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Tutorial and application guide for high-voltage fuses

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TECHNICAL REPORT

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Tutorial and application guide for high-voltage fuses

Guide explicatif et d'application pour les fusibles à haute tension

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

TUTORIAL AND APPLICATION GUIDE FOR HIGH-VOLTAGE FUSES

FOREWORD

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IEC 62655, which is a technical report, has been prepared by subcommittee 32A: High-Voltage Fuses, of IEC technical committee 32: Fuses

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

Enquiry draft	Report on voting
32A/296/DTR	32A/301/RVC

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

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

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- withdrawn,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

INTRODUCTION

0.1 Aims and objectives of this technical report

- a) To help prospective users and protection engineers understand the basics of high-voltage (>1 000 V a.c.) fuse technology and applications involving high-voltage (HV) fuses;
- b) to illustrate the particular and unique advantages of fuse protection for most service applications;
- c) to minimise possible misapplications of fuses which could lead to problems in the field;
- d) to list and describe the many types of fuse in use today, and the international standards that apply to them, including fuse types not specifically included in IEC or other recognized standards.

This technical report gathers information previously published in IEC and other publications, as well as new material. Duplicate information presently in these publications is therefore likely to be eliminated during their future revision.

0.2 How to use this technical report

0.2.1 General

If read from start to finish, this technical report will provide an in-depth study of HV fuses and their applications. It is essentially a tutorial covering all common (and some not so common) types of fuses and most fuse applications. However, it is assumed that few users will read the technical report in this way, but rather read the appropriate sections covering fuses and applications for which they require information. Based on this assumption, there is therefore some inevitable duplication of information. To assist the user in making best use of the document, a description of the content and relevance of each clause follows.

0.2.2 Fuse tutorial

After clauses on scope, references and definitions, Clause 4 contains primarily "tutorial" style information. The clause starts with a simple introduction to fuses, first with an explanation of how fuses work followed by information on basic fuse classifications and common fuse terms. Subclause 4.1.4 continues with lists of advantages gained by using fuses and then 4.1.6 provides a listing of basic fuse types for which application information will be given later. An in-depth look at the most common types of fuses is given in 4.2, current-limiting fuses and 4.3 expulsion fuses. The high level of detail given in 4.2 and 4.3, including information describing construction, operation, classification and published ratings and characteristics, may be necessary in order to understand the application information that follows in Clause 5. For completeness, 4.4 gives an overview of less common types of fuse (or fuse related) devices that may require additional testing to that covered in existing standards, and for which no further application information is provided. Subclause 4.5 covers fuse mountings.

0.2.3 Application information

Application information appears in Clause 5 and Annex A, and is split into four sections.

- a) Subclause 5.1: this covers information common to nearly all applications.
- b) Subclause 5.2: this contains information on specific applications.
- c) Subclause 5.3: this covers installation, operation, maintenance, and replacement of fuses.
- d) Annex A: this reproduces the current-limiting fuse temperature de-rating information previously published in IEC 60282-1:2009.

If a knowledgeable user requires application information on a specific subject in 5.2 (e.g. motor circuit fuses), it is possible that only the relevant subclause needs to be read – however in most cases additional information from 5.1 will be required for satisfactory fuse selection. It should be emphasized that the information contained in this report is intended to supplement

information supplied by the manufacturer of a fuse and not replace it. If there is any doubt or conflict of information, the fuse manufacturer should be consulted.

TUTORIAL AND APPLICATION GUIDE FOR HIGH-VOLTAGE FUSES

1 Scope

This technical report provides information for understanding the construction, operation and application of high-voltage fuses in general. Current-limiting, expulsion, electronic, and other, non-current-limiting, fuses rated above 1 kV a.c. are all covered, as are North American, European and other application practices. As a technical report, this document contains no requirement and is informative only.

2 Normative references

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

IEC 60038, *IEC standard voltages*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60076-1, *Power transformers – Part 1: General*

IEC 60076-7, *Power transformers – Part 7: Loading guide for oil-immersed power transformers*

IEC 60076-12, *Power transformers – Part 12: Loading guide for dry-type power transformers*

IEC 60282-1:2009, *High-voltage fuses – Part 1: Current-limiting fuses*

IEC 60282-2:2008, *High-voltage fuses – Part 2: Expulsion fuses*

IEC 60549, *High-voltage fuses for the external protection of shunt power capacitors*

IEC 60644, *Specification for high-voltage fuse-links for motor circuit applications*

IEC/TR 60890:1987, *A method of temperature-rise assessment by extrapolation for partially type-tested assemblies (PTTA) of low-voltage switchgear and controlgear*

IEC 60909-0, *Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents*

IEC 62271-100:2012, *High-voltage switchgear and controlgear – Part 100: Alternating current circuit-breakers*

IEC 62271-102, *High-voltage switchgear and controlgear – Part 102: Alternating current disconnectors and earthing switches*

IEC 62271-103, *High-voltage switchgear and controlgear – Part 103: Switches for rated voltages above 1 kV up to and including 52 kV*

IEC 62271-105:2012, *High-voltage switchgear and controlgear – Part 105: Alternating current switch-fuse combinations for rated voltages above 1 kV up to and including 52 kV*

IEC 62271-106, *High-voltage switchgear and controlgear – Part 106: Alternating current contactors, contactor-based controllers and motor-starters*

IEC 62271-107, *High-voltage switchgear and controlgear – Part 107: Alternating current fused circuit-switchers for rated voltages above 1 kV up to and including 52 kV*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purpose of this document, the terms and definitions contained in IEC 60282-1:2009 and IEC 60282-2:2008 apply.

3.2 Abbreviations

The following abbreviations are used in this document:

A²s – Amperes-squared-seconds, also A² × s, the unit of Joule integral (I^2t , see 4.2.4.4)

CL – Current-limiting

CLF – Current-limiting fuse

FEP – Fuse enclosure package

HV – High-voltage

I_{encl} – de-rated current (of a fuse in an enclosure)

I_r – Rated current (of a fuse)

u_c – TRV peak voltage in kV

t_3 – Time in microseconds to voltage u_c

I_1, I_2, I_3 – Prospective current in test Duty 1, Test Duty 2, and Test Duty 3 of IEC 60282-1, respectively

MAT – Maximum application temperature

TCC¹ – Time-current characteristic

TRV – Transient recovery voltage

4 Tutorial section

4.1 A simple introduction to fuses

4.1.1 General

Fuses have been in use since the very beginnings of electrical power distribution. While the true inventor of the fuse is not known, pioneers of electrical distribution soon incorporated them as "weak points" in their circuits to prevent overheating of wiring, due to excessive

¹ Footnote 1 applies only to the French version.

current, and to prevent damage to fragile lamps from fluctuations in voltage. Fuses rapidly developed into devices able to sense a current higher than normal and quickly interrupt (break) that current, all in a self-contained easily replaceable unit. Although the variety and complexity of fuses has grown to the point where user's guides, such as this one, are necessary, fuses still provide the highest degree of protection for the lowest initial cost.

The simplest definition of a "fuse" is that it is a device that carries current through a conductive part called the fuse element that, when the fuse is subjected to an excessive current, melts due to self-heating and initiates the interruption of the current. All conventional fuses interrupt current after some arcing across breaks in the element produced by the melting process. The melting time of a fuse is therefore also termed the "pre-arcing" time. A characteristic of fuses is that, because current interruption is initiated by a melting process, there are almost no "mechanical" aspects involved in their arc initiation. Fuses therefore have a very inverse time-current relationship (higher currents giving shorter pre-arcing times) as illustrated in Figure 1. This enables extremely short pre-arcing times at high currents, virtually without limit. It is this apparently simple phenomenon that is primarily responsible for the universal success fuses have enjoyed for a very long time.

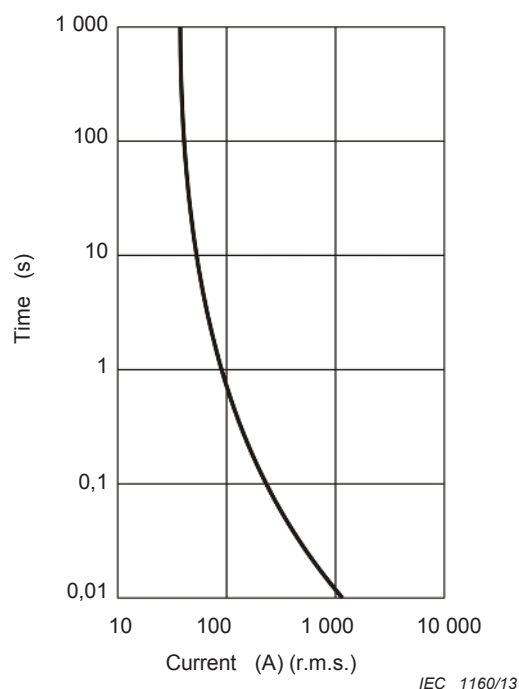


Figure 1 – Fuse pre-arcing time-current characteristic curve

In general, high-voltage fuses (defined as fuses rated above 1 000 V a.c.) are physically larger and generally more complex than low voltage fuses due to their need to operate at much higher voltages. HV fuses may perform one or both of two primary functions. The first function is to respond to moderately excessive currents, typically termed "overload" currents. In this case, the rated current of the fuse (the current it is designed to be capable of carrying indefinitely without deterioration) is exceeded by a relatively modest amount (typically less than 10 times). Such currents can be caused by too much load being connected to a circuit, or by a fault that by-passes only part of the load. It should be noted that not all types of fuses are designed to have the ability to operate successfully if melted by a very low overcurrent as some types are intended only for operation at high currents (see 4.1.2.1). If melted by a low current, such fuses may arc until a series device interrupts, possibly resulting in physical damage to the fuse and its surroundings. However, some fuses of this type can quickly initiate another device to interrupt such current, containing the arcing without damage until the second device interrupts.

The second function, which virtually all fuses are designed to perform, is to respond to overcurrents that are much higher, and that are usually termed "short-circuit" currents. In this case substantially all of the load is by-passed by a major fault and the available current (which, when not limited by a protective device, is termed the "prospective current") can be very high. However different types of fuse vary widely in exactly how high a current they can interrupt, and this may be a significant factor in choosing a fuse type for a particular application. The ways in which fuses respond to high and low overcurrents, as well as the ways in which they actually interrupt the current, causes HV fuses to be classified in various ways.

The first main classification is into "current-limiting" and "non-current-limiting" types (although because almost all commonly used non-current-limiting fuses are expulsion fuses, "expulsion fuse" is usually the term used in preference to "non-current-limiting"). "Current-limiting" (CL) describes a class of fuses defined by the behaviour that occurs when the current is so high that the fuse element melts before the first peak of the fault current (that is in less than a few ms). Upon melting, this type of fuse introduces resistance into the circuit so rapidly that the current stops rising and instead is forced quickly to zero (before a natural current zero would occur). Because the maximum prospective peak current is not reached, the fuse limits the current in magnitude as well as duration hence the "current-limiting" name. The current-limiting action is shown in Figure 2a. Note that during operation, the current-limiting fuse introduces a "spike" of overvoltage (the fuse switching voltage) into the system during the current-limiting action as shown in Figure 2a.

An expulsion fuse, melting under the same circumstances, introduces only a small resistance into the circuit, so the current continues to virtually the same peak as would occur if the fuse had not melted. An expulsion action (that is where gas is generated by the arc and expelled along with ionized material) produces a physical gap such that, at a natural current zero, the arc does not reignite and the current is interrupted. This type of fuse therefore limits the duration of a fault but not its magnitude. This action is illustrated in Figure 2b. For an explanation of TRV see 4.2.1.2).

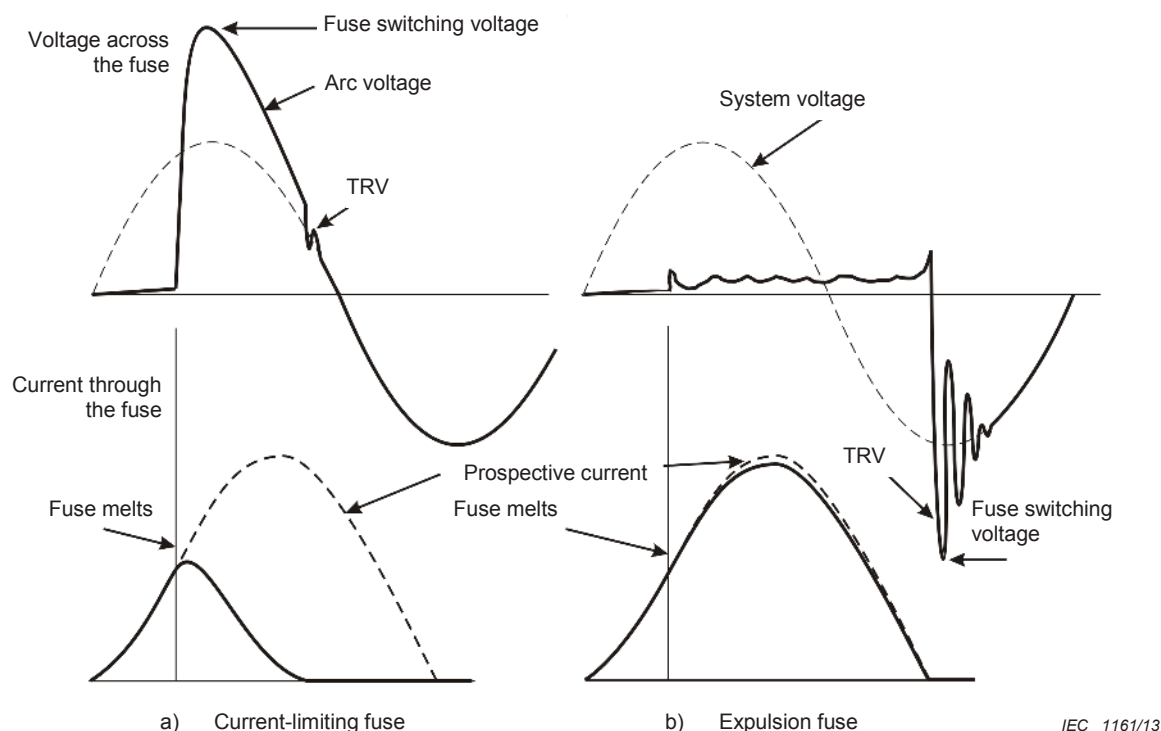


Figure 2 – High current interruption by current-limiting fuse and expulsion fuse ²

4.1.2 Fuse classifications and terms

4.1.2.1 Current-limiting fuse classifications

The ability of different types of CL fuse to interrupt currents lower than those that produce a current-limiting action result in different classes of CL fuse. Some CL fuses are designed to interrupt only high currents (i.e. their primary function is to provide a current-limiting action). They therefore have a limited low current interrupting ability and are termed "Back-Up" fuses. They are usually used in conjunction with another device in series; such devices include switches (most commonly tripped by a striker in a "switch-fuse combination", see 5.2.7.2), contactors, circuit breakers or another fuse having a lower current interrupting ability. It may be considered that they are "backing up" this other device and in addition to the important current-limiting function, also usually provide increased interrupting capability. This is because the series device frequently has a limited interrupting capability while Back-Up fuses can normally interrupt very high currents i.e. they have a very high "rated maximum breaking current".

High-voltage fuses having the ability to interrupt low values of overcurrent as well as high short-circuit currents are classed as either "General-Purpose" or "Full-Range" types. The term "General-Purpose" (which has historical origins, being used before Full-Range fuses were introduced) does not mean that the fuse can be used for any sort of application but merely that the fuse is designed to clear low values of fault/overload current. Testing is performed by the fuse manufacturer to show that fuse-links classed as General-Purpose can clear currents down to a value that causes melting of the fuse element in 1 h or more. This means that General-Purpose fuses can be used with overload currents that will cause them to melt in times of up to one hour, but no longer. The term "Full-Range" is used for the Class of fuse

² IEEE Std C37.48.1 -2012, "IEEE Guide for Operation, Classification, Application, and Coordination of Current-Limiting Fuses with Rated Voltages 1-38kV" - Reprinted with permission from IEEE, 3 Park Avenue, New York, NY 10016-5997 USA, Copyright 2002, by IEEE.

designed to clear even lower values of fault/overload current; in fact any continuous current that causes the fuse element to melt must be interrupted by such a fuse. Full-Range fuses are often used in enclosures, sometimes with the enclosure at elevated temperatures; both factors can reduce the lowest current that causes them to melt, and Full-Range fuse test methods reflect this.

4.1.2.2 Current-limiting fuse terminology

There now follows an explanation of common terminology relating to fuses used in fuse standards and in this report. A fuse is defined as all the parts that form a complete device, which is everything needed to connect it into a circuit. After operation, at least some of a fuse must be replaced to return the protection to "as new" condition. The part that is replaced after operation is called the "fuse-link", and is the part that performs the active function of current carrying and interruption. In some usage (IEEE standards for example) fuse-link refers only to the replaceable part of a distribution fuse-cutout (see 4.3.2.1.1). Current-limiting fuse-links are often termed "cartridge fuses". This is because they are almost always cylindrical in shape and contain the fuse element surrounded by an arc absorbing filler, usually quartz sand.

A complete CL fuse may employ a fuse-base (sometimes called a fuse support or fuse-mount). This base usually consists of clips and spade terminals, which are in turn mounted on insulators. They are used with a fuse-link having ferrules that fit in the clips. Cables or bus-bars attach to the terminals. This type of fuse is still extensively in use, normally in "live-front" gear (that is equipment that would have live conductors accessible if the access doors can be opened with the equipment live). Alternatively, fuse-links may be found installed in canisters (that is relatively tight fitting enclosures) or be moulded into rubber or epoxy for use with cables in submersible/dead-front installations ("dead-front" meaning that no live conductors are exposed). They are also used under oil, either in quite elaborate fuse-holders (for ease of replacement) or in simple cradles inside transformers when they do not have to be replaced by the user (see 5.2.2.6.4).

In some cases the fuse-link is also the fuse, that is it may include all of the components necessary for connection into a circuit, e.g. if the fuse-link has tags or spade/eyebolt terminals. An example of this method of mounting is an external CL fuse that may be hung from an overhead line or mounted on a distribution fuse-cutout or transformer insulator (in which case the cutout or insulator substitutes for the "fuse base").

4.1.2.3 Expulsion fuse classifications and terminology

Expulsion fuses are divided into two classes Class A and Class B (in some parts of the world called "Distribution Class" and "Power Class"). The majority of Class A fuses are of a specific fuse type called "distribution fuse-cutouts". They are characterized by a fuse base that holds a fuse-carrier. The fuse carrier is lined with arc quenching material and holds a fuse-link. The link initiates the arcing and the fuse-carrier provides for arc elongation and most of the expulsion gas produced at high currents. After the expulsion operation, the carrier hangs open giving indication and isolation. Only the fuse-link, comprising a fuse element attached to a flexible cable (tail) and surrounded by a small arc-quenching tube, has to be replaced. Because they are so common, they are often referred to simply as a "cutout" or a "fuse-cutout" and except where otherwise specified, the word "cutout" or "fuse-cutout" used in this document refers to this type of Class A distribution fuse-cutout. There are also designs, called open-link cutouts, that use no fuse-carrier, but rather the fuse-link contains all the parts necessary to connect to the fuse-base. They have quite low maximum breaking currents. There is a third type of Class A expulsion fuse, common in some countries. It is termed an enclosed fuse-cutout. This has all of the live parts enclosed in a housing (usually made of porcelain). They may be of a drop-out design but commonly are not. Additional types of Class A expulsion fuses include those intended for capacitor applications, and those that surround the fuse element with a liquid.

Class B fuses (sometimes termed "Power Fuses") are designed for circuits having lower power factor and higher Transient Recovery Voltage (TRV, see 4.2.1.2) values than Class A

and the fuses normally have higher maximum breaking currents. The fuse-link tends to be more elaborate than that of a distribution fuse-cutout and may constitute most, if not all, of the fuse carrier. Some designs use a renewable fuse-link that, after operation, may be restored by means of installing a refill unit (containing an element and arc-quenching material). Unlike distribution fuse-cutouts, not all Class B expulsion fuses drop to an open position after operation.

4.1.3 Basic principles of fuse operation

The following basic principles of fuse operation are common to all types of fuse, both current-limiting and non-current-limiting varieties.

In its passive or current-carrying mode, a fuse must be capable of carrying load current and permissible cyclic or transient overloads without deterioration essentially indefinitely (with a service life often measured in decades, see 5.1.1.7). When load current is passing through the fuse, its element temperature rises but as heat is dissipated to its surroundings, the temperature stabilises at some value below that at which the element material and connections to the power system would deteriorate. Under these conditions, the heat lost through conduction, convection and radiation exactly balances the heat generated by the current flowing through the fuse resistance.

In its active or fault-interrupting mode, more heat is generated in the fuse element than can be dissipated before its melting temperature is reached. The relationship between current and melting time is described with a time-current characteristic (TCC) curve. An example of a fuse pre-arcing TCC curve is shown in Figure 1. For most fuses, the pre-arcing current becomes asymptotic to the time axis at very long times, and is termed the "minimum fusing current". Standards specify the time to which curves must be drawn, depending on the type of fuse. Not all curves are drawn to a time that shows the minimum fusing current, and not all fuses are capable of interrupting this current (see 4.1.2.1).

Upon melting, a current interrupting (breaking) process occurs that is different according to whether the fuse in question is of the current-limiting or non-current-limiting type. The interrupting process will therefore be described for each type of fuse in the appropriate section of the report.

After the interrupting process, fuses must be capable of withstanding normal system voltage. To assist with this phase of operation, some fuses drop open, providing a visual and physical "gap". This is relatively common with expulsion type fuses, but much less common with current-limiting types.

4.1.4 Advantages of fuse protection

While fuses and other forms of protective device (such as circuit-breakers) all have their own advantages and disadvantages for a given application, fuses do have some unique benefits:

- a) because their operation is initiated by the melting of an element, there is no theoretical limit on how fast they can initiate the interruption process (the faster heat is generated in a fuse element the faster it melts). Generally there are no moving parts that require separation before the interrupting process can be initiated;
- b) rapid operation of fuses under short-circuit fault conditions minimises voltage dips on the system and ensures more effective protection of lines and equipment;
- c) fuses cannot be re-set when blown, thus the user is encouraged to identify and correct the fault condition before re-energising the circuit;
- d) fuses have no, or very few, moving parts that could become damaged by dust, oil or corrosion;
- e) fuse replacement after operation ensures protection is restored to its original state of integrity after circuit interruption unlike mechanical switching devices;

- f) use of fuses usually gives the most economic solution for a high degree of system protection;
- g) specific types of fuse are available for almost every service application.

4.1.5 Advantages of current-limiting fuses

4.1.5.1 General

In addition to the advantages detailed in 4.1.4, fuses of the current-limiting type offer additional important advantages:

- a) limitation of current and energy let-through into the location of the fault ensures maximum protection and minimises the risks of possible fire damage, explosion, or injury to persons;
- b) very high maximum breaking current ensures such fuses can always be employed on a given system even where the system is later modified to give a higher prospective fault level and hence there is no need to incur capital cost in installation of new more expensive protection equipment;
- c) silent operation with no emission of gas, flame or arcing products;
- d) compact size and much lower comparable cost than alternative forms of protection;
- e) ability to reduce the size of cables due to reduced short-circuit stresses;
- f) by reducing the I^2t (see 4.2.4.4 for an explanation of I^2t) flowing due to a fault, thermal stresses on all equipment in the fault circuit are reduced;
- g) since the peak current is reduced, the electro-dynamic forces, resulting from the magnetic fields surrounding the conductors of transformers and other equipment in the fault circuit, are reduced;
- h) because a current-limiting fuse reduces both the peak current and forces the current to zero before the natural current zero of the circuit, the fuse has a specific maximum operating (clearing) I^2t . Since upstream protective devices (see 5.1.4.1) require a minimum I^2t to initiate the interrupting process, it is possible to coordinate the devices to ensure that a failure at one point in a system will not cause operation of an up-stream device, thereby reducing the extent of the overall outage and helping to maintain service reliability.

4.1.5.2 Transformer protection

The most common application of high-voltage current-limiting fuses is for transformer protection. The use of such fuses for the primary-side protection of distribution transformers provides significant advantages due to their current-limiting action. Under most short-circuit conditions, they are able to interrupt fault currents within a few milliseconds after fault initiation. Hence, the prospective peak of the fault current will not be reached and the resulting let-through current and energy will be significantly reduced. This feature, that cannot be achieved by any other relay/switching device combination, makes current-limiting fuses particularly suited for distribution transformer protection since they are able to prevent or minimize any major consequences of internal transformer faults.

Figure 3 illustrates the operating I^2t versus prospective current for a non current-limiting fuse, which interrupts after one fully asymmetrical loop of current, and a current-limiting fuse. In principle, the lowest current rating of current-limiting fuse that meets the coordination requirements of 5.2.2 should be chosen. This is because a smaller fuse-link of a given design will generally have a lower operating I^2t . In the case of a low impedance internal transformer fault that produces a current-limiting action by the fuse-link, the I^2t limitation significantly reduces the likelihood of a disruptive failure, particularly with oil-filled transformers.

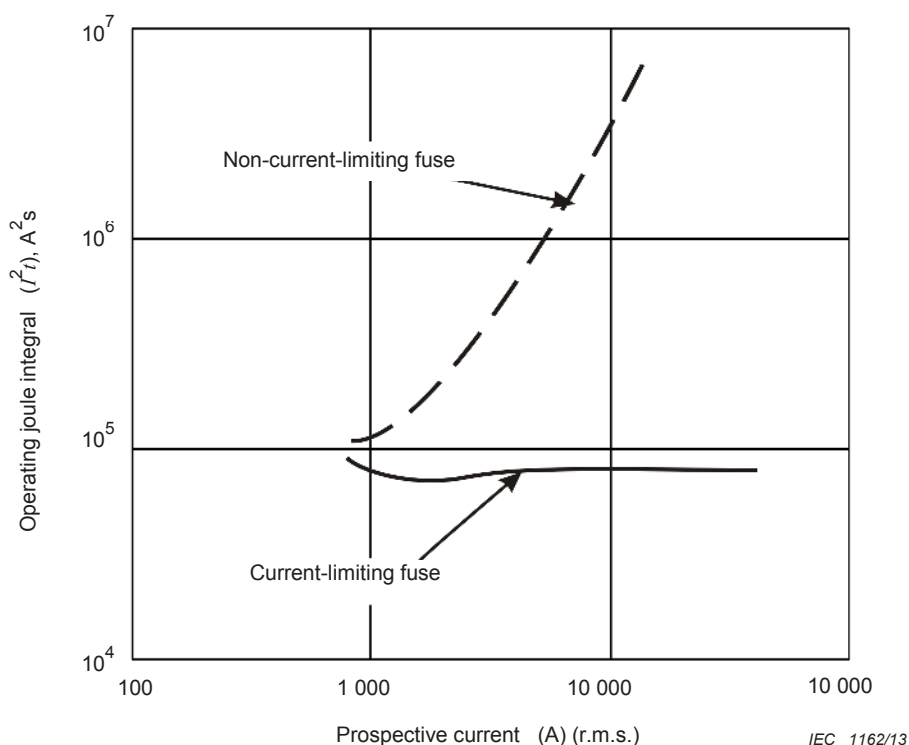


Figure 3 – Comparison of operating Joule integral (I^2t) versus prospective current for current-limiting fuses and non-current-limiting fuses

Experience has shown that the I^2t associated with a current-limiting fuse interruption is often an order of magnitude less than that causing a disruptive transformer failure, hence the effectiveness of current-limiting fuses in reducing the likelihood of such serious incidents.

It should be noted that the disparity in protection ability is even greater when the non-current-limiting device is a circuit breaker, due to the time delay introduced by the processes necessary to achieve current interruption. These are: the time needed for relay/current sensing, the time needed for the circuit-breaker contacts to open, and the time needed for the current to be extinguished. Therefore, in addition to the first loop I^2t , shown in Figure 3, I^2t from additional loops of current, that flow until the fault is interrupted, must be added. This has the effect of shifting the "non-current-limiting fuse" curve in Figure 3 upwards, typically increasing I^2t by a factor of approximately 2,5 times that shown.

Current-limiting fuses are available for the protection of distribution transformers up to approximately 5 MVA. For larger transformers with rated currents up to several thousand amperes, commutating current limiting devices (see 4.4.2.1 for a description) with high rated current can be applied. They are operated by an electronic sensing and triggering unit, which can be adapted to the required protection function. The electronics need to be able to distinguish between the fault current and the inrush current of the transformer.

4.1.6 Types of high voltage fuses

4.1.6.1 General

High voltage fuses of one type or another are available to meet almost every application for protection of high voltage circuits or equipment. It may be said that such fuses usually provide the simplest and most economical solution. There follows a listing of the most common types of fuse and fuse-related devices, that receive coverage in this report. They are grouped under four headings: current-limiting fuses, expulsion fuses, non-current-limiting fuses (that are not expulsion fuses), and fuse-related devices (devices that incorporate fuses into their operation, or are mounted in fuse-bases). A brief description is added for each device and places in the

report where they are addressed can be found in the index. It is believed that some types of device listed are obsolete and/or either not being currently manufactured, or manufactured in very low quantities. Such devices are followed by the word "obsolete". They are covered (if somewhat briefly) in this document because examples may still be found in service, and because they may require replacement by more modern devices.

4.1.6.2 Current-limiting fuses

When this type of fuse melts with a current high enough to cause it to melt before the first natural peak (the threshold current for a particular fuse), it introduces a sufficient resistance into the circuit that the current is quickly reduced to zero. They are enclosed fuses, normally filled with quartz sand, and the higher the fault current above the threshold current, the greater is the percentage reduction in let-through current peak and energy. Table 1 lists the most common types, covered by this report:

Table 1 – Common types of current-limiting fuse

	Type of CL fuse	Brief description
1	Full-Range	Fuses intended to interrupt all currents that cause the fuse to melt, up to the rated maximum breaking current of the fuse.
2	General-Purpose	Fuses intended to interrupt all currents from a low value, equal to a current that causes the fuse to melt in one hour, up to the rated maximum breaking current of the fuse.
3	Back-Up	Fuses intended to interrupt currents from their rated minimum breaking current, up to their rated maximum breaking current.
4	Types 1 – 3 using an indicator or striker	Indicators provide indication of fuse operation; strikers operate on fuse element melting (or at high temperature) typically causing a pin to emerge from the fuse, and trip associated switching equipment.
5	Motor circuit applications ("motor-starter fuses")	Fuses used in circuits that supply motors, and that are subjected to repeated starting surges higher than their rated current.
6	Voltage transformer fuse	Fuses used in the HV circuits of voltage transformers (and typically having very low current ratings).
7	Capacitor fuse	Fuses used to protect capacitors and that are required to interrupt capacitive currents.
8	Types 1 – 7 for use indoors, outdoors or immersed in an insulating liquid	Outdoor fuses may have special dielectric requirements compared to indoor fuses and also requirements for UV protection and/or moisture ingress. Fuses immersed in a liquid have special sealing requirements to avoid liquid ingress.
9	Exothermically assisted triggered fuse (obsolete)	A Full-Range type fuse that used exothermic material to provide multiple element breaks at low currents.

4.1.6.3 Expulsion fuses

These are fuses that work through an expulsion action. After the fuse element melts, an arc is formed, during which ionised material is expelled from a housing with the assistance of gas generated as a result of the arc interacting with components of the fuse. This enables the "gap" so produced to withstand circuit recovery voltage at a current zero. They do not significantly reduce the magnitude of a fault current, only its duration, and so are also called "non-current-limiting" fuses. Table 2 lists the most common types covered by this report.

Table 2 – Common types of expulsion fuse

	Type of Expulsion fuse	Brief description
1	Distribution fuse-cutout (Class A expulsion fuse) (open cutout)	A class "A" expulsion fuse that uses a replaceable fuse-link in a fuse carrier, which drops open after interruption. Used outdoors.
2	Enclosed fuse-cutout	An expulsion fuse in which live parts are enclosed. They may or may not be of a type that drops open after operation. Used outdoors.
3	Open-link cutout	A cutout that does not use a fuse carrier but a special type of fuse-link attached to spring loaded arms. Used outdoors.
4	Boric-acid power fuse (Class B expulsion fuse)	A class "B" expulsion fuse that uses boric acid to generate expulsion gasses. May or may not be of a type that drops open. Indoor versions are available.
5	Liquid-submerged expulsion fuse	Fuse-link immersed in a dielectric liquid with the element in contact with the liquid.
6	Liquid fuse (Liquid filled fuse)	Sealed fuse containing a dielectric liquid. Used outdoors.
7	Capacitor fuses	Fuses used to protect capacitors and that are required to interrupt capacitive currents.
8	Distribution oil fuse cutout (obsolete)	Small oil filled tank containing rotating switch device that includes a fuse-link.

4.1.6.4 Non-current-limiting fuses (non-expulsion type fuses)

Like expulsion fuses they produce little resistance during arcing and rely on achieving a "gap" having dielectric conditions such that when the arc is extinguished at a natural current zero, it is not re-established and current flow ceases. Types of non-current-limiting fuses mentioned in this report are listed in Table 3.

Table 3 – Types of non-current-limiting fuse

	Type of non-current-limiting fuse	Brief description
1	Horn gap fuse (Arcing-horn fuse)	Fuse that uses a wire between two arcing horns
2	SF ₆ fuse (obsolete – see 4.4.3.2)	Fuse uses a short element between two electrodes, in a small, sealed, enclosure with SF ₆ gas.
3	Vacuum fuse (obsolete – see 4.4.3.3)	Fuse uses a short element between two electrodes, in a small, sealed, enclosure with vacuum.

4.1.6.5 Fuse related devices

These devices use fuses as part of their operation or employ fuse bases as part of their construction. Common types referenced in this report are listed in Table 4.

Table 4 – Fuse-related devices

	Type of fuse-related device	Brief description
1	Commutating current-limiting devices with integral fuses	Device incorporates low resistance conductor, capable of very quickly transferring current to a parallel current-limiting fuse upon a signal supplied by a separate sensing device.
2	Electronic automatic sectionalising link (ASL)	A device, mounted in a distribution fuse-cutout base that can sense fault current and drop open, providing isolation during the "off" time of a recloser or similar device.
3	Disconnecting cutout	A distribution fuse-cutout base fitted with a solid blade in place of the fuse carrier.

4.1.7 Application of fuse types

Some applications commonly use just one type of fuse (for example motor circuit applications almost always use current-limiting fuses). However in other applications, more than one type of fuse is often found. This may be either as alternatives (e.g. an expulsion fuse or a current-limiting fuse) or a combination of fuses (for example a distribution fuse-cutout in series with a current-limiting back-up fuse). Combination fuses are available in which a current-limiting fuse is attached to an expulsion fuse (for example for capacitor applications). Particular advantages and disadvantages of different fuse types drive the selection process. While this report will compare and contrast different fuse types, it is not the intention to suggest any one fuse type is "better" or "worse" than another, but rather that some fuse types are better suited for certain applications than others depending on the desired protection requirements and the budget available.

4.2 Current-limiting fuses

4.2.1 Construction and operation of current-limiting fuses

4.2.1.1 General

In its passive or current carrying role the fuse must carry load current and permitted cyclic or other transient overloads for an indefinite time without deterioration (see 4.2.4.7 and 5.1.1.7). In its active or overload/fault current interrupting role, the fuse must disconnect the circuit, either relatively slowly, based on its pre-determined pre-arcing or operating time-current-characteristics, or very quickly with high fault currents, absorbing perhaps many kilojoules of resultant arc energy within itself and limiting the energy passed into the protected faulty circuit as much as possible.

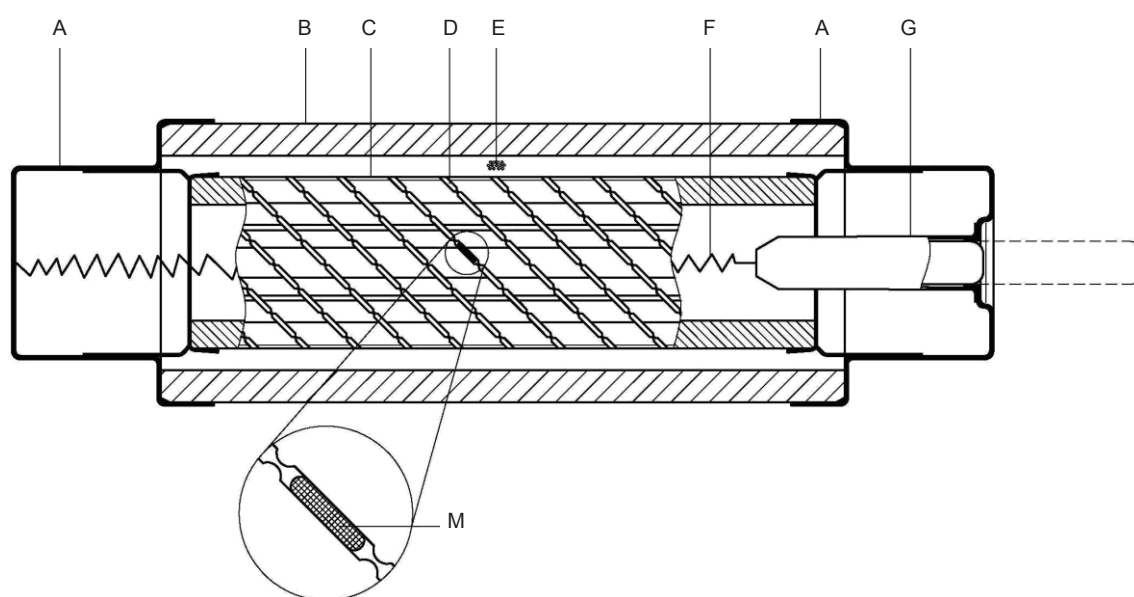
Figure 4 shows the construction of a typical back-up fuse-link having "DIN" dimensions. While other types of current-limiting fuse will show differences in construction, this figure illustrates the primary characteristics of such fuses. An insulating tube (the fuse body) of ceramic or organic resin/glass fibre material encloses parallel fusible current carrying fuse elements. These are connected at each end to metal caps, normally copper or brass, which seal the body and act as the electrical connections to the fuse. The body and caps are required to have the attributes of a pressure vessel, capable of withstanding the combination of high pressure and very high temperature that occurs at the instant of fuse operation. If the fuse is designed for use outdoors or under oil (or another dielectric liquid or gas such as synthetic or seed based oil, or SF₆), special additional sealing will usually be included to prevent ingress of moisture or fluid. For outdoor use, the manufacturer will use a material selection or special coating to prevent damage from weather and solar radiation over time.

The fuse elements are surrounded by granular insulating material, almost always compacted quartz sand of high purity and closely controlled grain size. The fuse shown, like many ratings, requires a fuse element length greater than the body length and so the fuse elements are wound in a spiral pattern around an inert former or "core", often, from its shape, known as a "star core". Other designs of fuse require fuse elements only of similar length to the body, and so are mounted parallel to the body (notably motor circuit fuses) as with low-voltage fuses. Low current ratings may often have only one fuse element while high current ratings will usually have many parallel fuse elements.

The fuse elements are the heart of the fuse, and are manufactured to a high degree of precision, normally from pure silver or copper wire or strip. The length of the fuse elements is proportional to the voltage rating of the fuse while the total cross-section and number of parallel fuse elements determine the current rating. The shape of the fuse elements together with their spacing and configuration determine many of the electrical characteristics of the fuse-link. They have a strong influence on the shape of the time-current characteristics, the degree of current limitation, and the peak overvoltage during high current operation (termed switching voltage or peak arc voltage – see 4.2.4.5).

Where fitted, strikers (often used to trip an auxiliary device) or indicating devices (to show that the fuse has operated), are wired in parallel with the fuse element system. During fuse

operation, when the main fuse elements are melted, the current transfers into the striker circuit, before quickly switching back to the main elements. Depending on the design, the current will either ignite a small pyrotechnic charge to expel the pin (typically British Standard type fuses or fuses that require a striker of type "heavy") or else melt a small latch wire (typically DIN-type fuses) to release a coil spring that expels the striker pin. In some designs, the latch is made thermally sensitive so that the striker will be released and trip the associated switchgear once the fuse has reached a given temperature, irrespective as to whether the fuse itself has actually operated. In the case where an indicating device rather than a striker is used, a relatively weak spring loaded indicator device may operate in a similar manner to a striker, or it may use a non-conducting filament, released by heat from the fuse arcing.



IEC 1163/13

Key

- A end cap (fuse-link contact)
- B body
- C former (core)
- D fuse element
- E granular filler
- F striker/indicator wire
- G striker or indicator
- M low temperature overlay ("M effect")

Figure 4 – Cut-away drawing of typical current-limiting fuse-link of the "DIN" dimensioned type

Fuses may be designed as simple ferrule fuses to fit into suitably shaped contact clips or they may be fitted with terminal tags for bolting onto bus-bars, etc. Some, intended for outdoor use, incorporate eye bolts for attaching cables or studs for mounting in eye-bolt terminals.

The high voltage current-limiting fuse has two distinct modes of interrupting fault currents, which will be described in 4.2.1.2 and 4.2.1.3. For a theoretical treatment of fuse interrupting phenomenon, see "Electric Fuses" by Wright and Newbery [2]³.

³ Numbers in square brackets refer to the Bibliography.

4.2.1.2 Operation under high-fault current conditions

At high fault currents (say more than ten to twenty times load current), all elements in a fuse-link reach melting temperature virtually simultaneously in only a few milliseconds or less. They break up along their length into multiple small series arcs. Strip fuse elements will usually include a pattern of holes or notches along their length to limit the number of these separate arcs, providing control over switching voltages (see also 4.2.4.5). Wire fuse elements also break up into multiple series arcs, due to complex thermal/magnetic forces. Since, for wires, the number of arcs tends to be very high, high switching voltages can result so wire fuse elements are normally used only for relatively low current ratings (see 4.2.4.5). The arcing, in effect, introduces a high resistance into the circuit and causes the current to be driven down long before the peak of the prospective fault current is reached (known as the cut-off effect). This is illustrated in Figure 2a. The arcs elongate, further increasing resistance. When the current has been driven down to a low value, the arcs are extinguished almost simultaneously within the first loop of fault current. Because the forced current zero occurs close to the circuit voltage zero, current-limiting fuses are much less sensitive to TRV than expulsion fuses, see Figure 2a) (TRV – Transient Recovery Voltage – is the brief transient oscillatory voltage that appears across an opened circuit, in this case across the fuse, after current interruption, and is due to damped current oscillation in the circuit inductance and intrinsic parallel capacitance).

Since both the peak value of the fault current and its duration are greatly reduced as compared with the operation of a non-current-limiting device, the energy released into the location of the fault or into the circuit being protected is very greatly reduced. The rapidity with which the fuse operates results in the appearance of a transient over-voltage in the circuit – the switching voltage. This is due to the collapse of the field associated with the circuit inductance and is more pronounced in circuits of low power factor. This switching voltage, appearing across the fuse, may be appreciably higher than the system voltage and should be allowed for when designing equipment clearances and creepage, and selecting lightning arresters.

The energy of the arcs within the fuse is dissipated in the formation of nodules of fulgurite from the sand filler surrounding the fuse elements. Fulgurite is the term used by fuse engineers to denote the mixture of sintered and fused sand grains together with globules of metal from the melted fuse elements. The amount of fulgurite produced during fuse operation is directly related to the quantity of arc energy absorbed by the fuse. Approximately 0,5 g of fulgurite are produced per kilo-joule of arc energy. Small increases in system voltage (above the rated voltage for the given fuse) cause a large increase in the arc energy and hence in the quantity of fulgurite produced. The fuse envelope has a definite upper-limit to the mass of hot fulgurite it can accommodate. Thus, in general, current-limiting fuses can only correctly interrupt short-circuit currents at system voltages not in excess of the fuse rated voltage.

4.2.1.3 Operation under low-fault current conditions

4.2.1.3.1 Temperature considerations

In the case of low faults currents, say up to around five times the fuse rated current, the fuse elements reach melting temperature gradually over a period of many seconds or minutes (or for Full-Range fuses, even hours). The melting temperature of silver is approximately 960 °C, that of copper, approximately 1 080 °C. If the melting time of a fuse is more than a few seconds (or for some types a few minutes), and the fuse as a whole had to reach such a high temperature during operation, damage to the fuse itself or its associated equipment could result. Various means are therefore employed to overcome this problem. Some fuse designs include a spot of low-melting alloy on the fuse element, known as M effect (after its discoverer Prof. Metcalf) as shown in Figure 4. If a typical tin alloy is used for the M-effect, at about 230 °C the alloy melts and the base fuse element material diffuses into it. This causes the fuse element to melt open at a lower temperature than its normal melting temperature, and initiate the process of current interruption. Where M-effect is not employed, other techniques that have been used include the incorporation of a low melting point section in series with a fuse element (common in some types of Full-Range fuse), the formation of a hot spot on the fuse element by creating a long narrow neck in the strip, or by enclosing part of the

element in thermal insulating material. The object, again, is to ensure that fuse element melting occurs without the strip as a whole having to reach an excessively high temperature.

An alternative solution, employed where the fuse is mounted in a striker-tripped switching device, is to use a thermal striker which is designed to operate and trip the associated switching device, when the temperature of the fuse reaches a pre-determined value. . In this particular case it is the switching device, and not the fuse, which performs the current interruption.

4.2.1.3.2 Low current interruption

In the case of low fault currents or overloads, with fuses having more than one fuse element, the parallel fuse elements do not melt and arc simultaneously, as with high fault currents, but instead melt randomly in turn, usually at one location on each element, until the last one melts. For fuses that employ fuse elements having a plain strip with restrictions, and that operate at more than a few thousand volts, more than one series break is necessary to interrupt current. The last fuse element to melt must therefore see sufficient current to achieve multiple melting during the arcing that then occurs. This arcing causes each of the remaining parallel fuse elements to re-strike and create multiple series arcs that, in turn, are extinguished when another element re-strikes. This process continues until all fuse elements have arced sufficiently to be able to withstand recovery voltage (including any TRV present).

Therefore, for many types of high voltage fuse, should the fault current be lower than a certain critical value (about 3 to 10 times rated current according to the particular design of fuse), the current density in each fuse element during arcing may be too low to initiate multiple series breaks in each element. The result is the formation of long single arcs that re-strike after each current zero, burning back and possibly causing eventual fuse failure. This type of fuse therefore has a defined "minimum breaking current" below which satisfactory circuit clearance cannot be assured.

Such fuses are termed Back-Up fuses (see 4.2.2 "classification") and are intended for use in applications where a) low fault levels are deemed very unlikely, b) where the fuse is used in conjunction with other protective devices which handle low level fault conditions or c) in the common application where the fuse is used in striker-tripped switchgear. In this latter case, under low fault conditions, the fuse striker pin is ejected immediately on the commencement of arcing within the fuse. The pin trips the switch in series with the fuse, thereby disconnecting the fuse from the fault current before it has time to overheat, so that satisfactory current interruption at all fault levels is assured. Back-Up fuses that are intended for use in series with other protective devices (expulsion fuses for example) may only have a rated minimum breaking current corresponding to a pre-arcing time of few seconds or less. In this case, the series device is coordinated with the Back-Up fuse's current rating and pre-arcing time-current characteristic so that the fuse cannot get hot enough on overloads to be damaged.

Fuses having built-in ability to handle low fault currents are also available. They are termed General-Purpose or Full-Range fuses (see 4.2.2 "classification"). In one version, an improved very low minimum breaking current capability is obtained by use of a large number of parallel fuse elements, each of small cross-section so that each fuse element when arcing on its own, has a high enough current density to break up into full multiple arcing and clear the fault current. In other cases, gas-evolving materials are used to increase the effectiveness of series arcs and improve low current interrupting ability. In another popular version, each current-limiting fuse element is connected in series with a fuse element working on the expulsion principle (see under expulsion fuses). In this arrangement, the expulsion fuse elements handle any low-level faults. For higher fault levels, the current-limiting fuse elements take over to clear the short circuit fault current. Fuses using this principle (sometimes called "dual-element" fuses) will have been tested using special tests, I_t , specified in IEC 60282-1:2009. This checks operation in the cross-over region from the current-limiting fuse element to the low-current fuse element. General-Purpose and Full-Range fuses can usually be employed as sole protection for all fault levels without the need of associated equipment to handle the lower fault currents.

4.2.2 Classification of current-limiting fuses

The classification of such fuses is related to their ability to interrupt low level fault currents as explained in 4.2.1.3).

Back-Up Class: this type of fuse must be capable of interrupting all levels of fault current from the rated maximum breaking current, usually many kiloamperes, down to the fuse rated minimum breaking current, typically 3 to 10 times fuse rated current. Such fuses are intended mainly for short-circuit protection. The fuse is not expected to clear lower levels of fault current unaided.

General-Purpose Class: This type of fuse must be capable of interrupting all fault currents from the rated maximum breaking current, down to those that cause fuse operation in one hour. For certain applications, such fuses are suitable for use as sole protection where they can provide some degree of overcurrent protection as well as short-circuit protection.

Full-Range Class. This type of fuse may have no definite value of minimum breaking current. While there are different test requirements for fuses intended to operate in a surrounding temperature either above or below 40 °C, the intent is that a Full-Range fuse is able to operate correctly for all values of continuous current that cause melting of the fuse elements up to its rated maximum breaking current. It is therefore particularly suitable for applications where use in a small enclosure causes considerable de-rating and hence the possibility of operation near to fuse rated current (see 5.1.4.2.7).

Figure 5 illustrates the current ranges over which the different classifications of fuse are intended to be used, and for which they are tested. In the Figure, I_{ACC} represents the maximum continuous current permitted by the application (see 5.1.1.1.3). In an enclosure it may be I_{encl} , (see Annex A) while in free air it will likely be I_r . The shaded portions represent currents above the allowable continuous current for which the fuse may be damaged and/or melt but fail to interrupt.

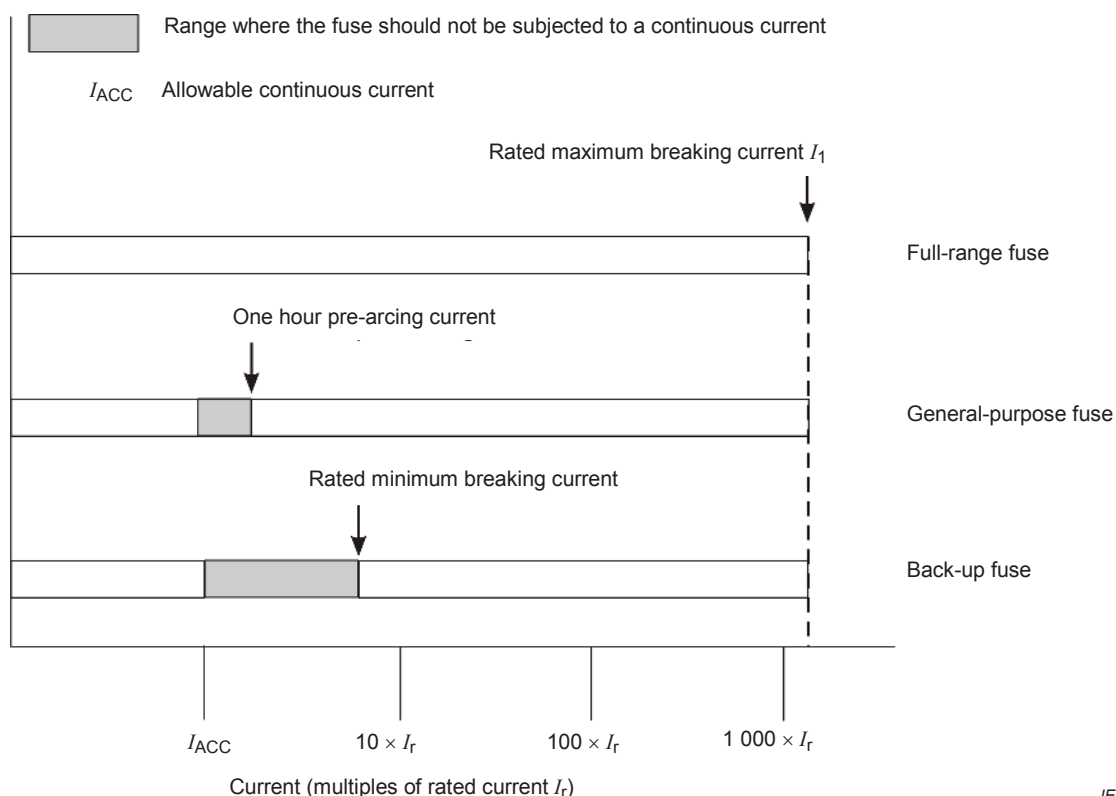


Figure 5 – Current ranges for which different fuse classifications are intended

4.2.3 Ratings of current-limiting fuses

4.2.3.1 Rated voltage

As explained in 4.2.1.2, current-limiting fuses are very voltage-sensitive. Hence, such a fuse must never be exposed to a recovery voltage even slightly higher than that used for testing. The recovery voltage that a fuse experiences in service depends not only on the system voltage but, in the case of three-phase circuits, also on the earthing of the system. Two aspects of an application must therefore be considered regarding fuse rated voltage. The first is that the rated voltage of a fuse must be at least equal to the "highest voltage of a system" (see IEC 60038) (i.e. maximum system voltage) not to the nominal system voltage (see also 5.1.3). Fuse voltage ratings therefore equate to "highest voltage for equipment" in IEC 60038. The second aspect is that unless the fuse is being used in a solidly earthed neutral three-phase system, an additional margin may be necessary. This is discussed in detail in 5.1.3.3. For example a fuse rated at 12 kV would be intended for use in a 10 or 11 kV system with solidly earthed neutral, but not in a single phase or resonant earthed system of the same nominal voltage.

Without special testing, fuses should not be connected in series in order to obtain an increased voltage rating since, due to manufacturing tolerances, one fuse of the series pair would probably operate before the other and so have more than its design voltage impressed upon it (see 5.1.6). It is permissible to use fuses of a given voltage rating in systems of lower voltage. The criterion here is that the spike of switching voltage during fuse operation should not exceed the insulation level of the system. A rule of thumb is that it is usually acceptable to use fuses down to about one half of their voltage rating.

4.2.3.2 Rated current

The current rating is determined largely by formalised temperature-rise tests in the design laboratory. Continuous load current should not normally exceed fuse rated current if deterioration of the fuse elements or other fuse components is to be avoided. However, in practice, high voltage fuses are generally run at load currents well below their rating for reasons connected with withstand against transient surge currents and de-rating due to use in thermally restrictive enclosures. To obtain higher rated currents, manufacturers often use parallel bodies permanently bonded together. Such fuses will be assigned an appropriate rated current by the manufacturer. Another way of providing an increased rated current is for the user to parallel individual fuses. The manufacturer should be consulted before this is done (see 5.1.5).

4.2.3.3 Rated maximum breaking current (rated maximum interrupting current)

Current-limiting fuses are usually tested at values of rated maximum breaking current (typically 25 kA to 50 kA) well above practical system fault levels. Manufacturers will not normally seek to find the highest current their fuses can interrupt, due to the high cost of such testing and/or test station limitations. However, a fuse should not be used at a higher prospective fault current than its rated maximum breaking current without consulting the manufacturer.

4.2.3.4 Rated minimum breaking current (rated minimum interrupting current)

It may not generally be realised that, unlike other circuit-breaking devices, current-limiting high voltage fuses of the Back-Up type (see 4.2.1.3)) do have a definite lower limit to the current that can be interrupted without external damage to itself or associated equipment. This rated value must be stated by the fuse manufacturer and has to be based on appropriate interrupting tests. It may be noted that the minimum breaking current value has no direct connection with the minimum fusing (melting) current of a fuse. The latter equates to the long-time end of the fuse time-current minimum pre-arcing curve (see 4.1.3) and may be typically 1,3 to 2 times fuse rated current, while rated minimum breaking currents are typically 3 to 10 times rated current.

4.2.3.5 Rated frequency

Within limits, this is not a critical parameter. A fuse tested at 50 Hz will be entirely suitable for use at 60 Hz. Also, in general, a current-limiting fuse tested at 60 Hz will be suitable for use at 50 Hz (unlike expulsion fuses see 4.3.4.4). While a fuse tested at 50 Hz or 60 Hz may be suitable for higher frequencies, no guidance can be given here, and the fuse manufacturer should be consulted for such applications. At lower frequencies than 50 Hz, more careful consideration may be needed since the longer half-loop time results in higher energy release in the fuse. Some de-rating in terms of voltage is usually necessary. In the extreme case of DC applications, the increase in arc energy can be so pronounced that a substantial voltage de-rating may be needed, and again the manufacturer should be consulted. Note that d.c. applications are not in the scope of IEC 60282-1:2009 or IEEE C37.41 [6]. For information on d.c. traction fuses see IEC 60077-5.

4.2.4 Characteristics of current-limiting fuses

4.2.4.1 General

The characteristics of a fuse, as published by the manufacturer, determine its suitability for use in a given application and enable comparisons to be made between fuses of different types so as to allow an optimum choice to be made.

4.2.4.2 Time-current characteristics

The most useful of the fuse characteristics, time-current characteristics enable co-ordination to be worked out between fuses and other protective devices on a given system. Manufacturers publish such data for all types and ratings of their products. Unless otherwise specified, the curves are drawn for an ambient temperature of 20 °C. For most fuses, the curve is valid for a range of temperatures. However depending on the type of fuse and the application, curves or correction factors valid for other temperatures may be produced. IEC 60282-1:2009 requires that Time-Current Characteristic (TCC) curves be drawn on a log-log scale and show the relationship between the virtual pre-arcing time and the prospective current. They may use mean or minimum values for current. European practice is to use mean values of current with a suitable tolerance to allow for manufacturing variance stated. They do not include the time during which actual arcing takes place. For very short melting times of less than 0,1 second the melting time could vary widely depending on the phase instant of the fault. Therefore, it is common to use "virtual time" rather than real time for the lower end of the curves. Virtual time is given by the joule-integral (I^2t) divided by the square of the prospective current r.m.s. value.

In North American practice, instead of a mean pre-arcing curve, a minimum pre-arcing curve is normally published (allowing for minimum manufacturing tolerances) together with a maximum operating (clearing) curve (including maximum manufacturing tolerances) which does include arcing time. Symmetrical currents are used to produce the pre-arcing curve to avoid the variability of asymmetry and "real" time, not virtual time, is normally used.

NOTE In practice the difference between a curve drawn with symmetrical current and a curve drawn using virtual time is small for most fuse designs. Therefore, time-current characteristic curves using either of these techniques can generally be used for coordination between fuses, and between fuses and other devices, down to approximately 0,01 s. Coordination at shorter time uses I^2t (see 4.2.4.4).

Time-current curves are developed with the fuse cold, i.e. off-load. In practice, preheating of the fuse, caused by the presence of load current causes operation to be slightly faster than shown on the published curves.

The value of the rated minimum breaking current for a Back-Up fuse is indicated by the point at which its TCC curve changes from a full line to a dotted line (see Figure 20).

Coordination between fuses and other devices (see 5.1 and 5.2) frequently require the use of minimum and maximum TCC curves (both pre-arcing TCC and operating [total clearing] TCC). If a nominal curve is published it must be shifted by the appropriate manufacturing tolerance.

(in terms of current). Pre-arcing TCC curve tolerances vary depending on the type of fuse; however fuses tested to IEC 60282-1:2009 are required to have a tolerance not to exceed $\pm 20\%$ for nominal curves and $+ 50\%$ for minimum to maximum curves. Modern fuses tend to have lower tolerances, more typically $\pm 10\%$. This is similar to the North American practice, which is not to exceed $+ 20\%$ from the minimum to the maximum curve.

4.2.4.3 Cut-off characteristics

These curves show the highest maximum instantaneous values of current a given fuse will let pass under fault conditions for varying values of prospective fault current. The characteristics are of use in enabling checks to be made on the degree of protection afforded by the fuse to cables bus-bars, switch contacts, etc. However, since the operation of the fuse is extremely rapid, while damage to associated equipment is a function of time as well as instantaneous current, such checks err on the conservative side. Figure 6 shows a set of cut-off characteristic curves for a "family" of fuses. Each fuse has a curve consisting of two parts (normally drawn as two straight lines). The line to the left is common to all fuses and represents the maximum peak current of a fully asymmetrical prospective current (having a peak current of approximately 2,5 times the r.m.s. current at a typical power factor for 50 Hz and a ratio of 2,6 for 60 Hz). The second part of the curve (at a shallower angle) represents the current limitation produced by the CL fuse. The "knee" where the two curves join, represents the lowest current for which a particular fuse can achieve some current limitation.

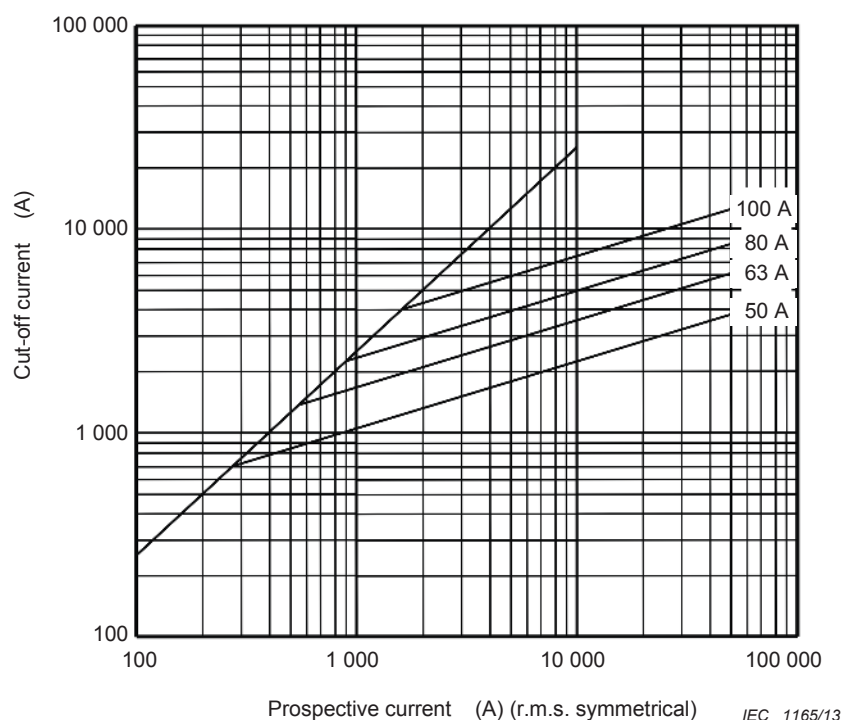


Figure 6 – Typical cut-off characteristics

4.2.4.4 Joule-integral (I^2t) characteristics

Joule-integral, or more commonly " I^2t " (which is more correctly $\int i^2 dt$) is an indication of the energy allowed through the fuse into the protected circuit under fault conditions. The energy released into a failure that results in an arc is the product of I^2t and the arc impedance. Because, for a given fuse, over a reasonable range of currents, I^2t tends to a somewhat constant value it is a helpful concept for co-ordination between the fuse and other protective devices in the zone of short operating times where the time of arcing becomes a significant factor. A manufacturer is required to publish two values "minimum pre-arcing (melting) I^2t " which represents the smallest I^2t to melt the fuse (at the maximum breaking current and with minimum manufacturing tolerances) and "maximum operating I^2t ", the highest I^2t likely to be

experienced in service at any current that causes a current-limiting action. It can occur at any current up to the rated maximum breaking current of the fuse, depending on the fuse design. Operating I^2t is the sum of pre-arcing I^2t and arcing I^2t (arcing I^2t being that which "flows" during the time when the fuse is arcing). In some literature, other terms that have been used for maximum operating I^2t include "maximum clearing I^2t ", "total I^2t value", maximum total I^2t , and "maximum let-through I^2t ". The presentation of I^2t values may be in simple tabular or diagrammatic form (for example, histograms) or may employ graphical presentation with prospective current as abscissa and I^2t as ordinate, both scales being logarithmic.

The value of operating I^2t is affected by circuit conditions such as power factor and in particular by the applied voltage. In service, the values of operating I^2t will usually be less than those indicated in the published data, which are based upon the most severe test conditions.

4.2.4.5 Switching voltage (peak overvoltage, peak arc voltage) characteristics

The short-duration spike of overvoltage produced during the operation of a fuse at high fault currents is made up of two components, one due to the instantaneous value of the supply voltage, the other due to the rate of change of current in the circuit inductance as the current is abruptly reduced to zero. The value of the switching or "peak arc" voltage is thus dependant on both supply voltage AND prospective fault current and power factor. Limiting values of switching voltage are set by all relevant fuse standards and are generally kept below these values by fuse manufacturers.

The significance of any fuse design exceeding the proscribed limits would be in terms of possible external insulation breakdown or even flashover during fuse operation and arrester failure (see 5.1.4.4).

Since switching voltage falls, to some extent, with supply voltage, it is often possible to use a fuse of given voltage rating in a system having a lower voltage without exceeding the specified switching limits for a fuse at that voltage, or incurring any danger of insulation breakdown. The manufacturer should be able to provide guidance as to the switching voltage reduction with reduced supply voltage.

Small rating fuses, which often use wire fuse elements, tend to produce higher switching voltages, but of a very short duration. Due to this short duration, fuse standards permit higher values to be developed with low current ratings (less than or equal to 12 A or 3,15 A depending on the voltage series used for testing). Voltages produced by wire elements are less affected by a reduction in system voltage than strip elements.

4.2.4.6 Power dissipation

A high voltage fuse produces an appreciable amount of heat in service. Example, a 100 A 12 kV fuse may generate 100 watts or more when carrying its rated current. This heat has to be effectively dissipated into the surroundings if the fuse is not to deteriorate. In the case of totally-enclosed switchgear, the heat produced by the fuse may be a serious limiting factor on the current rating of the equipment protected.

Fortunately, it is unusual for high voltage fuses to be run at their full rated current because of other factors such as transient current withstand, e.g. transformer inrush or motor starts. Manufacturers normally supply data on power dissipation ("watts loss") at rated current. In general, fuses of lowest power dissipation are to be preferred. Such fuses will require less derating when used in enclosed environments and will waste less energy.

The method of measuring power loss in a high voltage fuse, for most practical purposes, is to multiply the volt-drop across the fuse by the current through the fuse (see Annex A).

4.2.4.7 Cyclic and transient load withstand

Fuses are required to withstand permissible transient pulses of overcurrent such as those due to transformer magnetising inrush, capacitor charging current, or the starting current of motor loads. Withstand has to be proved during design by extensive tests, from which graphs, tables or formulae are derived to enable the user to choose a fuse which will withstand the value, duration, and frequency of repetition of expected surge currents. It should be noted that if a transient current exceeds these acceptable limits, one or more fuse elements may be locally damaged. This can result in a fuse having its characteristics changed such that it could melt at a current that it is not capable of interrupting. The use of larger current rating fuses can relieve this concern, but it must be borne in mind that the protection provided by the fuse may then be reduced.

4.2.4.8 Fuse striker characteristics

In many applications, the striker has the important task of initiating operation of associated switching devices permitting the use of Back-Up fuses with low fault current conditions and providing three-phase interruption with a single fuse striker operation (see 5.2.7). Therefore, the fuse striker is available in several versions. Medium type spring-operated strikers, have a travel of at least 20 mm and an energy output of 0,5 J or greater. Graphs of striker characteristics are usually available showing the striker force, in Newtons, versus the length of striker travel. Spring driven striker pins have a continuing force that is proportional to the travel and spring rate of the spring.

Pyrotechnically operated strikers (heavy type) that utilise a small explosive charge to eject the striker pin have a minimum travel of 10 mm and energy output greater than one joule. Since this type of striker is a ballistic device (kicked rather than pushed as with a spring operated type) it is not possible to provide meaningful force/travel characteristic, but it is possible to measure the energy provided by the striker, allowing comparison with the energy needed to trip a device, such as a switch, that is to be initiated by the fuse.

4.3 Expulsion fuses

4.3.1 General operating principles

There are many types of expulsion fuse, but their primary characteristic is that they are vented devices in which, after their fuse element melts and arcs, 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. Another common characteristic is that they are essentially non-current-limiting. They are characterized by a relatively low arc voltage and so do not significantly reduce the value of the first peak of a fault current. They also, therefore, extinguish current at a natural current zero, when the proper dielectric conditions have been established. This is illustrated in Figure 2b). Therefore, anything that increases the magnitude of the first major loop of an asymmetrical fault current makes interruption harder. Since the magnitude of this first major loop is a function of available fault current, the power factor (or X/R ratio) of the system, and the degree of asymmetry of the current, these fuse types are sensitive to low power factor (high X/R ratio) fault circuits (more so than are current-limiting fuses).

In addition to being sensitive to power factor, expulsion and other types of non-current-limiting fuses are sensitive to TRV (see 4.2.1.2 for an explanation of TRV). They do not significantly change the phase of the current relative to the circuit voltage, so at low power factor values the normal current zero occurs near the time of a system voltage crest. Upon reaching a current zero, they must be capable of dielectric recovery at a rate, and to a magnitude, greater than the TRV characteristic of the system. The TRV typically involves an overshoot of up to twice the power frequency voltage. If the recovery conditions are not met at the first current zero after melting, the device will conduct additional loops of current until interruption is achieved. At high currents, that produce melting in one or two cycles, this must occur in only a few loops or the fuse will not be able to interrupt. While, unlike current-limiting fuses (see 4.2.1.2), expulsion fuses are not particularly sensitive to the system voltage during a loop of arcing, they are very sensitive to the recovery voltage after a current zero. Therefore,

like current-limiting fuses, they should never be used at a voltage higher than their rated voltage (see 5.1.3.2).

Because of their typical applications, expulsion and other types of non-current-limiting fuses have been designed to interrupt any current from the overload current at which the fuse element melts up to their maximum fault rating. This, as has been seen, is not necessarily true for all types of current-limiting fuses.

In common with all fuses, expulsion fuse elements have a defined melting characteristic. However, because their fuse elements are relatively short, and the interrupting process relatively independent of the fuse element size and construction, it is possible for a single expulsion fuse to be available with many different pre-arcing time-current characteristics. Thus, for example, a distribution fuse-cutout may accept, and be compatible with, a number of fuse-links that have different curve shapes (see 4.3.5) but the same current rating.

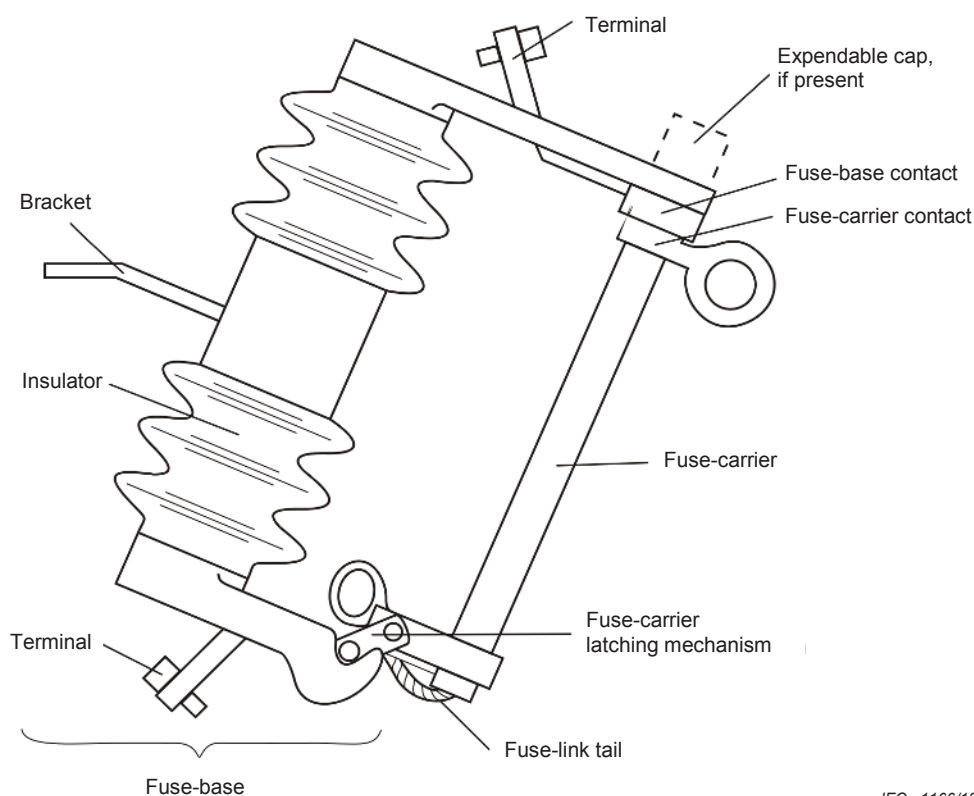
IEC standards recognize two classes of expulsion fuse Class A and B (see 4.3.3), which are similar to fuses recognized by other standards around the world. In theory, all types of non-current-limiting device can be tested to IEC 60282-2:2008, even if it would result in a very low rated maximum breaking current being assigned to them. However some common types of expulsion fuse are used where power factor and TRV values are less severe than called for in IEC standards, and so they may be tested to less onerous conditions either specified in a recognized standard (e.g. open-link cutouts in IEEE Std C37.41 [6]) or to no recognized standard. As they are similar to, or commonly used with, other types of fuse that are covered by standards, the most common types will be described in this document.

4.3.2 Construction and operation of expulsion fuses

4.3.2.1 Class "A" expulsion fuses

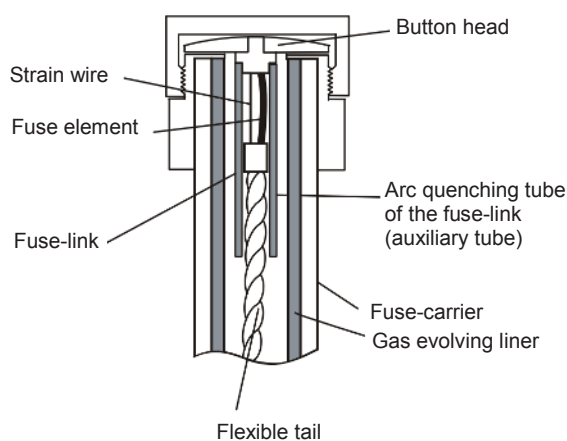
4.3.2.1.1 Distribution fuse-cutouts

The most common type of "Class A" expulsion fuses are termed distribution fuse-cutouts. Indeed, in most countries, they are the most widely used type of outdoor fuse. Figure 7a shows the components of a typical distribution fuse-cutout. The fuse-base (support) consists of an insulator, traditionally made of ceramic, but increasingly of "non-ceramic" (i.e. polymer-based) material. A bracket, in its middle, supports it on a cross-arm, attached to a power pole. Terminals and contacts at the top and bottom are attached to the circuit and make electrical contact with a pivoted fuse-carrier. The fuse-carrier includes a tube lined with gas-evolving material, which contains the fuse element, typically mounted in a replaceable fuse-link.



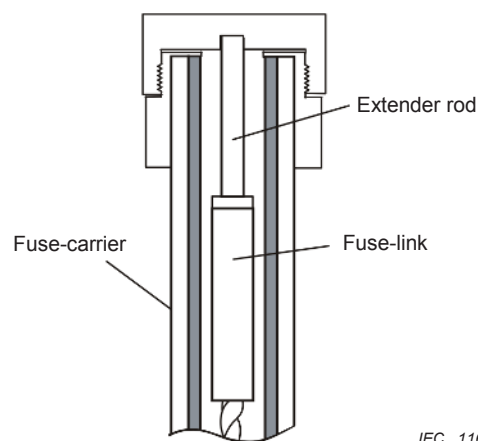
IEC 1166/13

7a) Distribution fuse-cutout components



IEC 1167/13

7b) Typical fuse-link arrangement



IEC 1168/13

7c) Fuse-carrier with extender rod

Figure 7 – Distribution fuse-cutout construction

Figure 7b) shows a typical fuse-link construction, mounted in a carrier, in which a small gas-evolving tube (termed arc quenching tube or auxiliary tube) surrounds the fuse element. The fuse element in this type of fuse is normally quite short (e.g. 30 mm) and is attached to a contact at the top of the fuse-link, and a flexible cable ("tail" or "leader") at the bottom. A strain wire in parallel with the fuse element permits the link to be mounted under mechanical tension. The flexible cable is attached to a contact at the bottom of the fuse-carrier, holding in place a latching mechanism that releases when the fuse element melts, enabling the fuse-carrier to swing open after current interruption. This provides an isolating distance (making it

a "drop-out" fuse) and also visual indication of fuse operation. The current rating and melting characteristics of the fuse are governed mainly by the design of the replaceable link.

When the fuse element (and strain wire) melt in response to an overcurrent, the resulting arc is only moderately confined and burns in the fuse carrier bore of gas evolving ("arc-quenching") material. This material was traditionally made of fibre, but now tends to be made from a polymer material. When the fuse element melts with a low current, the arc burns only in the auxiliary tube, while at higher currents, this tube bursts and the fuse-carrier lining supplies the expulsion gasses. The liner is ablated by the arc and will give off gases, such as hydrogen and various hydrocarbons. This protects the tube wall from excessive erosion, while the arc burns stably with temperatures in the centre as high as 20 000 °C. These gases expel the metal vapour and the flexible tail out of the fuse tube. The movement of the flexible tail increases the arc length to that of the fuse carrier and is very beneficial to the dielectric recovery that occurs at a natural current zero. The gas produced is proportional to the heat released by the arc energy. The gas flow effectively cools and deionises the arc gap at current zero and allows the gap to withstand the TRV. This results in interruption of current flow in the circuit. Expulsion fuses, under some conditions, expel solid materials at high velocities upon fault current interruption. This should be considered in the mounting location of the device.

Some designs employ an expendable cap (Figure 7a)) at the top of the tube. At high fault currents it opens to relieve pressure and allow expulsion gasses to escape from both ends of the tube. Expulsion fuses that expel gas during operation from both ends of the carrier tube are known as "double venting types". This is one of the techniques that have been used to achieve higher rated maximum breaking currents for cutouts. An older design of distribution fuse-cutout uses a fuse-carrier permanently open at both ends.

Another technique that has been used to increase the maximum breaking current of a cutout is termed an extender rod or arc shortening rod. This is a conductive rod attached to the top contact of the fuse-carrier and the top of the fuse-link. Its effect is to move the fuse element further down the fuse-carrier, so that arcing commences closer to the open end of the tube. This reduces the pressure in the fuse holder. The technique is illustrated in Figure 7c). Making the fuse-carrier tube stronger, e.g. by using a filament wound glass epoxy construction, also assists in achieving a higher breaking current. Manufacturers will therefore often have several models of fuse-carrier, each having a different rated maximum breaking current suitable for different locations in a power system. An advantage of "single-venting" types is that there is no emission of ionised gas in an upward direction which could impinge on adjacent overhead lines.

4.3.2.1.2 Open-Link Cutouts

Open-link cutouts (see Figure 8a)) do not employ a fuse carrier, but rather suspend an open-link fuse-link between fuse clips. The fuse-link contains all the parts for extinguishing the arc. The clips include a spring action to tension the fuse-link. They operate in a similar manner to distribution fuse-cutouts described in 4.3.2.1.1, but typically have a relatively low interrupting capability, and are often used in conjunction with a Back-Up current-limiting fuse. Their use is declining. Despite being defined in IEC 60282-2:2008, they are not normally available tested to this standard but rather to a lighter duty (e.g. that specified for open-link cutouts in IEEE C37.41 [6]).

4.3.2.1.3 Enclosed fuse-cutouts

An enclosed cutout (see Figure 8b)) is similar to a distribution fuse-cutout, but has all of the live parts enclosed in a housing (usually made of porcelain). A hinged "door" supports the fuse-carrier. They may be of a drop-out design but commonly are not, this feature often being selectable by the user. They operate in a similar manner to distribution fuse-cutouts described in 4.3.2.1.1.

4.3.2.1.4 Capacitor fuses

A common type of capacitor expulsion fuse uses a fuse carrier mounted to a bus bar. A spring "arm" attached to a capacitor insulator connects to the fuse-link flexible tail, keeping it in tension. Operating principles are similar to those described in 4.3.2.1.1.

4.3.2.1.5 Liquid-submerged expulsion fuses

These are expulsion fuses in which arc extinction is effected by having the melting fuse elements immersed in an arc quenching liquid. They are very common in many parts of the world, mounted submerged in an insulating liquid (traditionally oil) in transformers or switchgear. They employ a strong, small diameter, tube with a fuse element suspended between terminals at each end. The tube is open to, and filled with, the surrounding liquid. Various names have been used for these fuses, including "cartridge" and "weak-link" fuses, but they are referred to as "liquid-submerged expulsion fuses" in IEEE Std C37.41 [6]. They operate on a similar principle to distribution fuse-cutouts (described in 4.3.2.1.1), except that insulating liquid (usually oil) is used as the dielectric medium. After the fuse element melts, the resulting arc heats, vaporizes, and dissociates the liquid. The gas and arc products vent from one or both ends of the fuse into a bulk tank containing the fuse and, typically, other components under the liquid. The deionising effect of the gas permits current flow to cease when appropriate dielectric conditions are met at a natural current zero. In many cases, the gas produced from the liquid is sufficient to complete the interruption process. At higher currents, the fuse tube wall also supplies gas to facilitate the interruption process. They have a very limited maximum breaking current.

A variation of this type of fuse positions the fuse-link in a fuse-carrier at the end of a draw-out rod, suspended in a supporting housing containing electrical contacts, as shown in Figure 8C. The assembly is mounted at an angle, so that the fuse-link is submerged while the top of the draw-out rod is above the liquid. After operation the fuse-carrier can be withdrawn from the liquid, and the fuse-link replaced. This type of fuse is commonly known as a "bayonet fuse".

Liquid-submerged expulsion fuses may be used alone for light duty applications, or in conjunction with current-limiting fuses where circuit conditions are more severe. Therefore, many types have been tested to conditions less onerous than the "Class A" requirements of IEC 60282-2. IEEE Std C37.41 [6] recognizes specific testing requirements for this type of fuse when used in switchgear applications, where they are referred to as "liquid-submerged expulsion fuses". While test conditions are similar to Class A fuses in IEC 60282-2, fewer test series are required due to their generally limited maximum breaking current.

4.3.2.1.6 Liquid fuses

Another type of non-current-limiting fuse that surrounds the fuse element with liquid are called "liquid fuses" or sometimes "liquid power fuses" and are for outdoor use only. They usually consists of a glass tube sealed with ferrules at each end. The tube is filled with an arc extinguishing liquid, usually tetrachloroethylene and/or trichloroethylene. A short fuse element, usually a wire or notched strip, is connected to one end of the fuse. The fuse element is held in tension by a spring. A flexible lead connects the fuse element to the lower ferrule. These fuses operate in a similar manner to liquid-immersed expulsion fuses described in 4.3.2.1.5, except that no ablative tube is present to assist the interruption process at higher currents. However, when the fuse element melts, the spring draws the arc through the liquid increasing its length. To relieve the tube of excessive pressure, the fuse is fitted with a diaphragm at the upper end, which is ejected for all but the most modest of faults. They have a very limited maximum breaking current, and are tending to be replaced by more modern types of fuse.

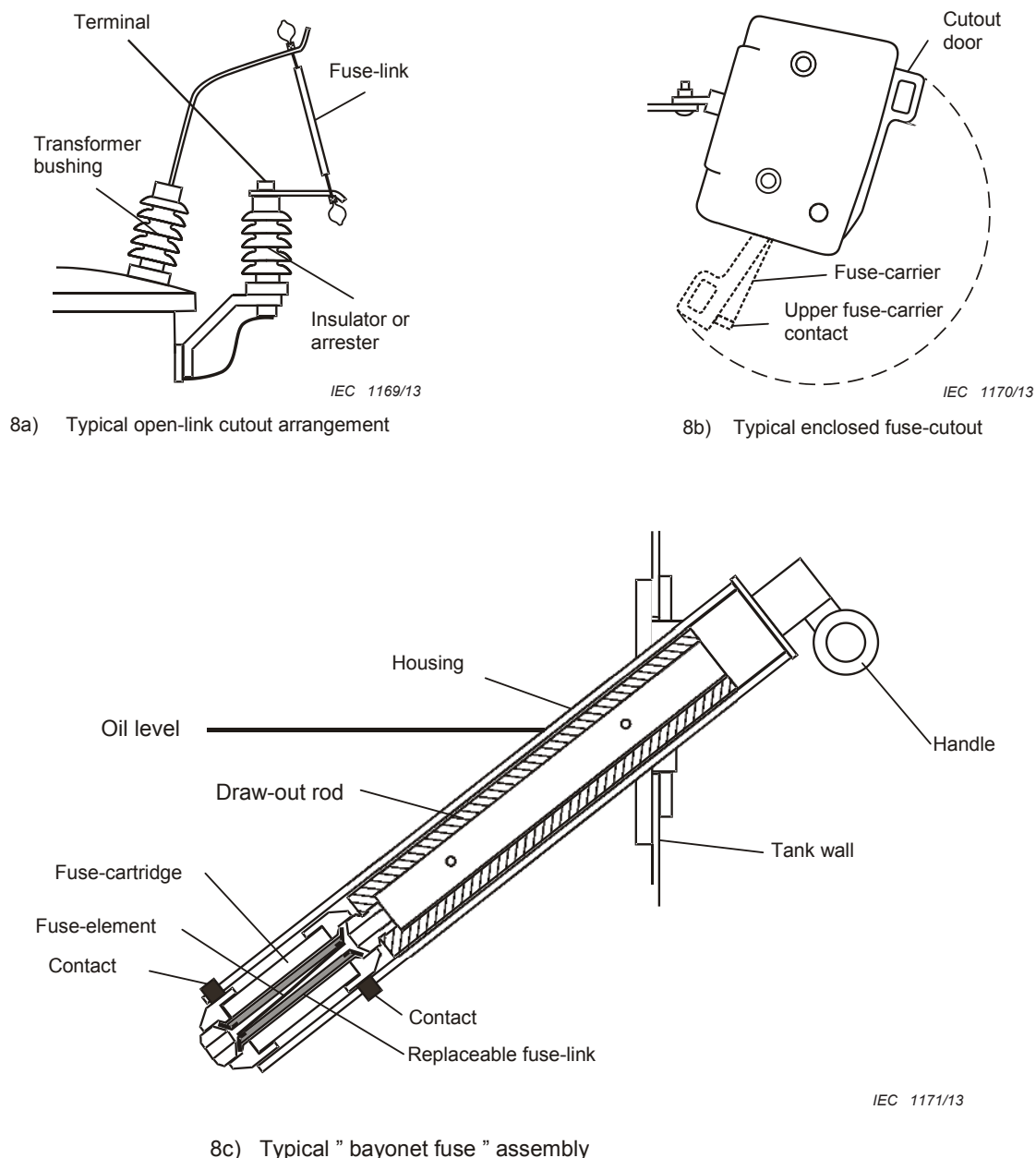


Figure 8 – Types of expulsion fuse

4.3.2.2 Class "B" expulsion fuses

These are commonly known as power-class expulsion fuses or boric-acid power fuses. The most common type, shown in Figure 9a), are expulsion fuses in which arc interruption is effected by use of a boric acid liner to the fuse-carrier tube. This gives them a higher interrupting capability, under more onerous circuit conditions, than Class A expulsion fuses. In addition, since water vapour is the primary gas produced during the interruption process, some power-class expulsion fuses can be provided with an exhaust-control device to condense the water vapour and virtually eliminate the effect of these gases. This allows their use indoors and in enclosures, in addition to outdoors. Some exhaust control devices do not require a reduction in the fuse's interrupting rating.

While in external appearance, Class B expulsion fuses can be similar to distribution fuse-cutouts described in 4.3.2.1.1, they employ a more complex internal structure, as shown in the simplified cutaway view of a typical fuse-carrier in Figure 9b). This includes a main fuse

for high-current interruption and, in some designs (not shown), a smaller, parallel, bore for low current interruption. They employ a rather short fuse element. Typically, the lower end of this fuse element is fixed within the carrier while the other end is connected to an arcing rod that is attached to a compressed spring. A strain wire usually parallels the fuse element to hold the arcing rod in place. When the fuse element melts (immediately followed by the strain wire), the arcing rod draws the arc through the boric acid block. This increases the arc length and length of boric acid exposed to the arc. Gasses produced by the arc are primarily water vapour, which cools the arc and produces a deionising effect. This effect is such that, at a natural current zero, the dielectric withstand of the arc gap is sufficient to withstand any transient and power frequency recovery voltage.

Boric-acid fuses typically use a replaceable refill unit, which contains the fuse element and associated parts necessary to restore a fuse to its original condition after an operation. Class B fuses can be drop-out fuses, like distribution fuse-cutouts, or remain in the fuse clips after operation like most current-limiting fuses.

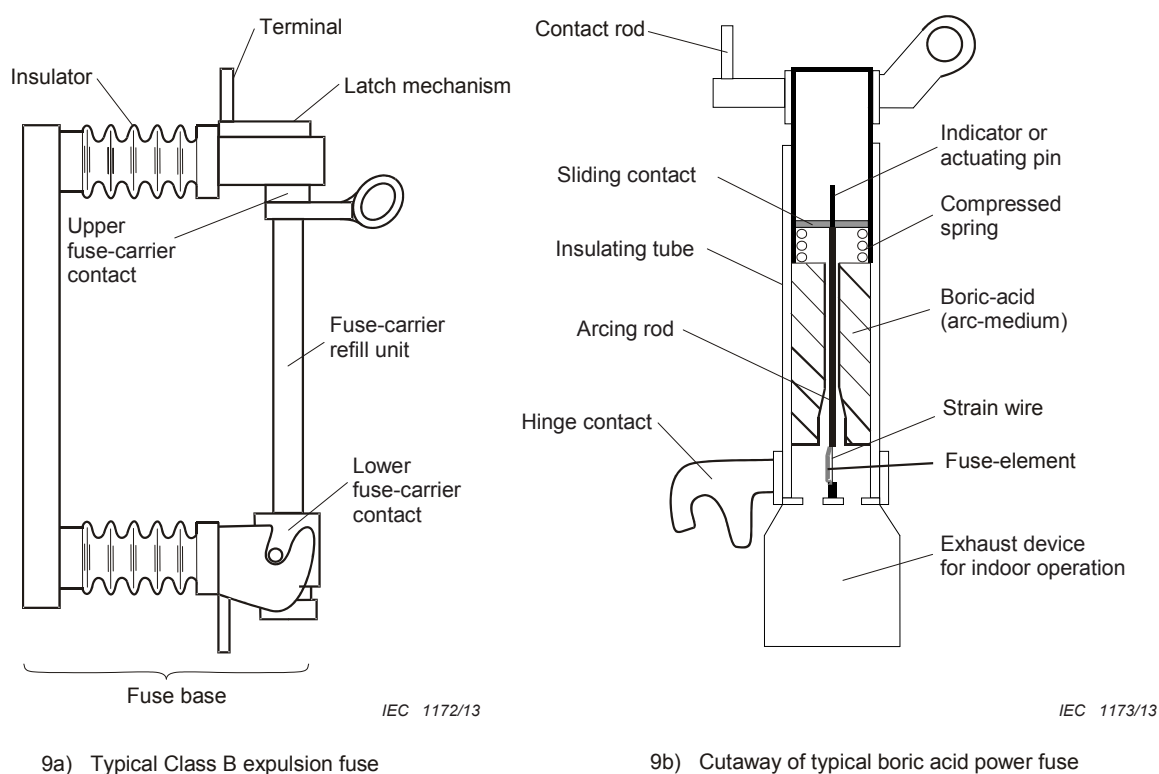


Figure 9 – Class B expulsion fuse

4.3.2.3 Application considerations

A consideration in the application of expulsion fuses is the criteria that the gases expelled are properly directed, and that the noise and pressure created is acceptable. Manufacturers' recommendations for the use of expulsion type fuses should be followed.

Distribution fuse-cutouts, or other types of fuses fitted with removable fuse-links, fuse-holders, or fuse carriers, have no inherent load-break ability when manually opened unless they are fitted, or used, with load-break means. There are three common ways to effect load breaking with such devices. The first is to use a separate load-break device, mounted on the switch-stick used to open the fuse. In this case no modification to the fuse is needed. The second way is to have a load-break mechanism, mounted to the fuse-base. Upon opening the fuse, the load current is initially carried by the separate device, which then effects the current

interruption, often by a spring-loaded contact and gas evolving materials. A third way is to use a link-break mechanism. In this case, the fuse-link of the cutout is broken by a mechanical means, and current interruption is achieved through the usual fuse arc interruption process. It should be noted that some fuse-links use a coiled silver fuse element that may be too long to be broken by this means. Where, as is common, no such load breaking means is employed, then even for very light loads, it cannot be guaranteed that the cutout, when opened, will clear the circuit without damage. In this case the line should be disconnected, upstream of the device, before manual operation.

4.3.3 Classification of expulsion fuses

When selecting the Class and type of fuse that should be used at a particular location, 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. As a general guide the following may be considered.

- Class A (termed "Distribution Class" in IEEE standards)

These fuses are generally applicable for the protection of small transformers and small capacitor banks used for power-factor correction or voltage control, located on power distribution systems of open-line type or cable type, and remotely placed from major substations. They are also applicable as protective devices at sectionalising points on such systems. TRV conditions are described by TRV test parameters, having lower values of u_c and longer values of t_3 than those for Class B fuses. They are generally used in single-phase applications, but are suitable for use in three phase applications where the high capabilities of the Class B (power) fuse are not required and other application requirements are met.

- Class B (termed "Power Class" in IEEE standards)

These fuses are generally applicable to protect similar equipment as Class A fuses but in closer proximity to a major supplying substation and feeder circuits leaving such substations. TRV conditions are more severe than those for Class A fuse applications, and therefore have more severe TRV test parameters specified. They are more likely to be used in three-phase applications and in substations, cabinets or vaults where a large amount of electrical power is being supplied to a distribution system or some facility that requires large quantities of energy. They are generally used in that part of a system where high dielectric properties are required for all equipment. Alternatively, they may be used in single-phase applications in an area where distribution fuses would normally be used, but where severe faults, high X/R , or severe TRV is anticipated.

4.3.4 Ratings of expulsion fuses

4.3.4.1 Rated current

The rated current of an expulsion fuse is equal to the rated current of the fuse-link or refill-unit used. The rated current assigned to a fuse-link is the maximum current that a new fuse-link will carry continuously, without exceeding specified temperatures and temperature rises, when mounted on a fuse-base and, if applicable, within a fuse-carrier specified by the manufacturer, at ambient temperature of not more than 40 °C or as specified by the manufacturer. At surrounding temperatures higher than the specified temperature, surrounding temperature adjustment factors are usually available from the manufacturer (see 5.1.1.3).

4.3.4.2 Rated Voltage

System voltages vary greatly; however, one of the standard fuse voltages should be suitable. In all cases a rated fuse voltage equal to or higher than the maximum voltage impressed across the fuse during its operation should be chosen. In general it can be stated that a fuse rated voltage must be higher than the maximum system voltage measured phase-to-phase (line-to-line), in the case of three-phase circuits, and phase-to-neutral (line-to-neutral), in the case of single-phase circuits. However, in certain locations, operating experience has led to the use of fuses having a rated voltage at least equal to the phase-to-neutral voltage in certain three phase applications (generally those having a solidly earthed neutral).

recognized, however, that special conditions, and assumptions, must be valid to permit this, and additional testing by the fuse manufacturer may be required. In some cases fuses are tested with the intention that they will only be used in three-phase circuits. When such devices are used in single-phase circuits, special fuse voltage selection considerations apply (see 5.1.3.2).

In general, expulsion fuses can be used at any voltage lower than their rated voltage without adverse consequences.

4.3.4.3 Rated maximum breaking current (rated maximum interrupting current)

The rated maximum breaking current assigned to a fuse and a fuse-carrier is the maximum breaking current (in amperes r.m.s. symmetrical) specified when tested in accordance with the appropriate standard (test duty 1 or I_1). It is the highest current that the fuse has been demonstrated to be capable of interrupting under specified conditions of frequency, a.c. current component, TRV, power frequency recovery voltage and power factor (or X/R).

The specified power factors are generally more severe than those experienced on actual power systems. For the rare cases where the system power factor is less than that specified in the testing of the fuse, reduction of the interrupting rating may be necessary. The fuse manufacturer should be consulted.

In many applications, the available fault current is within the maximum breaking current of a single expulsion fuse. In some applications, particularly where Class A fuses are being used, the available fault current may be higher than the maximum breaking current of a single fuse. In this case it is quite common to add a current-limiting fuse in series to interrupt currents higher than the expulsion fuse's rated maximum breaking current. The expulsion fuse is then used for clearing the low fault currents below the Back-Up fuse's minimum breaking current. Coordination of these two devices is covered in 5.1.4.2.4 and 5.2.2.4.

Since Class B 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.

4.3.4.4 Rated frequency

Standardized values of rated frequency are 50 Hz, 50/60 Hz and 60 Hz. Tests are performed at a frequency between 48 Hz and 52 Hz for fuses rated 50 Hz and 50/60 Hz, and between 58 Hz and 62 Hz for fuses rated 60 Hz. They may be used in circuits having a frequency between 48 Hz and 62 Hz for fuses rated 50 Hz and 50/60 Hz, and between 58 Hz and 62 Hz for fuses rated 60 Hz. Expulsion fuses are therefore suitable for use at higher frequencies than they are rated, but not lower frequencies. This is because expulsion fuses are sensitive to the I^2t flowing before a current zero is reached. The I^2t of the first loop of a fully asymmetrical current waveform, having the same r.m.s. symmetrical current value, is 20 % higher for 50 Hz than for 60 Hz.

4.3.5 Characteristics of expulsion fuses

Expulsion fuse manufacturers supply two fuse operating characteristics. They are the fuse's pre-arcing (melting) Time-Current Characteristic (TCC) curve and the operating (total clearing) TCC curve.

For coordination studies (see 5.1 and 5.2) a minimum pre-arcing curve is normally required. If only a nominal curve is available the minimum curve may usually be taken as 10 % less than the nominal curve (in terms of current) although for some fuse element types, a tolerance of 5 % is achieved. Consult the manufacturer for details. The operating time-current characteristic curve represents the maximum pre-arcing curve (nominal curve plus maximum tolerances) plus the arcing time of the fuse. This curve also is required to conduct coordination studies.