned of any excessive contamination, such as salt deposits and cement or road dust, to avoid flashover as a result of the accumulation of foreign substances on their surfaces. Cracked or broken insulators and other insulating parts should be replaced. To prevent flashover, consideration should be given to replacing badly burned insulating parts.
c) Current-contact surfaces should be examined for pitting, burning, and alignment, and to ensure that the contacts when closed are held together with adequate pressure. Badly pitted, burned, or distorted contacts should be replaced. Alignment and spring pressure should be adjusted if required.
d) Vent holes on equipment so equipped should be examined to ensure the holes are not plugged with dirt or other foreign substances, and cleaned if necessary.
e) If applicable to the equipment, the fuse unit or fuse tube and renewable element should be examined for corrosion of the fuse element or connecting conductors, excessive erosion of the inside of fuse tubes, tracking and dirt on the outside of the fuse tube, and improper assembly that may prevent proper operation. Components showing significant signs of deterioration should be replaced. Fuse tubes made of organic material may be refinished according to manufacturer's specifications.

f) Current-carrying parts, such as blades or fuse links, should be examined for thermal damage resulting from heavy short-circuit currents or overloads. Damaged fuse links and other parts significantly deformed should be replaced.
g) The mechanical operation should be checked according to manufacturer's recommendations.

7.4 Inspection of fuse links in distribution cutouts

Fuse links in distribution cutouts may require periodic replacement since corrosion of the lower terminal of the fuse link (generally a flexible cable) at the lower open-end of the fuse holder may cause breakage or melting at this point rather than at the current-responsive element. Link-break cutouts are more susceptible to this problem because of the mechanical strain placed upon the fuse link by the link-break mechanism.

8. Additional maintenance guidelines for specific devices

8.1 Capacitor fuses

Care should be taken to discharge and ground capacitors before maintenance is preformed. See 6.1.2 for further information.

8.2 Liquid-submerged expulsion fuses in enclosures

The following are additional requirements for liquid-immersed fuses.

8.2.1 Liquid

The level and quality of the liquid in the equipment may affect the performance of the expulsion fuse. All gasketed joints and seals should be properly maintained.

Inspection should include checking the tank for liquid leakage and for indications of any external damage or deterioration. The level of the liquid should be checked to see that it is in accordance with the switchgear manufacturer's recommendation. Liquid should not be withdrawn from, or added to, the switchgear while it is energized unless there is a suitable means or procedure for this function.

8.2.2 Inspection of fuse components

Manufacturer's recommendations and requirements for inspection and maintenance of fuse components should be followed. Replacement fuses should be those recommended by the switchgear manufacturer. Many users have established procedures to allow inspection and maintenance of energized equipment. In the absence of such procedures, the equipment should be de-energized before performing any inspection or maintenance.

The following are some general guidelines for inspecting and maintaining fuse components:

a) All current-carrying components of the fuse carrier or bayonet assembly should be inspected. Any components showing indication of excessive heating or damage from arcing should be replaced. Excessive arc damage or heating of contact surfaces may indicate the need to inspect internal contacts. This generally requires removing the unit from service.
b) Any fuse carrier or cartridge showing signs of cracks, erosion, tracking, or excessive wear should be replaced.
c) All seals and gaskets should be checked and any that are deteriorated or deformed should be replaced. Manufacturer-approved replacements should be used.

d) Electrical connections should be checked to determine that they are clean and tightly secured.
e) Satisfactory condition of the fuse should be verified, as recommended by the manufacturer.

8.3 Distribution oil cutouts (inspection)

In addition to items 7.3 a), b), c), f), and g), the following items should be considered and inspected:

a) Periodically, a sample of the insulating oil should be taken and tested for dielectric breakdown strength. Oil in cutouts that experience regular load break or fuse interrupting duty should be tested on a more frequent basis.
b) The fuse carriers of nonvented distribution oil cutouts generally incorporate insulating materials that may be damaged dielectrically by excessive exposure to moisture or humid atmosphere. The cutout should be kept sealed or the components and oil should be suitably protected from the contaminating exposure.
c) The fuse elements of these cutouts are generally not interchangeable and any substitution for the manufacturer's fuses may seriously affect the interrupting characteristics of the device.
d) The cutouts should be examined for any evidence of oil leakage and the prescribed oil level must be maintained.
e) Moveable bearing gasket surfaces, yoke compression, and interlocking features should be checked for satisfactory operation.