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TECHNICAL REPORT

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Low-voltage fuses –
Part 5: Guidance for the application of low-voltage fuses

IEC TR 60269-5:2014-03+AMD1:2020-12 CSV(en)

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Low-voltage fuses –
Part 5: Guidance for the application of low-voltage fuses

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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LOW-VOLTAGE FUSES –

Part 5: Guidance for the application of low-voltage fuses

FOREWORD

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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 60269-5 edition 2.1 contains the second edition (2014-03) [documents 32B/621A/DTR and 32B/624/RVC] and its amendment 1 (2020-12) [documents 32B/694/DTR and 32B/697A/RVDTR].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 60269-5, which is a technical report, has been prepared by subcommittee 32B: Low-voltage fuses, of IEC technical committee 32: Fuses.

This second edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) recommendations for fuse operations in high altitudes added
b) more details for operational voltages added
c) recommendations for photovoltaic system protection added
d) numerous details improved

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

A list of all parts of the IEC 60269 series, under the general title: *Low-voltage fuses*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Fuses protect many types of equipment and switchgear against the effects of over-current which can be dramatic:

– thermal damage of conductors or bus-bars;
– vaporisation of metal;
– ionisation of gases;
– arcing, fire, explosion,
– insulation damage.

Apart from being hazardous to personnel, significant economic losses can result from downtime and the repairs required to restore damaged equipment.

Modern fuses are common overcurrent protective devices in use today, and as such provide an excellent cost effective solution to eliminate or minimize the effects of overcurrent.

LOW-VOLTAGE FUSES –

Part 5: Guidance for the application of low-voltage fuses

1 Scope

This technical report, which serves as an application guide for low-voltage fuses, shows how current-limiting fuses are easy to apply to protect today's complex and sensitive electrical and electronic equipment. This guidance specifically covers low-voltage fuses up to 1 000 V a.c. and 1 500 V d.c. designed and manufactured in accordance with IEC 60269 series. This guidance provides important facts about as well as information on the application of fuses.

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 60050 (all parts), *International Electrotechnical Vocabulary*. Available from http://www.electropedia.org/

IEC/TR 60146-6, *Semiconductor convertors – Part 6: Application guide for the protection of semiconductor convertors against overcurrent by fuses*

IEC 60269 (all parts), *Low-voltage fuses*

IEC 60269-1:2006, *Low-voltage fuses - Part 1: General requirements*
IEC 60269-1:2006/AMD1:2009
IEC 60269-1:2006/AMD2:2014

IEC 60269-2, *Low-voltage fuses – Part 2: Supplementary requirements for fuses for use by authorized persons (fuses mainly for industrial application) – Examples of standardized systems of fuses A to K*

IEC 60269-3, *Low-voltage fuses – Part 3: Supplementary requirements for fuses for use by unskilled persons (fuses mainly for household or similar applications) – Examples of standardized systems of fuses A to F*

IEC 60269-4:~~2009~~, *Low-voltage fuses – Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices*

IEC 60269-6, *Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems*

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-4-43:2008, *Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent*

IEC 60364-5-52, *Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems*

IEC 60947 (all parts), *Low-voltage switchgear and controlgear*

IEC 60947-3:~~2008~~2015, *Low-voltage switchgear and controlgear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

IEC 60947-4-1:2009, *Low-voltage switchgear and controlgear – Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters*

IEC/TR 61912-1:2007, *Low-voltage switchgear and controlgear – Overcurrent protective devices – Part 1: Application of short-circuit ratings*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
switch (mechanical)
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions, which may include specified operating overload conditions and also carrying, for a specified time, currents under specified abnormal conditions such as those of short-circuits

Note 1 to entry: A switch may be capable of making but not breaking, short-circuit currents.

[SOURCE: IEC 60050-441:1984, 441-14-10]

3.2
disconnector
mechanical switching device that, in the open position, complies with the requirements specified for isolating function

Note 1 to entry: Some disconnectors may not be capable of switching load.

[SOURCE: IEC 60050-441:1984, 441-14-05, modified (modified definition and Note 1 to entry added)]

3.3
fuse-combination unit
combination of a mechanical switching device and one or more fuses in a composite unit, assembled by the manufacturer or in accordance with his instructions

[SOURCE: IEC 60050-441:1984, 441-14-04, modified (Note removed)]

3.4
switch-fuse
switch in which one or more poles have a fuse in series in a composite unit

[SOURCE: IEC 60050-441:1984, 441-14-14]

3.4.1
single-break and double-break
switch-fuse must be single break (it opens the circuit on one side of the fuse link) or double break (it opens the circuit on both sides of the fuse link)

3.5
fuse-switch
switch in which a fuse-link or a fuse-carrier with fuse-link forms the moving contact

[SOURCE: IEC 60050-441:1984, 441-14-17]

3.5.1
single-break and double-break
fuse-switch must be single break (it opens the circuit on one side of the fuse link) or double break (it opens the circuit on both sides of the fuse link)

3.6
Switching device SD
device designed to make or break the current in one or more electric circuits

Note 1 to entry: A switching device may perform one or both of these operations.

[SOURCE: IEC 60050-441:1984, 441-14-01, modified (Note 1 to entry added)]

3.7
short-circuit protective device SCPD
device intended to protect a circuit or parts of a circuit against short-circuits by interrupting them

3.8
overload protection
protection intended to operate in the event of overload on the protected section

[SOURCE: IEC 60050-448:1995, 448-14-31]

3.9
overload
operating conditions in an electrically undamaged circuit, which cause an over-current

[SOURCE: IEC 60050-441:1984, 441-11-08]

3.10
overcurrent
current exceeding the rated current

[SOURCE: IEC 60050-442:1998, 442-01-20]

3.11
rated conditional short-circuit current (of a switching device)
I_q
prospective current that a switching device, protected by a short-circuit protective device, can satisfactorily withstand for the operating time of that device under test conditions specified in the relevant product standard

3.12
selectivity of protection
ability of a protection to identify the faulty sections and/or phase(s) of a power system

Note 1 to entry: Whereas the terms “selectivity” and “discrimination” have a similar meaning according to the IEV definitions, this report prefers and uses the term “selectivity” to express the ability of one over-current device to operate in preference to another over-current device in series, over a given range of over-current. The effect of standing load current on selectivity in the overload zone is also considered.

[SOURCE: IEC 60050-448:1995, 448-11-06, modified (Note 1 to entry added)]

4 Fuse benefits

The current-limiting fuse provides complete protection against the effects of overcurrents by protecting both, electric circuits and their components. Fuses offer a combination of advantageous features, for example:

a) High breaking capacity (high current interrupting rating).

b) No need for complex short-circuit calculations.

c) Easy and inexpensive system expansion in case of increased fault currents.

d) High current limitation (low I^2t values).

e) Mandatory fault elimination before reenergizing.

Fuses cannot be reset, thus forcing the user to identify and correct the fault condition before re-energizing the circuit.

f) Reliability.

No moving parts to wear out or become contaminated by dust, oil or corrosion. Fuse replacement ensures protection is restored to its original level when the fuse is replaced.

g) Cost effective protection.

Compact size offers low cost overcurrent protection at high short-circuit levels.

h) ~~No damage for starters and contactors (type 2 protection according to IEC 60947-4-1).~~

~~By limiting short-circuit energy and peak currents to extremely low levels, fuses are particularly suitable for type 2 protection without damage to components in motor circuits.~~

Compact size offers economical overcurrent protections at high short-circuit levels

i) Safe, silent operation.

No emission of gas, flames, arcs or other materials when clearing the highest levels of short-circuit currents. In addition, the speed of operation at high short-circuit currents significantly limits the arc flash hazard at the fault location.

j) Easy coordination.

Standardized fuse characteristics and a high degree of current limitation ensure effective coordination between fuses and other devices.

k) Standardized performance.

Fuse-links designed and manufactured in accordance with IEC 60269 series ensure availability of replacements with standardized characteristics throughout the world.

l) Improved power quality.

Current-limiting fuses interrupt high fault currents in a few milliseconds, minimizing dips or sags in system supply voltage.

m) Tamperproof.

Once installed, fuses cannot be modified or adjusted thus preserving their level of performance and avoiding malfunction.

n) No maintenance.

Properly sized fuses require no maintenance, adjustments or recalibrations. They can remain in service providing originally designed overcurrent protection levels for many decades.

o) High level of energy efficiency.

The resistance and therefore the power dissipation of the fuse is very low compared with other protection devices. The magnitude of power loss compared to the power transmitted by rated current is much less than 0,1%.

p) Excellent personnel and equipment protection in case of arc flash.

q) Fuse-links will operate independent of the operation position of the fuse. The operation position is usually vertical. Other positions of use are permissible. The deratings of the manufacturers of the fuse must be observed.

Properly sized current limiting fuses operating in their current limiting range interrupt currents due to arcing fault in a few milliseconds, keeping arc energy well below hazardous and damaging levels.

5 Fuse construction and operation

5.1 Components

A fuse is a protective device comprising

- the fuse-link,
- the fuse-base,
- the fuse-carrier or replacement handle.

These components may be integrated in a fuse combination unit.

5.2 Fuse-construction

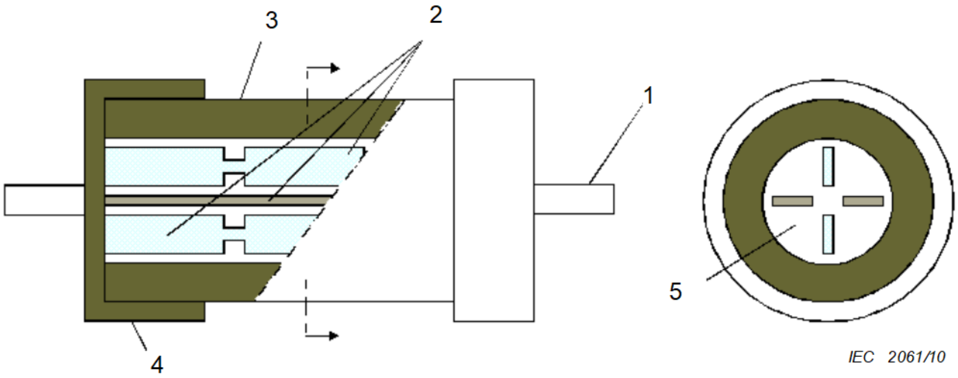
5.2.1 Fuse link

Figures 1 and 2 show the design of typical low-voltage fuse-links for industrial application. Such fuse-links are commonly called current-limiting or high breaking capacity fuse-links. Fuse-links according to IEC 60269-2 (fuses for industrial application) are available in current ratings up to 6 000 A.

Fuse-links according to IEC 60269-3 (fuses for household application) are available in current ratings up to 100 A.

The fuse-element is usually made of flat silver or copper with multiple restrictions in the cross-section~~, called notches~~. This restriction~~ (or notch) pattern~~ is an important feature of fuse design, normally achieved by precision stamping.

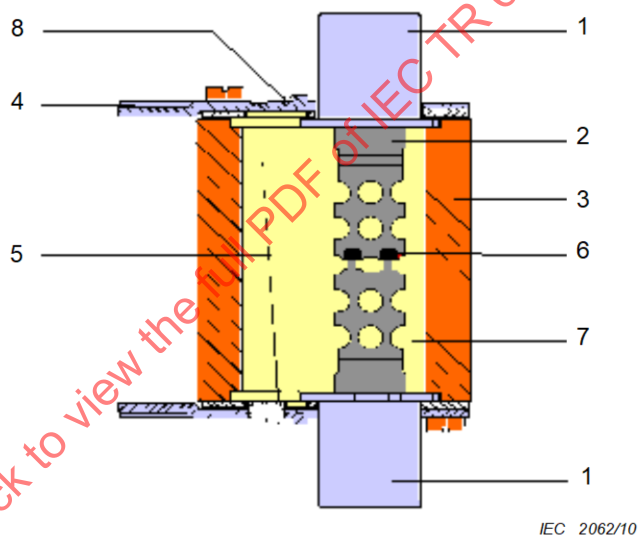
M-effect (see 5.3.3)~~ material~~ is sometimes added to the fuse-element to achieve controlled fuse operation in the overload range. The purity of the fuse-element materials and their precise physical dimensions are of vital importance for reliable fuse operation.



Key

1 Blade contact
2 Fuse-elements
3 Fuse body
4 End cap
5 Filler

Figure 1 – Typical fuse-link according to IEC 60269-2



Key

1 Blade contact
2 Fuse-element
3 Fuse body
4 Endplate (with gripping lug)
5 Indicator wire
6 M-effect material
7 Filler
8 Indicator

Figure 2 – Typical fuse-link according to IEC 60269-2

5.2.2 Fuse-link contacts

Fuse-link contacts provide electrical connection between the fuse-link and fuse-base or fuse carrier. The contacts are made of copper or copper alloys and are typically protected against the formation of non-conductive layers by plating.

5.2.3 Indicating device and striker

Some fuses are equipped with indicators or strikers for rapid recognition of fuse-link operation. Fuses equipped with strikers also provide means for mechanical actuation (e.g. for a switch of remote signalling) as well as a visual indication.

5.2.4 Fuse-base

The fuse-base is equipped with the matching contacts for accepting the fuse-link, connecting means for cables or busbars and the base insulator.

5.2.5 Replacement handles and fuse-holders

Replacement handles or fuse-carriers, where applicable, enable changing fuse-links in a live system under specified safety rules. They are made of insulating material and subjected to tests as required for safety tools. For some systems, fuse-carriers are an integral part of the fuse-holder, eliminating the need for an external replacement handle.

5.3 Fuse operation

5.3.1 General

Fuses are designed to operate under both short-circuit and overload conditions. Typically short-circuits are current levels at or above 10 times the fuse's rating, and overloads are current levels below 10 times the fuse's rating.

5.3.2 Fuse operation in case of short-circuit

During a short-circuit, the restrictions (notches) all melt simultaneously forming a series of arcs equal to the number of restrictions in the fuse element. The resulting arc voltage ensures rapid reduction in current and forces it to zero. This action is called "current limitation".

Fuse operation occurs in two stages (see Figures 3a and 3b):

- ~~the pre-arcing (melting) stage (t_m): the heating of the restrictions (notches) to the melting point and associated vaporization of the material;~~
- the arcing stage (t_a): the arcs begin at ~~each notch~~ restrictions and are then extinguished by the filler.
- M-effect (see 5.3.3) is sometimes added to the fuse-element to achieve controlled fuse operation in the overload range;

The operating time is the sum of the prearcing time and arcing time.

The energies generated by the current in the circuit to be protected during pre-arcing time and operating time are represented by the pre-arcing I^2t and operating I^2t values, respectively. The diagrams in Figure 3 illustrate the current-limiting ability of the fuse-link under short-circuit conditions.

Note that the fuse-link cut-off current i_c is well below the peak value of the prospective current I_P.

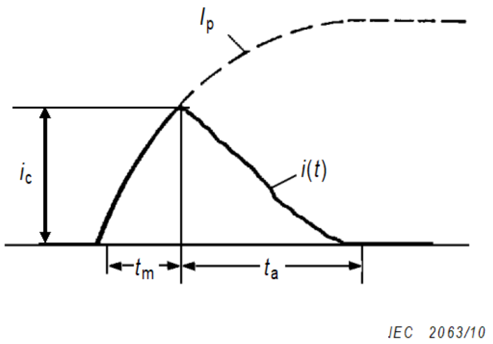


Figure 3a – DC current

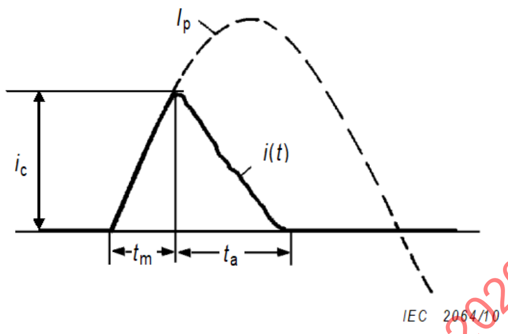


Figure 3b – AC current

Key

t_m pre-arcing time
t_a arcing time
I_p prospective current
i_c current limited by the fuse

Figure 3 – Current-limiting fuse operation

5.3.3 Fuse operation in case of overload

During an overload, the "M-effect" material melts and an arc forms between the two parts of the fuse element. The filler (typically clean granulated quartz) which surrounds the fuse element quickly extinguishes the arc forcing the current to zero. As it cools, the molten filler turns into a glass like material insulating each half of the fuse element from each other and preventing arc re-ignition and further current flow. Fuse operation still occurs in two stages (see Figures 4a and 4b):

- the pre-arcing (melting) stage (t_m): the heating of the fuse element to the melting point of the section containing the M-effect material. This period of time is typically longer than a few milliseconds and is inversely dependent on the magnitude of the overload current. Low level overloads result in long melting times from several seconds to several hours.
- the arcing stage (t_a): the arc initiated at the M-effect section is then extinguished by the filler. This time is dependent on the operating voltage
- Both stages make up the fuse operating time (t_m + t_a). The energy generated in the circuit ~~to be protected~~ by the overload current during pre-arcing (melting) time and operating time can still be represented by the pre-arcing I^2t and operating I^2t values, respectively; however under overload conditions the pre-arcing I^2t value is so high it provides little useful application data and the prearcing time is the preferred measure for times longer than a few cycles or few time constants. In this case, arcing time is negligible compared to the prearcing time.

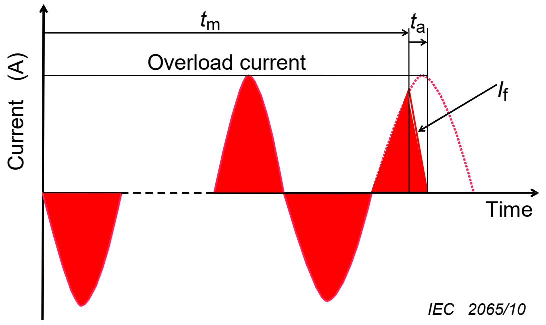


Figure 4a – AC current

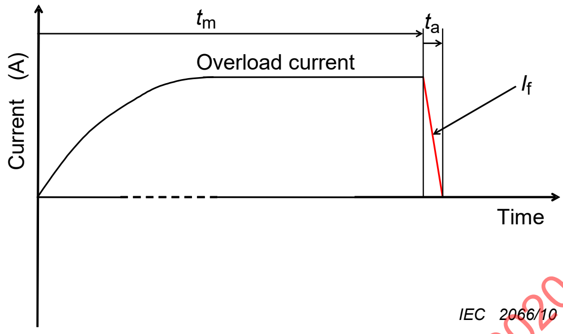
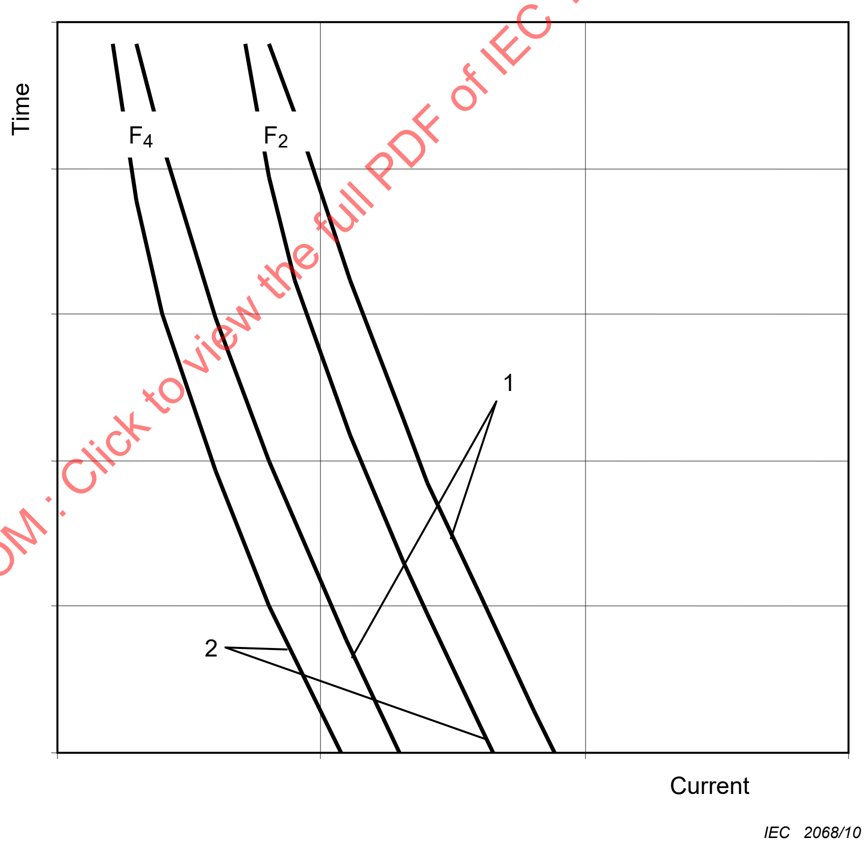


Figure 4b – DC current

Figure 4 – Fuse operation on overload

5.3.4 Fuse link pre-arcing time current characteristic:

The melting time of a fuse-link is therefore also termed the "pre-arcing" time. Fuse-links therefore have a very inverse time-current relationship (higher currents giving shorter pre-arcing times) as illustrated in Figure 5. This enables extremely short pre-arcing times at high currents, without limit. It is this apparently simple phenomenon that is primarily responsible for the universal success fuses have enjoyed for a very long time.



Key

1 Maximum operating time

2 Minimum pre-arcing time

Figure 5 – Time current characteristic for fuse-links

5.3.5 Fuse operation in altitudes exceeding 2 000 m

Low voltage fuse-links will carry rated current at altitudes of up to 2 000 m without any de-rating factor required. This is as stated in IEC 60269-1:~~2006~~2014, Subclause 3.2.

For the current carrying capacity of a fuse and the cable ~~is~~ to be influenced by the cooling effect of the surrounding air, the current carrying capacity is derated with ~~the~~ lower air pressure. This can be described by the following approximation:

Above 2 000 m a de-rating factor of 0,5 % for every 100 m above 2 000 m will be required, due to reduced convection of heat ~~away from the fuse-link with lower air density~~ and lower air pressure.

This can be described by the formula:

$$\frac{I}{I_n} = 1 - \frac{h - 2000}{100} \cdot \frac{0,5}{100}$$

I maximum current carrying capacity at altitude h

I_n rated current up to 2 000 m

h altitude in meters

Table 1 – Derating factors for different altitudes

Altitude *h* in m	Derating factor *I*/*I*n
2 000	1,000
2 500	0,975
3 000	0,950
3 500	0,925
4 000	0,900
4 500	0,875
5 000	0,850

6 Fuse-combination units

Fuse-combination units integrate both circuit protection provided by fuse-links and circuit switching provided by the switch in one unit. Fuse-combination units are ~~standardized in IEC 60947-3:2008, Table 2~~ shown in Table 2 (equivalent to Table 1 of IEC 60947-3:2008).

Two different types of fuse-combination units are available:

- switch-fuses, switch-disconnector-fuses are switches connected in series with the fuse-links and are usually operator independent devices with manual operation (snap action);
- fuse-disconnectors and fuse-switch-disconnectors which use the fuse-link itself to form the moving part are usually operator dependent devices with manual operation.

Definitions can be found in IEC 60947-3 or in IEC 60050-441. The main ones are shown here for easier reading and their full description can be found in Clause 3:

– switch (mechanical) (see 3.1);

– disconnector (see 3.2);

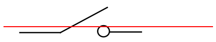
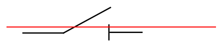
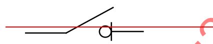
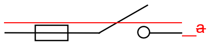
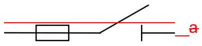
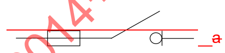
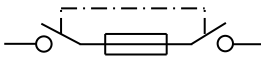
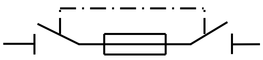
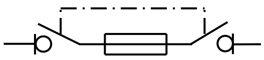
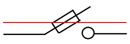
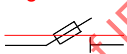
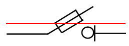
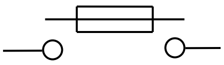
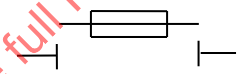
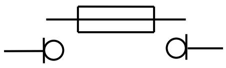
– fuse combination unit (see 3.3);

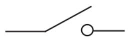
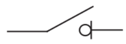
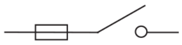
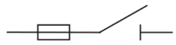
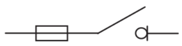
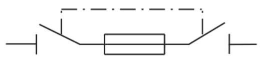
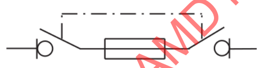
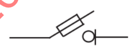
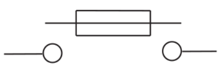
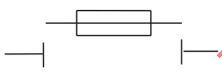
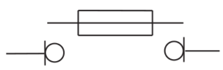
– switch-fuse (see 3.4);

– fuse-switch (see 3.5).

From these basic definitions, there are many variations of these devices as shown in Table 2.

Table 2 – Definitions and symbols of switches and fuse-combination units

~~Functions~~		
~~**Making and breaking current**~~	~~**Isolating**~~	~~**Making, breaking and isolating**~~
~~Switch~~ 	~~Disconnector~~ 	~~Switch-disconnector~~ 
~~Fuse-combination units~~		
~~Switch-fuse single break~~ 	~~Disconnector-fuse single break[b]~~ 	~~Switch-disconnector-fuse single break[b]~~ 
~~Switch-fuse double break~~ 	~~Disconnector-fuse double break[b]~~ 	~~Switch-disconnector-fuse double break[b]~~ 
~~Fuse-switch single break~~ 	~~Fuse-disconnector single break[b]~~ 	~~Fuse-switch-disconnector single break[b]~~ 
~~Fuse-switch double break~~ 	~~Fuse-disconnector double break[b]~~ 	~~Fuse-switch-disconnector double break[b]~~ 
~~Equipment shown as single break may be double break.~~ ~~NOTE Symbols are based on IEC 60617-7.~~		
~~[a] The fuse may be on either side of the contacts of the equipment or in a stationary position between these contacts.~~ ~~[b] Disconnection between line and load terminals only is verified by test.~~		

Functions		
Making and breaking current	**Isolating**	**Making, breaking and isolating**
Switch 	Disconnector 	Switch-disconnector 
Fuse-combination units		
Switch-fuse single opening[a] 	Disconnector-fuse single opening[a] 	Switch-disconnector-fuse single opening[a] 
Switch-fuse double opening[b] 	Disconnector-fuse double opening 	Switch-disconnector-fuse double opening[b] 
Fuse-switch single opening[a] 	Fuse-disconnector single opening[a] 	Fuse-switch-disconnector single opening[a] 
Fuse-switch double opening[b] 	Fuse-disconnector double opening 	Fuse-switch-disconnector double opening[b] 
NOTE 1 Equipment shown as single opening may comprise multiple openings in series NOTE 2 The symbols do not govern the design of switches, disconnectors and fuse-combination units (Fuse-switches, fuse-disconnectors)		
[a] The fuse may be on either side of the contacts of the equipment. [b] Depending on the design, breaking may take place on one or both sides of the fuse-link.		

The note to the definition of the switch, i.e. stating that a switch may be capable of making but not breaking, short-circuit currents, very clearly shows that a switch to IEC 60947-3 does not provide short-circuit breaking capacity. In the case of a fuse-combination unit the fuse takes over the breaking function.

Since most of the fuse-combination units with the fuse as an integral unit are designed as fuse-switch disconnectors, or switch-disconnector-fuses, they may be used for

- switching under load,
- isolation,
- short-circuit protection.

~~The fuse(s) fitted to a fuse combination switch also protect the switch itself against the effects of overcurrent.~~

The fuse(s) fitted to a fuse-combination unit or fuse-combination switch also protect the unit or the switch itself against the effects of overcurrent.

7 Fuse selection and markings

To select the proper fuse the nature of the equipment to be protected and the power that has to be interrupted, must be considered. With respect to power supply, the following parameters shall be defined:

– system voltage (operational voltage);

– frequency (for d.c. applications, see Clause 17);
– prospective short-circuit current;
– full load current (operational current).

Current limiting fuse-links are designed with very high rated breaking capacity. They are usually much higher than the minimum values specified in IEC 60269-2 and IEC 60269-3. Fuse-links are available with rated breaking capacities that cover the highest prospective current levels, that are met in service (e.g. up to 200 kA).

NOTE 1 Fuse-links can be safely applied at lower values than the rated breaking capacity.

Fuse selection for a specific application involves consideration of the time-current characteristics and breaking range. The time-current characteristics determine the field of application, while the breaking range indicates whether fuses are to be used together with additional overcurrent protection devices.

"Full range" means that the fuse can break any current able to melt the fuse-element up to the rated breaking capacity. Full range fuses can be used as stand-alone protection devices.

"Partial range", or back-up fuses, are designed to interrupt short-circuit currents only.

They are generally used to back-up another overcurrent protection device, (e.g. motor starter or circuit-breakers) at prospective currents exceeding the breaking capacity of the device alone.

IEC 60269 series and its various fuse systems specify the gates of time-current characteristics and the breaking range of the fuses shown in Table 3:

Table 3 – Fuse application

Utilization category	Application (characteristic)	Breaking range
gG, gK	General purpose	Full range
gM	Motor circuit protection	Full range
aM	Short-circuit protection of motor circuits	Partial range (back-up)
gN	North American general purpose for conductor protection	Full range
gD	North American general purpose time-delay	Full range
gPV	Photovoltaic (PV) protection	Full range
aR	Semiconductor protection	Partial range (back-up)
gR, gS	Semiconductor and conductor protection	Full range
gU	General purpose for conductor protection	Full range
gL, gF, gI, gII	Former types of fuses for general purpose (replaced by gG type)	Full range
gBat, aBat	Protection of batteries	Full and partial range

Fuses for use by authorized persons (industrial fuses) are generally interchangeable. Each fuse-link, fuse-base or fuse-holder is therefore legibly and permanently marked with the following information:

- name of the manufacturer or trade name;
- manufacturer's identification reference enabling any further information to be found;
- rated voltage a.c. and/or d.c. (see Tables 4 and 5);
- rated current;

- rated frequency if < 45 Hz or > 62 Hz;
- size*) or reference.

NOTE 2 The definition of fuse sizes, especially the dimensions are given by IEC 60269-2. In general fuse- links and fuse-bases and fuse-combination units shall have the same size. Some manufacturers offer to use a smaller fuse-link size in a bigger fuse-base or fuse-combination unit.

Example: size 1 fuse-link used in size 2 fuse-switch disconnector. Those combinations shall be tested and confirmed by the manufacturer.

In addition, each fuse-link is marked with

- letter code defining breaking range and utilization category (as applicable, see Table 3)
- rated breaking capacity

Fuse-bases and fuse-holders marked with a.c. ratings may also be used for d.c.

Fuse-links are marked separately if they are provided for a.c. and d.c. applications.

Fuses may be operated up to the maximum voltage as given in Table 4 and Table 5.

Table 4 – Maximum operational voltage of a.c. fuse-links

Utilization category	Rated voltage V a.c.	Maximum operational voltage V a.c.
gG, gM, aR [a, b], aM, gR [a, b], gS [a, b], gU, gK	230	253
	400	440
	500	550
	690	725
	1000	1100
gN[a], gD[a]	600	600

[a] For North American system of fuse-links, the maximum operational voltage is equal to the rated voltage.

[b] Other rated voltages are available depending on the application.

Table 5 – Typical operational voltage ratings of d.c. fuse-links

Utilization category	Typical rated d.c. voltage	Typical maximum d.c. operational voltage	Time constant
gG, gM, gU, gK	up to 500 V	+10 % over marked rating	15 to 20 ms
gN, gD	up to 500 V	+0 % over marked rating [a]	10 to 15 ms
aR, gR, gS	up to 1 500 V [b]	+5 % over marked rating [a]	15 to 20 ms
VSI (inverter rating)	up to 1 500 V [b]	+10 % over marked rating [a]	1 to 3 ms
gPV	up to 1 500 V [b]	+0 % over marked rating [a]	1 to 3 ms

[a] For North American system of fuse-links, the maximum operational voltage is equal to the rated voltage

[b] Other rated voltages are available according to application

The rated voltage of the fuse link should be recognized as the maximum system voltage in which the fuse link should be applied. The test voltage prescribed in the standard is a percentage above the rated voltage to allow for the allowable system deviations but it is also the safety factor built into products to the standard.

8 Conductor protection

8.1 General

Fuse-links are extensively used for the protection of conductors in accordance with IEC 60364-4-43.

Fuse-links can be used to ensure protection against both overload current and short-circuit current, simple and effective guidance for the selection of fuse-links are provided in the following:

- Utilization category gG see 8.2
- Utilization categorys gN and gD (North American) see 8.3
- Utilization categorys gR and gS (Semiconductor protection) see 8.4
- Utilization category gU see 8.5
- Utilization category gK see 8.6
- Utilization category gPV see 8.7

It should be stressed that IEC 60364-4-43 requires that every circuit shall be designed so that small overloads of long duration are unlikely to occur. For small overloads between 1 and 1,45 times the rated current of the overload protective device, the device may not operate within the conventional time. Ageing and deterioration of connections increase rapidly as operating temperatures exceed the rated values.

Caution: It is never acceptable to use the overload protective device as a load-limiting device. Continuous operation of the fuse-link above its rated current may result in overheating and nuisance operation.

In some applications fuse-links ensure protection against short-circuits only. In such cases overload protection shall be provided by other means.

Guidance for protection against short-circuits only is provided in 8.5 and Clause 13.

8.2 Utilization category gG

Fuse-links of utilization category gG are able to break overcurrents in the conductors before such currents can cause a temperature rise damaging the insulation.

Fuse-link selection can be easily made, taking the following steps:

a) The maximum operational voltage (see Table 4) of the fuse-link is selected to be greater or equal to the maximum system voltage.

b) The operational current I_B of the circuit is calculated.

c) The continuous current-carrying capacity of the conductor I_z is selected in accordance with IEC 60364-5-52.

d) The rated current I_n of the fuse-link is selected to be equal or greater than the operational current of the circuit and equal or smaller than the continuous current-carrying capacity of the conductor:

$$I_B \leq I_n \leq I_z$$

$$I_2 \leq 1{,}45 \cdot I_z$$

where

I_B is the operational current of the circuit;

I_z is the continuous current-carrying capacity of the conductor (see IEC 60364-5-52);

I_n is the rated current of the fuse-link;

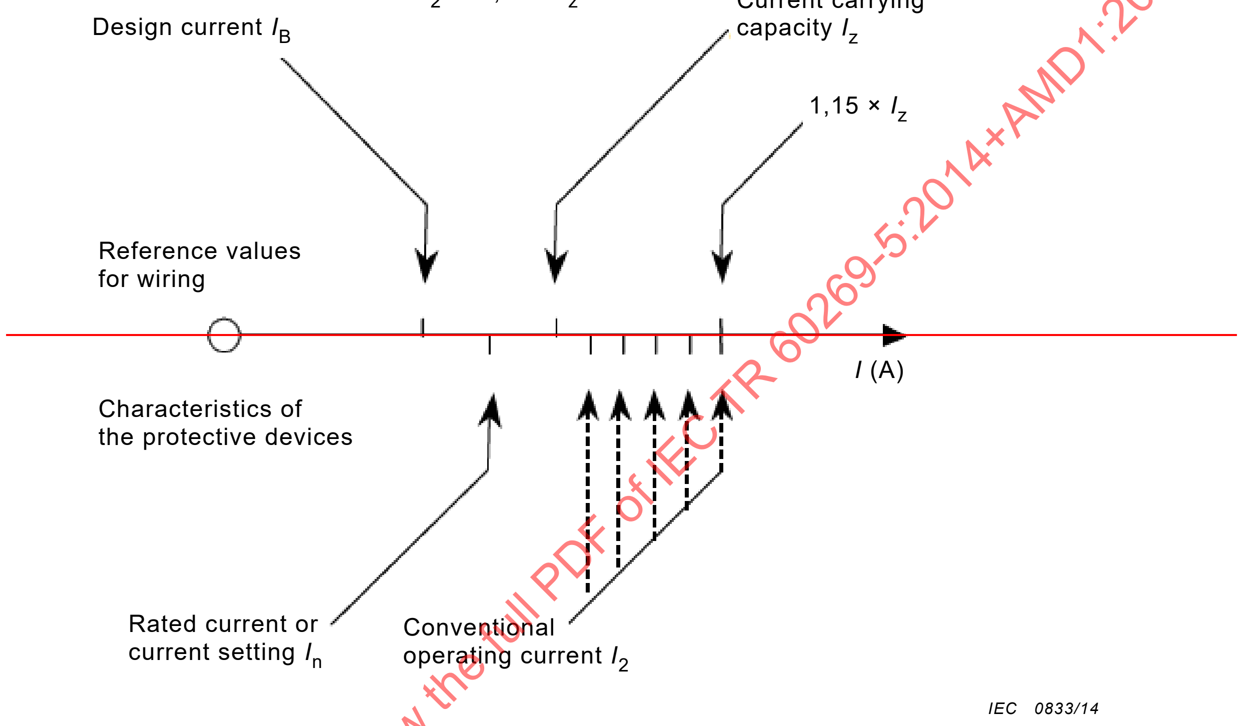
I_2 is the conventional tripping current [IEC 60050-442:1998, 442-05-55], see Figure 6

For gG fuses the I_2 (of IEC installation rules) is $I_t = 1{,}45 \cdot I_n$

When the fuse-links are selected on the above basis, the shape of the time-current characteristics ensures that the conductors are adequately protected at high over-currents.

$$I_B \leq I_n \leq I_z \quad (B.1)$$

$$I_2 \leq 1{,}45 \times I_z \quad (B.2)$$



$$I_B \leq I_n \leq I_z \quad (B.1)$$

$$I_2 \leq 1,45 \times I_z \quad (B.2)$$

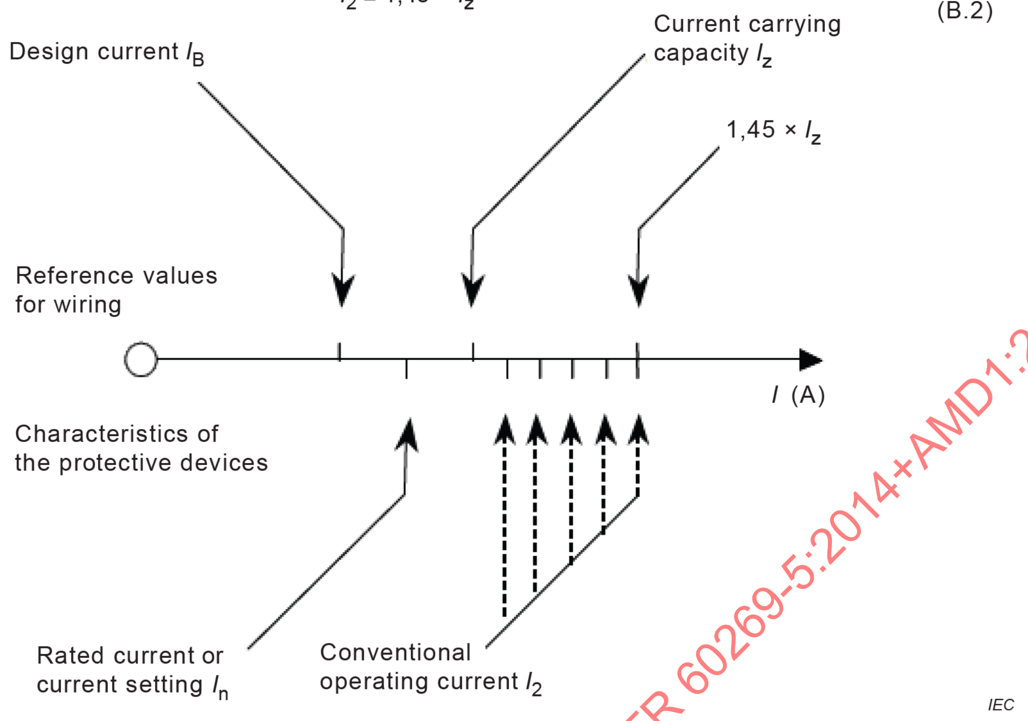


Figure 6 – Currents for fuse-link selection

8.3 Utilization category gN and gD

The requirements for the selection of fuses for the protection of conductors are found in the North American wiring regulations.

a) The voltage rating of the fuse is selected to be equal to or greater than the maximum system voltage.

b) The load current is calculated and multiplied by 1,25 for continuous loads (continuous loads are those which are present for 2 h or more).

c) The conductor size is selected from an ampacity (current-carrying capacity) table found in the wiring regulations.

d) The general rule for selecting the fuse is to select a standard fuse current rating to coincide with the conductor ampacity. For conductor ampacity less than 800 A, if the conductor ampacity falls between two standard fuse-link current ratings, the larger fuse-link current rating is used. For conductor ampacities of 800 A and over, if the ampacity falls in between two standard fuse-link current ratings, then the smaller fuse-link current rating is used.

e) The fuse selected protects the conductor under short-circuit and overload conditions. In practice, North American conductor standards have been coordinated with fuse standards so that short-circuit protection is achieved. For other types of conductors, short-circuit withstand ratings are compared with the fuse characteristics to make sure that conductor damage does not occur.

8.4 Utilization category gR and gS

Fuse-links for the protection of semiconductor devices are covered by IEC 60269-4 (see Clause 15). Most of such fuse-links are for short-circuit protection, utilization category aR. In some applications overload protection is required for the conductors feeding the semiconductor converter and this application is covered by utilization category gR, optimised to low I^2t values and utilization category gS, optimised to low power dissipation values.

The same selection process for the protection of conductors is used as in 8.2.

8.5 Utilization category gU

Fuse links to class gU are primarily for cable protection, as class gG, but their performance is optimised for use by supply utilities. The same selection process for the protection of cables should be used as in Subclause 8.2.

8.6 Utilization category gK

Fuse links to class gK are primarily for cable protection, as class gG, but their range of current ratings is up to 4 800 A and these are very ~~limitating~~ limiting current fuses and have very low cut-off current characteristics. The same selection process for the protection of cables should be used as in Subclause 8.2.

8.7 Utilization category gPV

Fuse-links for the protection of solar photovoltaic energy systems are covered by IEC 60269-6 (see Clause 19~~.~~). These fuse-links are for overload protection and strings, array and sub-array disconnection.

8.8 Utilization category gBat

Selection of a fuse for battery systems. These fuse-links are for overload and short circuit protection.

~~8.8~~8.9 Protection against short-circuit current only

In those applications where the fuse-links are to provide back-up or short-circuit protection to the conductors, then co-ordination must be ensured by providing fuse-links which ~~let through~~ operating I^2t values lower than those which can be withstood by the conductors. For fault durations of 5 s or less, the I^2t withstand of conductors may be determined from the expression

$$I^2t = k^2 \cdot S^2$$

in which S is the cross-sectional area of the conductor in square millimetres and k is a factor which depends on the conductor material and the limiting temperature which can be withstood by the insulation. Values of k for various conductor and insulation combinations are given in IEC 60364-4-43:2008, Table 43A.

9 Selectivity of protective devices

9.1 General

Selectivity of protective devices is an important point to be considered when designing low-voltage installations. The aim of selectivity is to minimize the effects of a fault. Only the faulted circuit shall be opened while the others shall remain in service. Selectivity is achieved if a fault is cleared by the protective device situated immediately upstream of the fault without operation of other protective devices.

The following explanation applies to the most widespread application, the radial network.

Selectivity may be explained using the network diagram in Figure 7. Using this diagram, several cases of selectivity may be considered:

between F_2 and F_4 ⇒ see 9.2

between F_1 and F_3 ⇒ see 9.2

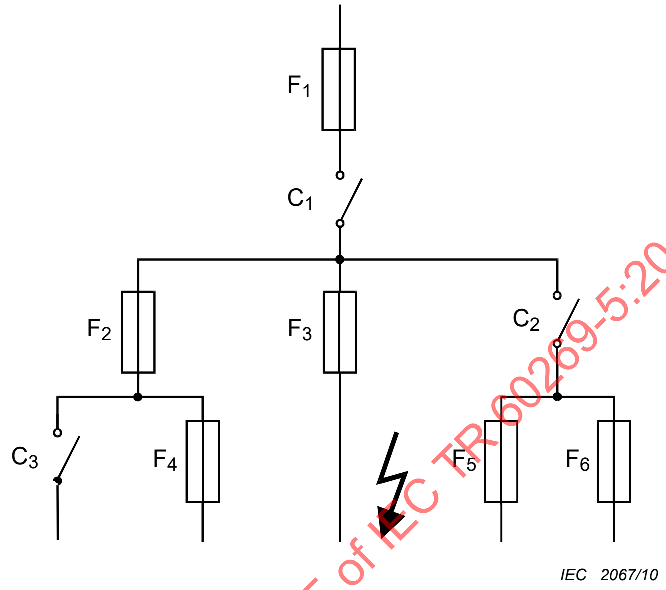
between C_1 and F_3 ⇒ see 9.3

between C_2 and F_5, F_6 ⇒ see 9.3

between F_2 and C_3 ⇒ see 9.4

between F_1 and C_1 ⇒ see Clause 14

The essential tools to investigate selectivity between protective devices are the time-current characteristics and I^2t values. IEC 60269-2 shows time-current characteristics for a time range of ≥ 0,1 s only. The values of I^2t for a time range < 0,1 s shall be supplied by the manufacturer.



Key

C Circuit Breaker

F Fuse

Figure 7 – Selectivity – General network diagram

9.2 Selectivity between fuses

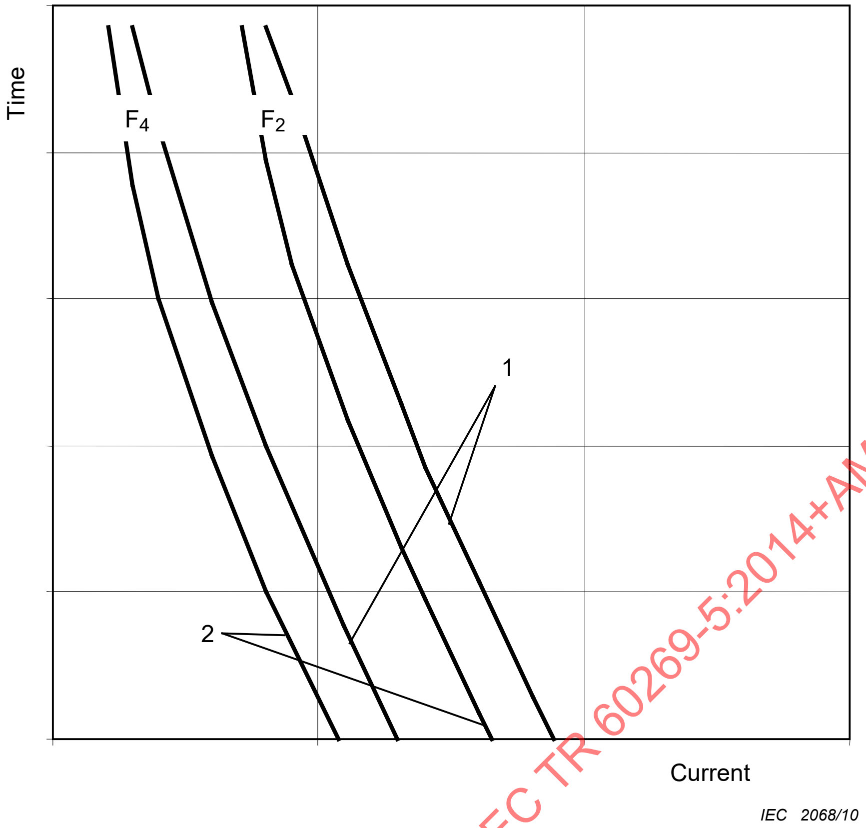
9.2.1 General

The selectivity between fuse-links is verified by means of the time-current characteristics (see Figure 8) for operating times ≥ 0,1 s and the pre-arcing and operating I^2t values for operating times < 0,1 s.

NOTE The fuse manufacturer will supply values of operating I^2t at the rated voltage(s) assuming very low impedance short-circuit fault. In practice the ~~let-through~~ operating I^2t will generally be a lower value due to the impedance of the fault and the actual voltage appearing across the fuse during operation.

9.2.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of F_4 shall be less than the minimum pre-arcing time of F_2 for each value of prospective current (see Figure 8).



Key

1 Maximum operating time

2 Minimum pre-arcing time

Where only one curve for the fuse link characteristic is given, the manufacturer should state the tolerance.

Figure 8 – Verification of selectivity between fuses F_2 and F_4 for operating time $t \geq 0,1$ s

9.2.3 Verification of selectivity for operating time < 0,1 s

For these operating times, the I^2t values shall be considered. The maximum operating I^2t value of F_4 shall be lower than the minimum pre-arcing I^2t of F_2.

9.2.4 Verification of total selectivity

Both above requirements set out in 9.2.1 and 9.2.2 shall be met to achieve total selectivity between F_2 and F_4. These verifications are made by examination of the manufacturer's time-current characteristics and I^2t values.

Fuses according to IEC 60269-2 of the same utilization category, e.g. gG, with rated currents ≥16 A, meet these total selectivity requirements by definition if the ratio of rated currents is 1,6: 1 or higher. No additional verification by the user is therefore needed. In case of gN or gD fuses with rated current above 15 A the ratio is 2:1.

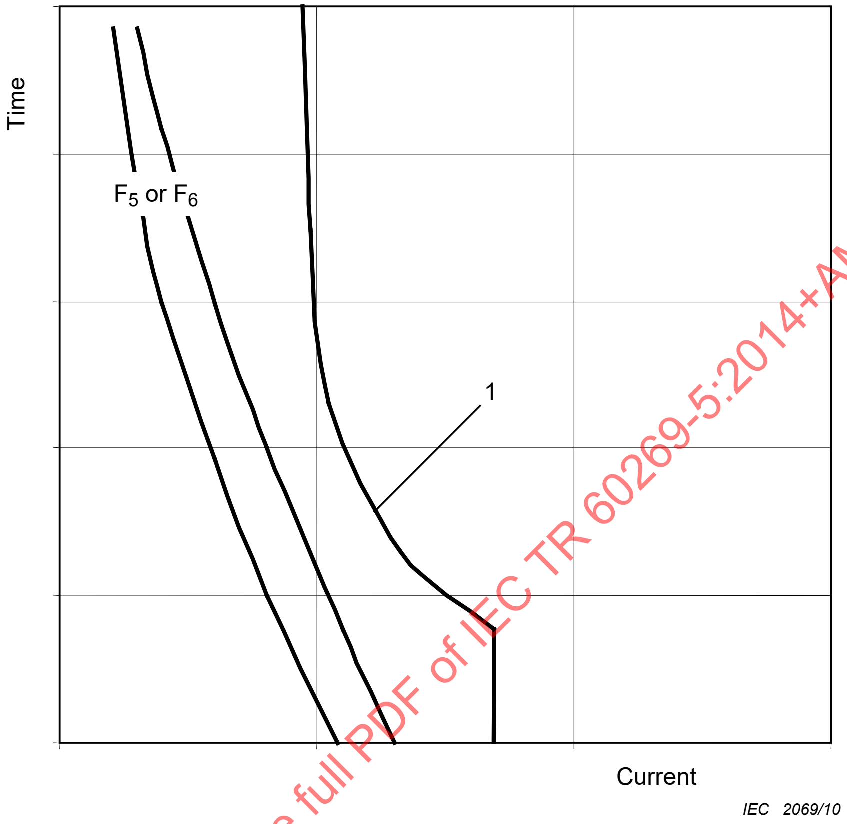
9.3 Selectivity ~~of~~ between circuit-breakers upstream ~~of~~ and fuses

9.3.1 General

The selectivity is verified by using time-current characteristics, I^2t values or by testing.

9.3.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of F_5 or F_6 shall be lower than the minimum tripping time of C_2 (see Figure 9).



Key

1 Minimum tripping characteristic of C_2

Figure 9 – Verification of selectivity between circuit-breaker C_2 and fuses F_5 and F_6

9.3.3 Verification of selectivity for operating time < 0,1 s

The operating I^2t value of the fuse must be smaller than the minimum tripping I^2t of the circuit breaker.

Data for I^2t values of fuses can be taken from the standard values.

Data from the circuit breaker can be taken out of its time-current characteristics and in the zone of instantaneous tripping, data must be provided by the manufacturer.

9.3.4 Verification of total selectivity

The requirements of both 9.3.2 and 9.3.3 shall be fulfilled to obtain total selectivity between C_2 and F_5 or F_6.

In practice, circuit-breaker manufacturers give selectivity tables between circuit-breakers and selected fuses. Such choices are also valid for equivalent or lower rated current fuses.

9.4 Selectivity ~~of~~ between fuses upstream ~~of~~ and circuit-breakers

9.4.1 General

The selectivity is verified by means of time-current characteristics and I^2t values or by testing.

9.4.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of the circuit-breaker C_3 shall be lower than the minimum pre-arcing time of the fuse F_2 (see Figure 10).

9.4.3 Verification of selectivity for operating time < 0,1 s

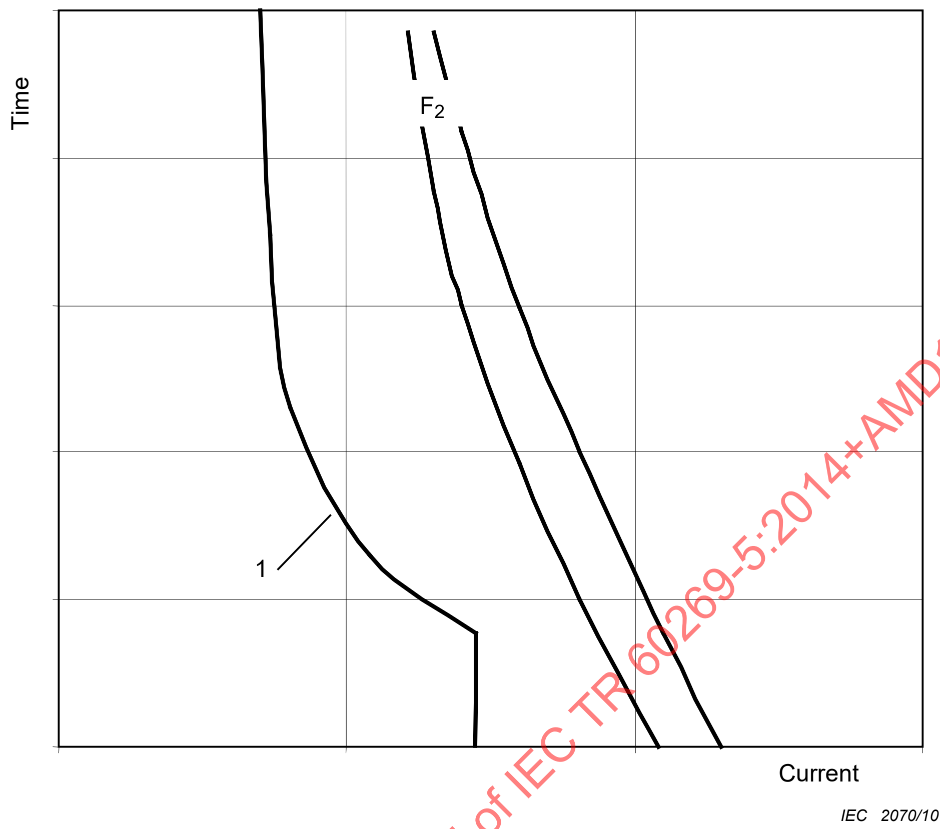
The minimum pre-arcing I^2t value of the fuse must be bigger than the maximum tripping I^2t of the circuit breaker.

Data for I^2t values of fuses can be taken from the standard values.

Data from the circuit breaker can be taken out of its time-current characteristics and in the zone of instantaneous tripping, data must be provided by the manufacturer.

9.4.4 Verification of total selectivity

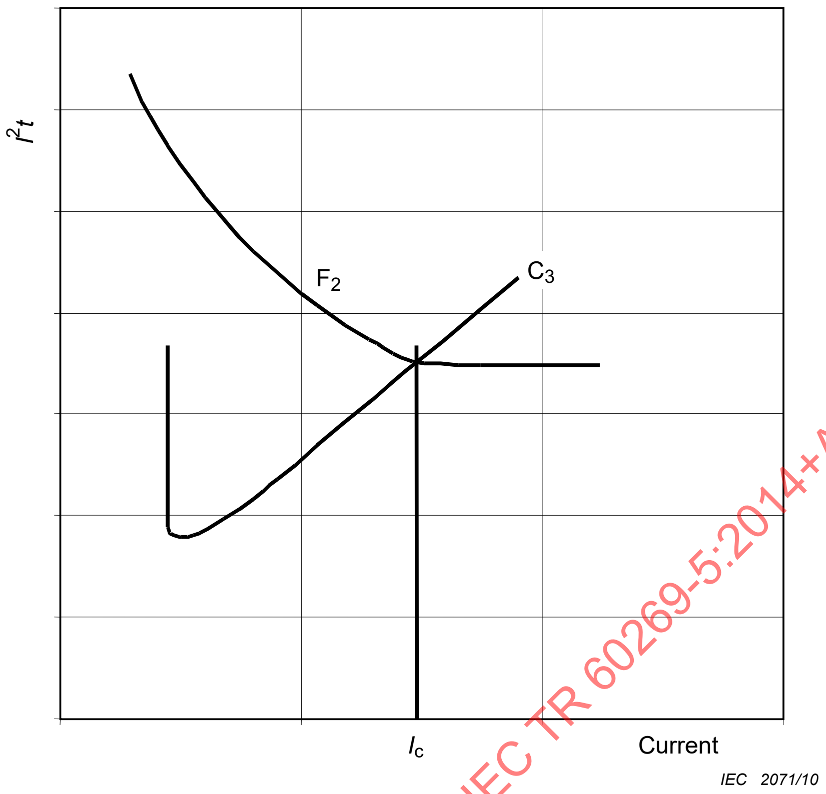
The requirements of both 9.4.2 and 9.4.3 shall be met to achieve total selectivity between C_3 and F_2. For prospective currents below I_c (see Figure 11) selectivity is achieved. For prospective currents above I_C, selectivity is not achieved.



Key

1 Tripping characteristic of C_3

Figure 10 – Verification of selectivity between fuse F_2 and circuit-breaker C_3 for operating time $t \geq 0,1$ s



NOTE ~~I_c~~ I_S is the selectivity limit current.

Figure 11 – Verification of selectivity between fuse F_2 and circuit-breaker C_3 for operating time t < 0,1 s

10 Short-circuit damage protection

10.1 General

A short-circuit or fault occurs when a low impedance current path becomes available between two live parts or between live parts and earth, usually due to insulation breakdown, mechanical damage, wiring error or accident.

10.2 Short-circuit current paths

If the current path is a solid connection, the current rises to a value dependent on the voltage and the impedance of the conductors involved. Typically, the connection is very low impedance and the current is then quite high so that mechanical and thermal damage to conductors and insulation systems result. Mechanical damage to conductors is due to magnetic forces which attract or repel circuit conductors thus bending them and destroying insulation systems. Thermal damage to conductors is due to overheating and compromised insulation systems, followed by conductor melting and arcing.

If the current path is not a solid connection, an electrical arc takes place at the point of poorest connection. This event is referred to as an “arcing fault”. The current rises to a value dependent on the impedance of the conductors plus the impedance of the arc. Typically conductor mechanical and thermal damage result accompanied by localized conductor melting and metal vaporization at the point of arcing. Metal vaporization in air in the presence of an electrical arc is a dangerous condition, and an explosion results (an arc blast). Its severity is dependent on a number of circuit parameters but primarily on how much electrical energy is available and how much melted material is available to vaporize.

10.3 Current limitation

Fuses offer one of the most cost effective methods for protecting equipment, personnel and components from damage due to short-circuits, faults, and arcing faults. The reason behind this is the inherent current limiting ability of fuse-links. As discussed earlier, fuse-links melt and break the current very rapidly when exposed to high current levels (see 5.3.2). Peak current I_C which occurs just after the fuse-link melts is well below the prospective current and operating I^2t is kept low since the filler within the fuse body extinguishes the arcs taking place between the parts of the fuse-link (typical fuse clearing times are less than half a cycle). These low I_C, less than half cycle clearing times, and low operating I^2t provide the following benefits in case of a short-circuit or arcing fault:

- No mechanical or thermal damage to conductors or insulation systems.
- Little or no melting or arcing at the site of the fault.
- High reduction of arc energy levels resulting in effective mitigation of arc blast.

10.4 Rated conditional short-circuit current, rated breaking capacity

Assemblies of and components in electrical systems are assigned a short-circuit rating by the manufacturer which is the maximum permissible prospective short-circuit current in terms of magnitude and time that the device will withstand at its terminals.

This rating is established by test. If such a device contains or includes a fuse-link as an integral part, it is expressed as I_{cc}, rated conditional short-circuit current (see IEC 61912-1:2007, Clause 5).

Typically current limiting fuses are designed for use in circuits with high prospective currents and when used in assemblies or switches afford a high I_{cc} rating for the assembly or switch. This enables the device or assembly to be more widely applied, since safe practice dictates that the I_{cc} rating of the device or assembly must be equal to or higher than the system prospective short-circuit current.

11 Protection of power factor correction capacitors

IEC 60269-1 and IEC 60269-2 do not contain any requirements or verification test duties for fuses in circuits containing primarily capacitors. The use of fuses according to IEC 60269-2, utilization categories gG and gN for short-circuit protection of power factor correction capacitors has been a well-established engineering practice for many years.

Reliable function of gG and gN fuses in such applications requires selection of fuse-links with respect to the following considerations:

– high inrush currents up to 100 times rated current of the capacitor;
– continuous operating current up to 1,5 times rated current of the capacitor (this includes harmonics);
– increasing service voltage up to 1,2 times during low-load periods for 5 min;
– fluctuation of the service voltage up to 1,1 times for 8 h.
– capacitance (and subsequently operating current) tolerances of +15 %;

The rated current of the fuse-link is selected so that

– the inrush currents do not melt or deteriorate the fuse-element,
– potential over-currents do not lead to premature operation of the fuse-links.

The rated current of the gG and gN fuses is selected to be 1,6 to 1,8 times the rated current of the capacitor unit or capacitor bank. Under this condition, the fuse provides reliable short-circuit protection to the capacitors. Overload protection, if necessary, must be provided by additional suitable means. As a general rule, fuses for power factor correction capacitors have to be oversized with respect to rated current and rated voltage. This is especially true as regards small capacitor units having a higher inrush current related to their rated current.

NOTE Cross-sections of the connecting cables are selected according to the fuse current rating (see 8.2).

Recommended fuse selection for the most common sizes and voltages of power factor correction capacitors is shown in Table 6.

Table 6 – Fuse selection for power factor correction capacitors (fuses according to IEC 60269-2, system A)

	Rated Voltage (three-phase 50 Hz system)			
Power factor correction capacitor	400 V k = 2,5	525 V k = 2	690 V k = 1,5	1 000 V k = 1,5
Fuse	500 V	690 V	1 000 V [a]	1 500 V [b]
Capacitor size Q_N	Rated Current I_N of the fuse			
Up to 5 kVAR	16 A			
Up to 7,5 kVAR	20 A			
Up to 12,5 kVAR	32 A (35 A)	32 A (35 A)		
Up to 20 kVAR	50 A		32 A (35 A)	
Up to 25 kVAR	63 A	50 A		
Up to 30 kVAR	80 A	63 A	50 A	32 A (35 A)
Up to 40 kVAR	100 A	80 A	63 A	
Up to 50 kVAR	125 A	100 A	80 A	50 A
Up to 60 kVAR	160 A	125 A	100 A	63 A
Up to 80 kVAR	200 A	160 A	125 A	80 A
Up to 100 kVAR	250 A	200 A	160 A	100 A
Up to 125 kVAR	315 A	250 A	200 A	125 A
Up to 160 kVAR	400 A	315 A	250 A	160 A
Up to 200 kVAR	500 A	400 A	315 A	200 A
Up to 250 kVAR	630 A	500 A	400 A	250 A

[a] 690 V may be possible under certain conditions, check with manufacturer.

[b] 1 200 V or 1 300 V may be possible under certain conditions, check with manufacturer.

The rated current of the fuse may be calculated from the following rule of thumb:

$$I_n = k \cdot Q_N$$

where

I_n fuse rated current, in A;

Q_n capacitor size, in kvar;

k factor from Table 6.

12 Transformer protection

12.1 Distribution transformers with a high-voltage primary

Transformers feed most low-voltage distribution systems from a high-voltage, above 1 000 V a.c. primary. Short-circuit protection of these transformers are generally provided by high voltage fuse-links on the primary, and such fuse-links are selected to withstand the transformer magnetising (inrush) current during energization.

Low-voltage fuse-links on the secondary side of such distribution transformers give protection to their associated feeder circuits. Such fuse-links have to be selective with the fuse-links on the primary side of the transformer, taking into account the appropriate transformation ratio.

12.2 Distribution transformers with a low-voltage primary

Low-voltage distribution systems following North American practice often have transformers with a low-voltage primary and secondary for example 480/277 V to 208/120 V. Such transformers may typically have ratings up to a few thousand kVA.

Fuse-links on the primary side are used to provide short-circuit protection and fuse-links may be used on the secondary side to provide overload protection to the transformer. In some cases only primary circuit fuse-links are used while in other cases additional feeder circuit fuse-links are used on the secondary side, as in 12.1.

The primary side fuse-links have to be selected to withstand the magnetising inrush current and an industry guide is:

- 20 times transformer primary full load current for 0,01 s and
- 12 times transformer primary full load current for 0,1 s.
- Selectivity for the primary and all the secondary fuse-links and any other over-current protection has to be made taking into account the appropriate transformation ratio.
- In some applications transformers with a low-voltage primary and secondary are used for example battery chargers and tools, for safety reasons, fed from voltages up to 110 V.

12.3 Control circuit transformers

For these low power transformers, the peak inrush magnetising current in the first half cycle can be as high as 100 times the full load current. Many control circuit transformers have internal thermal protection since the over current devices on the primary side shall be greatly oversized to account for the tremendous inrush currents.

13 Motor circuit protection

13.1 General

Fuses are commonly used as part of the protection in motors and motor-starters circuits. General-purpose fuses (utilization category gG and gN) can be used for this purpose. Their current rating shall be chosen to withstand the starting current of the motor, which is dependent on the method of starting used, e.g.

– 6 to 8 times the rated motor current for direct on line starting,
– 3 to 4 times the rated motor current for star delta or autotransformer.

The rated current of the fuse may therefore be significantly higher than the rated current of the motor.

Special types of fuses exist for this application, such as gD and gM utilization category fuses which are full range breaking capacity fuses and aM utilization category back-up fuses designed to provide short-circuit protection only. These special utilization categories of fuses are designed to withstand high motor starting currents without the need for increasing the current rating as required for general purpose utilization categories. Characteristics for these utilization categories can be found in IEC 60269-1 and IEC 60269-2.

Fuse manufacturers provide motor fuse application data. Fuses for motor circuit protection are chosen to be selective with the motor protection provided by the overload-relay associated with the motor-starter.

13.2 Fuse and motor-starter coordination

The coordination between motor-starters and the fuses which protect them is covered in IEC standards by requirements and tests such as those in IEC 60947-4-1. Two kinds of co-ordination are defined: type 1 and type 2 (see also Table A.3).

The aim of successful coordination is to ensure adequate protection against short-circuit current and selectivity between starter and fuses. Satisfactory selectivity will avoid damage to the contactor and unexpected opening of the motor circuit.

Recommendations for suitable fuse-links for use in combination with a contactor/motor-starter can be found in manufacturers' catalogues.

The aim of this subclause is to give guidance to the end-user to find an alternative replacement fuse to the one specified by the manufacturer of the starter. Relevant installation codes must be followed.

More detailed information is given in Annex A to specify the tests and calculation necessary to achieve the coordination between the motor-starter and the fuse which protects it.

Tests are specified at three levels of prospective current, according to IEC 60947-4-1:

a) in the region of the current I_{co} defined as the co-ordination at the crossover current (see 13.4). Tests are made at 0,75 I_{co} when the starter shall disconnect the current without damage and the fuse does not operate, and at 1,25 I_{co} when the fuse shall operate before the starter (see Figure 12). The verification of co-ordination at the crossover current is also possible by an indirect method (see B.4.5 of IEC 60947-4-1:2009);
b) at the appropriate value of prospective current "r" shown in IEC 60947-4-1:2009, Table 12 (see Table A.2);
c) at the rated conditional short-circuit current I_q stated by the manufacturer of the switching device, if higher than the test current "r".

The fuse selected shall withstand the motor starting current and is normally selected from the recommendations of the manufacturer and in compliance with national installation codes and wiring rules.

Examples of suitable fuse-links used for motor protection are given in Table A.1.

The cross-over point of the fuse and the starter characteristics shall be within the breaking capacity of the contactor and the fuse is selected so that it does not operate while carrying the starting current of the motor (see Figure 12).

13.3 Criteria for coordination at the rated conditional short-circuit current I_q

Guidance for choosing the maximum rated current of an alternative fuse type: Annex A of IEC 61912-1:2007 details the method to be used. Basically the following shall be fulfilled.

The values of the voltage, the current and the conditional short-circuit current (I_q) for the circuit shall not be higher than the reference tested data.

Considering the characteristics of the substitute fuse, the I_{co} and I^2t values shall be determined for the rated conditional short-circuit current I_q and at the voltage $U\sqrt{3}/2$.

The values of I_{CO} and of I^2t determined as above shall be not greater than the reference test values.

Conformity with the above shows that the fuse substitution is valid and no further verification tests are required.

13.4 Criteria for coordination at the crossover current I_{co}

I_{co} is the current corresponding to the intersection of the mean time-current characteristics of the fuse and the overload relay of the starter (see Figure 12). Tests are prescribed for ensuring proper coordination at I_{co} in IEC 60947-4-1:2009, Clause B.4.

Important factors are:

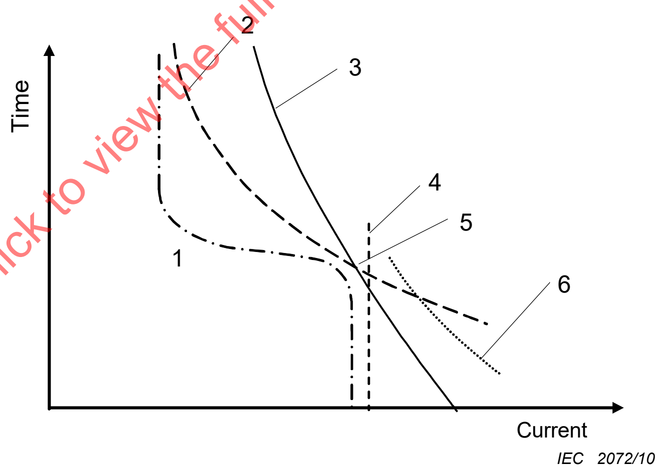
– the no-damage characteristic of the overload relay;

– I_{co} must be lower than the electrodynamic withstand current of contacts of the contactor and overload relay.;

– the operating time-current characteristic of the associated fuse at currents above I_{co} must be lower than the no damage characteristic of both the overload relay and the contactor in the region , where the fuse has take over the protective duty.

Thus, if an alternative replacement fuse type is used without further testing, its cross-over current shall not exceed the value of I_{co} observed in the type test, and its time-current characteristic at currents above I_{co} shall not show any greater times than the fuse used in the tested combination or damage to the starter may occur.

A fuse chosen in this way and in accordance with IEC 60947-4-1 provides protection for the starter and associated equipment at overcurrents exceeding the breaking capacity of the starter up to the rated conditional short-circuit current of the starter.



Key

1 Motor current
2 Time-current characteristic of the overload relay operation
3 Time-current characteristic of the fuse-link
4 Breaking capacity of the contactor
5 Crossover current I_{co}
6 Thermal limits of the overload relay

Figure 12 – Fuse and motor-starter coordination

13.5 Criteria for coordination at test current "r"

Basically, the characteristics to be considered for the alternative fuse are *the* I_c *and* I^2t values as suggested in Annex A of IEC 61912-1:2007. It is generally assumed that where these conditions are fulfilled for the I_q values, they are also fulfilled for the current "r".

14 Circuit-breaker protection in a.c. and d.c rated voltage circuits

Circuit-breakers having breaking capacities lower than the system prospective short-circuit current must be protected by an additional upstream short-circuit protective device (SCPD) having a sufficiently high breaking capacity.

Current limiting fuse-links offer an extremely cost-effective solution for this type of application (see Figure 7, F_1 and C_1). In case of short-circuits, current limiting fuse-links open rapidly (in less than ¼ cycle) thus reducing the prospective current and hence the electrical energy seen by the downstream circuit-breaker to levels well within the circuit-breakers capability.

The fuse used can be of the general purpose utilization category (gG and gN), the back-up utilization category (aM), or the full range utilization category as used on motor circuits (gD and gM).

Proper selection of fuse utilization category and its rating to protect a particular circuit-breaker is not simple, and reliable results cannot be completed solely by calculation.

The primary reason for this selection problem is that peak current and let-thru I^2t withstand levels vary between circuit-breaker types and among circuit-breaker manufacturers. To assure personnel safety and satisfactory protection of the circuit-breaker, fuse utilization category and ratings are tested in combination with downstream circuit-breakers.

The results of these tests and acceptable series fuse/circuit-breaker combinations are available by consulting the fuse or circuit-breaker manufacturers or appropriate notified bodies, who have witness tested these combinations.

It is possible to select an alternate utilization category of fuse types different from those fuses used in the series testing provided that alternate fuse type has values of I_p and operating I^2t less than or equal to the values of the fuse originally tested.

15 Protection of semiconductor devices in a.c. and d.c. rated voltage circuits

15.1 General recommendations

The I^2t withstand values of semiconductor devices of given ratings are considerably lower than those of other devices and circuits of corresponding ratings. Fuse-links used in circuits containing semiconductor devices shall therefore be capable of operating more rapidly at given currents than fuse-links used in other applications.

It is usual for several semiconductor devices to be present in one piece of equipment, such as a rectifier or inverter. The protective equipment should ideally ensure that the following conditions are met:

In the event of a semiconductor device failing, interruption should be effected quickly enough to prevent damage to other devices. (In this connection, experience has shown that semiconductors fail as a short-circuit protection and a large current results.)

For other faults in the equipment, interruption should take place before there is consequential damage to the semiconductor devices. Potentially damaging over-currents should be cleared before devices are damaged.

Operation of the fuse-links should not cause unacceptably high over-voltages to be impressed on any of the semiconductor devices.

The performance requirements for fuse-links for the protection of semiconductor devices are given in IEC 60269-4 and such fuse-links have traditionally been the “partial range” or “back-up" category, utilization class aR. While partial range rectifier protection fuse-links (aR) provide fast protection to devices, in many systems alternate protection of thermal triggered overload devices, gG fuse-links or other circuit protective devices may need to be included to protect other circuit elements. The lower limit of capability of a type aR fuse-link is defined in terms of the multiple of the rated current.

As protection schemes and practices have developed, there is a growing need for fuse-links for the protection of semiconductor devices with "full range" breaking capacity, which will eliminate the need for one or more of the components mentioned above. An example is to place fuse-links at the head of the supply, rather than in the converter cubicle. In this case the fuse-link needs to give protection to the cable, in addition to the power semiconductors in the converter equipment.

Two additional full range classifications were introduced into IEC 60269-4 namely "gR", optimised to give low I^2t and "gS" optimised to give low power dissipation. The "gS" fuse-links usually give compatibility with standardized fuse-bases and fuse combination units. Both gR and gS fuse-links must operate within the conventional time at 1,6 times their rated current, however they must carry the value shown in Table 7 for the conventional time.

Table 7 – Conventional non fusing current

Type "gS"	Type "gR"
1,25 I_n	1,13 I_n

Depending where the fuse-link is positioned in a circuit utilizing semiconductors the fuse-link may have to be rated for a.c. fault conditions, d.c. fault conditions or both. Fuse-links with adequate voltage ratings and breaking capacities should be chosen.

The d.c. voltage rating of the fuse-link is dependent of the circuit time constant that may be achieved by a fuse-link. The time constants to which fuse-links for the protection of semiconductors are tested are indicated in the standard and are representative of time constants in typical power systems. The protection of voltage source inverters (VSI) is a special case, provided when capacitors are used in the power circuit. In VSI's the circuit time constant may be significantly lower than traditional d.c. systems and thus IEC 60269-4 includes specific test requirements for fuse-links that can then be assigned a VSI voltage rating in addition to the a.c. and d.c. voltage ratings assigned.

Manufacturers of fuse-links for the protection of semiconductor devices give comprehensive guidance for the selection of fuse-links for a wide variety of applications. In addition, useful information is given in the following:

- Annex AA of IEC 60269-4:2009 gives some useful guidance for the coordination of fuse-links with semiconductor devices. This annex explains the performance to be expected from the fuse-links in terms of their ratings and in terms of the circuits of which they form a part; in such a manner that this may form the basis for the selection of the fuse-links.
- Annex BB of IEC 60269-4:2009 gives a survey of information to be supplied by the manufacturer in his literature (catalogue) for a fuse-link designed for the protection of semiconductor devices.
- IEC/TR 60146-6 is an application guide for the fuse protection of semiconductor converters against over-currents. It is limited to line commutated converters in single-way and double way connections. This technical report advises the specific fuse features and on the specific converter features that are to be observed to ensure correct application of semiconductor fuses in converters, and to give specific recommendations for trouble free operation of converters protected by fuses.

15.2 Fuse application with inverters

15.2.1 Inverters

Figures 17 to 19 show examples of inverters of voltage source type.

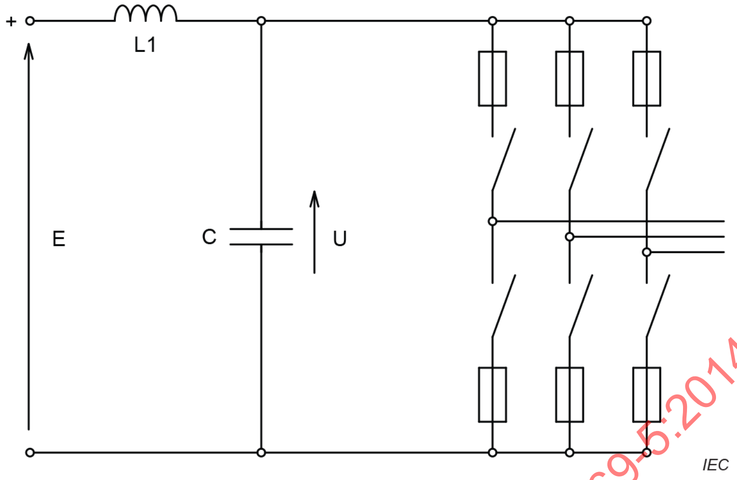


Figure 17 – Inverter double-way connection with arm fuses for regenerative or non-regenerative load

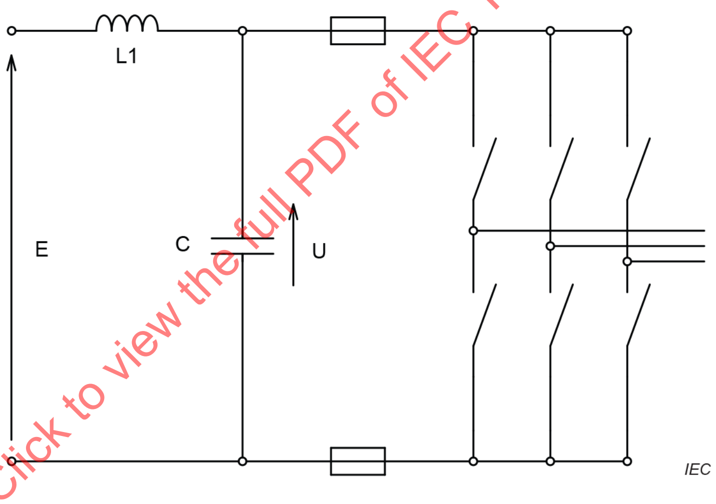


Figure 18 – Inverter double-way connection with d.c. loop fuses for regenerative or non-regenerative load

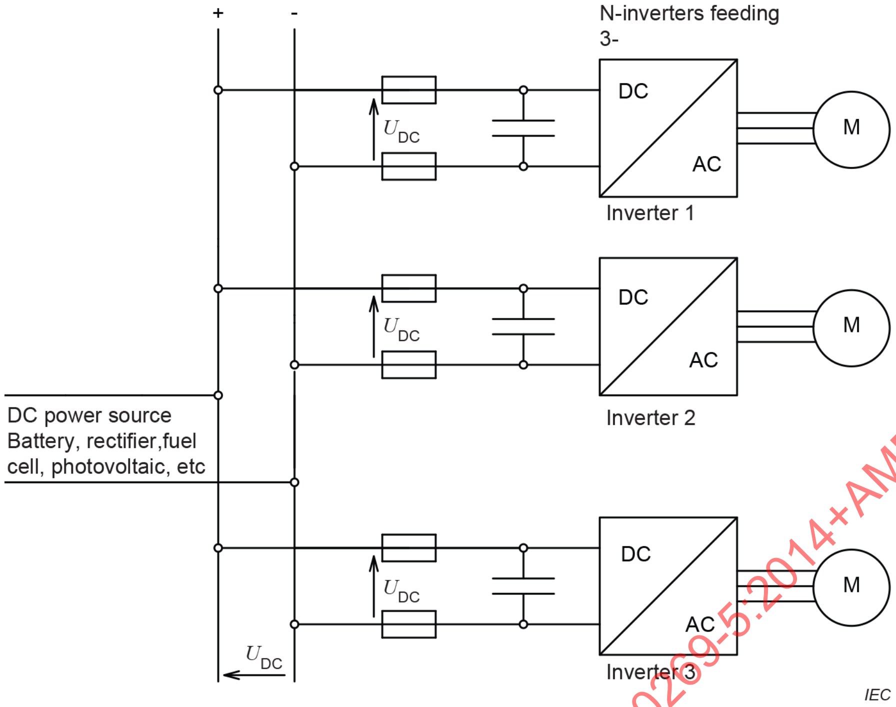


Figure 19 – Multi inverters systems double-way connection with d.c. loop fuses for regenerative or non-regenerative load

Fast fuses can protect the junction of a GTO thyristor against the effect of a large current. As for transistors, IGBT junctions cannot be protected by fuses because of their extremely low I^2t value. Nevertheless, as for other semiconductors, a high fault current will cause the explosion of the IGBT case because of the energy built up inside the component. A lot of power tests demonstrate that the explosion I^2t of the IGBT can be defined and show that fast fuses can prevent an IGBT from exploding.

Moreover tests have been made to measure the fuse contribution to the inductance of the circuit and the effect of high frequencies on the current carrying capability of the fuse. The fuse technology and the circuit design play a great part in the total inductance of the circuit.

The publication of appropriate curves and data is absolutely necessary to allow the selection of a fuse for the protection of power inverters.

15.2.2 Purpose of the fuse

15.2.2.1 General

The purpose of the fuse is to protect the equipment against a semiconductor explosion or when it is possible to protect the semiconductor junction in case of short circuit.

The fuse's main purpose is then to stop the capacitor discharge due to a short circuit made by two arms in series conducting simultaneously.

Two arms will create such a short circuit when one semiconductor is triggered at the wrong time or fails.

The fuse-link will operate very quickly as the di/dt is generally very high because of the very low value of the inductance L_1 (see Figure 20).

The short circuit current is the sum of the capacitor discharge current icap and the d.c. current id coming from the d.c. power source (Figure 6).

However the value of the inductance L (between the power source and the capacitor) is much larger than the value of the inductance of the capacitor discharge current. Then when the fuse-link operates the cut-off current I_c **would be** still very small and even negligible in comparison with the capacitor discharge current.

15.2.2.2 Location of the fuse

There are three possibilities:

- fuses in the arms of the inverter (Figure 17)
- fuses in the DC loop of the inverter (Figure 18): fuse current rating is √3 times the current rating of the fuse in the arms
- fuses in the DC feeder (Figure 19): between the capacitor and rectifier
- (or another kind of DC power supply)

It is possible to combine Figure 19 and Figure 17 or Figure 19 with Figure 18.

15.2.2.3 Specific characteristics for the fuse selection

When an IGBT or a GTO fails the capacitor is short-circuited and the fuse is protecting a circuit as described in Figure 20.

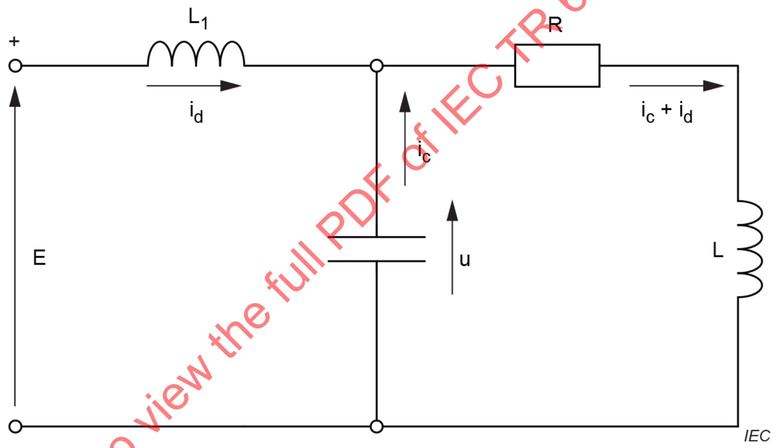


Figure 20 – Capacitor discharge

Parameters definition:

E voltage value of the DC power source.

U instantaneous value of the voltage across the capacitor

i_{cap} instantaneous value of the fault current supplied by the capacitor

i_d instantaneous value of the fault current supplied by the DC power source

L_1 total inductance of the capacitor discharge circuit

L_2 inductance between the DC power source and the capacitor

R resistance of the capacitor discharge circuit

C Capacitor

15.2.2.4 Conditions for quick fuse selection

- Inductance:

  In such inverters there is an inductance L_1 between the capacitor and the rectifier supplying the d.c. voltage. The L_1 value is normally large compared to the value of L_2 and in most cases it is possible to neglect the current i_d coming from the rectifier during the first half period of the capacitor discharge. In order to neglect i_d it is enough to verify the following condition:

$$L_1 \geq 10 \times L_2$$

- Resistance R:

  The resistance value R (including the resistance value of the fuses) is usually low enough to allow an oscillating capacitor discharge. The oscillation condition is:

$$R \leq 2 \cdot \sqrt{\frac{L_2}{C}}$$

This condition on R and the one on L_1 allows the use of the following simplified equations for the calculation of the oscillation period T, the fault current i(t) and voltage u(t):

$$T = 2 \cdot \pi \cdot \sqrt{L_2} \cdot \sqrt{C}$$

$$i(t) = E \cdot \sqrt{\frac{C}{L_2}} \cdot \exp(-\frac{R}{2 \cdot L_2}) \cdot sin\omega t$$

$$\mathrm{u(t) = E \cdot cos\omega t}$$

Higher values of R are acceptable in the circuits, but the simple method of fuse selection cannot be used in this case anymore. A solution can be made by calculating the respective values with specified software tools.

- Voltage across capacitor U

  Although the voltage U is oscillating, it does not mean the fuse-link is not working under an AC voltage. After the end of fuse-link pre-arcing time (at time t_p) the arc starts inside the fuse-link and the voltage across the capacitor is not oscillating anymore (the fuse-link is not any more a low resistance). The arcing inside the fuse-link changes the circuit characteristics. At the end of pre-arcing time the voltage U_P across the capacitor is:

$$U_P = E \cdot \cos\omega t$$

Since the fuse-link is arcing under a DC voltage it is necessary to specify the maximum voltage value UPM under which the fuse-link can start arcing. This value is a fuse-link characteristic and it allows to check the following condition:

$$U_P \leq U_{PM}$$

- DC voltage E

  Just after the arc extinction, there is a transient phenomenen during the recharge of the capacitor by the power source producing an over voltage across the capacitor, the peak value of which is Utransient. This value is significantly above the initial value E (Figure 21).

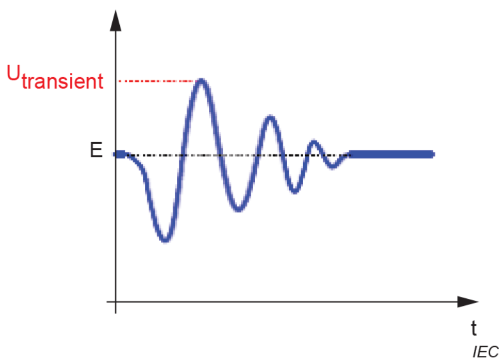


Figure 21 – Voltage across the capacitor

Assuming there is no resistance in the circuit and assuming the capacitor has been fully discharged, the maximum theoretical value of this transient over-voltage is 2 E.

The realistic value is: $U_{transient}$ = 1,75 E

Under such a peak value the arc can restrike inside the fuse-link. Therefore the initial source voltage value E must not exceed a maximum value E_M.

E_M is another fuse-link characteristic. Meeting the following condition is necessary.

$$E \leq E_M$$

- Pre-arcing time t_m

  Since the $U_{transient}$ value is function of the voltage decrease across the capacitor during the pre-arcing time of the fuse-link, the pre-arcing time t_m should not be too long. The recommended value when $E = E_M$ is:

$$t_m < T/6$$

  When t_m = T / 6 the voltage across the capacitor is: U_p = E / 2.

  Then the maximum transient peak voltage across the capacitor will be about 1,6 E.

  Obviously, these conditions are not critical when the rated DC voltage E is significantly below the E_M value of the selected fuse-link.

- Oscillating period T

  The purpose of the condition on T is to limit the time for which the voltage across the capacitor is maximal value. If this condition is not fulfilled the fault interruption is getting closer to the interrupting conditions of a d.c. circuit fed by a battery. The calculations are not anymore the same as the ones mentioned in this document.

  The required condition is: $T \leq 10$ ms.

15.2.2.5 Necessary information on fuses

All comments and conditions given in "Conditions for quick fuse selection" mean the fuse manufacturer should publish, within their literature for each fuse, specific value like E_M and U_{PM} and special curves allowing a quick calculation of t_m, pre-arcing I^2t, total I^2t (for example relation with di/dt) and arc voltage U_m.

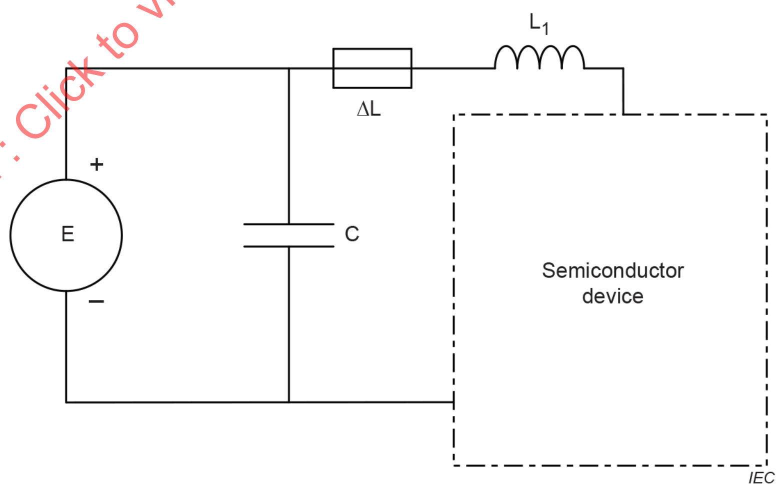


Figure 22 – Inductance of the circuit

The L value of a circuit inductance depends mainly on the shape and length of the circuit. When the fuse is introduced into the circuit, it changes the length and the shape of that the circuit. Consequently the inductance L of the circuit becomes L + ΔL (Figure 22).

ΔL is not an inductance located inside the fuse having a constant value. Fuse manufacturers measured ΔL of several fuses with the circuit in Figure 22. The value of the circuit with fuse and without fuse is obtained by measuring the di/dt when the circuit is closed.

Without fuse $di / dt = E/L_1$

With fuse $di / dt = E/(L_1 + \Delta L)$

For these measurements the fuse is replaced by a copper bar in order to minimize the change of length of the circuit. The ΔL value drastically decreases when the body of the fuse is flat.

NOTE The IGBT is also a large power component whose case rupture can cause large damages in the equipment and be dangerous to people. The protection of power IGBTs against explosion requires fuses electrically and mechanically adapted up to 7,2 kV, but requires knowing the real explosion i^2t of the IGBT in order to achieve an ideal coordination with the fuse. Fuse manufacturers are able to supply a safe and reliable protection of the IGBT converters. In case of need consult with them or their literature.

15.2.3 Current carrying capacity

15.2.3.1 Fuse rated current selection

When the fuse is intended to carry a continuous current, the RMS value is first calculated on a one-cycle basis, and this RMS value shall remain constant. Unless otherwise indicated by the manufacturer, the rated current shall be:

– at least the RMS value of the current, taking into account, if necessary the conditions, which might be different from standard conditions. For high frequency applications the influence of skin and proximity effect should be considered.

NOTE 1 There is a skin effect in the fuse elements, although they have a thickness smaller than 0.5 mm, because the current density varies alongside the width; there is no skin effect in the thickness as the skin depth is 0.95 mm at 5 kHz. There is a skin effect in contact parts.

NOTE 2 Proximity effect: The current is not equally shared between the fuse elements, when the return busbar is close to the fuse. The unbalance is function of the frequency and of the distance between the fuse and the return busbar (the shorter the distance, the larger the imbalance).

When this distance is above 200 mm and the frequency is lower than 20 kHz the proximity effect inside the fuse becomes negligible. The proximity effect is affecting the fuse behaviour much more than the skin effect.

The skin effect is much less dangerous but not negligible for frequencies above 1 kHz when the connecting bus bars do have higher dimensions.

Another problem with high frequencies is the overheating of magnetic parts due to the hysteresis losses. These losses can be avoided by using non-magnetic materials.

15.2.3.2 Mounting and surrounding ambient conditions

IEC 60146 applies.

15.2.4 Voltage considerations

15.2.4.1 Voltages during fault conditions

See “Voltage across capacitor U” in 15.2.2.2.

15.2.4.2 Selection of the fuse rated voltage

Single inverter: The fuse-link will interrupt the capacitor discharge current generated by the short circuit created by the failure or bad triggering of semiconductors (Figure 17 and Figure 18). The fuse selection is based on the knowledge of the fuse-link maximum DC voltage rating at time constants lower than 1 ms.

In case of multi-inverters systems (Figure 19) the fuses are installed on the DC side of each inverter and will interrupt the capacitor discharge currents from all capacitors in all other feeders (they are in parallel) and the DC current supplied by the DC power source. The fuse selection is based on the knowledge of the fuse-link maximum DC voltage rating at time constants lower than 1 ms.

Condition 1 for fuse voltage selection: Since the fuse-link is arcing under a DC voltage it is necessary to specify the maximum voltage value U_{PM} under which the fuse can start arcing. This value is a fuse-link characteristic and it allows checking the following condition:

$$U_P \leq U_{PM}$$

Condition 2 for fuse voltage selection: Under such a peak value the arc can restrike inside the fuse-link. Therefore the initial source voltage value E must not exceed a maximum value E_M.

$$E \leq E_M$$

15.2.4.3 Maximum arc voltage

IEC 60146 applies.The fuse manufacturer publishes values of maximum arc voltage referring U_P.

15.2.5 I^2t characteristics

The fuse manufacturer publishes in his literature pre-arcing I^2t and total I^2t.

15.2.6 Breaking range

15.2.6.1 Supplementary requirements for fuse-links for the protection of semiconductor devices

IEC 60269-4, *Low-voltage fuses – Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices*, used the name VSI for the protection of Voltage Source Inverters. IEC 60269-4 includes specific test requirements for fuse-links that can then be **to** assigned a VSI voltage rating. These tests are, due to test laboratory capabilities, the best available at the moment for application with high frequency short circuit currents

15.2.6.2 Frequencies

Inverter applications with frequencies lower than 1 kHz are covered by this document. For frequencies higher than 1 kHz consult the fuse manufacturer or their literature.

16 Fuses in enclosures

16.1 General

When fuses are installed in enclosures having restricted heat dissipation, their operating temperature may reach a level that changes their standardized characteristics. The conditions for operation in service according to IEC 60269-1 consider free air with ambient temperature up to 40 °C.

There is no general rule to determine the limits for the use of fuses in practical installations, with a confined space and whose fluid environment temperature is above 40 °C. In such cases, consult the fuse and equipment manufacturers.

16.2 Limiting temperature of utilization category gG fuse-links according to IEC 60269-2 – System A

Preliminary investigations show that the limiting blade temperature of 130 °C is appropriate. It is suggested to use this temperature limit to verify the temperature rise test in fuse gear assemblies.

This gives satisfactory results for gG fuse-links according to IEC 60269-2, system A. The advantages of measuring the blade contact temperature against ambient air or terminal temperature are as follows:

– closest accessible test point to fuse-element;
– dependable temperature measurement on solid metal contacts;
– applicable to all fuse gear designs.

The limiting temperature of 130 °C is a maximum for short-time operation. In the case of continuous operation a temperature limit of 100 °C is recommended.

16.3 Other fuse-links

For other fuse-links or unusual service conditions, the user should consult the fuse manufacturer.

17 DC applications

17.1 General

Power d.c. sources are more and more used and the application will increased in the near future such as for distributed generation and for applications supplied from d.c. sources: wind power, hydropower, PV systems, geothermal energy, fuel cells, electrical vehicles charging and/or supplying an installation, batteries and other power storage applications, distribution networks, intermediate direct current links for multiple drives, d.c. / d.c. as well as a.c. / d.c. converters and control circuits.

Some d.c. power supplies have different characteristics than a.c. sources. It is the case for batteries that serves a constant power and PV cells considered to be a current source. Consideration of the types of d.c. power sources need to be taken into account when protective measures are applied and when protective devices and equipment are selected.

17.2 Short-circuit protection

Current-limiting fuses are generally suitable for both a.c. and d.c. applications. The d.c. performance of fuse-links is different from a.c. performance and a.c. ratings cannot be used for d.c. applications. There is no simple rule that safely converts an a.c. voltage rating of a fuse-link to d.c. voltage rating. While in a.c. circuits the power factor is the major parameter to be considered, the time constant T = L/R (see Figure 13) is the determining factor in d.c. circuits. As the time constant increases, the maximum d.c. operating voltage decreases. The d.c. breaking capacity of a fuse-link is found by testing it in a representative circuit.

Under d.c. short-circuit conditions, the fuse operation is similar to a.c. behaviour (see Figure 3). The cut-off currents cannot be taken from the available a.c. cut-off current curves, since they are dependent on the time constant of the circuits. DC values are found in fuse manufacturers' literature or are determined by tests.

Polarity need not to be considered with fuses, as it may be necessary for other devices.

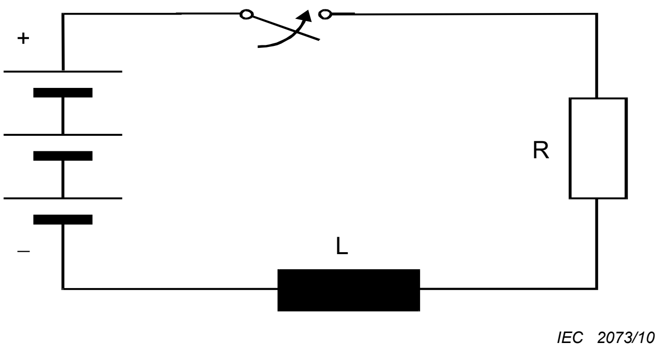
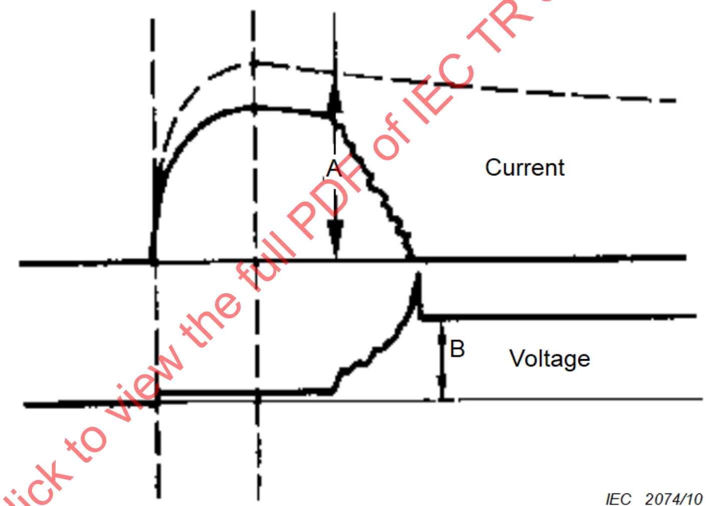


Figure 13 – DC circuit

17.3 Overload protection

Under overload conditions, i.e. non-current-limiting operation, fuse operation is different in a.c. and d.c. circuits (see Figure 14). As there is no periodic current zero, the d.c. voltage rating is lower than the a.c. voltage rating.



Key

A Prospective current

B Recovery voltage

Figure 14 – DC breaking operation

DC voltage ratings marked on fuse-links according to IEC 60269-2 are related to a time constant of 20 ms with a breaking capacity of at least 25 kA. Different voltage ratings apply for higher or lower time constants and may be taken from the fuse manufacturer's literature or determined by tests. The typical operational voltage ratings of d.c. fuses are given in Table 5. The time constants of some typical applications are given in Table 8.

Table 8 – Time constants of typical d.c. circuits

Application	Time constant ms
Industrial d.c. control and load circuits	≤ 10
Battery supplies for UPS	≤ 5
DC motors and drives	20 to 40
Magnets and field supplies	Up to 1 000

17.4 Time-current characteristics

Average time-current characteristics as supplied by fuse manufacturers give the r.m.s values of the operating currents, which are identical to the d.c. values under steady-state conditions. Under transient conditions, the instantaneous and r.m.s values may be significantly different. Thus, the time-current characteristic is dependent on the time constant of the faulted circuit (see Figure 15).

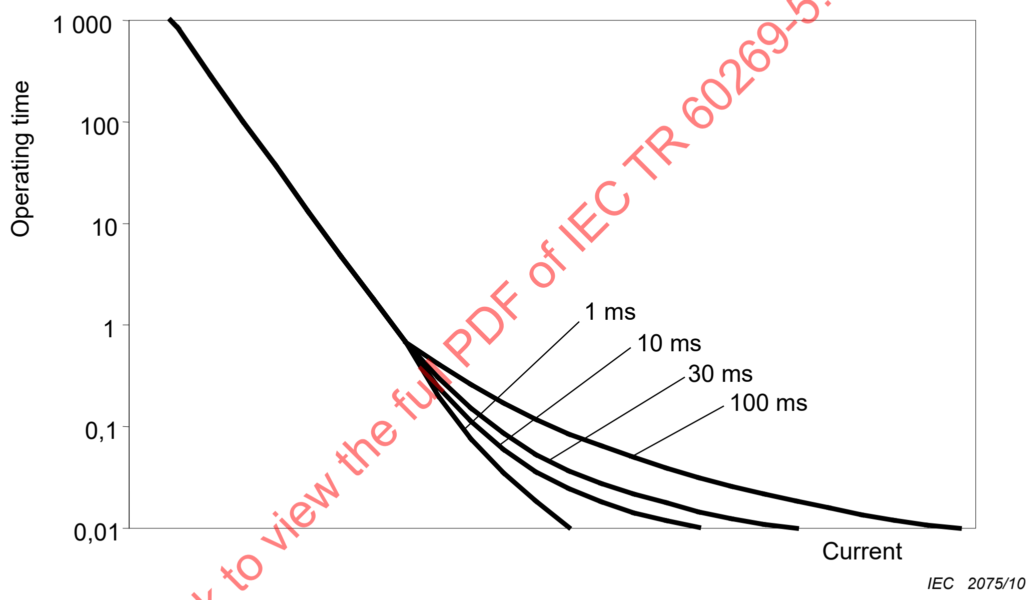


Figure 15 – Fuse operating time at various d.c. circuit time constants

18 Automatic disconnection for protection against electric shock for installations in buildings

18.1 General

A current-limiting fuse-link is a protective device which is able to provide excellent circuit protection. It can be used for protection against electric shock by automatic disconnection of supply.

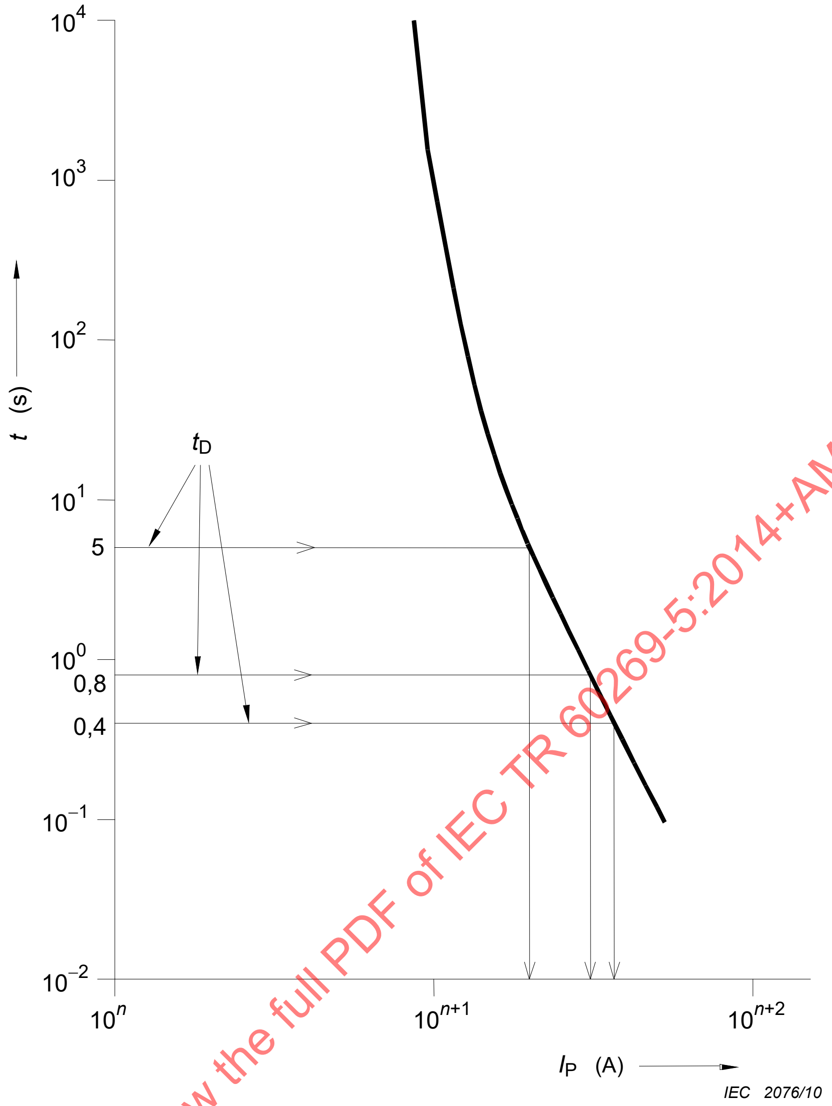
Protection by automatic disconnection of supply is dealt with in IEC 60364-4-41:2005, specifically in 413.1.

There are three basic systems of low-voltage distribution networks (TN, TT and IT).

18.2 Principle of the protection

Protection by automatic disconnection of supply is based on the fuse-link operation, which disconnects the supply circuit. In the event of a fault between a live part and an exposed (conductive) part or protective conductor, in the circuit or equipment, a prospective touch voltage exceeding 50 V a.c. or ripple-free 120 V d.c. must not persist long enough to cause harmful physiological effects to a person. Irrespective of the touch voltage, a disconnecting time not exceeding 5 s is allowed under certain circumstances. For some types of systems (TN, IT) shorter disconnecting times are required . Refer to examples in 18.3.

To determine the conditions for disconnecting the supply source with current-limiting fuse-links, the time-current characteristic shall be available. First, the required time for disconnection shall be considered according to the type of equipment protected, the type of system earthing and the environment. Second, the current I_a, which causes the operation of the fuse-link, is determined. The method is shown in Figure 16. Third, the current I_a is used to calculate the maximum permissible impedance of the fault loop or earth resistance.



Key

t Maximum operating time

I_P Prospective current

t_D Disconnecting times

Figure 16 – Time-current characteristic

18.3 Examples

Example 1: System TN, 230/400 V

Procedure: Using Table 41A of IEC 60364-4-41:2005 for U_o = 230 V, read the time for necessary automatic disconnection: 0,4 s. Then find the current I_a in Figure 16. The maximum permissible impedance of the fault loop can then be calculated according to the following formula:

$$Z_s \leq \frac{U_o}{I_a}$$

where

Z_s is the fault loop impedance including the source, the live conductor up to the point of the fault and the protective conductor between the point of the fault and the source;

I_a is the current causing the fuse operation within the time stated as a function of the nominal voltage U_o or, under the condition stated within a conventional time not exceeding 5 s;

U_o is the nominal voltage to earth.

Example 2: System TT, 230/400 V

Procedure: According to IEC 60364-4-41, a disconnecting time of 5 s is required. Determine the current I_a in Figure 16. The maximum permissible earth resistance can then be calculated according to the following formula:

$$R_A \leq \frac{50}{I_a}$$

where R_A is the total earthing resistance.

Example 3: System IT, 230/400 V, neutral not distributed, calculation for the second fault in the system.

Procedure: Read from IEC 60364-4-41 for U_o = 230 V, time for necessary automatic disconnection: 0,4 s. Then find out the current I_a in Figure 16. The impedance of the fault loop can then be calculated according to the following formula:

$$Z_s \leq \frac{\sqrt{3}\,U_o}{2\,I_a}$$

Example 4: System IT, 230/400 V, neutral distributed. Calculation for the second fault in the system.

Procedure: Read from IEC 60364-4-41 for U_o = 230 V, time for necessary automatic disconnection 0,8 s. Then find out the current I_a in Figure 16. The impedance of the fault loop can then be calculated according to the following formula:

$$Z_s' \leq \frac{U_o}{2\,I_a}$$

19 Photovoltaic (PV) system protection

19.1 General

PV systems consist of individual PV modules connected in series to form a “string” of modules providing a solar generated voltage which is the sum of the voltage of each cell. One or more strings may then be connected in parallel to provide a higher current level. These parallel combinations of strings are called arrays. In cases of large PV generators where multiple arrays are connected in parallel to provide even larger current levels, they are called sub-arrays. The d.c. currents generated must be changed into a.c. in order to be utilized by the power grid so an inverter (or inverters) must also be part of the system. Some PV systems contain a battery or other means of storing dc energy to improve reliability and deliver power when the sun is not present.

PV modules are inherently current-limiting and will withstand any current up to their rated short-circuit current I_{SC_STC} (see NOTE) and occasional over-currents due to irradiance levels exceeding the value under standard test conditions. Therefore, no fuse or protective overcurrent device is needed to protect the modules against forward overcurrents.

NOTE STC (standard test conditions): PV cell temperature: 25 °C, irradiance: 1 000 W/m^2, relative air mass factor: AM 1,5

PV modules will be damaged by reverse currents exceeding their reverse current withstand capability $I_{MOD\_REVERSE}$ as stated by the module manufacturer. Reverse currents can occur due to a number of conditions including shading and faulty modules. The effects of reverse fault currents include permanent damage to PV modules, reduced efficiency, damaged conductors, and possible electric arcs and fire. Therefore a fuse should be installed in series with each string to prevent reverse currents from other strings connected in parallel from damaging the module

The interconnecting wire and cables used to connect sub-arrays and arrays will be thermally damaged due to overcurrents beyond their rated current if allowed to persist. Therefore a fuse should be installed in each array conductor.

The following guidance for the selection of PV string fuses applies primarily to PV generators without storage batteries or with inverters that cannot back-feed from the grid. A PV system with other components, (such as batteries, converters, capacitors, etc.) will each require their own overcurrent protection. These components will not be protected by fuses installed to protect the string or array.

19.2 Selection of PV fuse-links

19.2.1 Fuse utilization category

Fuse-links specifically for PV module and array protection are described in IEC 60269-6 and are marked “gPV”. No other fuse utilization categories are suitable.

19.2.2 PV string fuses

PV string fuses are selected based on the reverse current withstand capability of the modules $I_{MOD\_REVERSE}$. PV module manufacturers provide these values as a multiple of I_{SC_STC}, or state a maximum fuse current rating. (Contact the module manufacturer for this information.)

No string fuse is required in PV systems with only one or two strings in parallel; since currents cannot exceed the reverse current withstand capability of the PV modules; providing the rating of the string cables is not exceeded, if the cable rating were to be exceeded then a gPV fuse link should be included to protect the cable. For PV systems with three strings or more connected in parallel, fuse protection is always required.

19.2.3 Fuse replacement

Fuse-switch combination units are recommended to permit safe fuse-link replacement.

19.2.4 Unearthed or Ungrounded PV Systems

Unearthed (called ungrounded in some countries) PV systems require fused over-current protection in both positive and negative poles of the PV strings.

19.2.5 Functional earthing fuses

Fuses may be used for the PV arrays earthing circuit protection. (Functional earthing fuse-link arrangements can be found in IEC 60364-7-712:2002, 4.101 and 532.103 and Table 101 and these recommendations should be followed.)

19.2.6 PV array and PV sub-array fuses

PV array and PV sub-array fuses must be installed to interrupt over-currents in these conductors before such current can cause a temperature rise damaging the insulation (see 19.2.10 for selection guidance).

19.2.7 Fuse monitoring

Fuse monitoring is recommended to identify fuse operation and to permit rapid investigation and repair of the string or array minimizing the loss of generated power.

19.2.8 Breaking capacity

PV string and array fuses are d.c. rated and must have a rated breaking capacity equal to or greater than the maximum expected fault current of the PV system.

19.2.9 Voltage of gPV fuses

The rated voltage Un of the fuse shall be equal to or greater than the maximum open circuit voltage V_{OC} of the PV array:

$$U_n \geq 1{,}2\ V_{OC\_STC}$$

A factor of 1,2 is used since the open circuit module voltage is higher under low ambient temperatures down to -25 °C. Colder atmospheric conditions may require a larger factor (contact PV module manufacturer).

19.2.10 Rated current of gPV fuses

a) gPV fuses for strings:

gPV string fuses must interrupt the circuit before the reverse current withstand capability stated by the manufacturer module is exceeded. Therefore the following rule can be used for gPV fuses:

$$I_n \leq I_{MOD\_REVERSE}$$

IEC 60 364-7-712 provides the following guidelines for the rated current In of the string fuse-link:

$$1{,}5 \times I_{SC\_MOD} < I_n \leq 2{,}4 \times I_{SC\_MOD}$$

b) gPV- PV array and sub-array fuses

IEC 60 364-7-712 provides the following guidelines for the rated current *I*n of the array and sub-array fuse-link:

$$1{,}25 \times I_{SC\ S\_ARRAY} < I_n \leq 2{,}4 \times I_{SC\ S\_ARRAY}$$

In addition, the rated current of the cables must be greater than that of any series fuse-link utilised.

20 Protection of wind mills

There are a number of key sections of windmill generators where fuse-links are used to provide protection. The final output voltage of windmill generators will vary greatly depending on the local grid connection. Many windmill systems are employing 690 V a.c. as the operating voltage within the generator.

Fuse-links are used in many parts of the installation, including:

- Control of the pitch of the rotor
- Control of nacelle direction
- Protection of semiconductors in the rectifier and inverter
- Protection of control equipment
- Protection of output transformer or grid link components

Selection of the fuse-links for the individual applications within the windmill are covered elsewhere in this guide. When applying fuse-links in windmills, appropriate de-ratings will need to be applied for temperature extremes and/or vibration requirements which may be outside the ranges specified within the standard. In such cases the fuse-link manufacturer should be consulted. If the application area has extreme environmental conditions which exceed those described in the standard, such as extreme salt atmosphere, special fuse-links may be required.

21 Guidance for the selection of a fuse for the protection of Battery systems

21.1 General

This clause is limited to the use of Battery fuse-links in circuits having the characteristics generally found in electrical energy storage systems of the d.c. Installation. It is the object of this annex to explain the selection of the fuse-links.

21.2 Voltage characteristics

21.2.1 Rated voltage

The rated voltage of the fuse-link selected shall be higher than the maximum voltage of the battery system.

In case of polarity inversion protection one fuse link must be installed for each battery polarity. Each single fuse must be able to interrupt the short circuit current under maximum voltage of the system.

21.3 Current carrying capability

21.3.1 Rated current

The rated current of the fuse-link selected shall take into account the operation current profile of the application. Ambient temperature may require higher current ratings of the fuse-link. In such case the manufacturer should be consulted.

21.4 Breaking capacity

The maximum short circuit current of the battery or battery module shall be lower than the rated breaking capacity of the fuse-link.

Annex A
(informative)

Coordination between fuses and contactors/motor-starters

A.1 General

Subclause 13.2 of this technical report provides guidance to select a fuse in place of (replacement fuse) the one that is specified by the contactor or motor-starter manufacturer. This annex gives additional information to select the initial fuse-link.

The coordination between motor-starters and the fuses which protect them is covered in IEC standards by test requirements such as those in the IEC 60947 series, in particular Parts 1 and 4.

Overcurrent protection of other equipment, such as motors, conductors, etc., is not covered by this annex.

A.2 Examples of suitable fuse-links used for motor protection

Recommendations for suitable fuse-links for use in combination with a contactor/motor-starter can be found in manufacturers' catalogues. The manufacturer of a contactor/motor-starter in accordance with IEC 60947-4-1 should also recommend a suitable choice of SCPD on the basis of tests he has made. The advice of the manufacturer is the best guide to the optimum choice of fuse-links for his range of products.

The current rating of the fuse most suitable for the protection of a given motor depends upon the full-load current of the motor and the magnitude and duration of its starting current. The most suitable rated current also depends upon the category of the fuse-link (gG, gM, aM, gD or gN, etc.) as is illustrated in the examples given in Table A.1 of typical fuses used in different countries in conjunction with a three-phase direct-on-line starter with a motor full-load current of 28 A. The examples are merely illustrative, and assume that the starting time is less than 10 s, that the maximum starting current does not exceed seven times full-load current, and that starts are infrequent.

Table A.1 – Examples of typical fuse-link ratings used for motor-starter protection illustrating how the category of fuse-link can influence the optimum current rating

Fuse type	Origin	Suitable rating
gG	General purpose IEC fuse	63 A
gM	Motor circuit fuse	32 M 63
aM	Back-up fuse	32 A
gN	North American fuse	70 A
gD	North American time-delay fuse	40 A

A suitable fuse-link rating should also ensure that the requirements of Clauses A.4, A.5 and 13.4 are met by the particular type and rating chosen. Of course, if the fuse-link is of the same type, rating and manufacture as was used by the manufacturer of the contactor/motor-starter in his tests, then all these requirements will be satisfied.

It is important to note that the manufacturer's recommendation should be observed if it differs from the value given in the table above.

NOTE 1 The examples are for an average motor-starting duty at a motor full-load current of 28A.

NOTE 2 For explanation of fuse type gM, see 5.7.1 of IEC 60269-1:2006.

A.3 Values of I^2t and cut-off current observed in successful tests of fuse-link/motor-starter combinations worldwide

Studies carried out by the IEC committee on "Fuses" in collaboration with motor-starter manufacturers worldwide have shown no difficulty in achieving satisfactory coordination with contactors using fuses selected according to IEC 60269-2.

The main target is to avoid welding contacts on starter operating components (such as contactors circuit breaker and switches). To achieve this objective the fuse cut-off current must be lower than withstand peak current value sustainable by contacts. This information can be observed on the characteristic curves.

The rated short-circuit current (I_{cm}) can only a be determined by testing the contactor, breaker or switch with a suitable current limiting fuse.

The results of an extensive survey of coordination tests in many countries were collated, and found to lie within a relatively narrow band of values of I^2t and cut-off current. These results are illustrated in Figures A.1, A.2 and A.3.

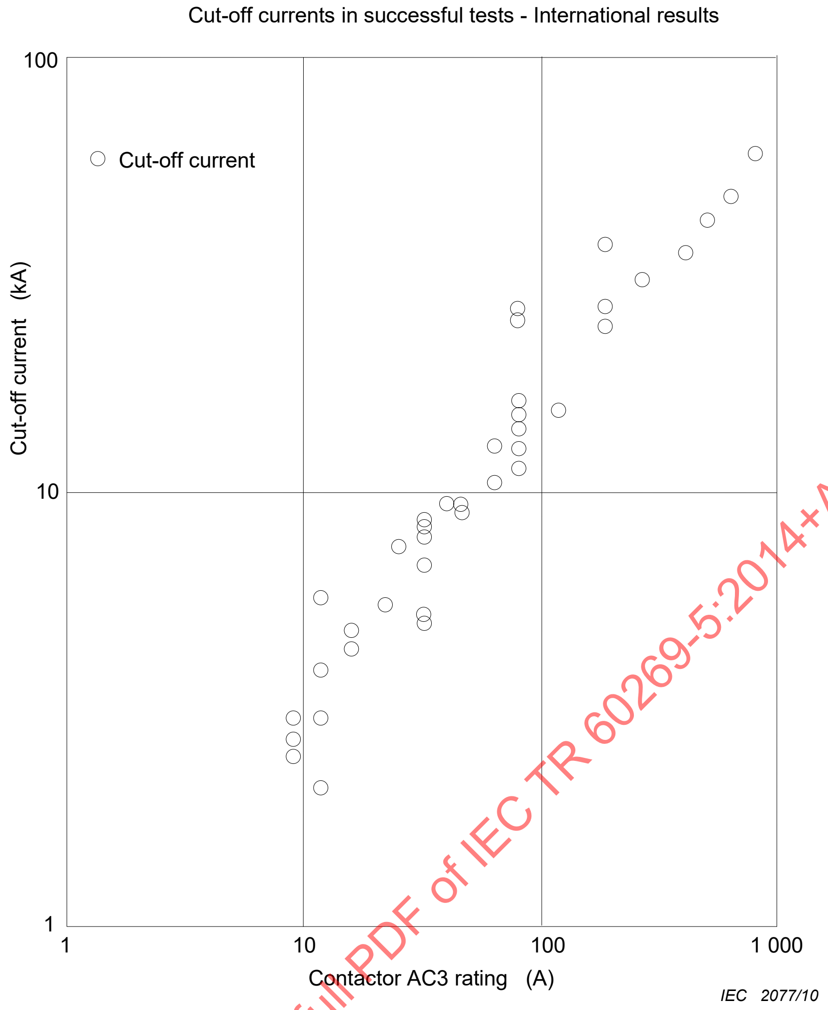


Figure A.1 – Collation of cut-off currents observed in successful coordination at I_q

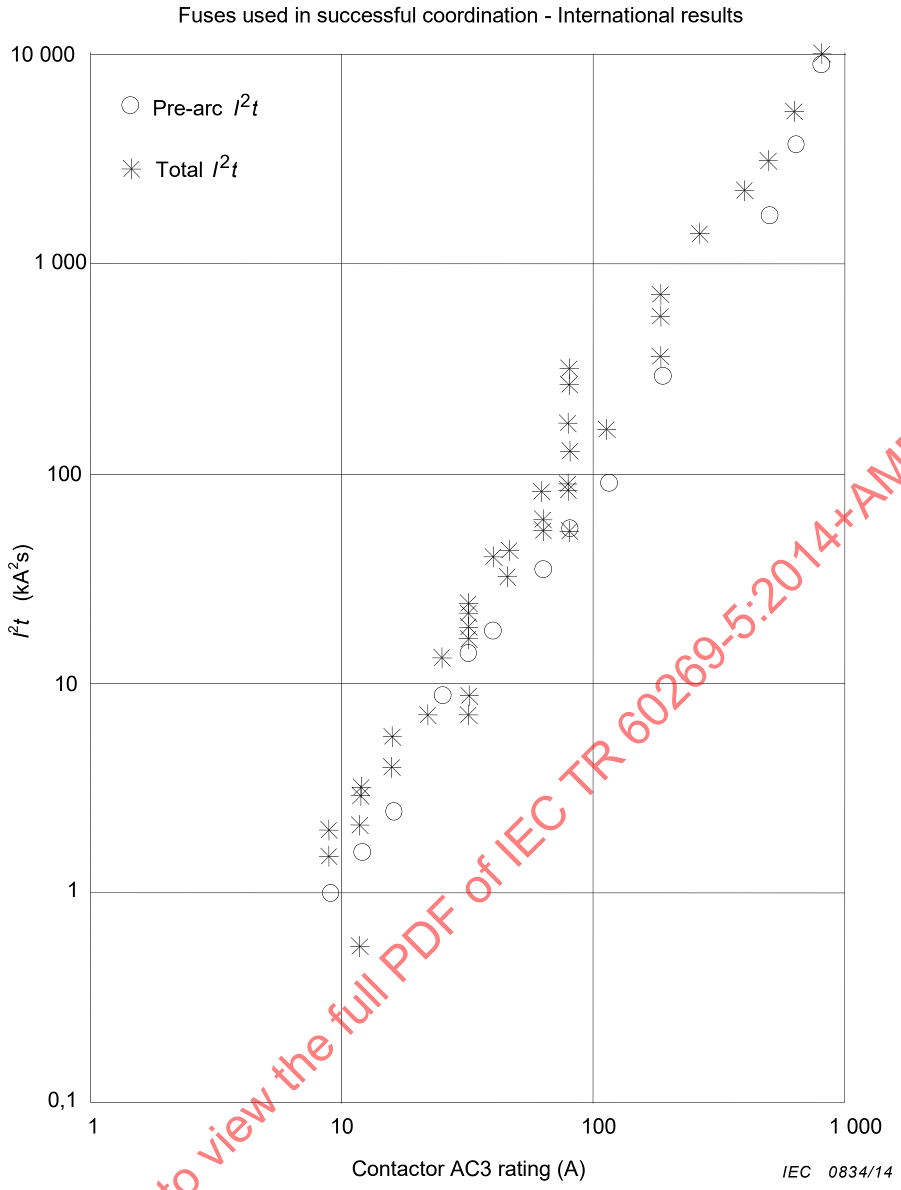


Figure A.2 – Pre-arcing and operating I^2t values of fuses used in successful coordination tests as a function of contactor rated current AC3

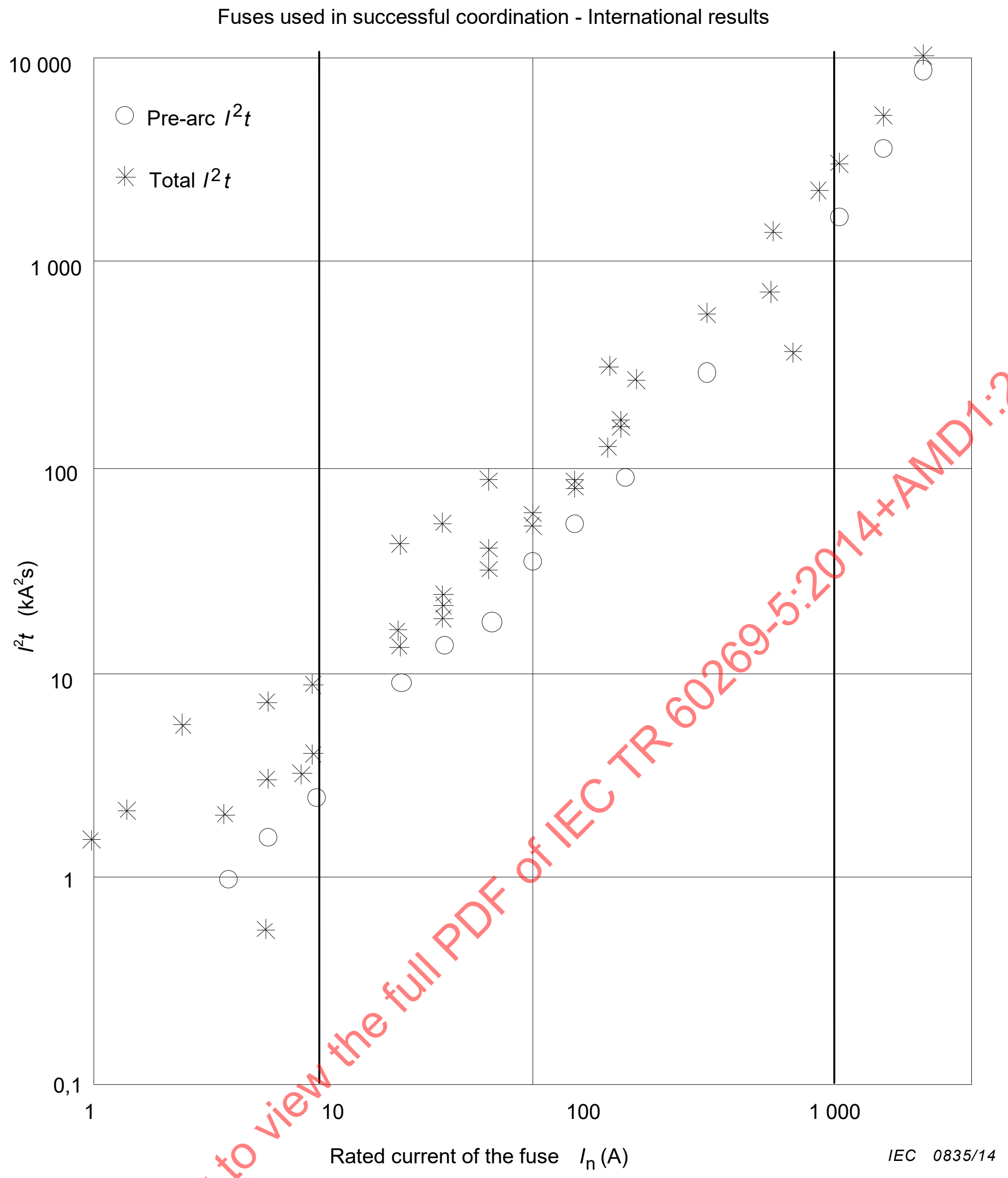


Figure A.3 – Pre-arcing and operating I^2t values of fuses used in successful coordination tests as a function of fuse rated current I_n

A.4 Criteria for coordination at the rated conditional short-circuit current I_q

A.4.1 General

IEC 60947-4-1:2009, 8.2.5 prescribes this test with the short-circuit test requirements given in 9.3.4. The acceptable damage criteria depends on the type of coordination.

A.4.2 Maximum operating I^2t and cut-off current

When a fuse is the SCPD being used, I_q can be any value up to 50 kA or more. Under these conditions, the most important parameters are the operating I^2t of the fuse-link (under the conditions of the three-phase coordination test with the starter in series with the fuse) and the maximum cut-off current of the fuse.

Values can be provided for all voltage systems and maximum I^2t values corresponding to a test voltage equivalent to the three-phase coordination test.

This will also limit the peak cut-off current, because the values are related. It has been verified, on the basis of international coordination tests at prospective currents from 50 kA to 200 kA, that at a prospective current of I_p (A), the cut-off current I_c (A) of a fuse-link of rated current I_n (A) is equal to or less than the value given by the formula:

$$I_C = 20 \cdot \sqrt[3]{I_n^2 \cdot I_p}$$

A.4.3 Guidance for choosing the maximum rated current of an alternative fuse type

From the successful results of coordination type tests at I_q, the starter manufacturer can plot the curves of the maximum I^2t withstand of the contactor and the overload relay and the maximum peak let-through current as a function of the rated operational current of the motor-starter (I_e). Such a curve is shown in Figure A.4a.

A fuse-link of a different utilization category cannot be used without further testing unless its I^2t and I_c values are equal to or less than the maximum values observed in the tests used to plot the curves. However, it may be possible to get data from the fuse manufacturer for operating I^2t values and cut-off currents measured under comparable conditions, (i.e. at an equivalent test voltage and at a prospective current equal to I_q). These will be plotted as a function of rated current I_n of the fuse. Typical curves derived from such data are shown for alternative fuses of type A in Figure A.4b and for fuses of type B in Figure A.4c. These must be plotted on the same scale as in Figure A.4a.

Note that without further testing a fuse with larger I^2t or cut-off current cannot be used. Therefore for a starter rated at I_e = X (A) the maximum permissible rated current of fuses of type A is seen to be Y (A), (see Figure A.4), the I^2t of rated current Y (A) is acceptable, but the cut-off current would be too high. In the case of replacement fuses of type B, however, the limiting factor is the I^2t, and Z′ (A) is therefore the highest permissible rated current to achieve satisfactory coordination with the starter at I_q (see Figure A.4).

Fuse-link types A and B could be any of the utilization categories used for motor circuit protection listed in Table A.1.

This procedure may lead to the choice of fuses of excessively low nominal current, because it does not take the additional impedance of the starter into account (e.g. in case the rated operational current of the starter is below 10 A, the overload relay impedance may have a noticeable influence). In these cases, if ~~tahe~~ the additional impedance is not taken into account to estimate the prospective short-circuit current more precisely then the fuses may not be suitable to protect the starter. Direct tests will then be needed to verify coordination with fuses of higher ratings than those determined by the procedure outlined in this technical report.

A.4.4 Further guidance

In addition, the following points should be noted:

High values of clearing time increase the risk of welding of the contacts of the contactor. In evaluating the "clearing time" for this purpose consider the current is "cleared" when it remains only a small percentage (ca. 5 %) of its limiting peak value. This value may be difficult to obtain, and an acceptable method is to assume that the limiting curve is a sinusoidal waveform and from the operating I^2t (value = $[I^2t]$ in A^2s) and the peak let-through current (value = $\hat{I}$ in A) an "equivalent clearing time" t_{eq} is given by:

$$t_{eq} = \frac{2 \times [I^2 t]}{\hat{I}^2}$$

A satisfactory value for this equivalent clearing time has been found to be: $t_{eq} < 5$ ms.

NOTE 1 Risk of contact welding increases, if these high currents still persist 5 ms after the beginning of the short-circuit.

The operating I^2t of the fuse in the case of a three-phase circuit with unearthed phase is equivalent to the operating I^2t with an applied voltage of $\sqrt{3} \div 2$ times the phase-to-phase voltage.

NOTE 2 This technique gives the maximum rating for coordination at prospective current I_q. A lower rating may be necessary to provide adequate coordination for test currents I_c and/or "r". The type of coordination obtainable is determined in IEC 60947-4-1 by the results of tests at all these current levels. Guidance for proper coordination at these levels is provided in Clauses A.5 and 13.4.

A.5 Criteria for coordination at test current "r"

IEC 60947-4-1:2009, 8.2.5 prescribes this test with the short-circuit test requirements given in 9.3.4. The acceptable damage criteria depends on the type of coordination. The test current "r" (I_r) depends on the rated operational current I_e of the starter (see Table A.2).

Table A.2 (Table 12 of IEC 60947-4-1:2009) – Value of the prospective test current according to the rated operational current

Rated operational current **I_e (AC-3)** A	**Prospective current "r"** kA
$0 < I_e \leq 16$	1
$16 < I_e \leq 63$	3
$63 < I_e \leq 125$	5
$125 < I_e \leq 315$	10
$315 < I_e \leq 630$	18
$630 < I_e \leq 1\,000$	30
$1\,000 < I_e \leq 1\,600$	42
$1\,600 < I_e$	Subject to agreement between manufacturer and user

In order to be able to select a suitable fuse for adequate coordination at I_r, it is necessary to establish (from the results of type tests) curves similar to those in Figure A.4a, showing the maximum I^2t withstand of contactor and overload relay and the maximum peak let-through current at I_r as a function of I_e. Since I_r increases in steps, these curves are not continuous, and a typical set of curves will be similar to those shown in Figure A.5.The maximum acceptable ratings to give adequate coordination at I_r for each utilization category of fuse can then be established by the same method as was used to establish the maximum rating at I_q (using the method illustrated in Figure A.4 for choosing the correct rating of type A or type B fuse-links, based on the type of coordination desired, usually type 2 (see Clause A.6).

The fuse cut-off curves for this purpose may be derived from the fuse manufacturer's published cut-off characteristics (for type A or type B) using the method shown in Figure A.6. The characteristics thus derived are substituted for Figures A.4b and A.4c in order to make the evaluation at I_r, with Figure A.5 substituted for Figure A.4a.

The additional guidance given in A.4.4 applies to tests at I_r, except that the following value of t_{eq} has been found acceptable at this level of current: $t_{eq} < 6$ ms.

NOTE Due to the lower rate of rise of current than for I_q currents, the electrodynamic separation of contacts (and subsequent reclosing) occurs after a longer delay than observed for I_q currents. For this reason, the acceptable t_{eq} for current "r" is greater than the value acceptable for current I_q (see NOTE 1 of A.4.4).

A.6 Types of coordination

IEC 60947-4-1 categorizes types 1 and 2 coordination between fuses (SCPDs) and motor-starters. Performance requirements are shown in Table A.3.

Table A.3 – Types of coordination

Performance requirements	Type 1	Type 2
The short-circuit is successfully interrupted	yes	yes
Persons are not endangered	yes	yes
Conductors and terminals remain intact and undamaged	yes	yes
No damage to an insulating base which dislodges live parts	yes	yes
No damage to overload relay or other parts	no	yes*
No replacement of parts permitted during tests (other than fuses)	no	yes
No change in overload relay tripping characteristics	no	yes
Starter insulation level satisfactory after test	no	yes
* Easily separable welding of contacts permitted		

Generally, it is possible to find a suitable fuse-link to achieve type 2 coordination (the more desireable of the two) for a motor starter by following the guidance given in Clauses A.4, A.5 and A.6.

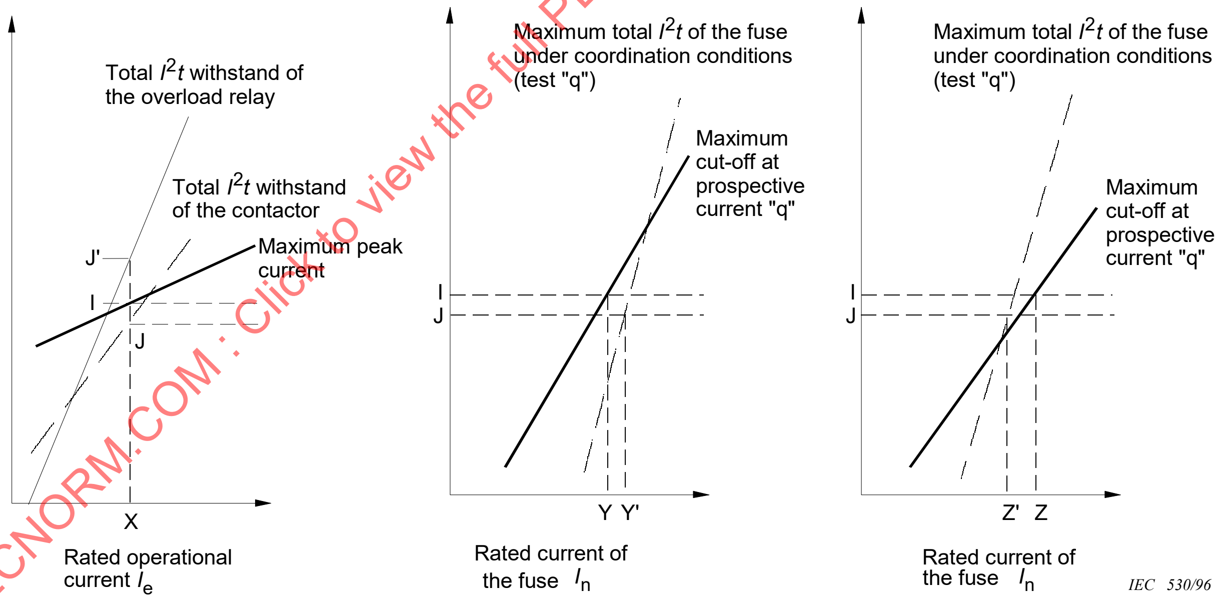


Figure A.4a – Contactor withstand at prospective current "q" (determined by the contactor manufacturer for his range of contactors)

Figure A.4b – I^2t and cut-off characteristics for fuses of type A: with cut-off current as the limitation criteria

Figure A.4c – I^2t and cut-off characteristics for fuses type B: with I^2t as the limitation criteria

NOTE Vertical scales: total I^2t values in A^2s and maximum peak current or cut-off current in kA are all plotted to the same scale.

Figure A.4 – Illustration of the method of selection of the maximum rated current of a fuse for back-up protection of a contactor of rating I_e = X amperes

Method: From Figure A.4a, the I^2t withstand of the contactor rated I_e = X (A) is seen to be J (A^2s) while that of the overload relay is seen to be J' (A^2s). J' is greater than J. Therefore, the lowest value J (A^2s) is chosen. The peak current withstand of the contactor at I_e = X (A) is seen to be I (kA).

To the right of Figure A.4a the I^2t and cut-off characteristics measured at a prospective current "q" of fuse type A (Figure A.4b) and fuse type B (Figure A.4c) are plotted on the same scale as in Figure A.4a.

For type A fuses, the cut-off current has a value of I (kA) for a fuse rated at Y (A), and a total I^2t of J (A^2s) at a rated current of Y′ (A). The lower of these ratings shall be selected. Y′ > Y, therefore the maximum rating of type A fuses to provide adequate protection is Y (A).

For type B fuses, the cut-off current has a value of I (kA) for a fuse rated at Z (A), and a total I^2t of J (A^2s) at a rated current of Z′ (A). The lower of these ratings shall be selected. Z > Z′, therefore the maximum rating of type B fuses to provide adequate protection is Z' (A).

This technique gives the maximum rating for coordination at I_q. It should be checked that this rating would also provide adequate coordination at I_{co} and I_r.

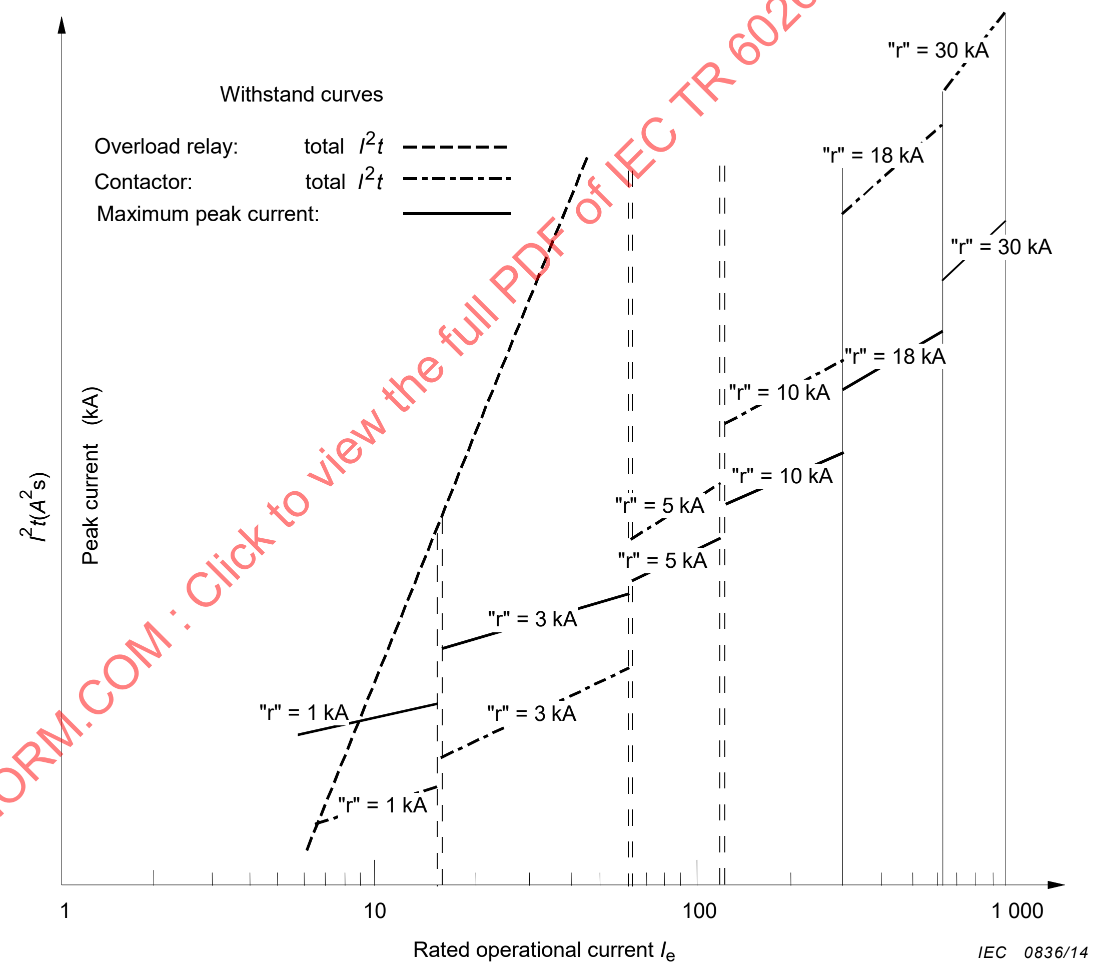
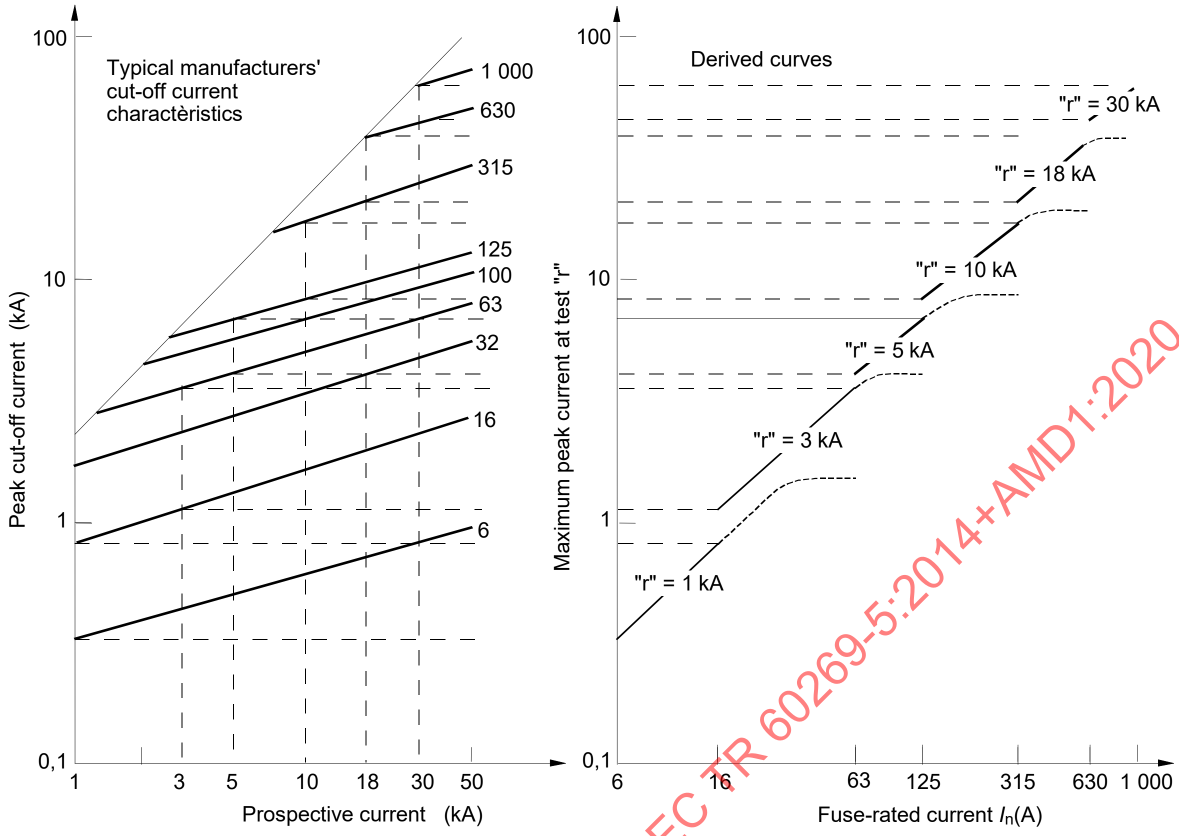


Figure A.5 – Withstand capabilities of a range of contactors and associated overload relays at test current "r"



NOTE 1 These values are maximum values. Actual peak currents will be lower due to the impedance of the contactor and its overload relay.

NOTE 2 Typical cut-off characteristics are generally obtained with a lower power factor than that used for test current "r". A correction may be necessary for values of test current "r" of 1 kA, 3 kA or 5 kA (in some cases cut-off currents of up to 20 % higher are observed at high power factor).

NOTE 3 Maximum peak currents for larger ratings cannot exceed the maximum peak (asymmetrical) of the prospective current at specified power factor. (Therefore the derived curves become constant at the maximum asymmetrical peak.)

NOTE 4 These derived curves can be used in the same way as illustrated in Figure A.4.

Figure A.6 – Illustration of a method of deriving curves of maximum peak current at test current "r" as a function of fuse rated current

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FINAL VERSION

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Low-voltage fuses –
Part 5: Guidance for the application of low-voltage fuses

IEC TR 60269-5:2014-03+AMD1:2020-12 CSV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

LOW-VOLTAGE FUSES –

Part 5: Guidance for the application of low-voltage fuses

FOREWORD

This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 60269-5 edition 2.1 contains the second edition (2014-03) [documents 32B/621A/DTR and 32B/624/RVC] and its amendment 1 (2020-12) [documents 32B/694/DTR and 32B/697A/RVDTR].

This Final version does not show where the technical content is modified by amendment 1. A separate Redline version with all changes highlighted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC 60269-5, which is a technical report, has been prepared by subcommittee 32B: Low-voltage fuses, of IEC technical committee 32: Fuses.

This second edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) recommendations for fuse operations in high altitudes added
b) more details for operational voltages added
c) recommendations for photovoltaic system protection added
d) numerous details improved

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

A list of all parts of the IEC 60269 series, under the general title: *Low-voltage fuses*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

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

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Fuses protect many types of equipment and switchgear against the effects of over-current which can be dramatic:

– thermal damage of conductors or bus-bars;
– vaporisation of metal;
– ionisation of gases;
– arcing, fire, explosion,
– insulation damage.

Apart from being hazardous to personnel, significant economic losses can result from downtime and the repairs required to restore damaged equipment.

Modern fuses are common overcurrent protective devices in use today, and as such provide an excellent cost effective solution to eliminate or minimize the effects of overcurrent.

LOW-VOLTAGE FUSES –

Part 5: Guidance for the application of low-voltage fuses

1 Scope

This technical report, which serves as an application guide for low-voltage fuses, shows how current-limiting fuses are easy to apply to protect today's complex and sensitive electrical and electronic equipment. This guidance specifically covers low-voltage fuses up to 1 000 V a.c. and 1 500 V d.c. designed and manufactured in accordance with IEC 60269 series. This guidance provides important facts about as well as information on the application of fuses.

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.

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IEC 60269-4, *Low-voltage fuses – Part 4: Supplementary requirements for fuse-links for the protection of semiconductor devices*

IEC 60269-6, *Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems*

IEC 60364-4-41:2005, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-4-43:2008, *Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent*

IEC 60364-5-52, *Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems*

IEC 60947 (all parts), *Low-voltage switchgear and controlgear*

IEC 60947-3:2015, *Low-voltage switchgear and controlgear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

IEC 60947-4-1:2009, *Low-voltage switchgear and controlgear – Part 4-1: Contactors and motor-starters – Electromechanical contactors and motor-starters*

IEC/TR 61912-1:2007, *Low-voltage switchgear and controlgear – Overcurrent protective devices – Part 1: Application of short-circuit ratings*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
switch (mechanical)
mechanical switching device capable of making, carrying and breaking currents under normal circuit conditions, which may include specified operating overload conditions and also carrying, for a specified time, currents under specified abnormal conditions such as those of short-circuits

Note 1 to entry: A switch may be capable of making but not breaking, short-circuit currents.

[SOURCE: IEC 60050-441:1984, 441-14-10]

3.2
disconnector
mechanical switching device that, in the open position, complies with the requirements specified for isolating function

Note 1 to entry: Some disconnectors may not be capable of switching load.

[SOURCE: IEC 60050-441:1984, 441-14-05, modified (modified definition and Note 1 to entry added)]

3.3
fuse-combination unit
combination of a mechanical switching device and one or more fuses in a composite unit, assembled by the manufacturer or in accordance with his instructions

[SOURCE: IEC 60050-441:1984, 441-14-04, modified (Note removed)]

3.4
switch-fuse
switch in which one or more poles have a fuse in series in a composite unit

[SOURCE: IEC 60050-441:1984, 441-14-14]

3.4.1
single-break and double-break
switch-fuse must be single break (it opens the circuit on one side of the fuse link) or double break (it opens the circuit on both sides of the fuse link)

3.5
fuse-switch
switch in which a fuse-link or a fuse-carrier with fuse-link forms the moving contact

[SOURCE: IEC 60050-441:1984, 441-14-17]

3.5.1
single-break and double-break
fuse-switch must be single break (it opens the circuit on one side of the fuse link) or double break (it opens the circuit on both sides of the fuse link)

3.6
Switching device SD
device designed to make or break the current in one or more electric circuits

Note 1 to entry: A switching device may perform one or both of these operations.

[SOURCE: IEC 60050-441:1984, 441-14-01, modified (Note 1 to entry added)]

3.7
short-circuit protective device SCPD
device intended to protect a circuit or parts of a circuit against short-circuits by interrupting them

3.8
overload protection
protection intended to operate in the event of overload on the protected section

[SOURCE: IEC 60050-448:1995, 448-14-31]

3.9
overload
operating conditions in an electrically undamaged circuit, which cause an over-current

[SOURCE: IEC 60050-441:1984, 441-11-08]

3.10
overcurrent
current exceeding the rated current

[SOURCE: IEC 60050-442:1998, 442-01-20]

3.11
rated conditional short-circuit current (of a switching device)
I_q
prospective current that a switching device, protected by a short-circuit protective device, can satisfactorily withstand for the operating time of that device under test conditions specified in the relevant product standard

3.12
selectivity of protection
ability of a protection to identify the faulty sections and/or phase(s) of a power system

Note 1 to entry: Whereas the terms “selectivity” and “discrimination” have a similar meaning according to the IEV definitions, this report prefers and uses the term “selectivity” to express the ability of one over-current device to operate in preference to another over-current device in series, over a given range of over-current. The effect of standing load current on selectivity in the overload zone is also considered.

[SOURCE: IEC 60050-448:1995, 448-11-06, modified (Note 1 to entry added)]

4 Fuse benefits

The current-limiting fuse provides complete protection against the effects of overcurrents by protecting both, electric circuits and their components. Fuses offer a combination of advantageous features, for example:

a) High breaking capacity (high current interrupting rating).

b) No need for complex short-circuit calculations.

c) Easy and inexpensive system expansion in case of increased fault currents.

d) High current limitation (low I^2t values).

e) Mandatory fault elimination before reenergizing.

Fuses cannot be reset, thus forcing the user to identify and correct the fault condition before re-energizing the circuit.

f) Reliability.

No moving parts to wear out or become contaminated by dust, oil or corrosion. Fuse replacement ensures protection is restored to its original level when the fuse is replaced.

g) Cost effective protection.

Compact size offers low cost overcurrent protection at high short-circuit levels.

h) Compact size offers economical overcurrent protections at high short-circuit levels

i) Safe, silent operation.

No emission of gas, flames, arcs or other materials when clearing the highest levels of short-circuit currents. In addition, the speed of operation at high short-circuit currents significantly limits the arc flash hazard at the fault location.

j) Easy coordination.

Standardized fuse characteristics and a high degree of current limitation ensure effective coordination between fuses and other devices.

k) Standardized performance.

Fuse-links designed and manufactured in accordance with IEC 60269 series ensure availability of replacements with standardized characteristics throughout the world.

l) Improved power quality.

Current-limiting fuses interrupt high fault currents in a few milliseconds, minimizing dips or sags in system supply voltage.

m) Tamperproof.

Once installed, fuses cannot be modified or adjusted thus preserving their level of performance and avoiding malfunction.

n) No maintenance.

Properly sized fuses require no maintenance, adjustments or recalibrations. They can remain in service providing originally designed overcurrent protection levels for many decades.

o) High level of energy efficiency.

The resistance and therefore the power dissipation of the fuse is very low compared with other protection devices. The magnitude of power loss compared to the power transmitted by rated current is much less than 0,1%.

p) Excellent personnel and equipment protection in case of arc flash.

q) Fuse-links will operate independent of the operation position of the fuse. The operation position is usually vertical. Other positions of use are permissible. The deratings of the manufacturers of the fuse must be observed.

Properly sized current limiting fuses operating in their current limiting range interrupt currents due to arcing fault in a few milliseconds, keeping arc energy well below hazardous and damaging levels.

5 Fuse construction and operation

5.1 Components

A fuse is a protective device comprising

- the fuse-link,
- the fuse-base,
- the fuse-carrier or replacement handle.

These components may be integrated in a fuse combination unit.

5.2 Fuse-construction

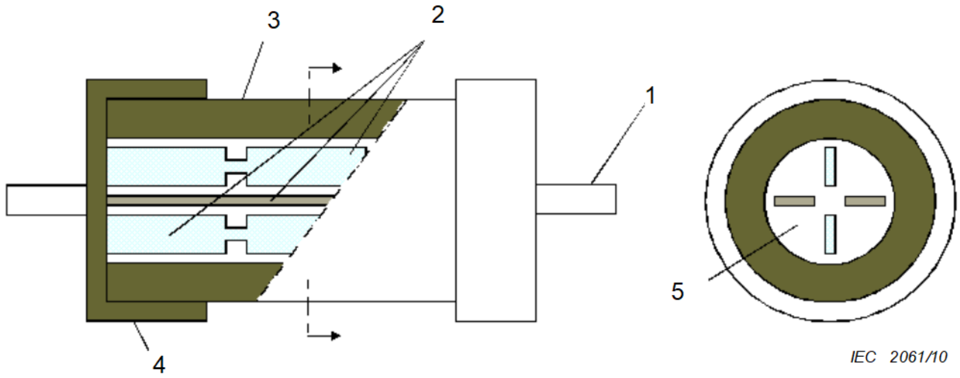
5.2.1 Fuse link

Figures 1 and 2 show the design of typical low-voltage fuse-links for industrial application. Such fuse-links are commonly called current-limiting or high breaking capacity fuse-links. Fuse-links according to IEC 60269-2 (fuses for industrial application) are available in current ratings up to 6 000 A.

Fuse-links according to IEC 60269-3 (fuses for household application) are available in current ratings up to 100 A.

The fuse-element is usually made of flat silver or copper with multiple restrictions in the cross-section. This restriction is an important feature of fuse design, normally achieved by precision stamping.

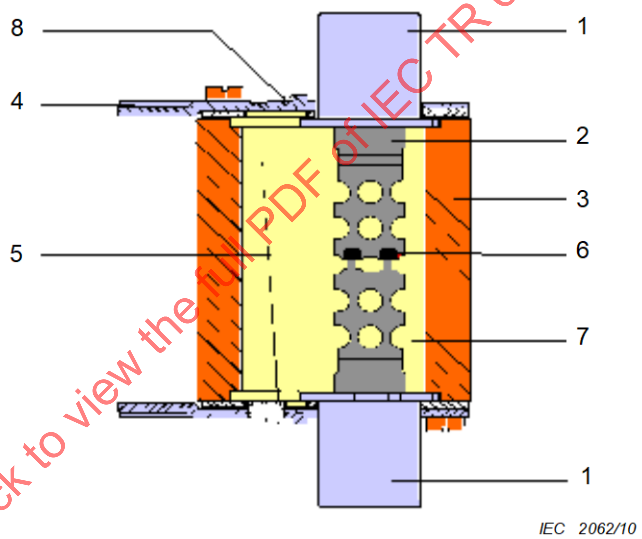
M-effect (see 5.3.3) is sometimes added to the fuse-element to achieve controlled fuse operation in the overload range. The purity of the fuse-element materials and their precise physical dimensions are of vital importance for reliable fuse operation.



Key

1 Blade contact
2 Fuse-elements
3 Fuse body
4 End cap
5 Filler

Figure 1 – Typical fuse-link according to IEC 60269-2



Key

1 Blade contact
2 Fuse-element
3 Fuse body
4 Endplate (with gripping lug)
5 Indicator wire
6 M-effect material
7 Filler
8 Indicator

Figure 2 – Typical fuse-link according to IEC 60269-2

5.2.2 Fuse-link contacts

Fuse-link contacts provide electrical connection between the fuse-link and fuse-base or fuse carrier. The contacts are made of copper or copper alloys and are typically protected against the formation of non-conductive layers by plating.

5.2.3 Indicating device and striker

Some fuses are equipped with indicators or strikers for rapid recognition of fuse-link operation. Fuses equipped with strikers also provide means for mechanical actuation (e.g. for a switch of remote signalling) as well as a visual indication.

5.2.4 Fuse-base

The fuse-base is equipped with the matching contacts for accepting the fuse-link, connecting means for cables or busbars and the base insulator.

5.2.5 Replacement handles and fuse-holders

Replacement handles or fuse-carriers, where applicable, enable changing fuse-links in a live system under specified safety rules. They are made of insulating material and subjected to tests as required for safety tools. For some systems, fuse-carriers are an integral part of the fuse-holder, eliminating the need for an external replacement handle.

5.3 Fuse operation

5.3.1 General

Fuses are designed to operate under both short-circuit and overload conditions. Typically short-circuits are current levels at or above 10 times the fuse's rating, and overloads are current levels below 10 times the fuse's rating.

5.3.2 Fuse operation in case of short-circuit

During a short-circuit, the restrictions (notches) all melt simultaneously forming a series of arcs equal to the number of restrictions in the fuse element. The resulting arc voltage ensures rapid reduction in current and forces it to zero. This action is called "current limitation".

Fuse operation occurs in two stages (see Figures 3a and 3b):

- the arcing stage (t_a): the arcs begin at restrictions and are then extinguished by the filler.
- M-effect (see 5.3.3) is sometimes added to the fuse-element to achieve controlled fuse operation in the overload range;

The operating time is the sum of the prearcing time and arcing time.

The energies generated by the current in the circuit to be protected during pre-arcing time and operating time are represented by the pre-arcing I^2t and operating I^2t values, respectively. The diagrams in Figure 3 illustrate the current-limiting ability of the fuse-link under short-circuit conditions.

Note that the fuse-link cut-off current i_c is well below the peak value of the prospective current I_P.

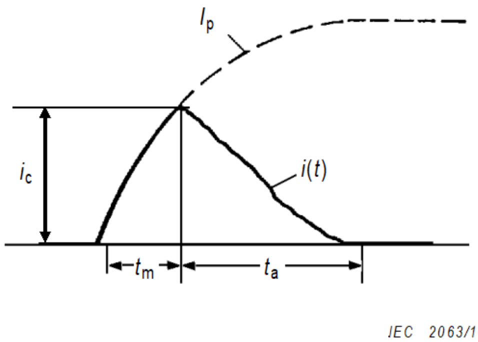


Figure 3a – DC current

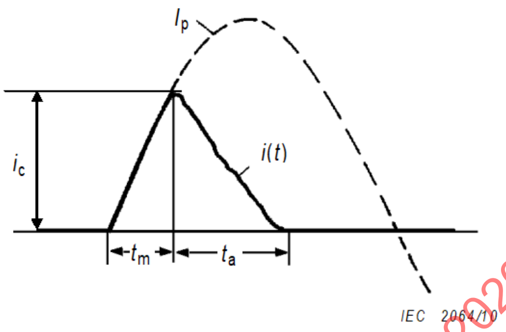


Figure 3b – AC current

Key

t_m pre-arcing time
t_a arcing time
I_p prospective current
i_c current limited by the fuse

Figure 3 – Current-limiting fuse operation

5.3.3 Fuse operation in case of overload

During an overload, the “M-effect” material melts and an arc forms between the two parts of the fuse element. The filler (typically clean granulated quartz) which surrounds the fuse element quickly extinguishes the arc forcing the current to zero. As it cools, the molten filler turns into a glass like material insulating each half of the fuse element from each other and preventing arc re-ignition and further current flow. Fuse operation still occurs in two stages (see Figures 4a and 4b):

- the pre-arcing (melting) stage (t_m): the heating of the fuse element to the melting point of the section containing the M-effect material. This period of time is typically longer than a few milliseconds and is inversely dependent on the magnitude of the overload current. Low level overloads result in long melting times from several seconds to several hours.
- the arcing stage (t_a): the arc initiated at the M-effect section is then extinguished by the filler. This time is dependent on the operating voltage
- Both stages make up the fuse operating time ($t_m + t_a$). The energy generated in the circuit by the overload current during pre-arcing (melting) time and operating time can still be represented by the pre-arcing I^2t and operating I^2t values, respectively; however under overload conditions the pre-arcing I^2t value is so high it provides little useful application data and the prearcing time is the preferred measure for times longer than a few cycles or few time constants. In this case, arcing time is negligible compared to the prearcing time.

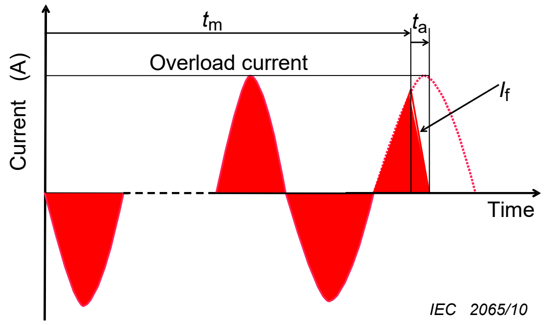


Figure 4a – AC current

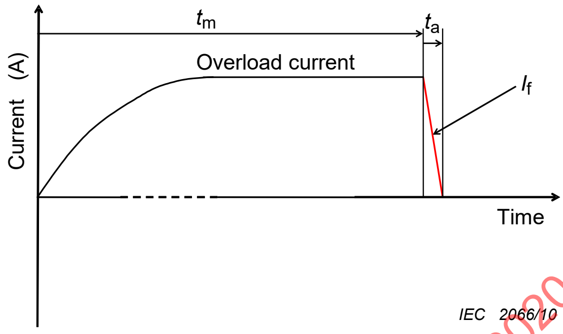
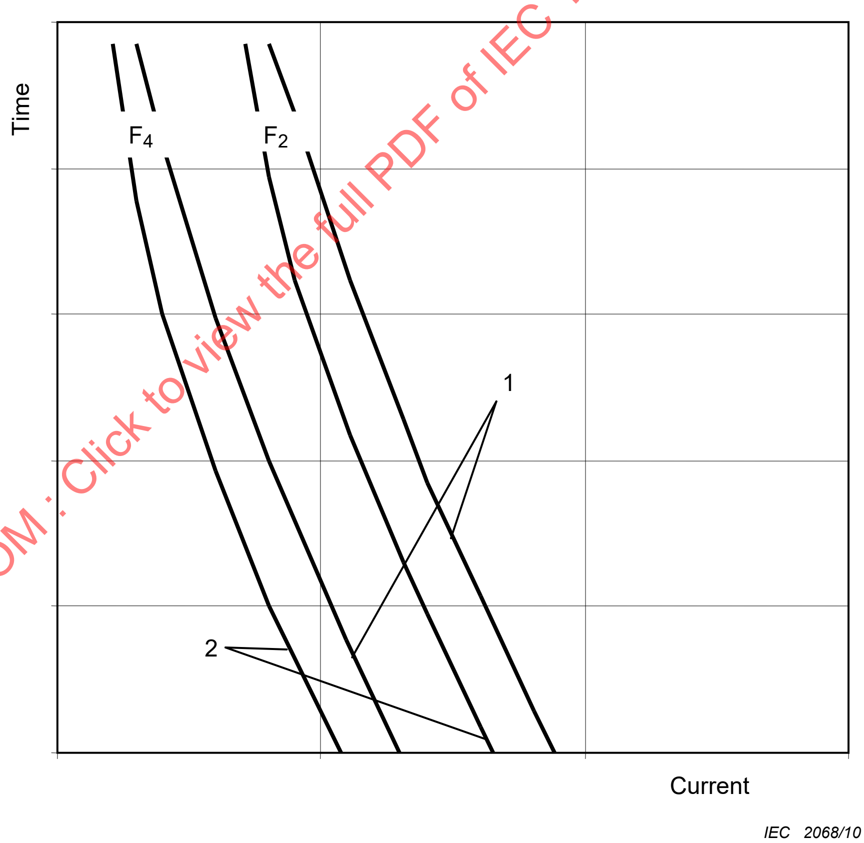


Figure 4b – DC current

Figure 4 – Fuse operation on overload

5.3.4 Fuse link pre-arcing time current characteristic:

The melting time of a fuse-link is therefore also termed the "pre-arcing" time. Fuse-links therefore have a very inverse time-current relationship (higher currents giving shorter pre-arcing times) as illustrated in Figure 5. This enables extremely short pre-arcing times at high currents, without limit. It is this apparently simple phenomenon that is primarily responsible for the universal success fuses have enjoyed for a very long time.



Key

1 Maximum operating time

2 Minimum pre-arcing time

Figure 5 – Time current characteristic for fuse-links

5.3.5 Fuse operation in altitudes exceeding 2 000 m

Low voltage fuse-links will carry rated current at altitudes of up to 2 000 m without any de-rating factor required. This is as stated in IEC 60269-1:2014, Subclause 3.2.

For the current carrying capacity of a fuse and the cable to be influenced by the cooling effect of the surrounding air, the current carrying capacity is derated with lower air pressure. This can be described by the following approximation:

Above 2 000 m a de-rating factor of 0,5 % for every 100 m above 2 000 m will be required, due to reduced convection of heat and lower air pressure.

This can be described by the formula:

$$\frac{I}{I_n} = 1 - \frac{h - 2000}{100} \cdot \frac{0{,}5}{100}$$

I maximum current carrying capacity at altitude h

I_n rated current up to 2 000 m

h altitude in meters

Table 1 – Derating factors for different altitudes

Altitude *h* in m	**Derating factor** *I*/*I*n
2 000	1,000
2 500	0,975
3 000	0,950
3 500	0,925
4 000	0,900
4 500	0,875
5 000	0,850

6 Fuse-combination units

Fuse-combination units integrate both circuit protection provided by fuse-links and circuit switching provided by the switch in one unit. Fuse-combination units are shown in Table 2 (equivalent to Table 1 of IEC 60947-3:2008).

Two different types of fuse-combination units are available:

- switch-fuses, switch-disconnector-fuses are switches connected in series with the fuse-links and are usually operator independent devices with manual operation (snap action);
- fuse-disconnectors and fuse-switch-disconnectors which use the fuse-link itself to form the moving part are usually operator dependent devices with manual operation.

Definitions can be found in IEC 60947-3 or in IEC 60050-441. The main ones are shown here for easier reading and their full description can be found in Clause 3:

– switch (mechanical) (see 3.1);

– disconnector (see 3.2);

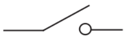
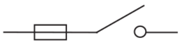
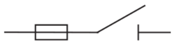
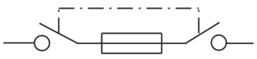
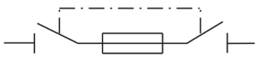
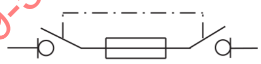
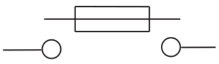
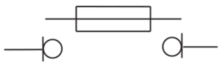
– fuse combination unit (see 3.3);

– switch-fuse (see 3.4);

– fuse-switch (see 3.5).

From these basic definitions, there are many variations of these devices as shown in Table 2.

Table 2 – Definitions and symbols of switches and fuse-combination units

Functions		
Making and breaking current	**Isolating**	**Making, breaking and isolating**
Switch 	Disconnector 	Switch-disconnector 
Fuse-combination units		
Switch-fuse single opening[a] 	Disconnector-fuse single opening[a] 	Switch-disconnector-fuse single opening[a] 
Switch-fuse double opening[b] 	Disconnector-fuse double opening 	Switch-disconnector-fuse double opening[b] 
Fuse-switch single opening[a] 	Fuse-disconnector single opening[a] 	Fuse-switch-disconnector single opening[a] 
Fuse-switch double opening[b] 	Fuse-disconnector double opening 	Fuse-switch-disconnector double opening[b] 
NOTE 1 Equipment shown as single opening may comprise multiple openings in series NOTE 2 The symbols do not govern the design of switches, disconnectors and fuse-combination units (Fuse-switches, fuse-disconnectors)		
[a] The fuse may be on either side of the contacts of the equipment. [b] Depending on the design, breaking may take place on one or both sides of the fuse-link.		

The note to the definition of the switch, i.e. stating that a switch may be capable of making but not breaking, short-circuit currents, very clearly shows that a switch to IEC 60947-3 does not provide short-circuit breaking capacity. In the case of a fuse-combination unit the fuse takes over the breaking function.

Since most of the fuse-combination units with the fuse as an integral unit are designed as fuse-switch disconnectors, or switch-disconnector-fuses, they may be used for

- switching under load,
- isolation,
- short-circuit protection.

The fuse(s) fitted to a fuse-combination unit or fuse-combination switch also protect the unit or the switch itself against the effects of overcurrent.

7 Fuse selection and markings

To select the proper fuse the nature of the equipment to be protected and the power that has to be interrupted, must be considered. With respect to power supply, the following parameters shall be defined:

– system voltage (operational voltage);
– frequency (for d.c. applications, see Clause 17);
– prospective short-circuit current;
– full load current (operational current).

Current limiting fuse-links are designed with very high rated breaking capacity. They are usually much higher than the minimum values specified in IEC 60269-2 and IEC 60269-3. Fuse-links are available with rated breaking capacities that cover the highest prospective current levels, that are met in service (e.g. up to 200 kA).

NOTE 1 Fuse-links can be safely applied at lower values than the rated breaking capacity.

Fuse selection for a specific application involves consideration of the time-current characteristics and breaking range. The time-current characteristics determine the field of application, while the breaking range indicates whether fuses are to be used together with additional overcurrent protection devices.

"Full range" means that the fuse can break any current able to melt the fuse-element up to the rated breaking capacity. Full range fuses can be used as stand-alone protection devices.

"Partial range", or back-up fuses, are designed to interrupt short-circuit currents only.

They are generally used to back-up another overcurrent protection device, (e.g. motor starter or circuit-breakers) at prospective currents exceeding the breaking capacity of the device alone.

IEC 60269 series and its various fuse systems specify the gates of time-current characteristics and the breaking range of the fuses shown in Table 3:

Table 3 – Fuse application

Utilization category	Application (characteristic)	Breaking range
gG, gK	General purpose	Full range
gM	Motor circuit protection	Full range
aM	Short-circuit protection of motor circuits	Partial range (back-up)
gN	North American general purpose for conductor protection	Full range
gD	North American general purpose time-delay	Full range
gPV	Photovoltaic (PV) protection	Full range
aR	Semiconductor protection	Partial range (back-up)
gR, gS	Semiconductor and conductor protection	Full range
gU	General purpose for conductor protection	Full range
gL, gF, gI, gII	Former types of fuses for general purpose (replaced by gG type)	Full range
gBat, aBat	Protection of batteries	Full and partial range

Fuses for use by authorized persons (industrial fuses) are generally interchangeable. Each fuse-link, fuse-base or fuse-holder is therefore legibly and permanently marked with the following information:

- name of the manufacturer or trade name;
- manufacturer's identification reference enabling any further information to be found;
- rated voltage a.c. and/or d.c. (see Tables 4 and 5);
- rated current;
- rated frequency if < 45 Hz or > 62 Hz;
- size*) or reference.

NOTE 2 The definition of fuse sizes, especially the dimensions are given by IEC 60269-2. In general fuse- links and fuse-bases and fuse-combination units shall have the same size. Some manufacturers offer to use a smaller fuse-link size in a bigger fuse-base or fuse-combination unit.

Example: size 1 fuse-link used in size 2 fuse-switch disconnector. Those combinations shall be tested and confirmed by the manufacturer.

In addition, each fuse-link is marked with

- letter code defining breaking range and utilization category (as applicable, see Table 3)
- rated breaking capacity

Fuse-bases and fuse-holders marked with a.c. ratings may also be used for d.c.

Fuse-links are marked separately if they are provided for a.c. and d.c. applications.

Fuses may be operated up to the maximum voltage as given in Table 4 and Table 5.

Table 4 – Maximum operational voltage of a.c. fuse-links

Utilization category	Rated voltage V a.c.	Maximum operational voltage V a.c.
gG, gM, aR [a, b], aM, gR [a, b], gS [a, b], gU, gK	230	253
	400	440
	500	550
	690	725
	1000	1100
gN[a], gD[a]	600	600

[a] For North American system of fuse-links, the maximum operational voltage is equal to the rated voltage.

[b] Other rated voltages are available depending on the application.

Table 5 – Typical operational voltage ratings of d.c. fuse-links

Utilization category	Typical rated d.c. voltage	Typical maximum d.c. operational voltage	Time constant
gG, gM, gU, gK	up to 500 V	+10 % over marked rating	15 to 20 ms
gN, gD	up to 500 V	+0 % over marked rating [a]	10 to 15 ms
aR, gR, gS	up to 1 500 V [b]	+5 % over marked rating [a]	15 to 20 ms
VSI (inverter rating)	up to 1 500 V [b]	+10 % over marked rating [a]	1 to 3 ms
gPV	up to 1 500 V [b]	+0 % over marked rating [a]	1 to 3 ms

[a] For North American system of fuse-links, the maximum operational voltage is equal to the rated voltage

[b] Other rated voltages are available according to application

The rated voltage of the fuse link should be recognized as the maximum system voltage in which the fuse link should be applied. The test voltage prescribed in the standard is a percentage above the rated voltage to allow for the allowable system deviations but it is also the safety factor built into products to the standard.

8 Conductor protection

8.1 General

Fuse-links are extensively used for the protection of conductors in accordance with IEC 60364-4-43.

Fuse-links can be used to ensure protection against both overload current and short-circuit current, simple and effective guidance for the selection of fuse-links are provided in the following:

- Utilization category gG see 8.2
- Utilization categorys gN and gD (North American) see 8.3
- Utilization categorys gR and gS (Semiconductor protection) see 8.4
- Utilization category gU see 8.5
- Utilization category gK see 8.6
- Utilization category gPV see 8.7

It should be stressed that IEC 60364-4-43 requires that every circuit shall be designed so that small overloads of long duration are unlikely to occur. For small overloads between 1 and 1,45 times the rated current of the overload protective device, the device may not operate within the conventional time. Ageing and deterioration of connections increase rapidly as operating temperatures exceed the rated values.

Caution: It is never acceptable to use the overload protective device as a load-limiting device. Continuous operation of the fuse-link above its rated current may result in overheating and nuisance operation.

In some applications fuse-links ensure protection against short-circuits only. In such cases overload protection shall be provided by other means.

Guidance for protection against short-circuits only is provided in 8.5 and Clause 13.

8.2 Utilization category gG

Fuse-links of utilization category gG are able to break overcurrents in the conductors before such currents can cause a temperature rise damaging the insulation.

Fuse-link selection can be easily made, taking the following steps:

a) The maximum operational voltage (see Table 4) of the fuse-link is selected to be greater or equal to the maximum system voltage.
b) The operational current I_B of the circuit is calculated.
c) The continuous current-carrying capacity of the conductor I_z is selected in accordance with IEC 60364-5-52.
d) The rated current I_n of the fuse-link is selected to be equal or greater than the operational current of the circuit and equal or smaller than the continuous current-carrying capacity of the conductor:

$$I_B \leq I_n \leq I_z$$

$$I_2 \leq 1,45 \cdot I_z$$

where

I_B is the operational current of the circuit;

I_z is the continuous current-carrying capacity of the conductor (see IEC 60364-5-52);

I_n is the rated current of the fuse-link;

I_2 is the conventional tripping current [IEC 60050-442:1998, 442-05-55], see Figure 6

For gG fuses the I_2 (of IEC installation rules) is $I_t = 1,45 \cdot I_n$

When the fuse-links are selected on the above basis, the shape of the time-current characteristics ensures that the conductors are adequately protected at high over-currents.

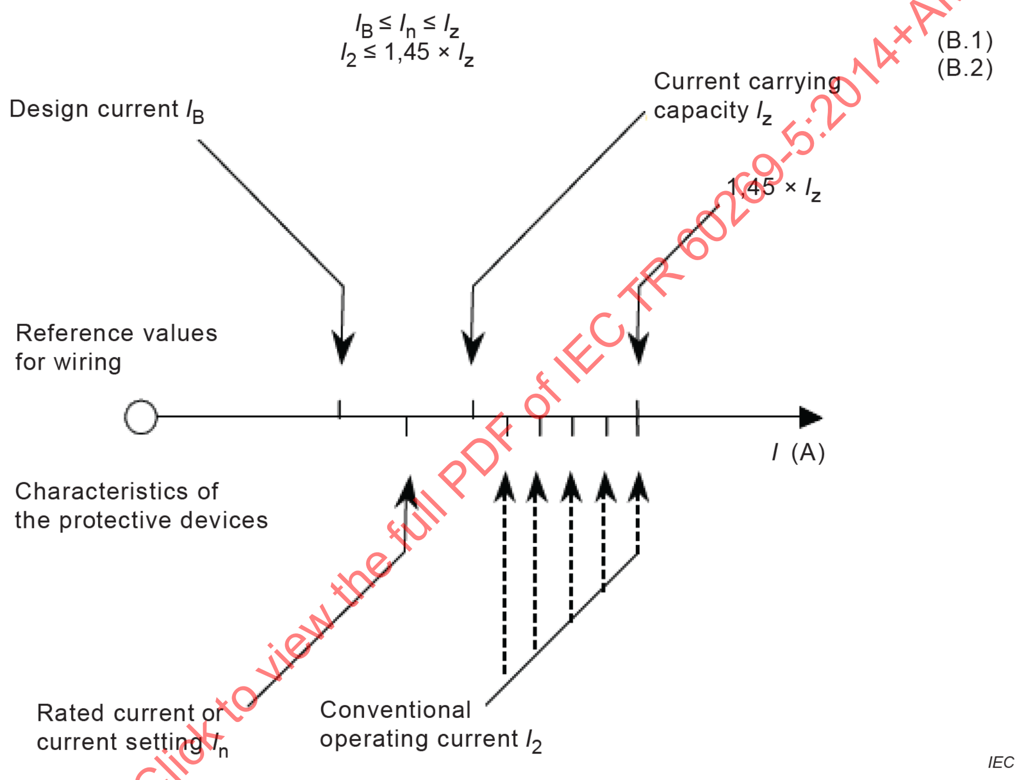


Figure 6 – Currents for fuse-link selection

8.3 Utilization category gN and gD

The requirements for the selection of fuses for the protection of conductors are found in the North American wiring regulations.

a) The voltage rating of the fuse is selected to be equal to or greater than the maximum system voltage.

b) The load current is calculated and multiplied by 1,25 for continuous loads (continuous loads are those which are present for 2 h or more).

c) The conductor size is selected from an ampacity (current-carrying capacity) table found in the wiring regulations.

d) The general rule for selecting the fuse is to select a standard fuse current rating to coincide with the conductor ampacity. For conductor ampacity less than 800 A, if the conductor ampacity falls between two standard fuse-link current ratings, the larger fuse-link current rating is used. For conductor ampacities of 800 A and over, if the ampacity falls in between two standard fuse-link current ratings, then the smaller fuse-link current rating is used.

e) The fuse selected protects the conductor under short-circuit and overload conditions. In practice, North American conductor standards have been coordinated with fuse standards so that short-circuit protection is achieved. For other types of conductors, short-circuit withstand ratings are compared with the fuse characteristics to make sure that conductor damage does not occur.

8.4 Utilization category gR and gS

Fuse-links for the protection of semiconductor devices are covered by IEC 60269-4 (see Clause 15). Most of such fuse-links are for short-circuit protection, utilization category aR. In some applications overload protection is required for the conductors feeding the semiconductor converter and this application is covered by utilization category gR, optimised to low I^2t values and utilization category gS, optimised to low power dissipation values.

The same selection process for the protection of conductors is used as in 8.2.

8.5 Utilization category gU

Fuse links to class gU are primarily for cable protection, as class gG, but their performance is optimised for use by supply utilities. The same selection process for the protection of cables should be used as in Subclause 8.2.

8.6 Utilization category gK

Fuse links to class gK are primarily for cable protection, as class gG, but their range of current ratings is up to 4 800 A and these are very limiting current fuses and have very low cut-off current characteristics. The same selection process for the protection of cables should be used as in Subclause 8.2.

8.7 Utilization category gPV

Fuse-links for the protection of solar photovoltaic energy systems are covered by IEC 60269-6 (see Clause 19). These fuse-links are for overload protection and strings, array and sub-array disconnection.

8.8 Utilization category gBat

Selection of a fuse for battery systems. These fuse-links are for overload and short circuit protection.

8.9 Protection against short-circuit current only

In those applications where the fuse-links are to provide back-up or short-circuit protection to the conductors, then co-ordination must be ensured by providing fuse-links which operating I^2t values lower than those which can be withstood by the conductors. For fault durations of 5 s or less, the I^2t withstand of conductors may be determined from the expression

$$I^2t = k^2 \cdot S^2$$

in which S is the cross-sectional area of the conductor in square millimetres and k is a factor which depends on the conductor material and the limiting temperature which can be withstood by the insulation. Values of k for various conductor and insulation combinations are given in IEC 60364-4-43:2008, Table 43A.

9 Selectivity of protective devices

9.1 General

Selectivity of protective devices is an important point to be considered when designing low-voltage installations. The aim of selectivity is to minimize the effects of a fault. Only the faulted circuit shall be opened while the others shall remain in service. Selectivity is achieved if a fault is cleared by the protective device situated immediately upstream of the fault without operation of other protective devices.

The following explanation applies to the most widespread application, the radial network.

Selectivity may be explained using the network diagram in Figure 7. Using this diagram, several cases of selectivity may be considered:

between F_2 and F_4 ⇒ see 9.2

between F_1 and F_3 ⇒ see 9.2

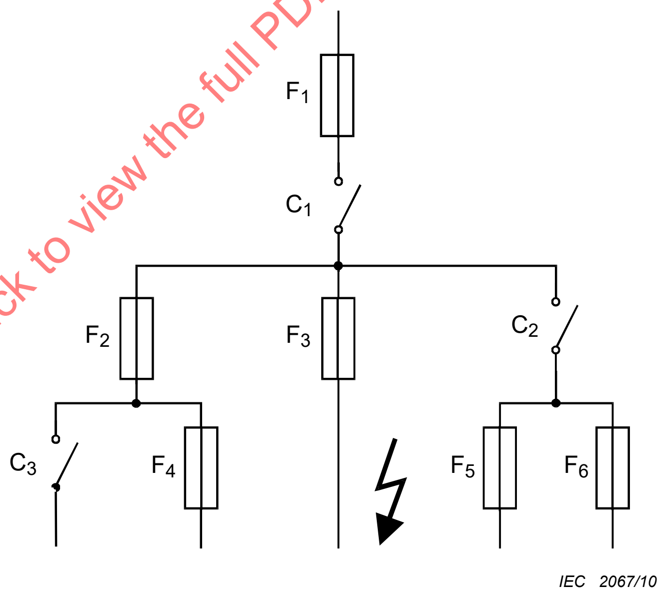
between C_1 and F_3 ⇒ see 9.3

between C_2 and F_5, F_6 ⇒ see 9.3

between F_2 and C_3 ⇒ see 9.4

between F_1 and C_1 ⇒ see Clause 14

The essential tools to investigate selectivity between protective devices are the time-current characteristics and I^2t values. IEC 60269-2 shows time-current characteristics for a time range of ≥ 0,1 s only. The values of I^2t for a time range < 0,1 s shall be supplied by the manufacturer.



Key

C Circuit Breaker

F Fuse

Figure 7 – Selectivity – General network diagram

9.2 Selectivity between fuses

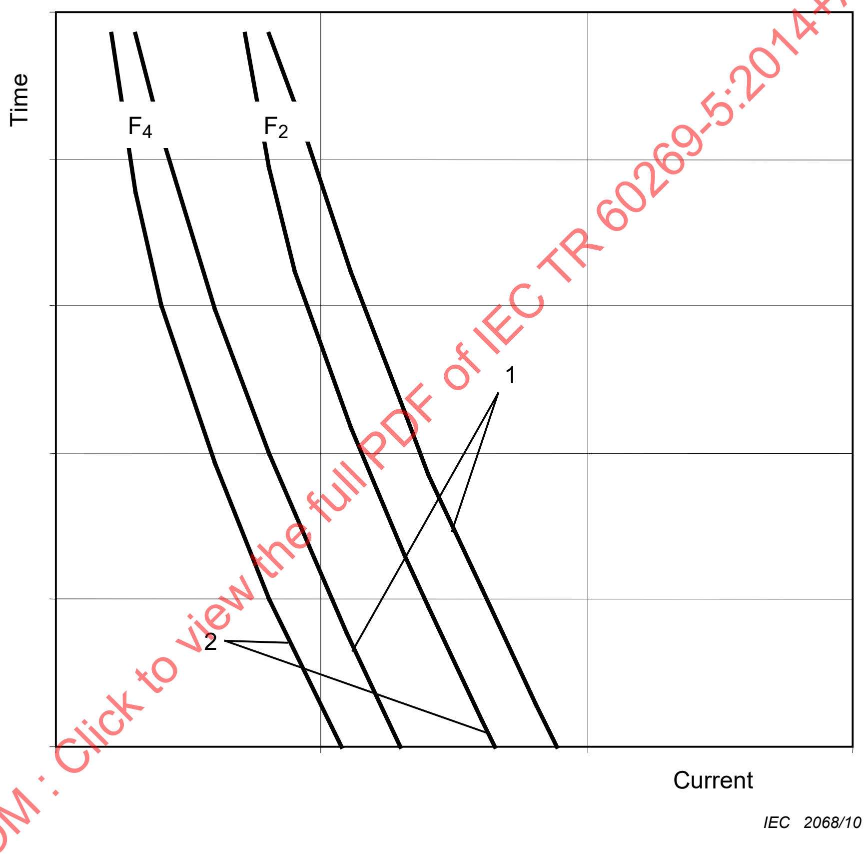
9.2.1 General

The selectivity between fuse-links is verified by means of the time-current characteristics (see Figure 8) for operating times ≥ 0,1 s and the pre-arcing and operating I^2t values for operating times < 0,1 s

NOTE The fuse manufacturer will supply values of operating I^2t at the rated voltage(s) assuming very low impedance short-circuit fault. In practice the operating I^2t will generally be a lower value due to the impedance of the fault and the actual voltage appearing across the fuse during operation.

9.2.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of F_4 shall be less than the minimum pre-arcing time of F_2 for each value of prospective current (see Figure 8).



Key

1 Maximum operating time

2 Minimum pre-arcing time

Where only one curve for the fuse link characteristic is given, the manufacturer should state the tolerance.

Figure 8 – Verification of selectivity between fuses F_2 and F_4 for operating time t ≥ 0,1 s

9.2.3 Verification of selectivity for operating time < 0,1 s

For these operating times, the I^2t values shall be considered. The maximum operating I^2t value of F_4 shall be lower than the minimum pre-arcing I^2t of F_2.

9.2.4 Verification of total selectivity

Both above requirements set out in 9.2.1 and 9.2.2 shall be met to achieve total selectivity between F_2 and F_4. These verifications are made by examination of the manufacturer's time-current characteristics and I^2t values.

Fuses according to IEC 60269-2 of the same utilization category, e.g. gG, with rated currents ≥16 A, meet these total selectivity requirements by definition if the ratio of rated currents is 1,6: 1 or higher. No additional verification by the user is therefore needed. In case of gN or gD fuses with rated current above 15 A the ratio is 2:1.

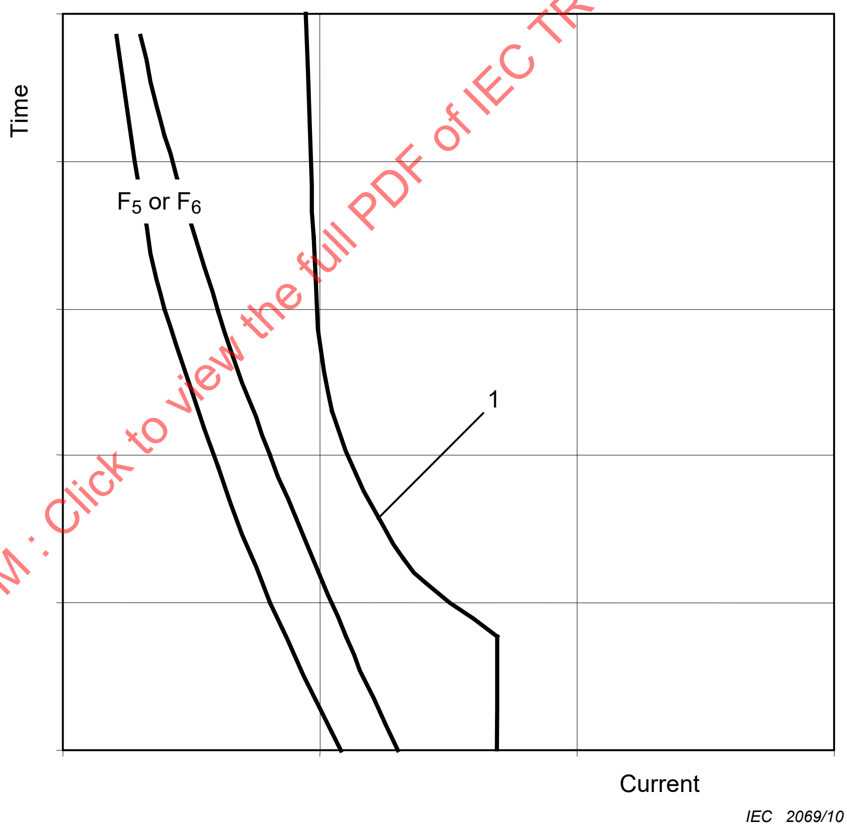
9.3 Selectivity between circuit-breakers upstream and fuses

9.3.1 General

The selectivity is verified by using time-current characteristics, I^2t values or by testing.

9.3.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of F_5 or F_6 shall be lower than the minimum tripping time of C_2 (see Figure 9).



Key

1 Minimum tripping characteristic of C_2

Figure 9 – Verification of selectivity between circuit-breaker C_2 and fuses F_5 and F_6

9.3.3 Verification of selectivity for operating time < 0,1 s

The operating I^2t value of the fuse must be smaller than the minimum tripping I^2t of the circuit breaker.

Data for I^2t values of fuses can be taken from the standard values.

Data from the circuit breaker can be taken out of its time-current characteristics and in the zone of instantaneous tripping, data must be provided by the manufacturer.

9.3.4 Verification of total selectivity

The requirements of both 9.3.2 and 9.3.3 shall be fulfilled to obtain total selectivity between C_2 and F_5 or F_6.

In practice, circuit-breaker manufacturers give selectivity tables between circuit-breakers and selected fuses. Such choices are also valid for equivalent or lower rated current fuses.

9.4 Selectivity between fuses upstream and circuit-breakers

9.4.1 General

The selectivity is verified by means of time-current characteristics and I^2t values or by testing.

9.4.2 Verification of selectivity for operating time ≥ 0,1 s

The maximum operating time of the circuit-breaker C_3 shall be lower than the minimum pre-arcing time of the fuse F_2 (see Figure 10).

9.4.3 Verification of selectivity for operating time < 0,1 s

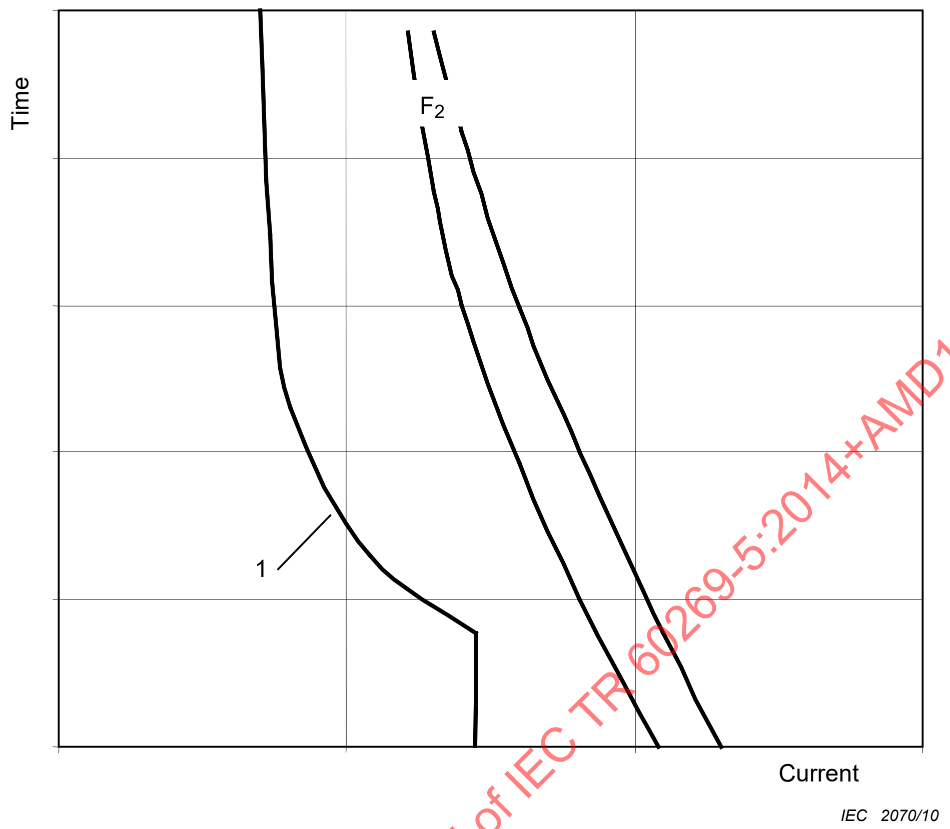
The minimum pre-arcing I^2t value of the fuse must be bigger than the maximum tripping I^2t of the circuit breaker.

Data for I^2t values of fuses can be taken from the standard values.

Data from the circuit breaker can be taken out of its time-current characteristics and in the zone of instantaneous tripping, data must be provided by the manufacturer.

9.4.4 Verification of total selectivity

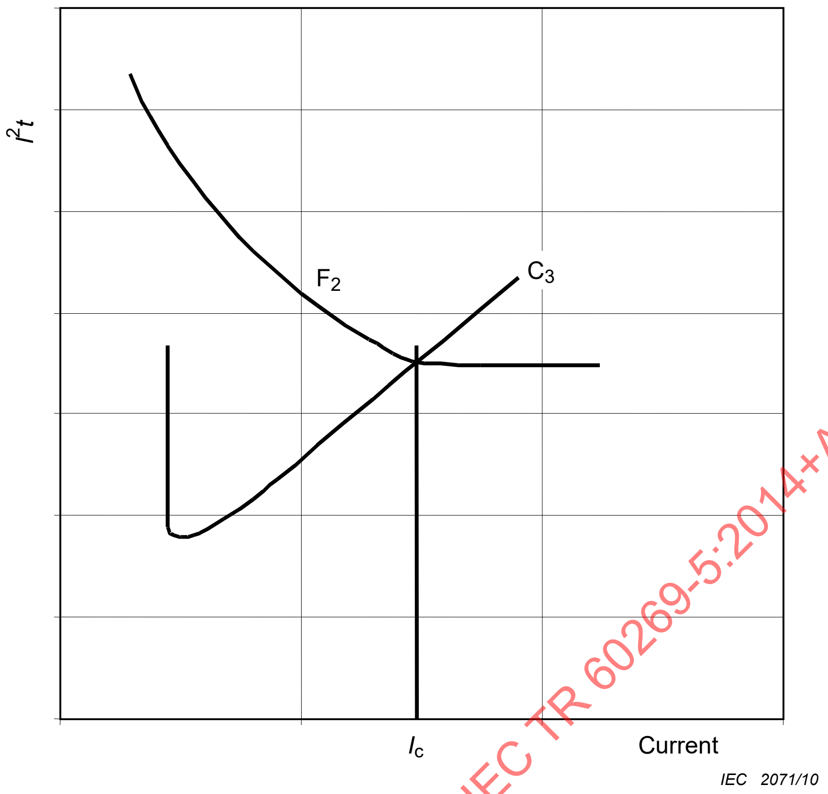
The requirements of both 9.4.2 and 9.4.3 shall be met to achieve total selectivity between C_3 and F_2. For prospective currents below I_c (see Figure 11) selectivity is achieved. For prospective currents above I_C, selectivity is not achieved.



Key

1 Tripping characteristic of C_3

Figure 10 – Verification of selectivity between fuse F_2 and circuit-breaker C_3 for operating time $t \geq 0,1$ s



NOTE I_S is the selectivity limit current.

Figure 11 – Verification of selectivity between fuse F_2 and circuit-breaker C_3 for operating time $t < 0,1$ s

10 Short-circuit damage protection

10.1 General

A short-circuit or fault occurs when a low impedance current path becomes available between two live parts or between live parts and earth, usually due to insulation breakdown, mechanical damage, wiring error or accident.

10.2 Short-circuit current paths

If the current path is a solid connection, the current rises to a value dependent on the voltage and the impedance of the conductors involved. Typically, the connection is very low impedance and the current is then quite high so that mechanical and thermal damage to conductors and insulation systems result. Mechanical damage to conductors is due to magnetic forces which attract or repel circuit conductors thus bending them and destroying insulation systems. Thermal damage to conductors is due to overheating and compromised insulation systems, followed by conductor melting and arcing.

If the current path is not a solid connection, an electrical arc takes place at the point of poorest connection. This event is referred to as an “arcing fault”. The current rises to a value dependent on the impedance of the conductors plus the impedance of the arc. Typically conductor mechanical and thermal damage result accompanied by localized conductor melting and metal vaporization at the point of arcing. Metal vaporization in air in the presence of an electrical arc is a dangerous condition, and an explosion results (an arc blast). Its severity is dependent on a number of circuit parameters but primarily on how much electrical energy is available and how much melted material is available to vaporize.

10.3 Current limitation

Fuses offer one of the most cost effective methods for protecting equipment, personnel and components from damage due to short-circuits, faults, and arcing faults. The reason behind this is the inherent current limiting ability of fuse-links. As discussed earlier, fuse-links melt and break the current very rapidly when exposed to high current levels (see 5.3.2). Peak current I_C which occurs just after the fuse-link melts is well below the prospective current and operating I^2t is kept low since the filler within the fuse body extinguishes the arcs taking place between the parts of the fuse-link (typical fuse clearing times are less than half a cycle). These low I_C, less than half cycle clearing times, and low operating I^2t provide the following benefits in case of a short-circuit or arcing fault:

- No mechanical or thermal damage to conductors or insulation systems.
- Little or no melting or arcing at the site of the fault.
- High reduction of arc energy levels resulting in effective mitigation of arc blast.

10.4 Rated conditional short-circuit current, rated breaking capacity

Assemblies of and components in electrical systems are assigned a short-circuit rating by the manufacturer which is the maximum permissible prospective short-circuit current in terms of magnitude and time that the device will withstand at its terminals.

This rating is established by test. If such a device contains or includes a fuse-link as an integral part, it is expressed as I_{cc}, rated conditional short-circuit current (see IEC 61912-1:2007, Clause 5).

Typically current limiting fuses are designed for use in circuits with high prospective currents and when used in assemblies or switches afford a high I_{cc} rating for the assembly or switch. This enables the device or assembly to be more widely applied, since safe practice dictates that the I_{cc} rating of the device or assembly must be equal to or higher than the system prospective short-circuit current.

11 Protection of power factor correction capacitors

IEC 60269-1 and IEC 60269-2 do not contain any requirements or verification test duties for fuses in circuits containing primarily capacitors. The use of fuses according to IEC 60269-2, utilization categories gG and gN for short-circuit protection of power factor correction capacitors has been a well-established engineering practice for many years.

Reliable function of gG and gN fuses in such applications requires selection of fuse-links with respect to the following considerations:

– high inrush currents up to 100 times rated current of the capacitor;
– continuous operating current up to 1,5 times rated current of the capacitor (this includes harmonics);
– increasing service voltage up to 1,2 times during low-load periods for 5 min;
– fluctuation of the service voltage up to 1,1 times for 8 h.
– capacitance (and subsequently operating current) tolerances of +15 %;

The rated current of the fuse-link is selected so that

– the inrush currents do not melt or deteriorate the fuse-element,
– potential over-currents do not lead to premature operation of the fuse-links.

The rated current of the gG and gN fuses is selected to be 1,6 to 1,8 times the rated current of the capacitor unit or capacitor bank. Under this condition, the fuse provides reliable short-circuit protection to the capacitors. Overload protection, if necessary, must be provided by additional suitable means. As a general rule, fuses for power factor correction capacitors have to be oversized with respect to rated current and rated voltage. This is especially true as regards small capacitor units having a higher inrush current related to their rated current.

NOTE Cross-sections of the connecting cables are selected according to the fuse current rating (see 8.2).

Recommended fuse selection for the most common sizes and voltages of power factor correction capacitors is shown in Table 6.

Table 6 – Fuse selection for power factor correction capacitors (fuses according to IEC 60269-2, system A)

	Rated Voltage (three-phase 50 Hz system)			
Power factor correction capacitor	400 V k = 2,5	525 V k = 2	690 V k = 1,5	1 000 V k = 1,5
Fuse	500 V	690 V	1 000 V [a]	1 500 V [b]
Capacitor size Q_N	Rated Current I_N of the fuse			
Up to 5 kVAR	16 A			
Up to 7,5 kVAR	20 A			
Up to 12,5 kVAR	32 A (35 A)	32 A (35 A)		
Up to 20 kVAR	50 A		32 A (35 A)	
Up to 25 kVAR	63 A	50 A		
Up to 30 kVAR	80 A	63 A	50 A	32 A (35 A)
Up to 40 kVAR	100 A	80 A	63 A	
Up to 50 kVAR	125 A	100 A	80 A	50 A
Up to 60 kVAR	160 A	125 A	100 A	63 A
Up to 80 kVAR	200 A	160 A	125 A	80 A
Up to 100 kVAR	250 A	200 A	160 A	100 A
Up to 125 kVAR	315 A	250 A	200 A	125 A
Up to 160 kVAR	400 A	315 A	250 A	160 A
Up to 200 kVAR	500 A	400 A	315 A	200 A
Up to 250 kVAR	630 A	500 A	400 A	250 A

[a] 690 V may be possible under certain conditions, check with manufacturer.

[b] 1 200 V or 1 300 V may be possible under certain conditions, check with manufacturer.

The rated current of the fuse may be calculated from the following rule of thumb:

$$I_n = k \cdot Q_N$$

where

I_n fuse rated current, in A;

Q_n capacitor size, in kvar;

k factor from Table 6.

12 Transformer protection

12.1 Distribution transformers with a high-voltage primary

Transformers feed most low-voltage distribution systems from a high-voltage, above 1 000 V a.c. primary. Short-circuit protection of these transformers are generally provided by high voltage fuse-links on the primary, and such fuse-links are selected to withstand the transformer magnetising (inrush) current during energization.

Low-voltage fuse-links on the secondary side of such distribution transformers give protection to their associated feeder circuits. Such fuse-links have to be selective with the fuse-links on the primary side of the transformer, taking into account the appropriate transformation ratio.

12.2 Distribution transformers with a low-voltage primary

Low-voltage distribution systems following North American practice often have transformers with a low-voltage primary and secondary for example 480/277 V to 208/120 V. Such transformers may typically have ratings up to a few thousand kVA.

Fuse-links on the primary side are used to provide short-circuit protection and fuse-links may be used on the secondary side to provide overload protection to the transformer. In some cases only primary circuit fuse-links are used while in other cases additional feeder circuit fuse-links are used on the secondary side, as in 12.1.

The primary side fuse-links have to be selected to withstand the magnetising inrush current and an industry guide is:

- 20 times transformer primary full load current for 0,01 s and
- 12 times transformer primary full load current for 0,1 s.
- Selectivity for the primary and all the secondary fuse-links and any other over-current protection has to be made taking into account the appropriate transformation ratio.
- In some applications transformers with a low-voltage primary and secondary are used for example battery chargers and tools, for safety reasons, fed from voltages up to 110 V.

12.3 Control circuit transformers

For these low power transformers, the peak inrush magnetising current in the first half cycle can be as high as 100 times the full load current. Many control circuit transformers have internal thermal protection since the over current devices on the primary side shall be greatly oversized to account for the tremendous inrush currents.

13 Motor circuit protection

13.1 General

Fuses are commonly used as part of the protection in motors and motor-starters circuits. General-purpose fuses (utilization category gG and gN) can be used for this purpose. Their current rating shall be chosen to withstand the starting current of the motor, which is dependent on the method of starting used, e.g.

– 6 to 8 times the rated motor current for direct on line starting,
– 3 to 4 times the rated motor current for star delta or autotransformer.

The rated current of the fuse may therefore be significantly higher than the rated current of the motor.

Special types of fuses exist for this application, such as gD and gM utilization category fuses which are full range breaking capacity fuses and aM utilization category back-up fuses designed to provide short-circuit protection only. These special utilization categories of fuses are designed to withstand high motor starting currents without the need for increasing the current rating as required for general purpose utilization categories. Characteristics for these utilization categories can be found in IEC 60269-1 and IEC 60269-2.

Fuse manufacturers provide motor fuse application data. Fuses for motor circuit protection are chosen to be selective with the motor protection provided by the overload-relay associated with the motor-starter.

13.2 Fuse and motor-starter coordination

The coordination between motor-starters and the fuses which protect them is covered in IEC standards by requirements and tests such as those in IEC 60947-4-1. Two kinds of co-ordination are defined: type 1 and type 2 (see also Table A.3).

The aim of successful coordination is to ensure adequate protection against short-circuit current and selectivity between starter and fuses. Satisfactory selectivity will avoid damage to the contactor and unexpected opening of the motor circuit.

Recommendations for suitable fuse-links for use in combination with a contactor/motor-starter can be found in manufacturers' catalogues.

The aim of this subclause is to give guidance to the end-user to find an alternative replacement fuse to the one specified by the manufacturer of the starter. Relevant installation codes must be followed.

More detailed information is given in Annex A to specify the tests and calculation necessary to achieve the coordination between the motor-starter and the fuse which protects it.

Tests are specified at three levels of prospective current, according to IEC 60947-4-1:

a) in the region of the current I_{co} defined as the co-ordination at the crossover current (see 13.4). Tests are made at 0,75 I_{co} when the starter shall disconnect the current without damage and the fuse does not operate, and at 1,25 I_{co} when the fuse shall operate before the starter (see Figure 12). The verification of co-ordination at the crossover current is also possible by an indirect method (see B.4.5 of IEC 60947-4-1:2009);
b) at the appropriate value of prospective current "r" shown in IEC 60947-4-1:2009, Table 12 (see Table A.2);
c) at the rated conditional short-circuit current I_q stated by the manufacturer of the switching device, if higher than the test current "r".

The fuse selected shall withstand the motor starting current and is normally selected from the recommendations of the manufacturer and in compliance with national installation codes and wiring rules.

Examples of suitable fuse-links used for motor protection are given in Table A.1.

The cross-over point of the fuse and the starter characteristics shall be within the breaking capacity of the contactor and the fuse is selected so that it does not operate while carrying the starting current of the motor (see Figure 12).

13.3 Criteria for coordination at the rated conditional short-circuit current I_q

Guidance for choosing the maximum rated current of an alternative fuse type: Annex A of IEC 61912-1:2007 details the method to be used. Basically the following shall be fulfilled.

The values of the voltage, the current and the conditional short-circuit current (I_q) for the circuit shall not be higher than the reference tested data.

Considering the characteristics of the substitute fuse, the I_{co} and I^2t values shall be determined for the rated conditional short-circuit current I_q and at the voltage $U\sqrt{3}/2$.

The values of I_{CO} and of I^2t determined as above shall be not greater than the reference test values.

Conformity with the above shows that the fuse substitution is valid and no further verification tests are required.

13.4 Criteria for coordination at the crossover current I_{co}

I_{co} is the current corresponding to the intersection of the mean time-current characteristics of the fuse and the overload relay of the starter (see Figure 12). Tests are prescribed for ensuring proper coordination at I_{co} in IEC 60947-4-1:2009, Clause B.4.

Important factors are:

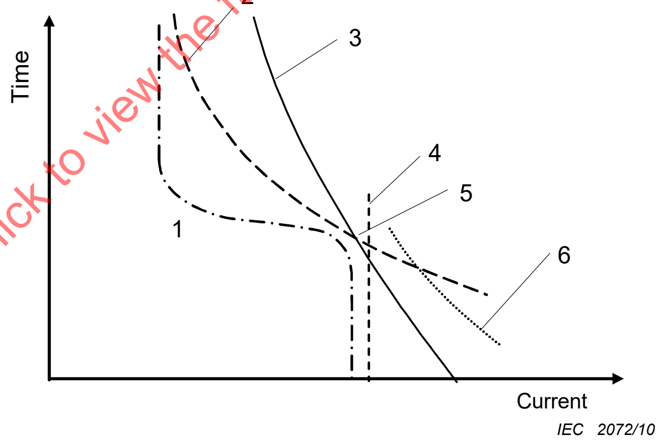
– the no-damage characteristic of the overload relay;

– I_{co} must be lower than the electrodynamic withstand current of contacts of the contactor and overload relay.;

– the operating time-current characteristic of the associated fuse at currents above I_{co} must be lower than the no damage characteristic of both the overload relay and the contactor in the region , where the fuse has take over the protective duty.

Thus, if an alternative replacement fuse type is used without further testing, its cross-over current shall not exceed the value of I_{co} observed in the type test, and its time-current characteristic at currents above I_{co} shall not show any greater times than the fuse used in the tested combination or damage to the starter may occur.

A fuse chosen in this way and in accordance with IEC 60947-4-1 provides protection for the starter and associated equipment at overcurrents exceeding the breaking capacity of the starter up to the rated conditional short-circuit current of the starter.



Key

1 Motor current
2 Time-current characteristic of the overload relay operation
3 Time-current characteristic of the fuse-link
4 Breaking capacity of the contactor
5 Crossover current I_{co}
6 Thermal limits of the overload relay

Figure 12 – Fuse and motor-starter coordination

13.5 Criteria for coordination at test current "r"

Basically, the characteristics to be considered for the alternative fuse are *the* I_c *and* I^2t values as suggested in Annex A of IEC 61912-1:2007. It is generally assumed that where these conditions are fulfilled for the I_q values, they are also fulfilled for the current "r".

14 Circuit-breaker protection in a.c. and d.c rated voltage circuits

Circuit-breakers having breaking capacities lower than the system prospective short-circuit current must be protected by an additional upstream short-circuit protective device (SCPD) having a sufficiently high breaking capacity.

Current limiting fuse-links offer an extremely cost-effective solution for this type of application (see Figure 7, F_1 and C_1). In case of short-circuits, current limiting fuse-links open rapidly (in less than ¼ cycle) thus reducing the prospective current and hence the electrical energy seen by the downstream circuit-breaker to levels well within the circuit-breakers capability.

The fuse used can be of the general purpose utilization category (gG and gN), the back-up utilization category (aM), or the full range utilization category as used on motor circuits (gD and gM).

Proper selection of fuse utilization category and its rating to protect a particular circuit-breaker is not simple, and reliable results cannot be completed solely by calculation.

The primary reason for this selection problem is that peak current and let-thru I^2t withstand levels vary between circuit-breaker types and among circuit-breaker manufacturers. To assure personnel safety and satisfactory protection of the circuit-breaker, fuse utilization category and ratings are tested in combination with downstream circuit-breakers.

The results of these tests and acceptable series fuse/circuit-breaker combinations are available by consulting the fuse or circuit-breaker manufacturers or appropriate notified bodies, who have witness tested these combinations.

It is possible to select an alternate utilization category of fuse types different from those fuses used in the series testing provided that alternate fuse type has values of I_p and operating I^2t less than or equal to the values of the fuse originally tested.

15 Protection of semiconductor devices in a.c. and d.c. rated voltage circuits

15.1 General recommendations

The I^2t withstand values of semiconductor devices of given ratings are considerably lower than those of other devices and circuits of corresponding ratings. Fuse-links used in circuits containing semiconductor devices shall therefore be capable of operating more rapidly at given currents than fuse-links used in other applications.

It is usual for several semiconductor devices to be present in one piece of equipment, such as a rectifier or inverter. The protective equipment should ideally ensure that the following conditions are met:

In the event of a semiconductor device failing, interruption should be effected quickly enough to prevent damage to other devices. (In this connection, experience has shown that semiconductors fail as a short-circuit protection and a large current results.)

For other faults in the equipment, interruption should take place before there is consequential damage to the semiconductor devices. Potentially damaging over-currents should be cleared before devices are damaged.

Operation of the fuse-links should not cause unacceptably high over-voltages to be impressed on any of the semiconductor devices.

The performance requirements for fuse-links for the protection of semiconductor devices are given in IEC 60269-4 and such fuse-links have traditionally been the "partial range" or "back-up" category, utilization class aR. While partial range rectifier protection fuse-links (aR) provide fast protection to devices, in many systems alternate protection of thermal triggered overload devices, gG fuse-links or other circuit protective devices may need to be included to protect other circuit elements. The lower limit of capability of a type aR fuse-link is defined in terms of the multiple of the rated current.

As protection schemes and practices have developed, there is a growing need for fuse-links for the protection of semiconductor devices with "full range" breaking capacity, which will eliminate the need for one or more of the components mentioned above. An example is to place fuse-links at the head of the supply, rather than in the converter cubicle. In this case the fuse-link needs to give protection to the cable, in addition to the power semiconductors in the converter equipment.

Two additional full range classifications were introduced into IEC 60269-4 namely "gR", optimised to give low I^2t and "gS" optimised to give low power dissipation. The "gS" fuse-links usually give compatibility with standardized fuse-bases and fuse combination units. Both gR and gS fuse-links must operate within the conventional time at 1,6 times their rated current, however they must carry the value shown in Table 7 for the conventional time.

Table 7 – Conventional non fusing current

Type "gS"	Type "gR"
1,25 I_n	1,13 I_n

Depending where the fuse-link is positioned in a circuit utilizing semiconductors the fuse-link may have to be rated for a.c. fault conditions, d.c. fault conditions or both. Fuse-links with adequate voltage ratings and breaking capacities should be chosen.

The d.c. voltage rating of the fuse-link is dependent of the circuit time constant that may be achieved by a fuse-link. The time constants to which fuse-links for the protection of semiconductors are tested are indicated in the standard and are representative of time constants in typical power systems. The protection of voltage source inverters (VSI) is a special case, provided when capacitors are used in the power circuit. In VSI's the circuit time constant may be significantly lower than traditional d.c. systems and thus IEC 60269-4 includes specific test requirements for fuse-links that can then be assigned a VSI voltage rating in addition to the a.c. and d.c. voltage ratings assigned.

Manufacturers of fuse-links for the protection of semiconductor devices give comprehensive guidance for the selection of fuse-links for a wide variety of applications. In addition, useful information is given in the following:

- Annex AA of IEC 60269-4:2009 gives some useful guidance for the coordination of fuse-links with semiconductor devices. This annex explains the performance to be expected from the fuse-links in terms of their ratings and in terms of the circuits of which they form a part; in such a manner that this may form the basis for the selection of the fuse-links.
- Annex BB of IEC 60269-4:2009 gives a survey of information to be supplied by the manufacturer in his literature (catalogue) for a fuse-link designed for the protection of semiconductor devices.
- IEC/TR 60146-6 is an application guide for the fuse protection of semiconductor converters against over-currents. It is limited to line commutated converters in single-way and double way connections. This technical report advises the specific fuse features and on the specific converter features that are to be observed to ensure correct application of semiconductor fuses in converters, and to give specific recommendations for trouble free operation of converters protected by fuses.

15.2 Fuse application with inverters

15.2.1 Inverters

Figures 17 to 19 show examples of inverters of voltage source type.

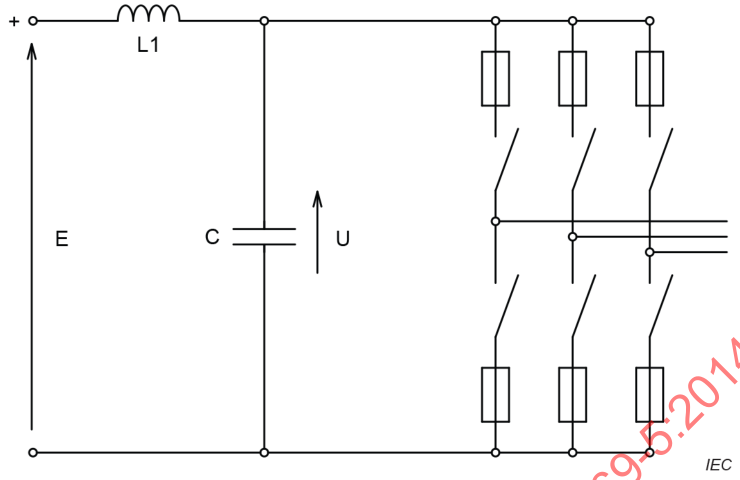


Figure 17 – Inverter double-way connection with arm fuses for regenerative or non-regenerative load

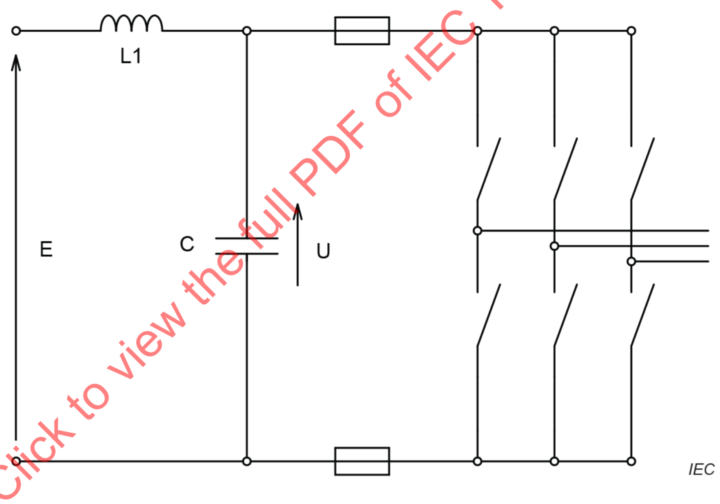


Figure 18 – Inverter double-way connection with d.c. loop fuses for regenerative or non-regenerative load