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(Revision of IEEE Std C37.48-1997)

IEEE Standards

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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

IEEE Power Engineering Society

Sponsored by the
Switchgear Committee

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Approved 24 January 2005

IEEE-SA Standards Board

Abstract: Information on the application, operation and maintenance of high-voltage fuses (above 1000 V and through 169 kV), distribution enclosed single-pole air switches, fuse disconnecting switches, and accessories for use on ac distribution systems is provided. These include enclosed, open, and open-link types of distribution cutouts and fuses; distribution current-limiting fuses; distribution enclosed single-pole air switches; power fuses, including current-limiting types; outdoor and indoor fuse disconnecting switches; fuse supports, mountings, and links, all of the type used exclusively with the above; and removable switch blades for certain products among the above.

Keywords: current-limiting fuses, expulsion type fuses, distribution class fuses, power class fuses, fuse enclosure packages, high-voltage fuses, fuse, fuse applications, fuse disconnecting switches

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Introduction

This introduction in not part of IEEE Std C37.48-2005, 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 IEEE Std C37.48™-1997 to bring it up-to-date and in line with present day requirements for high-voltage fuses and switches. Significant changes include the clarification and expansion of application areas that have been reported as causing some confusion. Some additional information regarding the effect of ambient temperature on the current rating of a fuse has been added, as well as information regarding parallel fuses.

This guide was prepared by the Revision of Fuse Standards working group of the IEEE Subcommittee on High-Voltage Fuses. Liaison was maintained with the International Electrotechnical Commission (IEC) during the development of the revisions in order to incorporate the latest activities at the time of publication. It is one of a series of complementary standards covering various types of high-voltage fuses and switches, arranged so that certain standards apply to all devices while other standards provide additional specifications for a particular device. For any device, IEEE Std C37.40™-2003, IEEE Std C37.41™-2000, plus any additional standards covering that device, constitute a complete standard for the device. In addition, this document provides application, operation, and maintenance guidance for all the devices, and is supplemented by IEEE Std C37.48.1™-2002, which is an operation, classification, application, and coordination guide for current-limiting fuses.

The following standards make up this series:

ANSI C37.42-1996, American National Standard Specifications for High Voltage Expulsion Type Distribution Class Fuses, Cutouts, Fuse Disconnecting Switches and Fuse Links.

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

ANSI C37.46-2000, American National Standard for High Voltage Expulsion and Current-limiting Type Power Class Fuses and Fuse Disconnecting Switches.

ANSI C37.47-2000, American National Standard for High-Voltage Current-limiting Type Distribution Class Fuses and Fuse Disconnecting Switches.

IEEE Std C37.40™-2003, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.41™-2000, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.48™ -2004, IEEE Guide for Application, Operation, and Maintenance of High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.48.1™-2002, IEEE Guide for the Operation, Classification, Application, and Coordination of Current-Limiting Fuses with Rated Voltages 1–38 kV.

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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

1.1 Scope

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. Devices with rated maximum voltages to 169 kV are covered. 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 1.3 and 1.4).

e) Fuse supports, and fuse mountings, 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.

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.

1.2 Background

The distribution class and power class expulsion-type fuses listed in 1.1 are similar to those now covered in IEC 60282-2. The distribution class expulsion-type fuses are similar to the class “A” fuses covered in the IEC document and the power class fuses are similar to their class “B” fuses. At present, IEEE and ANSI standards do not cover the class “C” fuses listed in the IEC standard. Some of the current-limiting type fuses listed in 1.1 are similar to those now covered in IEC 60282-1. However, significant differences exist in the testing requirements of IEC and IEEE/ANSI. IEEE fuse standards reflect, primarily, applications common in North America, and in countries that use electrical systems designed using similar principles. IEC standards tend to rely heavily on practices common in Europe. Since IEC testing differences include testing at different voltages for the same fuse rated voltage, and different or no testing for fuses intended for use in a surrounding temperature above 40 °C, the user is advised to exercise extreme caution if devices specified and tested per IEC standards are compared to those specified and tested per IEEE/ANSI standards. The differences in test requirements may result in devices tested to IEC not being suitable for applications where devices tested to IEEE and ANSI standards are required, or vice versa.

In the headings and the text of this document there will be some areas where information is included in brackets [ ]. The information in the brackets is a term used in IEC standards that may be similar to the term used in this document, a term that is common in some parts of the world, or a term that has been used previously in IEEE or ANSI standards. Caution is again advised when making comparisons.

1.3 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)

1.4 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

It is intended that this standard be used in conjunction with the following referenced standards. When the standard referenced below is superseded by an approved revision, the revised document may or may not apply. At the time of publication of this document, the editions listed below were valid. Since all standards are subject to revision at varying times, a revised document may or may not apply. In the interim period prior to revision of this standard, all parties making agreements based on these documents are encouraged to investigate the possibility of using the most recent editions of the relevant standards.

ANSI C37.46-2000, American National Standard for High Voltage Expulsion and Current-Limiting Type Distribution Class Fuses and Fuse Disconnecting Switches. [1]

ANSI C37.47-2000, American National Standard for High Voltage Current-Limiting Type Distribution Class Fuses and Fuse Disconnecting Switches.

IEC 60282-1 (2002-01-29), High-voltage fuses—Part 1:Current-limiting fuses.[2]

IEC 60282-2 (1997-12-17), High Voltage Fuses—Part 2: Expulsion fuses.

IEEE Std 18™-2002, IEEE Standard for Shunt Power Capacitors.[3, 4]

IEEE Std C37.40™ -2003, IEEE Standard Service Conditions and Definitions for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.41™-2000, IEEE Standard Design Tests for High-Voltage Fuses, Distribution Enclosed Single-Pole Air Switches, Fuse Disconnecting Switches, and Accessories.

IEEE Std C37.48.1™-2002, IEEE Guide for the Operation, Classification, Application, and Coordination of Current-limiting Fuses with Rated Voltages 1–38 kV.

IEEE Std C37.99™ -2000, IEEE Guide for the Protection of Shunt Capacitor Banks.

IEEE Std C62.92.2™, IEEE Guide for the Application of Neutral Grounding in Electrical Utility System Part II—Introduction.

IEEE Std C62.92.4™, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems Part IV –Distribution.

NEMA CP 1-2000, Shunt Capacitors.[5]

NFPA 70-2002: National Electrical Code® (NEC®).[6]

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[1] ANSI publications are available from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[2] IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 25 West 43rd Street, 4th Floor, New York, NY 10036, USA (http://www.ansi.org/).

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[6] The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org). Copies are also available from the Institute of Electrical and Electronics Engineers, Inc., 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

NFPA 70E, 2004 Edition: Electrical Safety in the Workplace.

NOTE—Fuse standards listed as “ANSI C37.xx”, were formerly developed by NEMA. The responsibility for maintaining them has passed to the IEEE and, at their next revision, they will carry the designation “IEEE C37.xx”.[7]

3. Abbreviations

FEP	fuse enclosure package
F/C	fuse container
RMAT	rated maximum application temperature
TCC	time-current characteristic

4. General application guidelines for all fuse types

4.1 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 system-specific 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 faulted 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, or in some cases prevent, 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, including quality assurance and quality control processes, 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.

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. (In some cases, NFPA 70E, 2004 Edition may be applicable.)

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[7] Notes in text, tables, and figures are given for information only, and do not contain requirements needed to implement the standard.

4.2 Service conditions

4.2.1 Usual

Usual service conditions conforming to this guide are defined in IEEE Std C37.40-2003. These conditions specify limits in altitude and ambient temperature.

4.2.2 Unusual

Unusual service conditions are defined in IEEE Std C37.40-2003, which gives examples of such conditions. Equipment covered by IEEE Std C37.40 that depends on air at atmospheric pressure for its insulating and cooling medium will have a higher temperature rise and a lower dielectric withstand when operated at altitudes higher than 1000 m. Historically, equipment covered by IEEE Std C37.40 has used correction factors for dielectric strength and rated continuous current when applied at altitudes above 1000 m. In addition, equipment designed for standard temperature use could be used at its normal rated continuous current without exceeding ultimate standard temperature limits if the ambient temperature did not exceed the maximum ambient temperature assigned to the device in accordance with IEEE Std C37.40-2003, multiplied by an appropriate factor. Altitude correction factors are being studied by the Switchgear Committee, and will be added to IEEE Std C37.40-2003 directly or by reference when they are approved. In the meantime, users should consult the manufacturer for appropriate derating when the equipment is applied above 1000 m.

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.

4.3 Selection of class and type of fuse

No generalizations can be made about selecting the class and type of fuse that should be used 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.

4.3.1 Fuse class

4.3.1.1 Power class fuses

Power class fuses are as follows:

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 in a 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.

4.3.1.2 Distribution class fuses

Distribution class fuses are as follows:

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.

4.3.2 Fuse types

4.3.2.1 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 is 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.

4.3.2.2 Non-expulsion-type fuses

Non-expulsion-type fuses may be current-limiting or non-current-limiting. When a current-limiting fuse is exposed to a current high enough to produce melting before the first peak of current, it abruptly introduces sufficient resistance into the circuit to prevent that peak being reached. The lowest current at which a particular fuse exhibits this current-limiting action is called its threshold current. Typically, this current may be from about 25 to 50 times the fuse's current rating, depending on fuse design and circuit X/R. This guide will refer to such currents as "high" currents. Current-limiting fuses can also interrupt lower currents, ones that do not produce a current-limiting action. However, differences in the ability of certain types of design to interrupt these "low" currents leads to three different classes of current-limiting fuses—backup, general-purpose, and full-range. IEEE Std C37.48.1 discusses the design and application of current-limiting fuses in more detail. The major uses for non-expulsion-type fuses are in applications where the clearances to grounded parts are limited or the current-limiting properties of current-limiting fuses are required.

4.3.2.2.1 Backup current-limiting fuse

This is a current-limiting fuse that provides only fault current interrupting duty from its rated maximum interrupting current down to its rated minimum interrupting current (see 5.1.3.1). Some auxiliary device is used to interrupt any lower faults or overcurrents. The low current interrupting ability of different types of backup fuses varies significantly. The minimum interrupting current of a particular type or rating may produce a melting time as short as a few cycles to as long as 1000 s or more.

4.3.2.2.2 General-purpose current-limiting fuse

This is a current-limiting fuse that can satisfactorily interrupt high and low fault currents and overcurrents. It is required that a fuse must demonstrate an interrupting capability with currents as low as will cause the melting time of the fuse to be at least 1 h (see 5.1.3.2).

4.3.2.2.3 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 the fuse to melt, with the fuse applied at its rated maximum application temperature specified (see 4.12.1 and 5.1.3.3).

4.3.2.2.4 Non-current-limiting fuses

There are other types of non-expulsion-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 non-expulsion fuses do not appreciably limit the circuit's prospective fault current.

4.4 Clearances and spacing

Minimum electrical spacings and clearances for power fuse and disconnecting switch installations shall be in accordance with tables 7, 8, and 9 of ANSI C37.46-2000. The application should recognize the conditions prevalent during design testing (per IEEE Std C37.41-2000) 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.

4.5 Fuse position

The positioning of the fuses should be such that their operation is facilitated. When devices are used by a utility, the operating practices of that utility should be adhered to.

4.6 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.

4.7 Selection of fuse voltage rating

(See 5.4.2.2 and 5.4.3.2 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.

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.

4.7.1 Power class fuses

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

Most power fuses are used on three-phase applications. When used on a single-phase circuit of an effectively grounded system (see IEEE Std C62.92 for a description of system grounding), the fuse should have a maximum voltage rating of at least 1.15 times maximum line-to-ground voltage of the system. However, if the fuse has been tested for rated interrupting current at rated maximum voltage, or if 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 a single-phase circuit of an effectively grounded system.

4.7.2 Distribution class fuses

4.7.2.1 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.

4.7.2.2 Fuses for effectively grounded-neutral (multigrounded) systems

4.7.2.2.1 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. It should have a BIL coordinated with the line-to-ground insulation of other connected apparatus. Another device may be required to clear transformer secondary faults, should they occur.

4.7.2.2.2 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 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 C37.40-2003, Clause 3, 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.

4.8 Selection of continuous current rating (all applications except capacitor fuses and fuses used in enclosures—see 5.2, 5.3, and 5.4)

Selecting a fuse for its continuous current rating is a very complex procedure as it generally also involves selecting appropriate melting and clearing time-current characteristics. Different fuse designs that have the same current rating will generally have somewhat different TCC curves. There are therefore few generalizations as to 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. Considerations include 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 ability to withstand cold load pick-up after extended outages, and coordination with other series protective devices.

This portion of the guide cannot, therefore, provide a step-by-step procedure for current rating selection, but can only provide what considerations should be taken into account. A listing of the most commonly used applications for high-voltage fuses follows, together with commonly accepted "desirable" objectives that can be achieved with proper fuse type, ampere rating, and time-current characteristics (TCC) selection. However, in some cases, compromises will be required as desired requirements may be contradictory (e.g., some desired result may be met by using a higher current rating than is preferred to meet a different characteristic). The effect of ambient temperature on the current rating and TCC of the fuse is presented in 4.12.

4.8.1 Fuse applications on primary distribution systems

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

Some desirable protection characteristics to be considered in selecting fuses for these applications are as follows:

a) To protect the distribution system from the effect of 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. The degree of transformer protection is determined by comparing the total clearing time-current curve for the selected fuse 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 detection and isolation of internal transformer faults and reduce the possibility of transformer case rupture.
d) To permit loading 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) To withstand surge discharges through a transformer with a grounded primary winding that experiences saturation of its magnetic circuit by a lightning-induced surge voltage with a long time wave shape (primarily with small transformers 25 kVA and lower).

h) To withstand surge currents that may be discharged through an arrester located on the load side of the fuse and ahead of the protected transformer. This surge may be in addition to that referred to in item g) above.

4.8.1.2 Fuses for reclosers or circuit-breaker bypass switches

Some desirable protection characteristics to be considered in selecting 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.

4.8.1.3 Fuses for sectionalizing

Some desirable protection characteristics to be considered in selecting 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 be maximum loading practice of the user.

c) To properly coordinate with main circuit downstream overcurrent protective devices.

4.8.2 Fuse applications on subtransmission systems

Some desirable protection characteristics to be considered in selecting 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. The degree of transformer protection is determined by comparing the total clearing time-current curve for the selected fuse 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 specific transformer connection involved and the types of possible faults in the secondary circuit.

c) To provide detection and isolation of internal transformer faults and reduce the possibility of a transformer case rupture.

d) To permit loading 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.

4.8.3 Fuses for motor protection

Some desirable protection characteristics to be considered in selecting 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.

4.8.4 Parallel fuses

For many years, fuse manufacturers have manufactured both current-limiting and expulsion-type multi-barrel fuse units comprising up to four barrels that are mounted in a parallel arrangement. These factory-assembled units have been fully tested in these arrangements and are considered to be single fuse units. A catalog and/or style number, covering the parallel arrangement, identifies such parallel assemblies. Such “factory” paralleled arrangements are not the subject of this subclause.

Configurations of two or more fuses have been successfully used in parallel for many years. This has been accomplished by installing two or more fuses and/or their fuse supports [mounting(s)] connected in parallel. This may be done by a user, a third party assembler, or by a manufacturer supplying a device that holds two or more fuses in a single fuse support. This provides for increased current ratings. The continuous current carrying capability of the combination will usually be somewhat less than the sum of the current ratings of the individual parallel fuses due to variations in path resistances and proximity heating effects. The fuse manufacturer should be consulted to determine the appropriate derating factor; in many cases, a 10% derating factor for two fuses and a 15% derating factor when three or more fuses are used in parallel have been used. For installations and equipment covered by the National Electrical Code® (NEC®) (NFPA 70-2002), any provisions of that code prohibiting or governing the paralleling of fuses shall be observed.

Before a user places fuses and their supports in parallel, the manufacturer should be consulted to verify that the fuse and the fuse support would function correctly when used together and to obtain guidelines on how to connect the fuses so they have equal current paths. Only fuses from the same manufacturer and that have the same type reference and rating should be connected in parallel.

The fuses and the fuse support(s), or the manufacturer’s device to hold multiple fuses, form a resistive current divider that divides the current flowing through each fuse according to the resistance of each current path. Adequate sharing is normally achieved if the resistance of the current path for each fuse lies within approximately 2% to 3% of the other fuse(s) current path(s). This assures that each of the fuses will experience approximately the same current under both steady state and fault interrupting conditions. If the current path of any given fuse has a significantly lower resistance than the other(s), more current will flow through that path, increasing the duty on that fuse. In some cases, the duty may cause damage to the fuse and it may not successfully carry its share of the load current or interrupt a faulted circuit.

Fuses that are paralleled need to be tested in their fuse support(s), or with an equivalent mounting arrangement, as both the fuse resistance and the impedance of the current path through the fuse support(s) control the current distribution through the fuses. Generally, the manufacturer can provide information as to how the fuses have been tested, to verify performance, particularly for continuous current and circuit interruption tests. These tests are specified in the fuse standards. Unless the manufacturer advises otherwise, the maximum breaking capacity of the parallel combination of fuses should be taken as being no greater than that for a single fuse, while the minimum breaking current of the combination should be taken as being no lower than n times that for a single fuse of the same given type, where n is the number of parallel fuses.

When very large continuous current ratings are achieved by paralleling current-limiting fuses, these parallel combinations may not provide any current-limiting action (that is reduce the peak current value) even at current levels as high as the typical interrupting ratings of 50 kA or 63 kA. The I^2t values associated with paralleled current-limiting fuses during operation will be approximately equal to $n^2 \times I^2t$ of a single fuse-link, where n is the number of fuse-links connected in parallel.

4.8.5 Fuse selection for multiphase applications

Care should be exercised when selecting fuses for applications in multiphase circuits. The application of some fuses, such as power fuses that were tested only at 87% of their rated maximum voltage, slant-voltage-rated cutouts, and other types of fuses rated line-to-neutral used in grounded-wye, grounded-wye applications, may require certain operational assumptions. These devices are often applied under the premise that the majority of the faults will include ground or that with a phase-to-phase fault, two fuses will be effectively in series and will share the phase-to-phase voltage. For two fuses to share the voltage, they must arc simultaneously. Consequently, fuses in all phases should be of the same fuse rating, and the same model or type of fuse, In most cases, the fuses should also be from the same manufacturer; consult the manufacturers for more information.

4.9 Selection of interrupting rating

All fuses are assigned a rated maximum interrupting current (their maximum demonstrated current interrupting capability) and some current-limiting fuses may also have an assigned rated minimum interrupting current (their minimum demonstrated current interruption capability). In many applications, the available fault current is within the interrupting capability of a single fuse. In some applications, the available fault current is either higher or lower than the interrupting capability of a single fuse, and two interrupting devices are then used in series. In many of these types of 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. When a single fuse is used for an application, the interrupting rating of the fuse shall be equal to or greater than the maximum fault current available at the fuse location. The fuse shall also have the capability to interrupt the lowest fault current that it sees and that persists for sufficient time to cause it to melt. When two devices are used in series, generally the device used for clearing the high fault currents is a backup current-limiting fuse or possibly another type of current-limiting fuse. The device for clearing the low fault currents is generally an expulsion fuse or some other type of low fault clearing interrupter. The rated maximum interrupting current of the high fault-clearing device should be equal to or greater than the maximum fault current available at this location. The maximum current interrupting rating of the low current fault-clearing device should be greater than the minimum current interrupting rating of the high current fault-clearing device. The low current fault-clearing device should also have the capability to interrupt the lowest fault current that it sees and that persists for sufficient time to cause it to melt. The low current fault-clearing device should also have the capability to withstand the maximum I^2t let-through of the high current fault-clearing device when it is interrupting the maximum fault available at this location.

Modern fuses normally have their rated maximum interrupting current specified in symmetrical amperes. However, the standard interrupting tests also check their ability 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.

Since power fuses are often used for three-phase applications, some manufacturers provide equivalent three-phase interrupting ratings so they may be compared with other types of circuit interrupters that are rated for three-phase capability.

4.10 Fuse-to-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 protective devices that are used in the system. A discussion on the procedures necessary to achieve this with all possible series devices is beyond the scope of fuse standards; however, some of the most popular devices are covered in IEEE Std C37.48.1-2002. For coordination information not covered in this standard, or IEEE Std C37.48.1-2002, consult the manufacturers of the fuses and/or devices that are connected in series. When the series devices are two fuses, the procedure by which coordination is accomplished is called fuse-to-fuse coordination. The coordination information that follows applies to fuses that use a current responsive element for detecting and melting when a particular current and time occurs (a fuse as defined in IEEE Std C37.40-2003). Electronic and other types of fuses not addressed in IEEE test standards are specialty devices, and their manufacturer should be consulted for coordination considerations.

The primary 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 characteristic 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 characteristic 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 C37.41-2000).

For all types of fuses, both the minimum melting curves and total clearing curves are plotted on log-log scales with a lower time limit of 0.01 s. The upper limit of time depends on the type of fuse, and is specified in 12.1.5 of IEEE Std C37.41-2000. As current increases, the melting time of a fuse decreases, and the melting I^2t decreases towards a fixed value, which is a function of the fusible element material and geometry.

For fuses that are not current-limiting, clearing cannot occur until a natural current zero occurs. For long melting times this may require several cycles of arcing, while at short melting times, it cannot occur before the first current zero. Time-current curves are generated using symmetrical currents because, with asymmetrical currents, each fuse would have an infinite number of curves depending on the current initiation closing angle and circuit X/R. However, for coordination purposes at high currents, the longest time that a fuse might take to clear is one asymmetrical loop, no matter how high the current. This value is approximately 0.013 s (0.8 of a cycle) for typical test X/R values. Consequently, the total clearing time-current characteristic curve of a non-current-limiting fuse is drawn down to a time of approximately 0.013 s, at which time it becomes a horizontal line giving a constant clearing time for all higher currents. On the curves, this time is often labeled “minimum time for safe coordination.” As a result, the total clearing curve of a non-current-limiting fuse will always cross the minimum melting curve of any larger fuse when these devices are compared for coordination purposes, resulting in special coordination considerations that will be discussed later.

Current-limiting fuses, when operating in their current-limiting range, are capable of clearing the circuit in less than one half cycle. Additional characteristic information for current-limiting fuses is therefore provided by most manufacturers in terms of I^2t (strictly $½i^2dt$). The minimum melting I^2t and total clearing I^2t of a fuse is generally presented in tabular form or as curves showing I^2t as a function of the available fault current. Maximum melting I^2t may also be provided for some fuses. When coordinating fuses in a system, it is generally desired that the protecting fuse (down stream fuse, fuse closest to the load) melt and then clear the circuit before the protected (upstream fuse, fuse closest to the source) melts. This method isolates the faulted portion of the circuit with a minimum of disruption to the remainder of the circuit. Properly coordinating fuses in the area above 0.01 s is basically a matter of keeping the minimum melting curve of the protected fuse (upstream fuse) above and to the right of the total clearing curve of the protecting fuse (down stream fuse) within the range of fault current available at the protecting fuse. To allow for variables such as preloading and ambient temperature variations, the manufacturer may be consulted. In the absence of manufacturer's data, one of the following commonly used techniques may be used. A value of 75% of the minimum melting time of the protected fuse is generally used to make allowances for operating variables such as preheating of the fuse element by the load current, normal variations in ambient temperature, and preventing damage to the protected fuse's element. To use this 75% method, align the 4-second line of the protected fuse minimum melt curve with the three-second line of the protecting fuse total clearing curve. Another method is to allow a 10% safety margin in current for any value of time.

When the protecting fuse is a non current-limiting device, its clearing curve will become a constant value at 0.013 s and will cross the minimum melting curve of the protected fuse. Coordination exists only up to the point where the clearing curve crosses the shifted minimum melt TCC curve of the protected fuse. If the fault current at the protecting fuse exceeds this value, a possible solution is to use a larger protected fuse. If this is not an option, the combination of a backup current-limiting fuse in series with the non-current-limiting protecting fuse is an option that can be explored to achieve coordination. Here again the melting curve of the protected fuse should be above and to the right of the clearing curve of the combination fuses. This is discussed in detail for combinations of current-limiting and expulsion fuses in the current-limiting fuse application guide IEEE Std C37.48.1-2002. When a combination of fuses is used at a particular location, these two fuses also need further coordination between them. This additional coordination is discussed in 5.1.3.1 and IEEE Std C37.48.1-2002 (if duplicate data is presented in these documents, the document with the latest date is the preferred.)

When the protecting fuse is a current-limiting type, coordination can be achieved at times 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 the protecting current-limiting fuse. Consult the fuse manufacturer for appropriate safety margins in this regard. In the absence of advice from the manufacturer, a margin that has been used is that 75% of the minimum melt I^2t of the protected fuse should be greater than the total clearing (let-through) I^2t of the protecting fuse.

For additional coordination information on current-limiting fuses, see 5.1 and IEEE Std C37.48.1-2002.

4.11 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 C37.46-2000). This coordinates with the motor starter overcurrent protective device settings to give full protection to the motor circuit. However, it is necessary to ensure that the allowable continuous current of the fuse, at the application ambient temperature, is adequate for the full load current of the motor, or any sustained motor overload conditions.

4.12 Effects of ambient temperature on a fuse

4.12.1 Rated maximum application temperature

IEEE Std C37.40-2003 recognizes that fuses can be designed and tested as being suitable for two sets of usual service conditions. The difference between the conditions lies in the value of the rated maximum application temperature assigned to the fuse by its manufacturer. If it is not intended that a fuse be applied under conditions where the temperature of the fluid in contact with the fuse exceeds 40 ºC, the first set of usual service conditions applies. Interrupting tests are performed at the temperature conditions prevailing at the site of the testing (between –30 ºC and 40 ºC). This covers outdoor applications in most of the world, and use in large enclosures where there is relatively free fluid circulation around the fuse (e.g., a vault). If the manufacturer rates a fuse as being suitable for use in a surrounding temperature higher than 40 ºC, the second set of conditions apply, with the acceptable ambient temperature now being from –30 ºC to the rated maximum application temperature (RMAT) specified by the manufacturer. Fuses suitable for this second set of conditions are subject to the same testing as fuses of the first category, together with additional interrupting current tests, performed at the fuse's RMAT (with some exceptions for expulsion fuses, see 5.3.4). Because surrounding temperatures above 40 ºC can normally only occur if the fuse is mounted in an enclosure of some sort, this latter testing is often called “fuses in enclosures testing.” If the fuse is in a relatively close fitting container, or if the container significantly changes the heat flow from the fuse, testing of the “fuse enclosure package” (FEP), that is the combination of fuse and enclosure, is normally necessary. Testing the FEP may be required even if the RMAT of the FEP were not higher than 40 ºC if, inside the FEP, the fuse itself is subjected to immediately surrounding temperatures above 40 ºC.

Obviously, the higher the ambient temperature, the greater its effect will be on a fuse. Information relating to the effect of ambient temperature on fuses in enclosures is covered in 5.2 and 5.3. The rest of 4.12 will relate specifically to fuses not in enclosures, i.e., fuses not intended for use in ambient temperatures above 40 ºC.

4.12.2 Rated continuous current and allowable continuous current

Fuses designed and tested to present standards are required to carry a current at least equal to their rated continuous current (name-plate current) in an ambient temperature of up to 40 ºC without exceeding the maximum temperatures specified in Table 1 of IEEE Std C37.40-2003. It should be noted, however, that some older designs of expulsion fuses use an ambient temperature of 30 ºC as a basis for their rated continuous current. If the ambient temperature is less than the above values, it is likely that most fuses could carry a higher continuous current without exceeding the specified maximum temperatures. In addition, many fuses have been designed to achieve lower temperatures than those specified, when carrying their rated continuous current. The current that a fuse can carry continuously, at a particular ambient temperature, without deterioration and without exceeding the specified temperatures, is defined as its allowable continuous current. When manufacturers assign such ratings to their fuses, the information is usually in the form of de-rating (re-rating) factors applied to the fuse’s rated continuous current, or presented as a table of current ratings related to temperature.

It should be noted that there are some designs of fuses for which the maximum contact temperatures specified in IEEE Std C37.40-2003 are not the limiting factor in setting an acceptable continuous current for the fuse. For example, some full-range fuses melt at currents that do not cause their contacts to exceed the temperature rise specified in IEEE Std C37.40-2003. This is particularly true of fuses in a homogeneous series that have a current rating less than the maximum. The definition for allowable continuous current in IEEE Std C37.40 prior to the 2003 publication required that allowable continuous current be the maximum current that did not cause the specified contact temperature to be exceeded. Therefore, the manufacturer of such a fuse was unable to assign allowable continuous currents, but instead would use some other, non-standard, term such as “maximum continuous current” to indicate a current that would not cause long term deterioration of the fuse’s elements. This situation has been corrected in IEEE Std C37.40-2003, with allowable continuous current just being defined as a current that does not cause the contact temperature to exceed the specified maximum value.

4.12.3 Time-current characteristics

The time-current characteristic (TCC) curve of a fuse is determined at 25 ºC ± 5 ºC. Ambient temperatures that differ from this may cause a shift in the TCC, with higher temperatures causing the fuse to melt faster for a given current. The degree of change to a fuse’s TCC is a function of the individual fuse design, and is different for different types of fuse.

The most significant area of concern is usually change to the long time melting characteristics of fuses, since this may change the way a fuse is affected by an overload.

4.12.4 Fuse selection

The effects of ambient temperatures below 25 ºC generally do not have to be considered, as these temperatures produce longer melting times than those shown on the minimum melting TCC curves, and the operating temperatures are less than those obtained during the temperature rise tests. In most applications between 25 ºC and 40 ºC, the effects of ambient temperature do not have to be considered since the decrease in melting current is generally less than 5% and most coordinating margins are greater than this.

5. Additional application guidelines for specific devices

5.1 Current-limiting fuses

5.1.1 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 the referenced 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.

5.1.2 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 maximum interrupting current down to its rated minimum interrupting current. It is 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 maximum interrupting current down to the current that causes melting of the fusible element(s) in 1 h or more.

c) A full-range current-limiting fuse is capable of interrupting all currents from its rated maximum interrupting current down to the minimum continuous current that can cause the fusible element to melt with the fuse applied at its rated maximum application temperature, a temperature specified by the fuse manufacturer.

5.1.3 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.

5.1.3.1 Backup current-limiting fuse coordination

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. This leads to particularly rigorous coordination rules being needed for the successful application of backup fuses. The backup fuse is always applied in series with another interrupting device that will interrupt currents below its rated minimum interrupting current. The series device may be another fuse or a breaker. In some cases, currents below the fuse's minimum interrupting current may be interrupted by a device that is tripped by a striker, deployed when the backup fuse's element(s) melt open and begin to arc. This device is coordinated to protect the backup fuse from failure. Special testing of the fuse (not covered in the IEEE/ANSI C37 series of fuse standards) is necessary for this type of coordination to be successful (see IEC 60282-1). More commonly, expulsion fuses are used with backup fuses to achieve the necessary low current 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 ampere 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, some of the following coordination information may apply.

Four fundamental areas have to be addressed to ensure that proper coordination exists between backup fuses and series-connected low current interrupting devices. Because the series connected device is frequently an expulsion fuse, this is the series device that will be discussed in the following paragraphs. However, the protection principles involved are the same for other series devices.

First, each fuse must protect the other in its area of non-operation; second, unless the backup fuse is to be replaced after each expulsion fuse operation, it must not be damaged by such an operation; and third, overload currents must not damage the backup fuse. The fourth area, strictly speaking, is not directly related to the coordination with the expulsion fuse, but it is the requirement that the backup fuse, like the expulsion fuse, is not damaged by surges, such as transformer inrush current. The same rules that are used to select an expulsion fuse for this requirement also apply to the backup fuse, and so this area will not be discussed further. However, it may be noted that if the expulsion fuse has been correctly chosen, a backup fuse that coordinates correctly with it usually meets those same surge requirements.

5.1.3.1.1 Devices protecting each other

Primary coordination between the series expulsion fuse and the backup current-limiting fuse ensures that the two will work together to clear all currents from the lowest current that will cause the expulsion fuse's element to melt up to the current corresponding to the rated maximum interrupting current of the current-limiting fuse. Achieving this primary coordination requires that when the appropriate time-current characteristic curves for the two devices are overlaid, **the total clearing characteristic curve of the expulsion fuse must cross the minimum melting characteristic curve of the current-limiting fuse at a point corresponding 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.** When this occurs, each fuse protects the other fuse in its zone of "vulnerability." The curves must always cross at a current higher than the minimum interrupting rating of the backup fuse, or it may be called upon to try and interrupt a current that it cannot. Depending upon the relative location of the two curves, one of two different types of coordination will exist. These two methods of coordination are commonly referred to as "matched-melt" coordination and "time-current curve crossover" coordination, although matched-melt coordination should in fact be considered a form of time-current curve crossover coordination with some additional requirements. Figure 1 and Figure 2 illustrate the principles involved.

a) *Matched-melt coordination:* For this method of coordination, in addition to the basic coordination rules described above, another criterion must be met. This is to ensure that the expulsion fuse melts open any time the two-fuse combination clears an overload or fault. In general, matched-melt coordination will result in the minimum melting time-current characteristic of the expulsion fuse lying to the left of the minimum melting TCC of the backup fuse for all times longer than 0.01 s, as shown in Figure 1. However, this is not a reliable method of ensuring that the expulsion fuse will melt at times shorter than 0.01 s. To be certain that the expulsion fuse will always melt open at any current that causes the current-limiting fuse to operate, the *minimum* total I^2t let through by the current-limiting fuse should be equal to, or greater than, the *maximum* melt I^2t of the series expulsion fuse., at 0.01 s and less. It is this criterion from which the method's name is derived.

One conservative approach to ensuring that the current-limiting fuse will let through sufficient energy to melt open the expulsion fuse is to choose a current-limiting fuse that has a minimum melting I^2t greater than the maximum melting I^2t of the expulsion fuse used in series with it. However, 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. Minimum melting I^2t values correspond to very short fuse melting times, and worst-case manufacturing tolerances. Therefore, not only will the actual I^2t that causes melting likely be higher than the published minimum values, additional I^2t will be let through as a result of the current during the arcing that occurs after melting, and that 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. The only circumstances under which such an approach could result in the failure of the expulsion fuse to melt open is if a very short duration surge of current (e.g,. a lightning surge) were to occur and its magnitude just happened to be such that the I^2t of the surge exceeded the melting I^2t of the current-limiting fuse, but was less than the melting I^2t of the expulsion fuse. Obviously, such a situation would very rarely develop, and thus need not be a significant consideration in selecting the best current-limiting fuse for a particular application.

As is obvious from the preceding paragraph, in order to use the matched-melt method of coordination, one must know the values of the short-time 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 expulsion fuse manufacturer does not normally publish the former. 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. For many published curves this might be the current corresponding to three (3) quarter cycles (0.0125 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. Obviously, should the expulsion fuse manufacturer publish 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 which 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 most three-phase applications, the voltage rating of the backup current-limiting fuse 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.

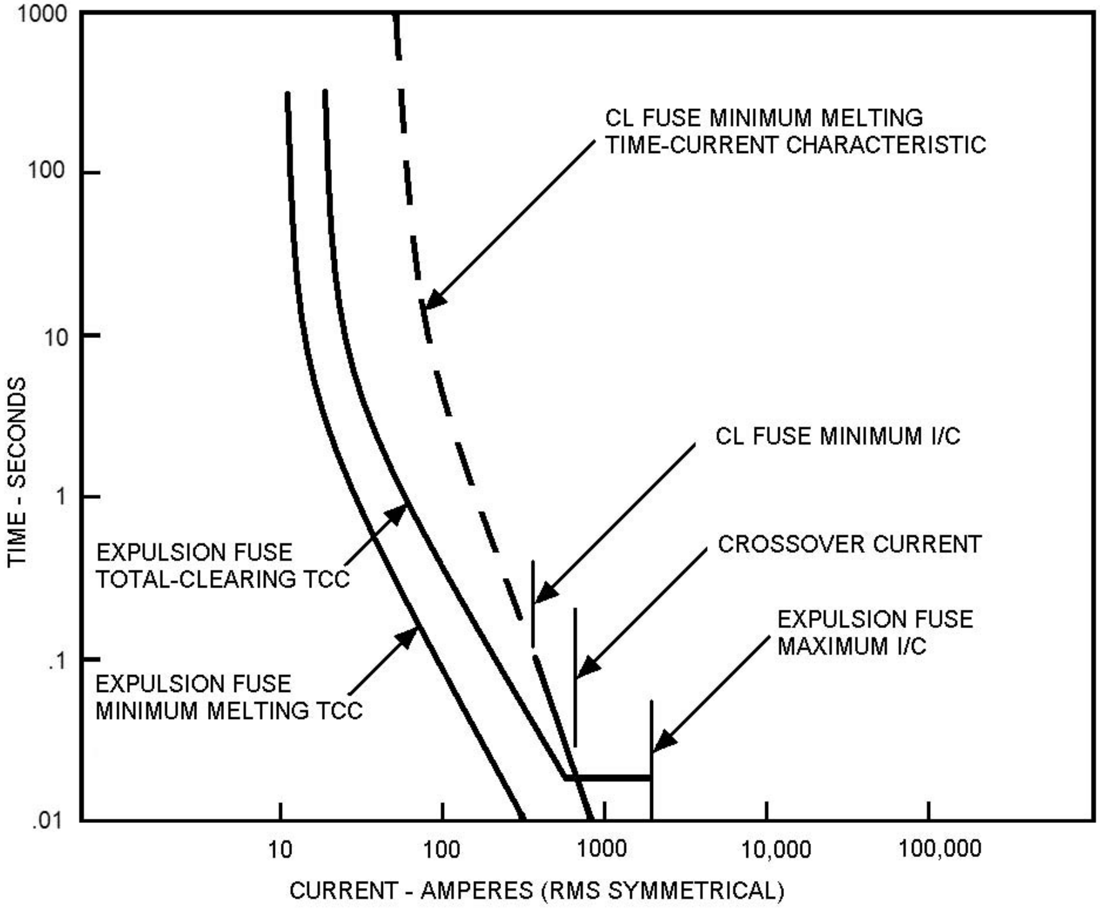


Figure 1—An example of matched-melt coordination

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, and is illustrated in Figure 2. In the example shown, the minimum melting TCC curve of the expulsion fuses crosses the minimum melting TCC curve of the expulsion fuse at a time longer than 0.01 s, making it less likely that the combination would meet the requirements for matched-melt coordination. When a fault current is higher than this crossover point, the current-limiting fuse may melt and clear without letting through sufficient energy to melt the expulsion fuse. Time-current crossover curve coordination is rarely used in applying outdoor backup current-limiting fuses, since there is no assurance that a series cutout would melt and drop open using this method. If the cutout does not open, full voltage can be impressed on a weathered outdoor backup fuse that may no longer have full voltage withstand capability.

Because of the location of the intersection or crossover point of the expulsion fuse's total clearing TCC curve and the backup fuse's minimum melt TCC curve, one need not be concerned with the melt I^2t values of the two fuses when using this method of coordination. The principal criterion to be satisfied is that the previously discussed crossover point must correspond to a current that is greater than the rated minimum interrupting current of the current-limiting fuse, but less than the rated maximum interrupting current of the expulsion fuse. The manufacturers of the expulsion fuse and the current-limiting fuse are required to publish values for these performance characteristics.

The principal advantage of the time-current curve crossover method, compared to matched-melt coordination, is that it normally permits the use of a fuse having a smaller current rating. This can be significant in several regards.

First, the lower the current-limiting fuse's current rating is, the less energy it is apt to 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 is apt to be and the less space it is apt to require for installation.

Third, when this method of coordination is used rather than matched-melt coordination, often the largest available backup fuse rating can then be used to protect larger transformers.

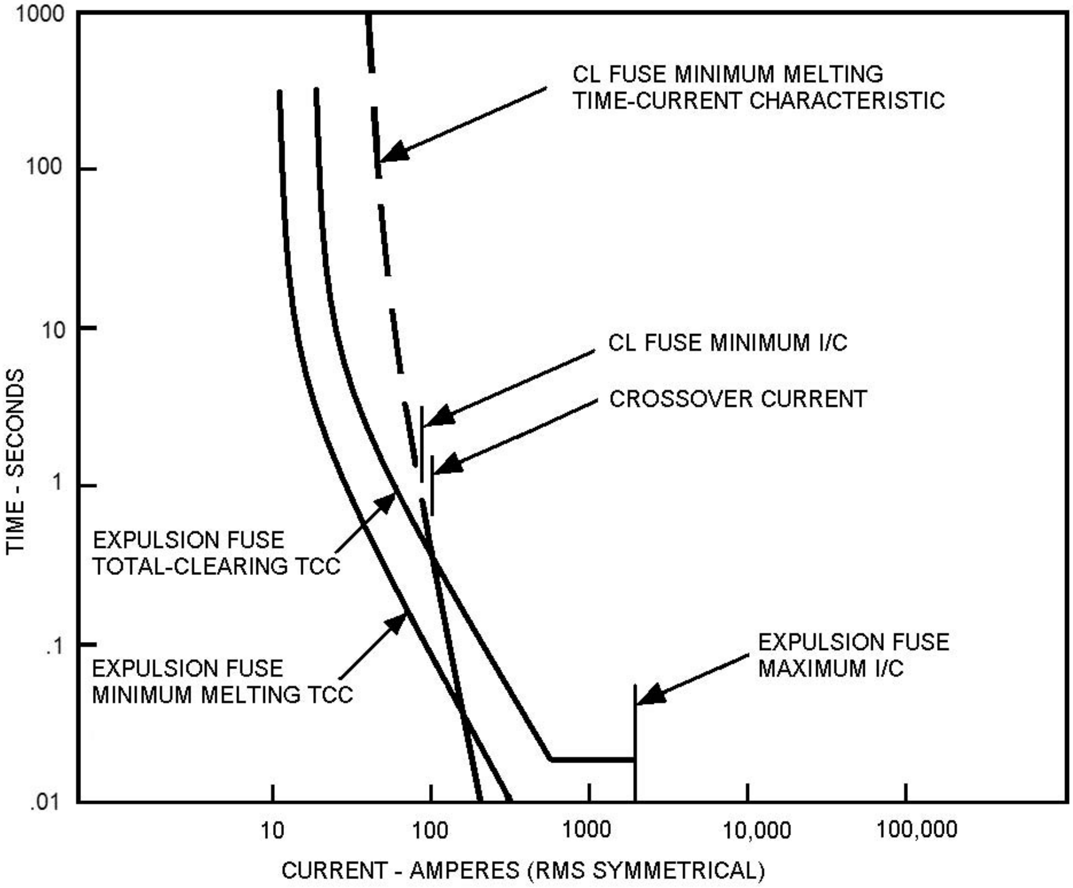


Figure 2—An example of time-current crossover coordination

5.1.3.1.2 Prevention of damage to the backup current-limiting fuse

For applications of backup current-limiting fuses on the primaries of transformers, there is another selection criterion that is particularly important from the standpoint of serviceability and operability. The concepts to be discussed are illustrated in Figure 3, and involve currents up to the value corresponding to a bolted fault at the secondary terminals of the transformer (i.e., a fault limited only by the transformer's impedance). A current-limiting fuse should be chosen such that this current is less than the current corresponding to the crossover point of the expulsion fuse's total-clearing curve and the backup fuse's minimum melt curve by an appropriate margin. This ensures that the backup fuse does not melt with, and more importantly is not damaged by, a fault external to the transformer. A damaged backup fuse could later melt at a current below its minimum I/C and fail to interrupt this current. The “appropriate margin” is discussed in the following paragraphs.

Although not published by the fuse manufacturer, one can envision a “no-damage” characteristic curve, which lies slightly below and to the left of the minimum melting curve of a backup current-limiting fuse. The separation between the published minimum melting curve and the imaginary no-damage curve represents a margin of safety and is intended to compensate for various factors associated with real-life (practical) applications. Some factors affect the accuracy of the calculation of the bolted secondary fault current. These include the tolerances on the transformer impedance, system line voltage fluctuations, and the use of taps. Other factors involve actual damage to the fuse element(s), caused by partial melting and mechanical stress, which can occur prior to the complete severing of the element. Only after the element(s) completely melts open can arcing be initiated, indicating the end of the “melting time,” and it is this time that is used to plot the TCC curve.

If the fuse manufacturer has a recommended margin, this should be used. In the absence of appropriate information, a commonly used method involves setting the no-damage current equal to 80% of the current shown on the minimum melting curve for any particular melting time. Since proper coordination between the backup current-limiting fuse and the series expulsion fuse requires that the current-limiting fuse not be damaged by any current equal to or less than the bolted secondary fault current, this method requires that the calculated bolted secondary fault current be no greater than 80% of the current-limiting fuse minimum melting current at a time corresponding to the total-clearing time of the expulsion fuse (with a current equal to the bolted secondary fault current). Conversely, the backup fuse’s minimum melt current must equal at least 125% of the calculated bolted secondary fault current at a time corresponding to the expulsion fuse’s total-clearing time at that current.

When a backup current-limiting fuse has been chosen using appropriate bolted secondary fault current coordination, it is not necessary to provide access to permit a current-limiting fuse located inside the transformer to be replaced “in the field.” If bolted secondary fault coordination is **not** achieved, then **the backup fuse must also be replaced** any time the expulsion fuse operates.

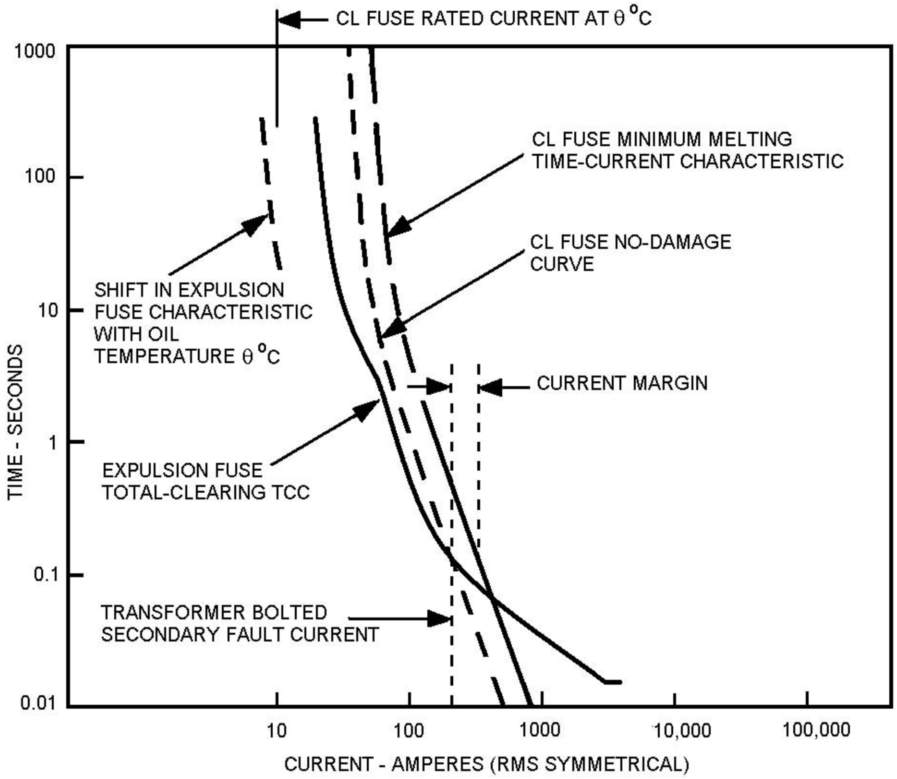


Figure 3—Fuse “no-damage” margin

5.1.3.1.3 Overload protection for the backup current-limiting fuse

There is another aspect of coordination that must be considered before one can be sure that a backup fuse is properly coordinated. This requires that checks be made to show that the backup current-limiting fuse will not melt or be damaged as a result of overloads. This is also illustrated in Figure 3. First, when the backup fuse is used for transformer protection, the total-clearing curve of the expulsion fuse should not cross the no-damage curve discussed in 5.1.3.1.2 for all currents below the bolted secondary fault current of the transformer. This is particularly important for “dual-element” expulsion fuses that may have a “knee” that causes the curve to approach the backup fuse minimum melting curve at times longer than those considered during the coordination described in 5.1.3.1.2. In other words, for all expulsion fuse clearing times from the value corresponding to the clearing time at the bolted secondary fault current up to 1000 s or more, the corresponding current on the expulsion fuse’s total-clearing curve should be no more than 80% of the corresponding current on the current-limiting fuse’s minimum melting curve (unless the fuse manufacturer specifies a different no-damage criterion). Preloading should not affect this coordination as any shifting to the left of the characteristic curves due to I^2R heating of the fuse elements, or ambient oil temperature rise will be as much or more for the expulsion fuse as for the current-limiting fuse.

The second condition to be satisfied is that under preloaded conditions, the maximum current that the expulsion fuse can carry without melting for a relatively long period of time (i.e,. greater than 5 min) must be less than the maximum continuous current rating of the current-limiting fuse. When the expulsion fuse is located inside equipment, such as a transformer, any shifting of the curve caused by temperatures produced by overload conditions should be taken into account when this criterion is examined. For example, some types of expulsion fuses experience a significant shift in their total-clearing TCC curve at elevated temperatures. A “dual” element type fuse in oil at 100 ºC can have its long time melting characteristic shifted, in terms of current, to about 60% of the values published at 25 ºC. Overload protection for the backup fuse can also be provided by secondary protection.

5.1.3.1.4 Presentation of backup current-limiting fuse operating characteristics

For backup current-limiting 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 versus 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, or the series device with which it is coordinated, after either, or both, have operated. Coordination between the two devices is critical to preventing damage to the devices and the 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. Because backup fuses are always coordinated with another device, care is often necessary when the series device has operated. See 5.1.3.1.2 for coordination techniques to prevent backup fuse damage, and 6.6.3 for a discussion of fuse damage caused by the operation of a series device.

5.1.3.2 General-purpose current-limiting fuses

A general-purpose fuse is defined by standards (IEEE Std C37.40 and IEEE Std C37.41) as a device that can interrupt any fault current between a current that will cause the fuse to melt in not less than 1 h and its rated maximum interrupting current. Typically, these fuses are used for transformer through-fault protection (for melting times less than about 1 h), 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 liquid-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 applied, 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 airflow 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 that 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 versus available current.

5.1.3.3 Full-range current-limiting fuses

A full-range current-limiting fuse, as defined by standards (IEEE Std C37.40 and IEEE Std C37.41), 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 versus 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.

5.2 Current-limiting fuses used in fuse enclosure packages

5.2.1 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 C37.41-2000, ANSI C37.46-2000, and ANSI C37.47-2000.

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

5.2.2 Applicable devices

See 1.4 for fuse container and enclosure package (FEP) types covered by this clause.

5.2.3 Clearances and spacing

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

5.2.4 Considerations for ambient temperature

5.2.4.1 Rated maximum application temperature

The FEP application should take into consideration any higher fuse operating temperatures caused by its confinement or by elevated ambient temperatures. The supplier of the FEP specifies the rated maximum application temperature, (RMAT) in degrees Celsius, preferably selected from the R20 series of preferred numbers (typically 56, 63, 71, 80, 90, 100, 112, 125, or 140). It is the maximum ambient temperature at which a device is suitable for use without causing any deterioration that would inhibit its ability to interrupt the circuit. In addition to the usual testing, a fuse has to demonstrate successful current interruption in an enclosure with the ambient temperature equal to the RMAT. The R20 series is comprised of the numbers 1, 1.12, 1.25, 1.40, 1.60, 1.80, 2.00, 2.24, 1.50, 2.80, 3.15, 3.55, 4.00, 4.50, 5.00, 5.60, 6.30, 7.10, 8.00, 9.00, and their multiples of 10.

5.2.4.2 Rated continuous current and allowable continuous current for an FEP

Fuses used in an FEP may not be able to carry their rated continuous current (nameplate rating or rating marked on the fuse) without deterioration or without exceeding the maximum temperatures specified in IEEE Std C37.40-2003. This would also be the case for a fuse not in an enclosure, but subject to an ambient temperature over 40 ºC (30 ºC for some older designs). The current a fuse can carry continuously under these different circumstances, without exceeding the specified temperatures, is defined as its allowable continuous current. This current is linked to a specific ambient temperature. Such a rating, when the fuse is a part of an FEP, should be available from the FEP manufacturer, or often the fuse manufacturer. Information would normally be provided in the form of de-rating (re-rating) factors applied to the fuse's rated continuous current, and would allow for the effect of enclosure and/or ambient temperature. Alternatively, a table of current ratings related to temperature may be supplied.

In some cases, the RMAT assigned to a fuse may be higher than the maximum temperatures permitted in Table 1 of IEEE Std C37.40-2003. This is because it may be anticipated that, in practice, the RMAT will occur in equipment experiencing severe overload or failure conditions. In this case, the fuse cannot be assigned an allowable continuous current at its RMAT, since the permitted temperatures would be exceeded even without taking into account any temperature rise caused by current in the fuse. It cannot be assumed, therefore, that a fuse will have an allowable continuous current at its RMAT. In some cases, fuses will only be assigned such a current rating at a lower temperature where they would be expected to operate continuously. There are some circumstances under which a fuse may be required, and is able, to carry a particular continuous current at some ambient temperature, or in an enclosure, which produces temperatures in excess of those specified in Table 1 of IEEE Std C37.40-2003. In this case, the application should be by agreement between the manufacturer and user.

5.2.4.3 Time-current characteristics

The modification of the thermal environment for the fuse due to it being in an enclosure will cause some shift of the fuse TCC. The largest shift occurs at the long time end. Details of the resulting effect on the TCC because of a particular enclosure should be available from the FEP manufacturer. It is normally in the form of multiplying factors applied to the fuse's TCC.

It may be noted that 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 to 1000 s region. However, for general-purpose and full-range fuses, this rule may be insufficient for times longer than 1000 s. Consult the manufacturer for specific adjustment information.

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 ambient temperature around the FEP compared to 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

5.2.4.4 Fuse selection

When a fuse is to be used at an ambient temperature over 40 ºC, or in an FEP, it is important to assess the effect of the environment on the fuse. The actual maximum application temperature should be compared to the fuse’s RMAT and the effect on current rating and TCC are relevant. It is important that conditions are not such as to cause deterioration of the fuse and associated components; an example of such a condition would be overloading backup and general-purpose current-limiting fuses. It is also very important to ensure that changes in the fuse’s TCC do not result in a fuse being called upon to interrupt a current for which it is not designed and tested. Attention should therefore be given to fuse coordination under all anticipated ambient temperature conditions.

Change to the melting TCC due to enclosure and elevated ambient temperature is usually of significance to general-purpose and full-range current-limiting fuses, while the change in TCC is usually much less significant for backup fuses. Therefore, backup-type current-limiting fuses that are coordinated with other fuses (or overload sensing devices) intended to operate at low overload currents require no TCC derating factors. However, care should still be taken to ensure that backup fuses used at high temperatures do not have their permissible current rating reduced to the point that they are subject to overloading and possible deterioration.

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

5.3 Expulsion fuses in enclosures

5.3.1 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 4.

5.3.2 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 subclause applies to the use of fuses that are in conformance with applicable sections of ANSI C37.46-2000 and IEEE Std C37.41-2000.
b) Some applications require expulsion fuses to be immersed in a liquid.

This clause also applies to expulsion fuses that are immersed in liquid and used in switchgear (not directly associated with transformers).

5.3.3 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.

5.3.4 Rated maximum application temperature

Expulsion fuses used in enclosures or containers are assigned a rated maximum application temperature, (RMAT) in degrees Celsius, preferably selected from the R20 series of preferred numbers (typically 56, 63, 71, 80, 90, 100, 112, 125, or 140). It is the maximum ambient temperature at which a device is suitable for use without causing any deterioration that would inhibit its ability to interrupt the circuit. In addition to the usual testing, a fuse has to demonstrate successful current interruption in the enclosure with the ambient temperature equal to the normal test ambient temperature, if the assigned RMAT is 55 ºC or less, and at the RMAT if it is higher than 55 ºC.

5.3.5 Reduction of allowable continuous current capability

An 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 designated value of 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 a F/C. This factor adjusts for the condition that the temperature of air surrounding the fuse inside the container will be higher than the ambient temperature of the air surrounding the F/C.

5.3.6 Time-current characteristics

When an expulsion fuse is used in an enclosure or container, an increase in surrounding temperature can cause a change in the fuse's melting time-current characteristics. Information on the resulting effect on the TCC because of a particular enclosure should be available from the enclosure manufacturer. Care should be taken if the change in characteristics affects coordination with other devices in a system. In the case of expulsion fuses used under oil, some designs are significantly more sensitive to oil temperature than are others and so it is difficult to generalize. However, since present standards only cover such fuses when used in switchgear, and switchgear oil temperatures are not usually very high, this does not usually present a coordination problem.

5.3.7 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.

5.4 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 C37.41-2000. This document (IEEE Std C37.48) supplements information shown in IEEE Std C37.99-2000 regarding fuse application.

5.4.1 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. For many installations, reducing the risk of capacitor tank rupture is a primary concern. 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 (also commonly referred to as "group" fuses) are used for the protection of the entire capacitor bank installation, whereas capacitor unit fuses (often referred to as "individual" fusing) are used for the protection of individual capacitor units. Some installations incorporate both capacitor line fuses and capacitor unit fuses. Often, small distribution capacitor banks are protected by just 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 rating of the capacitor unit or capacitor bank in terms of volt-amperes reactive (usually divided by 1000 and expressed as *kvar*), 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.

5.4.2 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.

5.4.2.1 Application characteristics of capacitor line fuses

Some desirable characteristics for capacitor line fuses may be to

a) 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) 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) 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 (a fuse is often chosen to have an allowable continuous current of 135% of the nominal capacitor current, see 5.4.2.3.1).

d) 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) Withstand the transient energizing current from the system and from other nearby energized capacitor banks.

f) Withstand or operate (user’s choice) on discharge current from the capacitor bank into a fault on the system near the capacitor bank. It may be noted that a fuse melting characteristic that would be required if the bank is to remain connected during such a fault may provide less desirable bank protection than that obtained with a fuse having a characteristic that would result in operation with a fault close to the bank.

Some considerations where only capacitor line fuses are used

- 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.

5.4.2.2 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 assure 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 capacitor banks (ungrounded-wye or delta-connected), the voltage across the second line fuse to clear is system line-to-line voltage, regardless of the system grounding at the capacitor bank (ungrounded systems, including uni-grounded systems, or grounded-wye systems, including impedance grounded systems). For ungrounded-wye or delta-connected capacitor banks, 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 (e.g., 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 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 expulsion and current-limiting fuses may be tested as three-phase devices. One test series at rated (maximum) interrupting current may be performed at only 87% of rated maximum voltage, with another test series performed at full rated maximum voltage but 87% of rated interrupting current. As a result, power class 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 (e.g., 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 (e.g., 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).

It may be noted that, 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 4.7 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.

5.4.2.3 Selection of current rating for capacitor line fuses

5.4.2.3.1 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, which 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):

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

where

$kvar_{3\phi}$ is the nominal three-phase rating of the capacitor bank, measured in volt-amperes reactive divided by 1000 (kvar), 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):

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

where

kvar is the nominal single-phase rating of the capacitor bank (in kvar),

kV is the nominal single-phase voltage rating of the capacitor bank (in kilovolts).

Equation (1) and Equation (2) provide a method for calculating the nominal phase current for single-phase 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):

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

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 by considering the possibility of a system voltage higher than nominal, capacitor manufacturing tolerances, and the presence of harmonics. Past capacitor standards allowed a 6% higher system voltage (excluding harmonics), a +15% capacitance tolerance, and a +10% higher current due to harmonic content. 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% ($1.06 \times 1.15 \times 1.1 = 1.34$). This was typically rounded to an allowance of 35% when conservatively selecting a capacitor line fuse. Recent capacitor standards, currently IEEE Std 18-2002 and NEMA CP 1-2000, have changed the allowable variations listed earlier. This new tolerance results in an allowance of 29% ($1.06 \times 1.10 \times 1.1 = 1.29$). Since the age of the capacitors to be used in an installation is not generally known, the use of the older allowance of 35% is usually prudent.

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 ampere), 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 higher 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.

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

5.4.2.3.2 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.

5.4.2.3.3 Maximum size fuse

Subclauses 5.4.2.3.1 and 5.4.2.3.2 guide the selection of the minimum size fuse. The maximum size fuse for the application is determined by case rupture considerations. (See 5.4.2.5)

For ungrounded-wye-connected banks, the ability of the capacitor units in the unfaulted phases to withstand the overvoltage described in 5.4.2.1 until the fault is cleared should be considered.

The smallest size fuse that meets the guidelines in 5.4.2.3.1 and 5.4.2.3.2 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.

5.4.2.4 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 is 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.

5.4.2.5 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 being 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. For typical case rupture curves, see Figure 4. 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 time-current characteristic 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.

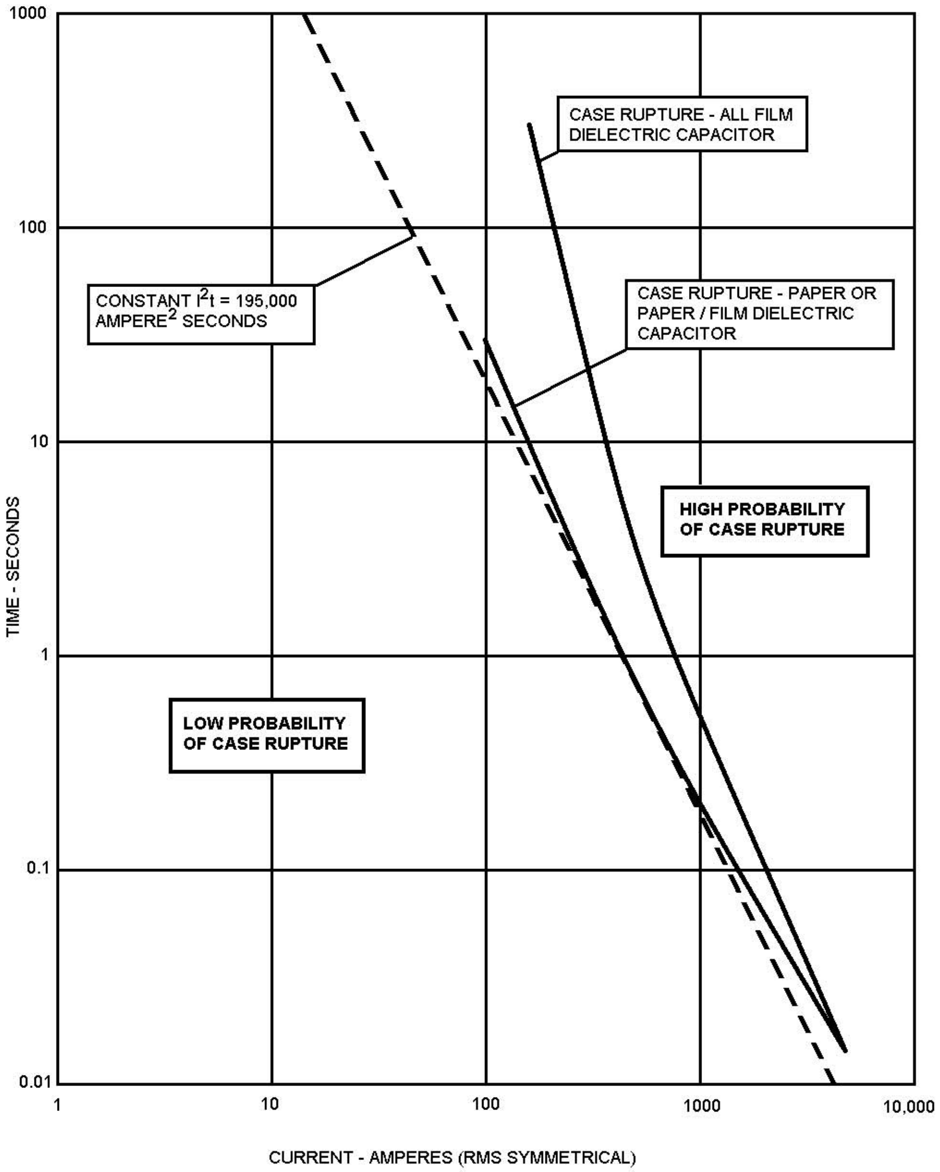
For inductive fault currents, the symmetrical current available at the bank should be used instead of the asymmetrical current available. This is an acceptable practice for rupture protection comparisons since capacitors usually will degenerate into a total unit failure at or near a peak voltage, thereby 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 fuse's 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 a capacitor case rupture curve characteristics is shown in Figure 4.

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 towards 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.



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

Figure 4—An example of capacitor case rupture curve characteristics

5.4.3 Guide for capacitor unit fuse application

Capacitor unit fuses are used to protect individual capacitor units in a capacitor bank. An unbalance protection scheme is used for capacitor bank protection. The setting of the unbalance protection may affect the voltage across the individual fuse when it clears, and should be considered in determining the fuse rating. Some single series group grounded-wye capacitor banks on grounded-wye systems and some single series group delta connected capacitors banks (regardless of system grounding) may not require unbalance protection for reliable capacitor bank protection.

5.4.3.1 Application characteristics of capacitor unit fuses

Some desirable characteristics for capacitor unit fuses may be to:

a) Provide earliest possible isolation of a faulted capacitor unit.
b) 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) Withstand the discharge transient outrush current from an individual capacitor unit into a faulted capacitor unit within the same series group.

5.4.3.2 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 C37.99-2000 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.

The unbalance protection in a capacitor bank should be fast enough to avoid the last fuse in a series group ever having to operate without a capacitor in parallel and with a very high recovery voltage. Refer to IEEE Std C37.99-2000 for information on unbalance protection.

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.

5.4.3.3 Selection of current rating for capacitor unit fuses

5.4.3.3.1 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):

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

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

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

$$I_{\text{nominal}} = \frac{kvar_{3\phi}}{\sqrt{3}kV_{\phi-\phi}} \text{ A} \tag{5}$$

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

Equation (4) and Equation (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):

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

where
I_{nominal} is the nominal capacitor unit current,
$kV_{\text{operating}}$ is the expected operating voltage of the capacitor unit (in kilovolts), and
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 reactive power (kvar) ratings. The capacitor unit may operate for some extended time at a voltage 10% higher than its nominal voltage rating. Further, the capacitance tolerance, permitted by standards, has been as high as +15%. 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% (l.1 × 1.15 × 1.1 = 1.39).

In practice, however, the operating variables described previously 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 time-current-characteristics (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 by 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.

5.4.3.3.2 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).

5.4.3.4 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 is 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 is 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 previously, 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.

5.4.3.5 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 increase. 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, the current 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 time-current characteristic 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 fuse's 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 a capacitor case rupture curve characteristics is shown in Figure 4.

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 the following:

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 non-gassing operation
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.

5.4.3.6 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. For the calculation of stored energy, see the definition of *capacitor stored energy* in IEEE Std C37.40-2003.

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 as follows:

a) To use more series groups and less parallel units
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. Typical 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 are usually 40 kJ or higher.

6. Operation guidelines for various fuse types

6.1 Use of nonexpendable cap on expendable-cap cutouts

Installation of 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.

6.2 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.

6.3 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.

6.4 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.

6.5 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.

6.6 Replacement and handling of fuses

Replacement fuses should be those recommended by the manufacturer. Care is particularly required in certain applications, see 4.8.5 and 5.1.3.1.4.

6.6.1 Replacement of fuses

Replacement of fuses should be done with the circuit de-energized, unless their design, testing, and the manufacturer's recommendations permit replacement while energized. In the case of fuses that are under the control of a utility, fuse replacement should be done using utility practices developed in conjunction with the fuse's manufacturer. However, expulsion fuses should never be replaced from within the venting area with the circuit energized.

6.6.2 Handling of current-limiting fuses

Careless handling of current-limiting fuses may result in damage to the fuse. This damage may be clearly visible, such as denting of the fuse cap or cracking or breakage of the fuse tube. On the other hand, it may be invisible—such as breakage of an element inside the fuse or disruption of a seal in an under-oil fuse. This damage can interfere with key performance requirements placed on the fuse, that is a damaged fuse may not be able to carry its rated continuous current or it may not be able to interrupt a faulted circuit. If either occurs, other equipment, as well as those working on the equipment, can be affected adversely.

Some typical causes of damage include, but are not limited, to the following:

- Dropping or mishandling a fuse
- Excessive force in closing a fuse into its mounting
- Improper alignment of the fuse with its fuse support during insertion or removal
- Over-tightening connection points
- Excessive lead size or weight causing too high a cantilever force being placed on a fuse
- Using a fuse in a thermal environment beyond its rating.

The manufacturer should be consulted as to proper installation force and acceptable mountings as well as safe handling guidelines. If damage is suspected, the fuse should be removed from service.

6.6.3 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 phase(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.

6.6.4 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.

6.7 Replacement of exhaust control device

The exhaust-control device on the fuse may be 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.

6.8 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 amperes, this time delay could be as long as 10 min.

6.9 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. Consult the manufacturer for recommendations.

7. Additional operation guidelines for specific devices

The following operational guidelines are in addition to those in Clause 6.

7.1 Capacitor fuses

7.1.1 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 5.4 for complete capacitor fuse application guidelines.

7.1.2 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 18-2002 or NEMA CP 1-2000 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.

7.2 Liquid-submerged expulsion fuses in enclosures

7.2.1 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 Clause 8 and Clause 9 for additional information.

7.2.2 Removal and replacement of fuses

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

8. Maintenance for all fuse types

8.1 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.

8.2 Frequency of maintenance

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

8.3 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, 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 or delamination 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 per manufacturer's recommendations.

8.4 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.

9. Additional maintenance guidelines for specific devices

9.1 Capacitor fuses

Care should be taken to discharge and ground capacitors before maintenance is performed. See 7.1.2 for further information.

9.2 Liquid-submerged expulsion fuses in enclosures

The following is additional requirement for liquid-immersed fuses.

9.2.1 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.

9.2.2 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 a 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.

Annex A

(informative)

Bibliography

[B1] ANSI C37.42-1996, American National Standard Specifications for High Voltage Expulsion Type Distribution Class Fuses, Cutouts, Fuse Disconnecting Switches and Fuse Links.

[B2] ANSI C37.45-1981 (Reaff 1992), American National Standard Specifications for High Voltage Distribution Class Enclosed Single-Pole Air Switches.

[B3] ANSI C37.53.1-1989, American National Standard for Switchgear – High-Voltage Current-Limiting Motor-Starter Fuses—Conformance Test Procedures.

[B4] IEEE Std C37.100™-1992, IEEE Standard Definitions for Power Switchgear.

[B5] IEEE Std 1036™ -1992, IEEE Guide for Application of Shunt Power Capacitors.