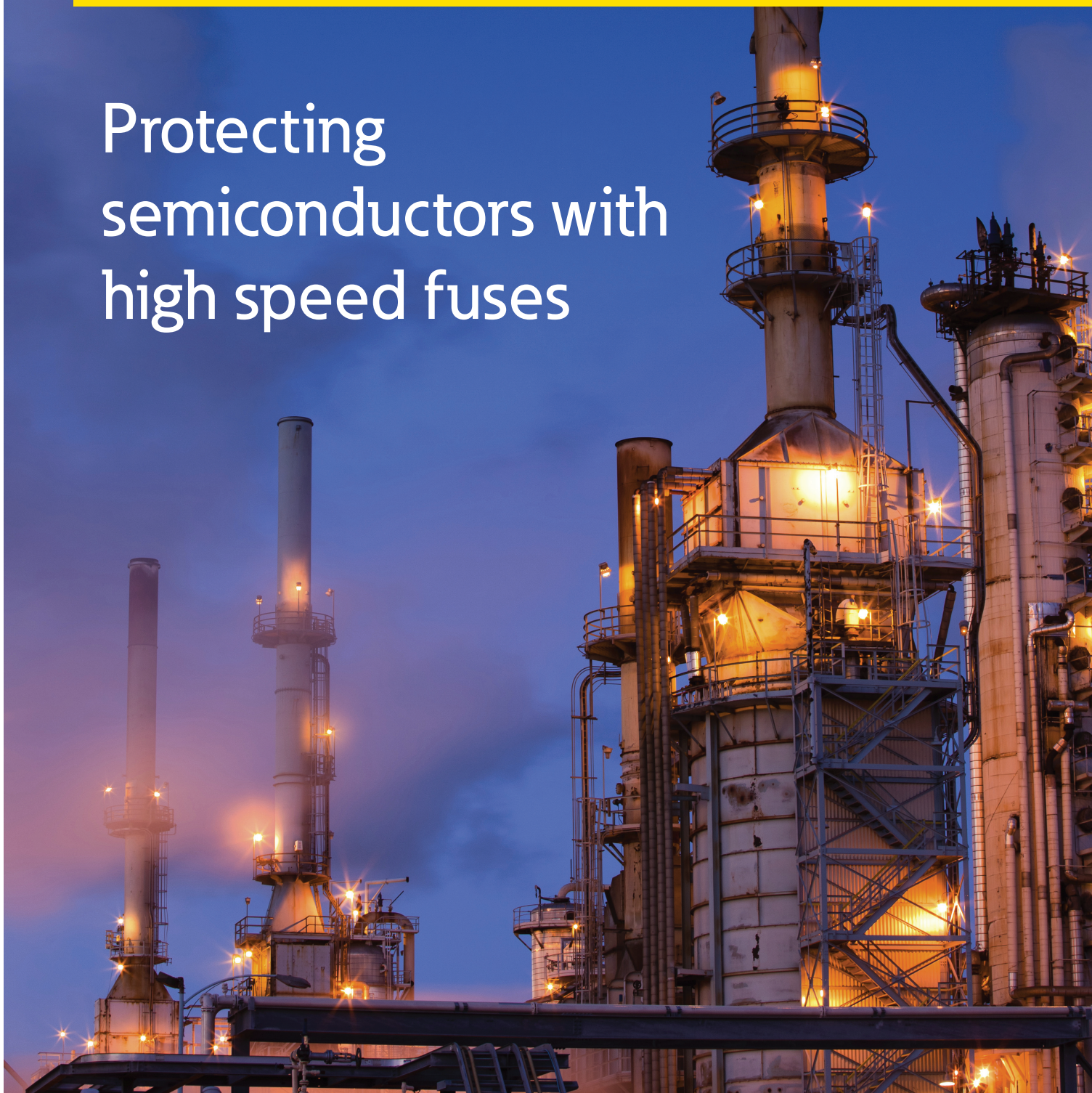


# Protecting semiconductors with high speed fuses



*Powering Business Worldwide*

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## Bussmann® series high speed fuse portfolio

These high speed fuse styles are available in the voltages and ampacities indicated. For details, see Bussmann series high speed fuse catalog no. 10506 or full line catalog no. 1007.



### Compact high speed fuses

- 500 Vac/dc, 50 to 400 A



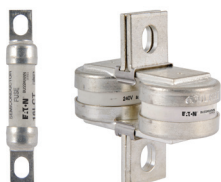
### IGBT fuses

- Up to 1000 Vdc, 25 to 630 A



### North American fuses

- Up to 1000 Vac/ 800 Vdc, 1 to 4000 A



### British Standard BS 88

- Up to 700 Vac/500 Vdc, 6 to 710 A



### DFJ UL Class J drive fuse

- Full range, 600 Vac/450 Vdc, 1 to 600 A



### Square body fuses

- Up to 1300 Vac/700 Vdc, 10 to 5500 A



### Ferrule fuses

- Up to 2000 Vac/1000 Vdc, 5 to 100 A



### About this guide

This guide's objective is to provide engineers easy access to Bussmann series high speed fuse data. It also provides detailed information on the Bussmann series high speed fuse reference system. The various physical standards are covered with examples of applications along with the considerations for selecting rated voltage, rated current and similar data for protecting power semiconductors. Guidelines for fuse mounting is covered, with explanations on how to read and understand product data sheets and drawings.

This document is not a complete guide for protecting all power semiconductor applications. The market is simply too complex to make such a document, and, in some cases, the actual fuse selection will require detailed technical discussions between the design engineers specifying the equipment and Application Engineering personnel.

Regardless, the data presented here will be of help in daily work and provide the reader with the basic knowledge of our products and their application.

### Background

The fuse has been around since the earliest days of the telegraph and later for protecting power distribution and other circuits.

The fuse has undergone considerable evolution since those early days. The modern High Breaking Capacity (HBC)/high interrupting rating fuse provides economical and reliable protection against overload and fault currents in modern electrical systems.

Basic fuse operation is simple: excess current passes through specially designed fuse elements causing them to melt and open, thus isolating the overloaded or faulted circuit. Fuses now exist for many applications with current ratings of only a few milliamps to many thousands of amps, and for use in circuits of a few volts to 72 kV utility distribution systems.

The most common use for fuses is in electrical distribution systems where they are placed throughout the system to protect cables, transformers, switches, control gear and equipment. Along with different current and voltage ratings, fuse operating characteristics are varied to meet specific application areas and unique protection requirements.

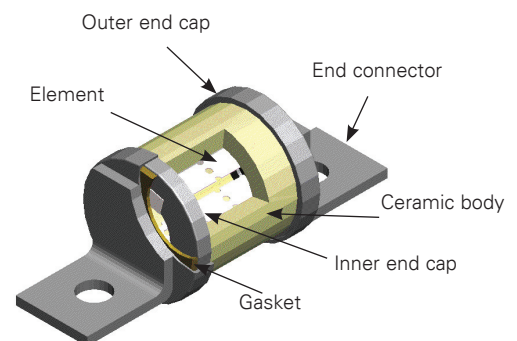
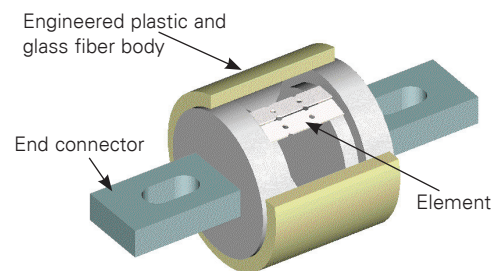
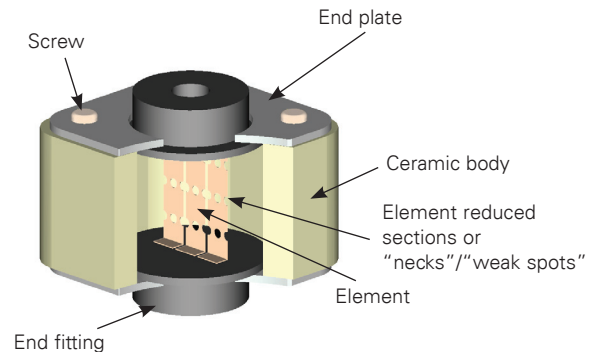
The definitions on how fuses are designed for a certain purpose (fuse class) are included in the glossary.

### Typical fuse construction

Modern high speed fuses are made in many shapes and sizes (Figure A1), but all have the same key features. Although all fuse components influence the total fuse operation and performance characteristics, the key part is the fuse element. This is made from a high conductivity material and is designed with a number of reduced sections commonly referred to as "necks" or "weak spots." It is these reduced sections that will mainly control the fuse's operating characteristics.

The element is surrounded with an arc-quenching material, usually graded quartz, that "quenches" the arc that forms when the reduced sections melt and "burn back" to open the circuit. It is this function that gives the fuse its current-limiting ability.

To contain the quartz arc-quenching material, an insulated container (commonly called the fuse body) is made of ceramic or engineered plastic. Finally, to connect the fuse element to the circuit it protects there are end connectors, usually made of copper. The other fuse components vary depending on the type of fuse and the manufacturing methods employed.



**Figure A1. Typical square body and round body high speed fuse constructions.**

### Fuse operation

Fuse operation depends primarily on the balance between the rate of heat generated within the element and the rate of heat dissipated to external connections and surrounding atmosphere. For current values up to the fuse's continuous current rating, its design ensures that all the heat generated is dissipated without exceeding the pre-set maximum temperatures of the element or other components.

Under conditions of sustained overloads, the rate of heat generated is greater than that dissipated, causing the fuse element temperature to rise. The temperature rise at the reduced sections of the elements ("necks" or "weak spots") will be higher than elsewhere, and once the temperature reaches the element material melting point it will start arcing and "burn back" until the circuit is opened. The time it takes for the element to melt and open decreases with increasing current levels.

The current level that causes the fuse to operate in a time of four hours is called the continuous current rating, and the ratio of minimum fusing current to the rated current is called the fusing factor of that fuse. Under higher overloading, or short-circuit conditions, there is little time for heat dissipation from the element, and the temperature at the element's reduced sections (necks) reach the melting point almost instantaneously. Under these conditions, the element will commence melting well before the prospective fault current (AC) has reached its first major peak.

The time taken from the initiation of the short-circuit to the element melting is called the pre-arcing time. This interruption of a higher current results in an arc being formed at each reduced section with the arc offering a higher resistance. The heat of the arcs vaporize the element material; the vapor combines with the quartz filler material to form a non-conductive, rock-like substance called fulgurite. The arcs also burn the element away from the reduced sections to increase the arc length and further increase the arc resistance.

The cumulative effect is that the arcs are extinguished in a very short time along with the complete isolation of the circuit. Under such heavy overload and short-circuit conditions the total time taken from initiation of fault to the final isolation of the circuit is very short, typically in a few milliseconds. Therefore, current through the fuse has been limited. Such current limitation is obtained at current levels as low as four (4) times the normal continuous current rating of the fuse.

The time taken from the initiation of the arcs to their being extinguished is called the arcing time. The sum of the pre-arcing and arcing time is the total clearing time (see Figure A2). During the pre-arcing and the arcing times a certain amount of energy will be released depending on the magnitude of the current. The terms pre-arcing energy and arcing energy are similarly used to correspond to the times. Such energy will be proportional to the integral of the square of the current multiplied by the time the current flows, and often abbreviated as  $I^2t$ , where "I" is the RMS value of the prospective current and "t" is the time in seconds for which the current flows.

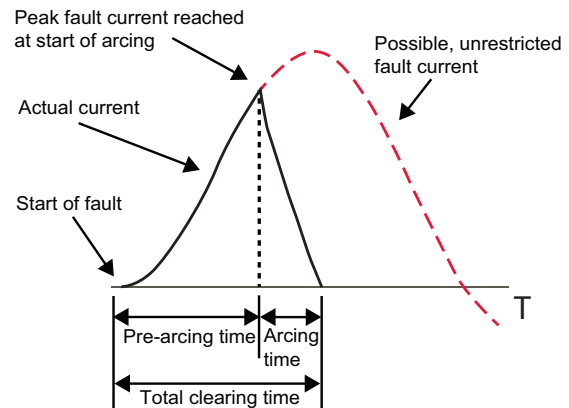
For high current values, the pre-arcing time is too short for heat to be lost from the reduced section (is adiabatic) and pre-arcing  $I^2t$  is therefore a constant. The arcing  $I^2t$ , however, also depends on circuit conditions. The published data is based on the worst possible conditions and is measured from actual tests. These will be covered in detail later.

The arcing causes a voltage across the fuse element reduced sections (necks) and is termed the arc voltage. Although this depends on the element design, it is also governed by circuit conditions. This arc voltage will exceed the system voltage. The design of the element allows the magnitude of the arc voltage to be controlled to known limits. The use of a number of reduced sections (necks) in the element, in series, assists in controlling the arcing process and also the resulting arc voltage.

Thus, a well-designed fuse not only limits the peak fault current level, but also ensures the fault is cleared in an extremely short time and the energy reaching the protected equipment is considerably smaller than what's available.

### Power semiconductors

Silicon-based power semiconductor devices (diodes, thyristors, Gate Turn-Off thyristors [GTOs], transistors and Insulated Gate Bipolar



**Figure A2. Pre-arcing time plus arcing time equals total clearing time.**

Transistors [IGBTs]) have found an increasing number of applications in power and control circuit rectification, inversion and regulation. Their advantage is the ability to handle considerable power in a very small physical size. Due to their relatively small mass, their capacity to withstand overloads and overvoltages is limited and thus require special protection means.

In industrial applications, fault currents of many thousands of amps occur if a short-circuit develops somewhere in the circuit. Semiconductor devices can withstand these high currents for only an extremely short period of time. High current levels cause two harmful effects on semiconductor devices.

First, non-uniform current distribution at the p-n junction(s) of the silicon creates abnormal current densities and causes damage.

Second, a thermal effect is created that's proportional to the RMS current squared ( $I^2$ ) multiplied by the amount of time (t) that the current flows expressed as either  $I^2t$  or  $A^2s$  (amps squared second).

As a result, the overcurrent protective device must:

- Safely interrupt very high prospective fault currents in extremely short times
- Limit the current allowed to pass through to the protected device
- Limit the thermal energy ( $I^2t$ ) let-through to the device during fault interruption

Unfortunately, ultra-fast interruption of large currents also creates high overvoltages. If a silicon rectifier is subjected to these high voltages, it will fail due to breakdown phenomena. The overcurrent protective device selected must, therefore, also limit the overvoltage during fault interruption.

So far, consideration has mainly been given to protection from high fault currents. In order to obtain maximum utilization of the protected device, coupled with complete reliability, the selected overcurrent protective device must also:

- Not require maintenance
- Not operate at normal rated current or during normal transient overload conditions
- Operate in a predetermined manner when abnormal conditions occur

The only overcurrent protective device with all these qualities (and available at an economical cost) is the modern high speed fuse (also commonly referred to as a "semiconductor fuse" or " $I^2t$  fuse").

While branch circuit and supplemental fuses possess all the qualities mentioned above (with the exception of special UL Class J high speed fuses), they do not operate fast enough to protect semiconductor devices.



## B: High speed fuse characteristics

### How high speed fuses are different

High speed fuses are specially designed to minimize the  $I^2t$ , peak current let-through and arc voltage. Ensuring fast opening and clearing of a fault requires rapid element melting. To achieve this, the high speed fuse element has reduced sections (necks) of a different design than a similarly rated industrial fuse and typically have higher operating temperatures.

As a result of their higher element temperatures and smaller packages, high speed fuses typically have higher heat dissipation requirements than other fuse types. To help dissipate heat, the body (or barrel) material used is often a higher grade with a higher degree of thermal conductivity.

High speed fuses are primarily for protecting semiconductors from short-circuits. Their high operating temperatures often restrict using element alloys with a lower melting temperature to assist with overload operation. The result is that high speed fuses are generally not “full range” (operate on short-circuit and overload conditions) and have more limited capability to protect against low-level overcurrent conditions.

Many high speed fuses are physically different from branch circuit and supplemental fuse types, and require additional mounting arrangements to help prevent installing an incorrect replacement fuse.

### Application factors

Protecting semiconductors requires considering a number of device and fuse parameters. And there are a number of influencing factors associated with each parameter (see Table B1). The manner in which these are presented and interpreted will be covered in the following pages. These parameters and influencing factors need to be applied and considered with due reference to the specific requirements of the circuit and application. These are covered in the sections on selecting the voltage rating, current rating and applications.

**Table B1. Factors to consider in high speed fuse selection.**

Parameter	Factors affecting parameter		Data provided	
	Fuse	Diode or thyristor*	Fuse	Diode or thyristor*
Steady state RMS current	Ambient temperature, attachment, proximity of other apparatus and other fuses, cooling employed	Ambient temperature, type of circuit, parallel operation, cooling employed	Maximum rated current under specified conditions, factors for ambient, up-rating for forced cooling, conductor size	Comprehensive curves (mean currents generally quoted)
Watts dissipated for steady state	Function of current	Function of current	Maximum quoted for specified conditions	Comprehensive data
Overload capability	Pre-loading, cyclic loading surges, manufacturing tolerances	Pre-loading, cyclic loading surges	Nominal time/current curves for initially cold fuses – calculation guidelines for duty cycles	Overload curves, also transient thermal impedances
Interrupting capacity	AC or DC voltage/short-circuit levels	—	Interrupting rating	—
$I^2t$ ratings	Pre-loading; total $I^2t$ dependent on: circuit impedance, applied voltage, point of initiation of short-circuit	Pre-loading fault duration	For initially cold fuses: total $I^2t$ curves for worst case conditions, pre-arcing $I^2t$ constant fuse clearing time	Half cycle value or values for different pulse duration
Peak let-through current	Pre-loading; fault current (voltage second order effect)	Pre-loading fault duration	Curves for worst conditions for initially cold fuse-links	Peak current for fusing
Arc voltage	Peak value dependent on: applied voltage, circuit impedance, point of initiation of short-circuit	Peak inverse voltage ratings (non-repetitive)	Maximum peak arc voltages plotted against applied voltage	Peak inverse voltage rating quoted (non-repetitive)

\* The protection of transistors is more complex and will be described in the section on IGBT protection.

### What is this symbol?



The term “semiconductor fuse” used for high speed fuses is misleading. Although high speed fuses often display a fuse and diode symbol on their label (like the one above), there is no semiconductor material in their construction. The symbol on their label is there solely to denote their application is for protecting “semiconductor” devices.

## B: High speed fuse characteristics

### Influencing factors

#### Ambient temperature

Fuses protecting semiconductors may need derating for ambient temperatures above or below 21°C (70°F). Adjusted fuse ratings at other ambient temperatures can be found using derating graphs.

Factors affecting ambient temperature include poor fuse mounting, enclosure type and proximity to other heat-generating devices and fuses. The maximum high speed fuse rating should be determined for each application using the ambient temperature of the fuse's installed location as described in the section on selecting the current rating.

#### Fuse operating temperatures

Operating temperatures vary by fuse construction and materials. Fiber tube fuses tend to run hotter than ceramic body fuses. Generally, for fuses with a ceramic body that are fully loaded under IEC conditions, the temperature rise lies from 70-110°C (158-230°F) on the terminals and from 90-130°C (194-266°F) on the ceramic body. The fuse load constant for porcelain body fuses is normally 1.0 and with fiber body fuses the factor is normally 0.8. Keep in mind that temperature measurements can be misleading when determining whether a particular fuse is suitable for a given application. For details, see the chapter *Determining fuse amp ratings* starting on page 11.

#### Forced cooling

To maximize ratings in many installations, diodes or thyristors are force cooled by an air stream. Fuses can be similarly uprated if placed in an air stream. However, air velocities above 5 m/s (16.5 ft/s) do not provide any substantial increase in the ratings. For further information see the sections on selecting rated current and data sheets.

#### Mean, peak and RMS currents

Care must be taken in coordinating fuse currents with the circuit currents. Fuse currents are usually expressed in "Root-Mean Square" (RMS) values, while diodes and thyristors currents are expressed in "mean" values.

#### Time-current characteristics

These are the time and current levels needed for a fuse element to melt and open. They are derived using the same test arrangement as the temperature rise test, with the fuse at ambient temperature before each test. For branch circuit and supplemental fuses, the nominal melting times are plotted against RMS current values down to 10 ms. For high speed fuses, the virtual melting time ( $t_v$ ) is used and plotted down to 0.1 ms. The formula for determining virtual melting time can be found in the glossary.

The melting time plus arcing time is called total clearing time, and for long melting times the arcing time is negligible.

#### Cyclic loading/surges

Effects of cyclic loading, or transient surges, can be taken into account by coordinating the effective RMS current values and surge durations with the time-current characteristics. The following conditions should be accounted for when using published characteristics:

- They are subject to a 10 percent (10%) tolerance on current
- For times below one second, circuit constants and instants of fault occurrence affect the time-current characteristics. Minimum nominal times are published according to symmetrical RMS currents.
- Pre-loading at maximum current rating reduces the actual melting time. Cyclic conditions are detailed in the section on selecting rated current.

#### Short-circuit performance

The fuse's short-circuit operation zone is usually taken as operating times less than 10 ms (1/2 cycle on 60 Hz supply in AC circuits). It's in this short-circuit operation zone that high speed fuses are current limiting. Since the majority of high speed fuse applications are on AC circuits, their performance data are usually given for AC operation. Where applicable, prospective RMS symmetrical currents are used.

#### I<sup>2</sup>t ratings

The pre-arcing (melting) I<sup>2</sup>t tends to be a minimum value when the fuse is subjected to high currents (this value is shown in the data sheet). The total clearing I<sup>2</sup>t varies with applied voltage, available fault current, power factor and the point on the AC wave when the short circuit initiates. The total clearing I<sup>2</sup>t values shown are for the worst of these conditions.

The majority of power semiconductor manufacturers give I<sup>2</sup>t ratings that should not be exceeded for their product during fusing at all times below 10 ms. These are statistically the lowest values the device has been tested to.

For effective device protection, the total I<sup>2</sup>t value of the fuse must be less than the I<sup>2</sup>t capability of the device.

#### Peak fuse currents

Under short-circuit conditions, high speed fuses are inherently current limiting (the peak let-through current through the fuse is less than the peak short-circuit current). The "cut-off" characteristic, (the peak let-through current against prospective RMS symmetrical current) are shown in the data sheets. Peak let-through currents should be coordinated with diode or thyristor data in addition to I<sup>2</sup>t values.

#### Arc voltage

The arc voltage produced during fuse opening varies with the applied system voltage. Curves showing variations of arc voltage versus system voltage are included in the data sheets. Care must be taken in coordinating the peak arc voltage of the fuse with the semiconductor device's peak transient voltage limit.

#### Conductor size

The RMS current ratings assigned to Bussmann series fuses are based upon standard sized conductors at each end of the fuse during rating tests. These are based on a current density between 1 and 1.6 A/mm<sup>2</sup>. Using smaller or larger conductors will affect the fuse's current rating.

#### Package protection

Some semiconductor devices are so sensitive to overcurrents and overvoltages that high speed fuses may not operate fast enough to prevent some or complete damage to the protected device. Regardless, high speed fuses are still employed in such cases to minimize the affects of overcurrent events when the silicon or small connection wires melt. Without using high speed fuses, the packaging surrounding the silicon may open, with the potential to damage equipment or injure personnel.

## C: Fuse performance data

High speed fuse performance data can be found in various curves and documents. This information is generally presented in what is called a data sheet, or spec sheet. The following is a synopsis of what they contain.

### The time-current characteristic curve

The time-current curve, also called the TCC curve, provides vital information for the selection and determination phase. See Figure C1.

The horizontal axis represents the prospective short-circuit current ( $I_p$ ) in RMS symmetrical amps. The vertical axis represents virtual pre-arcing time ( $t_v$ ) in seconds, as specified in IEC 60269. The melting time of a given fuse can be found based on a known available fault current value. In practice, virtual times longer than 10 ms are equivalent to real time ( $t_r$ ) where times that are below this value are based upon an instantaneous, adiabatic fuse interruption derived from minimum pre-arcing values discussed later in this guide.

It is at these virtual times, using  $I_p$  and  $t_v$  directly from the fuse time-current curve, that permits calculating its melting integral ( $I_p^2 \times t_v$ ) for the actual value of prospective current (see Figure C1). The following method shows two examples ( $I_1$  and  $I_2$ ) with guidelines to determine the effect on a fuse from an overload or short-circuit:

- First, the actual overload/fault current must be known, either in the form of a curve (Figure C2,  $I_1=f(t_r)$  and  $I_2=f(t_r)$ ), or from Equation C1:

$$I_{RMS}(t_1) = \sqrt{\frac{\int_0^{t_1} i^2 dt}{t_1}}$$

### Equation C1. Overload/fault current.

- Calculate the RMS current over time. The RMS value at a given time is determined using the formula above. (RMS symmetrical currents for standard sine waves will be  $I_{peak}/\sqrt{2}$ ).
- Plot the RMS current values as coordinates  $I_{RMS}$ ,  $t_r$  onto the fuse time-current curve as shown in Figure C1
- If the plotted curve crosses the fuse's melting curve ( $I_{RMS2}$  in Figure C1), the fuse melts at the time which can be found at the crossing point in real time ( $t_r$ )

If the plotted curve does not cross the fuse's melting curve ( $I_{RMS1}$  in Figure C1), the fuse will not open.

In this case, the minimum horizontal distance (expressed in %  $I_p$ ) between the plotted curve and the fuse's melting curve indicates how well the fuse will perform when encountering a given overload.

The above method, together with the guidelines given on overloads in the section selecting rated current, will determine if the fuse can withstand the type of overload in question.

This can be done even if the axes of the melting curve are in  $I_p$  and  $t_v$ . It can be shown that a relabeling of the axes designation:  $I_p = I_{RMS}$  and  $t_v = t_r$  can be done without changing the shape of the melting curve.

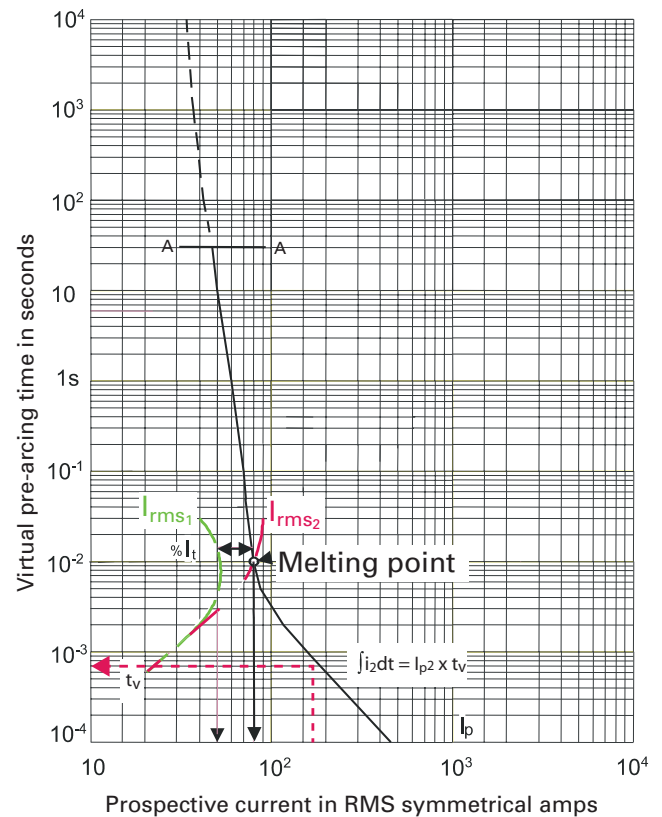


Figure C1. Time-current curves.

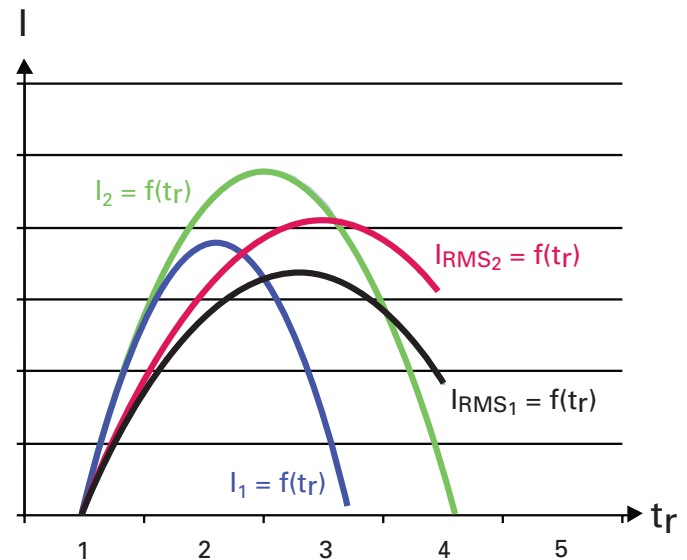
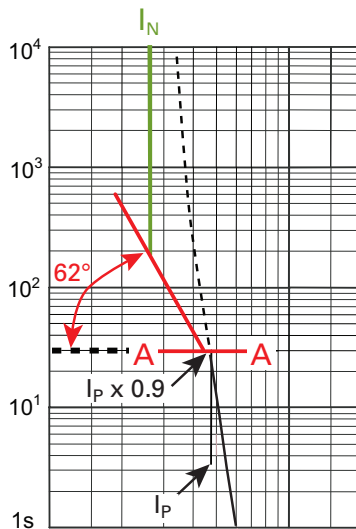


Figure C2. Overload and fault current curves.



## The A-A curve



**Figure C3. A-A curve.**

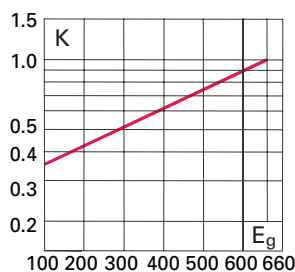
As a part of the melting curve for Type aR fuses only, an “A-A curve” plot is given. Melting or loading beyond this point in the melting curve is not allowed. This is due to the thermal overload risk that might reduce the fuse’s interrupting capacity and won’t operate in the A-A zone.

Often, the A-A curve is plotted only by a horizontal line. In order to plot the complete A-A curve for a given fuse, the following guidelines should be observed:

- The prospective short-circuit current ( $I_P$ ) found for the time equal to the intersection between the A-A curve and the actual melting curve should be multiplied by 0.9 ( $I_P \times 0.9$ ) and this point is marked on the A-A curve (Figure C3)
- From here can be drawn a straight line at sixty two degrees ( $62^\circ$ ) from the A-A curve and melting curve intersection to where the fuse’s rated current ( $I_N$ ) vertical line is plotted

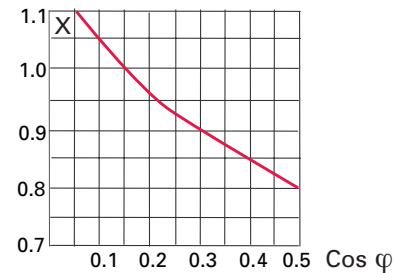
This completes the A-A curve (Note  $62^\circ$  is only valid if the graph decade relation is 1:2, which is typical for IEC standard fuses, as opposed to a 1:1 decade relation, which is common for North American fuses).

## Clearing integral information



**Figure C4. K factor curve.**

Normally the maximum  $I^2t$  under short-circuit conditions will be the 10 ms clearing integral  $I^2t_{cl}$  of the fuse, which is given at the applied working voltage ( $E_g$ ) equal to the fuse’s voltage rating ( $U_N$ ) at power-factor of  $\cos \varphi = 0.15$  and at a short-circuit level of 10–15 times the rated current.



**Figure C5. X factor curve.**

The fuse  $I^2t_{cl}$  (based upon  $20^\circ\text{C}/68^\circ\text{F}$  ambient) should be compared with the equivalent 10 ms fusing integral  $I^2t_{scr}$  of the semiconductor (normally given at  $125^\circ\text{C}/257^\circ\text{F}$ ) to see if protection is ensured. And even if  $I^2t_{cl} = I^2t_{scr}$ , a reasonable safety margin can be expected (cold fuse versus warm SCR). If the fuse is clearing at a lower voltage than stated above and at a different power factor, then two correction factors should be used in conjunction with the given  $I^2t_{cl}$ .

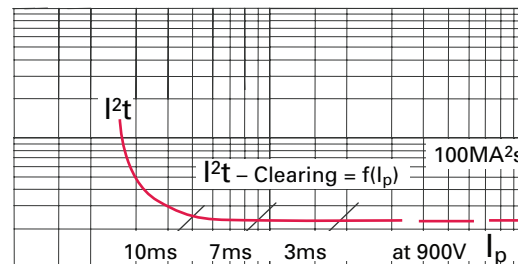
The resultant clearing integral will be equal to:

$$I^2t_{cl} \times K \times X$$

(Factors K and X can be found in Figures C4 and C5)

The  $I^2t_{scr}$  of the device should be compared with this result.

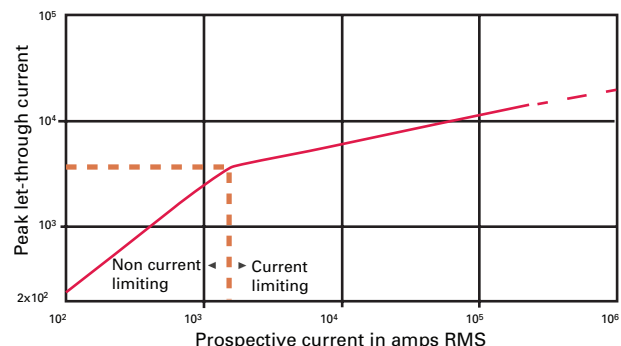
## The $I^2t$ curve



**Figure C6.  $I^2t$  curve.**

An  $I^2t$  curve may also be presented (or available on request). It shows the clearing  $I^2t$  and time as a function of the prospective short-circuit current for a given system voltage (Figure C6). This can ease the selectivity coordination between the fuse and the semiconductor to be protected or other devices in the short-circuit path.

## Peak let-through



**Figure C7. Peak let-through curve.**

## C: Fuse performance data

High speed fuses, by their design and purpose, are current-limiting devices. This means they will reduce the prospective short-circuit current, and destructive thermal and mechanical forces in equipment to an acceptable level if a short-circuit should occur. In practice the short-circuit current is given as the symmetrical RMS value of the available fault current, called  $I_p$ . The actual maximum peak (asymmetrical) current depends on the circuit's power factor. For  $P.F. = \cos \varphi = 1.0$  to 0.15, or 100 percent to 15 percent the peak value will lie between:

$$\sqrt{2} \times I_p \text{ and up to } 2.3 \times I_p$$

From the peak let-through curve in Figure C7, it can be seen that a certain magnitude of  $I_p$ , relative to the fuse's  $I_N$  is needed before the current-limiting effect will take place.

### The arc voltage curve

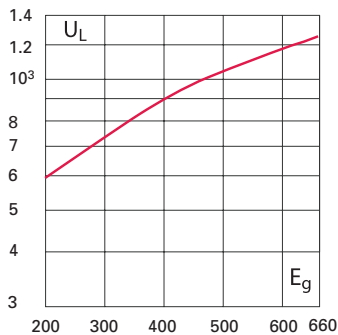


Figure C8. Arc voltage curve.

The peak arc voltage of the fuse and peak reverse voltage of the semiconductor should always be coordinated.

An arc voltage is generated due to the specially designed element restrictions (necks) that are packed in arc-quenching sand. This forces the current to zero during the arcing time and finally, isolation is established. This permanent isolation is built up at the restriction sites that are converted into fulgurite, a composition of metal and sand made during the arcing process.

For a given fuse voltage rating, the peak arc voltage  $U_L$  depends mainly on the applied working voltage level  $E_g$  in RMS, according to Figure C8.

### Watt loss correction curve

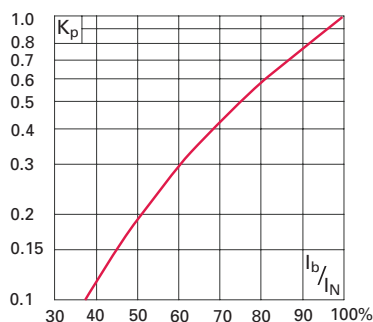


Figure C9. Watts loss correction curve.

The rated watt loss is given for each fuse under specified conditions. To calculate the loss at a load current lower than rated current, the rated watt loss is to be multiplied by correction factor  $K_p$ . This factor is given as a function of the RMS load current  $I_b$ , in percent of the rated current, see Figure C9.

## D: Determining fuse voltage ratings

The fuse voltage rating is the maximum AC, DC or AC/DC voltages it is designed for. Most commercial fuses are rated for AC RMS voltages (45-62 Hz), unless otherwise stated on the fuse label.

For proper application, the fuse voltage rating must be less than or equal to the system voltage. All Bussmann series high speed fuses are designed to the UL 248-13, IEC 60269 1 and 4, or the BS88 standards. This allows designers to select a high speed fuse that can be used anywhere around the world.

### IEC voltage rating

IEC requires AC voltage tests to be performed at 110 percent of the rated voltage (with the exception of 105 percent for 690 V), with power factors between 10 and 20 percent.

This enables the fuse to be used at rated voltage virtually anywhere without fear of exceeding the maximum tolerances of the test conditions. The extra percentages take into account supply voltage fluctuations found in some converters.

### North American voltage rating

A North American voltage rating requires that all fuses be tested at their nominal RMS rated voltage only, with power factors between 15 and 20 percent. In many instances, a fuse is chosen with a voltage rating well above the system voltage.

Under some circuit conditions, there can be normal circuit fluctuations of  $\pm 10$  percent. It is a good practice to be aware of this when investigating North American style fuses as they are not tested at any voltages above their rating.

### Simple rated voltage determination

In most converter circuits, the amount and nature of the voltage rating is evident and the voltage selection can be made right away.

Generally, a single fuse on its own should be able to open and clear against the maximum system voltage. If two fuses are applied in series in the same short-circuit path, each fuse must be rated at the system voltage.

### Frequency dependency

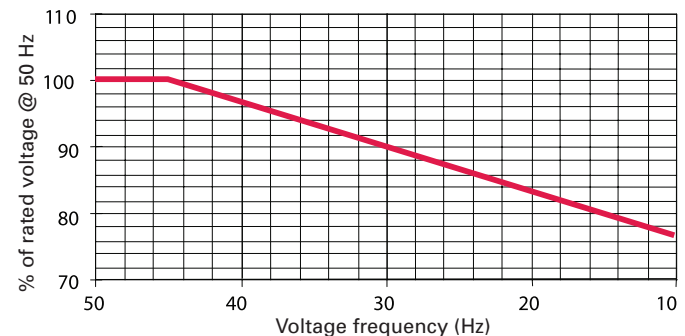
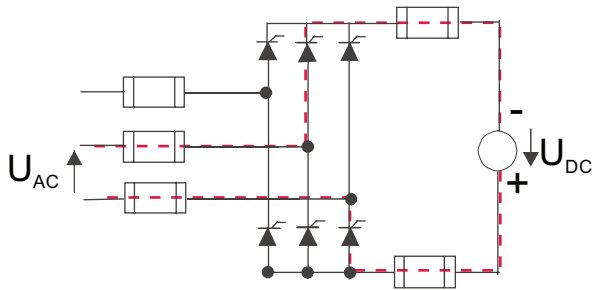


Figure D1. Rated voltage vs. frequency.

The stated, AC rated voltage of Bussmann series high speed fuses are valid at frequencies from 45 to 1000 Hz. Below 45 Hz please refer to Figure D1. The interrupting process at lower AC frequencies (beyond the scale of Figure D1) tends to behave more like DC voltage and the voltage rating should conform with what is described in DC Applications in this guide.

## D: Determining fuse voltage ratings

### Possible AC/DC combinations



**Figure D2. Six-pulse bridge circuit.**

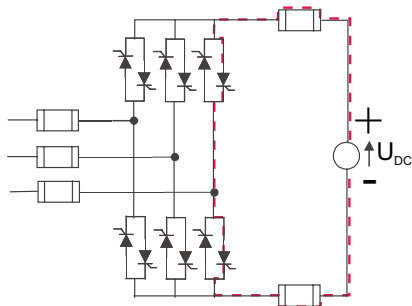
Even in relatively simple converters like the six-pulse bridge, etc. (see Figure D2) there is the possibility that the fuse's rated voltage is required to be much higher than the AC supply voltage itself.

This is so, because the converter is regenerative (it is able to return energy to the supply). Here, in case of a commutation fault, the AC supply voltage  $U_{AC}$  and the output DC voltage will be superimposed. To withstand this increased voltage, the rated voltage  $U_N$  of the fuse must be:

$$U_N \geq 1.8 \times U_{AC}$$

For further details please refer to section *Fuses protecting regenerative drives* starting on page 20.

### AC fuses in DC circuits



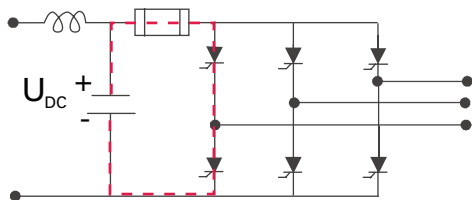
**Figure D3. AC fuses in a DC motor drive circuit.**

If AC fuses are used in DC motor and drive circuits, the selection process becomes more complex (Figure D3).

The determining parameters will be the system DC voltage, the minimum short-circuit current and the associated maximum time constant (L/R).

For details, refer to the section on *AC fuses in DC circuit applications* starting on page 18.

### Fuses under oscillating DC



**Figure D4. AC fuses protecting GTOs and IGBTs on the DC side of voltage commutated inverters.**

AC fuses can be used for the protection and isolation of GTOs and IGBTs on the DC side of voltage commutated inverters (Figure D4).

In case of a DC shoot-through with a very high  $d_i/d_t$  of short-circuit current, it may be possible for the DC rating to be greater than the AC voltage rating (either IEC or UL).

For further information, please contact Application Engineering at [FuseTech@eaton.com](mailto:FuseTech@eaton.com).

### Fuses in series

It is not common to connect fuses directly in series. Under low overcurrent conditions, only a small variation in fuse performance would cause one of the fuses to open before the other and thus the opening fuse should be capable of clearing the full system voltage. Under higher fault currents both fuses will open, but it is unlikely the voltage will be shared equally. Therefore, if fuses are connected in series the following should be observed:

- Fault currents sufficient to cause melting times of 10 ms or less should always be available
- The voltage rating of each fuse ( $U_N$ ) should be at least 70 percent of the system voltage
- If the available fault current can only produce melting times more than 10 ms, then the voltage rating of the fuse must, at a minimum, be the same as the applied voltage



## E: Determining fuse amp ratings

The fuse's rated amperage is the RMS current it can continuously carry without degrading or exceeding the applicable temperature rise limits under well defined and steady-state conditions. This is in contrast to semiconductors, whose rated current is given as a mean or average value. Many conditions can effect the fuse's current carrying capability. To prevent premature fuse aging, following Parts 1, 2 and 3 below will allow the rated current selection to be on the safe side.

### Part 1 — Basic selection

This covers the basic selection criteria for only the fuse's rated amperage and not the influence from overload and cyclic loading. The actual RMS steady-state load current passing through the fuse should be lower or equal to the calculated maximum permissible load current called  $I_b$ .

$$I_b = I_n \times K_t \times K_e \times K_v \times K_f \times K_a \times K_b$$

Where:

$I_b$  = Maximum permissible continuous RMS load current\*

$I_n$  = Rated current of a given fuse

$K_t$  = Ambient temperature correction factor (Figure E1)

$K_e$  = Thermal connection factor (Figure E2)

$K_v$  = Cooling air correction factor (Figure E3)

$K_f$  = Frequency correction factor (Figure E4)

$K_a$  = High altitude correction factor (Equation 1)

$K_b$  = Fuse load constant. (Normally 1.0 for porcelain body fuses and 0.8 for fiber body fuses.)

\* NB: For any periods of 10 minutes duration or more the RMS value of the load current should not exceed this.

In case of water cooled fuse terminals, please consult Application Engineering at FuseTech@eaton.com.

### Busbar current density

The nominal busbar current density on which the fuses are mounted should be 1.3 A/mm<sup>2</sup> (IEC 60269 Part 4 defines 1.0 to 1.6/mm<sup>2</sup>). If the busbar carries a current density more than this, then the fuse should be derated. Figure E2 shows the thermal correction factor ( $K_e$ ).

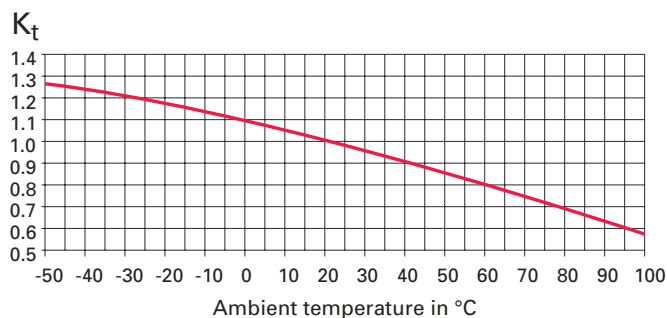


Figure E1. Ambient temperature correction factor.

This curve shows the influence of the ambient temperature on the fuse's current-carrying capability.

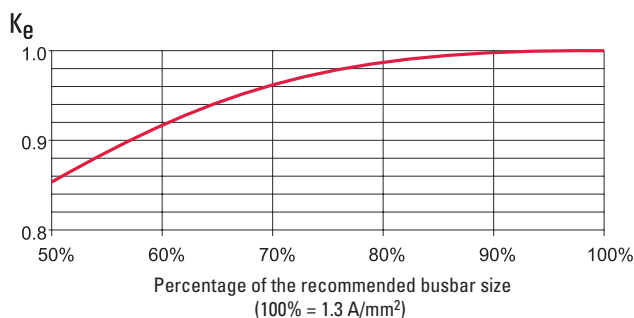


Figure E2. Thermal connection factor.

If two connections are not equal, the equivalent  $K_e$  factor can be found using the following formula:

$$K_e = \left( \frac{K_{e1} + K_{e2}}{2} \right)$$

Where:

$K_{e1}$  = Thermal correction factor for busbar 1

$K_{e2}$  = Thermal correction factor for busbar 2

Fuse mounting inside an enclosure will reduce the convection cooling compared with the IEC test conditions. An additional  $K_e$  thermal connection factor should be chosen here based on judgement. Often, enclosure mounted fuses are given an additional  $K_e$  factor of 0.8.

### Voltage frequency

Fuses under high frequency loads (like in voltage commutated inverters) call for special attention. At higher frequencies, the fuse's current carrying capability can be reduced due to the imposed skin and proximity effect on the current-carrying elements inside the fuse. Using the curve given in Figure E4 normally ensures a sufficient margin ( $K_f$ ).

### High altitude

When fuses are used at high altitudes, the atmosphere's lower density reduces the cooling effect on the fuse. An altitude correction factor ( $K_a$ ) should be applied to the fuse's continuous rating when used above 2000 m. The correction factor  $K_a$  can be determined using Equation E1:

#### Equation E1

$$K_a = \frac{I}{I_n} = \left( 1 - \left( \frac{h-2000}{100} \times \frac{0.5}{100} \right) \right)$$

Where:

$I$  = Current rating at high altitude

$I_n$  = The fuse's rated current

$h$  = Altitude in meters

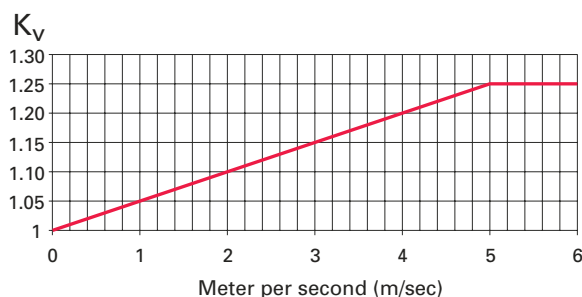


Figure E3. Forced air cooling correction factor.

The curve shows the influence of forced air cooling on the fuse.

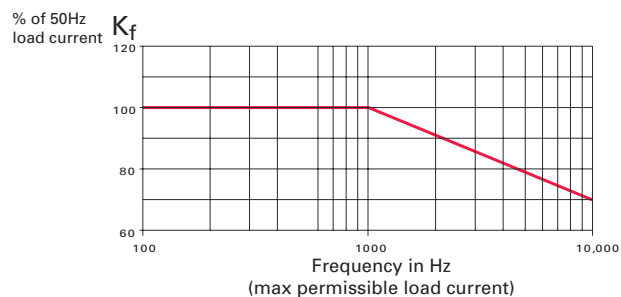


Figure E4. Voltage frequency correction factor.

## E: Determining fuse amp ratings

### Example 1

A 200 A porcelain square body fuse is applied at an ambient temperature of 40°C/104°F, and wired with cables having a 120 mm<sup>2</sup> cross section. Forced air cooling is applied at a rate of 4 m/s. The load current frequency is 3000 Hz.

What is the maximum allowed steady-state RMS current  $I_b$ ?

To accurately estimate the correct permissible load of the square body fuse it is necessary to evaluate each correction factor to the application.

From the current determining formula given, and the correction factors shown in Figures E1 through E4, we have:

$$I_b = I_n \times K_t \times K_e \times K_v \times K_f \times K_a \times K_b$$

Where:

$$I_n = 200 \text{ A}$$

$$K_t = 0.9 \text{ for } 40^\circ\text{C ambient (Figure E1)}$$

$$K_e = 0.98 \text{ at } 78\% \text{ (Figure E2)}$$

$$\begin{aligned} \text{Current density} &= 200 \text{ A}/120 \text{ mm}^2 \\ &= 1.54 \text{ A/mm}^2 \end{aligned}$$

$$\begin{aligned} \% \text{ Density} &= 1.3/1.54 \\ &= 78\% \end{aligned}$$

$$K_v = 1.2 \text{ for } 4 \text{ m/s forced air cooling (Figure E3)}$$

$$K_f = 0.85 \text{ for a frequency of } 3000 \text{ Hz (Figure E4)}$$

$$K_a = 1, \text{ at sea level, below } 2000 \text{ meters (Equation E1)}$$

$$K_b = 1.0 \text{ porcelain body fuse load constant}$$

That results in:

$$\begin{aligned} I_b &= 200 \times 0.9 \times 0.98 \times 1.2 \times 0.85 \times 1 \times 1 \\ &= 180 \text{ A RMS} \end{aligned}$$

In other words the 200 A fuse should only be subjected to a maximum 180 A RMS under the described steady-state conditions.

### Checking permissible load current

A fuse's maximum permissible steady-state load current ( $I_b$ ) can be checked by making simple voltage measurements under actual operating conditions. This should be done after the fuse is installed in its operating location and loaded at the calculated  $I_b$  value:

$$E_2/E_1 \times (0.92 + 0.004 \times T_a) \leq N$$

Where:

$$E_1 = \text{Voltage drop across fuse after 5 seconds}$$

$$E_2 = \text{Voltage drop across fuse after 2 hours}$$

$$T_a = \text{Air temperature at start of test in } ^\circ\text{C}$$

$$N = \text{Constant (if available, from data sheet, normally 1.5 or 1.6)}$$

### Part 2 — Influence of overloads

The maximum overload current  $I_{\max}$  that can be imposed on the fuse found under Example 1 depends upon the duration and frequency of occurrence.

Time durations fall into two categories:

1. Overloads longer than one second
2. Overloads less than one second (termed impulse loads)

Table E1 gives general application guidelines. In the expression  $I_{\max} < (\text{percent factor}) \times I_t$ ,  $I_t$  is the melting current corresponding to the time  $t$  of the overload duration as read from the time-current curve of the fuse. The limits given permit the determination of  $I_{\max}$  for a given fuse rating or, conversely, the fuse current rating required for a given overload, expressed by:

$$I_{\max} < (\text{percent factor}) \times I_t$$

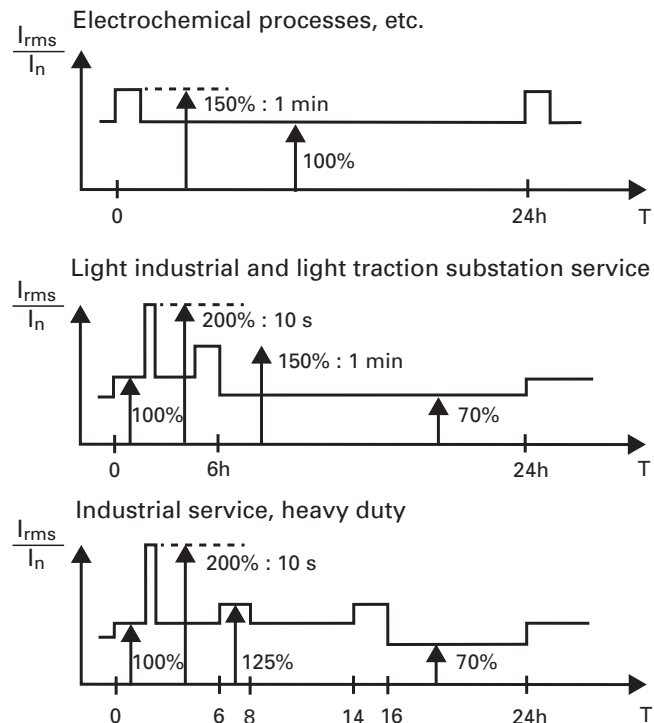
Typical examples of load cycles including overload currents are given in Figure E5.

The percentage factor for each overload should be checked against the melting curve of the selected fuse in question, based upon the guidelines in Part 1.

There is a grey area between a sole overload and a pure cyclic load situation. In particular, the three examples shown in Figure E5 are typical of this dilemma and for safety, treat this example like a cyclic load based upon the guidelines in Part 3 of this section.

**Table E1. Influence of overloads.**

Frequency of occurrence	Overloads (>1 sec)	Impulse loads (<1 sec)
Less than one time per month	$I_{\max} < 80\% \times I_t$	$I_{\max} < 70\% \times I_t$
Less than twice per week	$I_{\max} < 70\% \times I_t$	$I_{\max} < 60\% \times I_t$
Several times a day	$I_{\max} < 60\% \times I_t$	$I_{\max} < 50\% \times I_t$



**Figure E5. Typical load cycles.**

### Example 2

A 200 A fuse has been selected, but is subjected to temporary overloads of 300 amps for 5 seconds, and these overloads occur three to five times a day. From the time-current curve of the fuse found on Figure E8, we find the melting current ( $I_t$ ) corresponding to the time ( $t = 5$ ) in seconds of overload duration to be,  $I_t = 750 \text{ A}$ .

From Table E1, the formula for the maximum overload current ( $I_{\max}$ ) can be found based on an overload occurring three to five times per day for a duration of 5 seconds and is shown below. Applying the melting current ( $I_t$ ) of the 200 A fuse will yield the following maximum overload current:

$$\begin{aligned} I_{\max} &= < 60\% \times I_t \\ &< 60\% \times 750 \text{ A} \\ &< 450 \text{ A} \end{aligned}$$

This means that temporary overloads of up to 450 A can be withstood and the 200 A fuse selected will work in this application.

### Part 3 — Cyclic loading and safety margins

Cyclic loading that leads to premature fuse fatigue is defined as regular or irregular load current variations, each of a sufficient magnitude and duration to change the temperature of the fuse elements in such a way that the very sensitive restrictions (necks) will fatigue. In order to avoid this condition, calculations can be made to ensure there is an appropriate safety margin for the selected fuse.

While using the following empirical rules will cover most cyclic loading conditions, it is impossible to set up general rules for all applications. For applications not covered in this section, please contact Application Engineering at FuseTech@eaton.com.

#### Rule 1: $I_b > I_{rms} \times G$

Where:

$I_b$  = The maximum permissible load current based upon the criteria presented in Part 1 "Basic selection"

$I_{RMS}$  = the RMS value of the cyclic loading condition

$G$  = Cyclic load factor (for most cases a sufficient margin is assured by using 1.6)

Some cyclic load factors  $G$  can be found from the example profiles in Figure E7, or can be provided upon request.

The required rating for the fuse can, therefore, be found using the following formula:

$$I_n \geq \frac{I_{RMS} \times G}{K_t \times K_e \times K_v \times K_f \times K_a \times K_b}$$

#### Rule 2: $I_{pulse} < I_t \times B$

Once a fuse has been selected using the above criteria, a check is required to see if the individual cyclic load pulses (each expressed in  $I_{pulse}$ ,  $t_{pulse}$  coordinates) have a sufficient safety margin in relation to the fuse's melting current at each pulse duration.  $I_t$  is the fuse's melting current corresponding to each pulse ( $t = t_{pulse}$ ) duration, and the cyclic pulse factor  $B$  can be found in Figure E6 for a period ( $T$ ) of a cyclic loading condition.

This should ensure a sufficient fuse life when subject to the cyclic loadings encountered in an application.

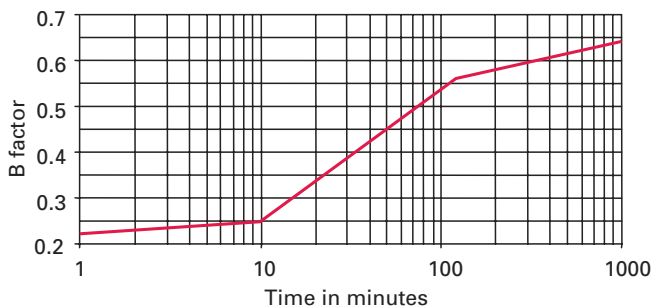


Figure E6. Cyclic pulse factor B.

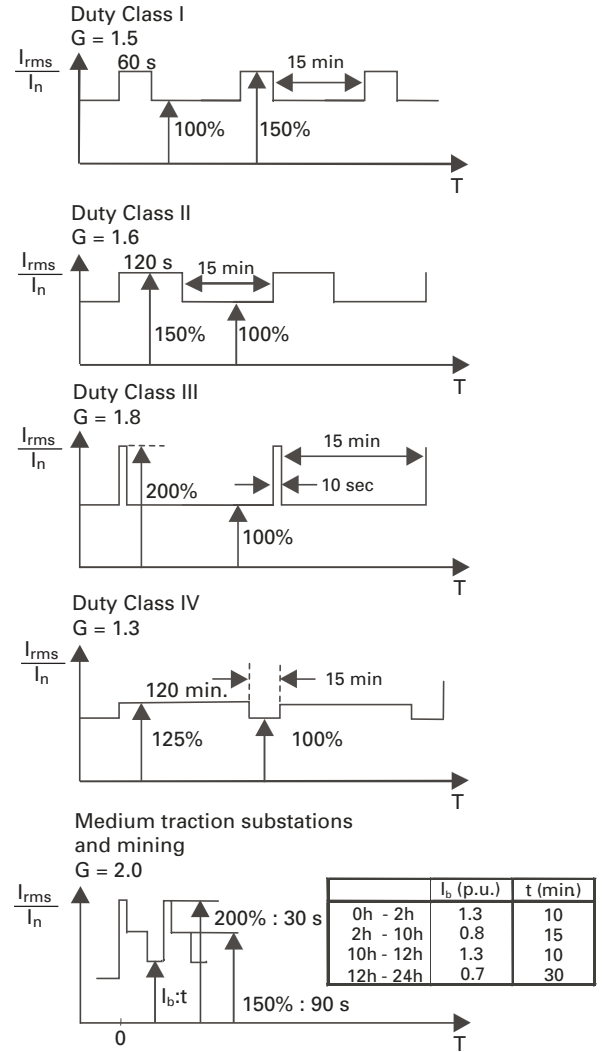


Figure E7. Cyclic loading profile examples and duty class.

#### Example 3

For a 200 A fuse, there is cyclic loading of 150 A for two minutes followed by 100 A for 15 minutes.

This requires a cyclic load factor of  $G = 1.6$  from the example profiles in Figure E7. The RMS-value of the cyclic load for a period of  $T = 17$  minutes is determined by the RMS formula below and expressed as:

$$\sqrt{\frac{(150^2 \times 2) + (100^2 \times 15)}{17}} \approx 107 A_{rms}$$

Assuming there aren't any fuse current derating factors (i.e.,  $K_t \times K_e \times K_v \times K_f \times K_a \times K_b = 1$ ), the maximum permissible load current ( $I_b$ ) for the fuse's 200 A rating will be:

$$\begin{aligned} I_b &> I_{rms} \times G \\ &> 107 \times 1.6 \\ &> 171 \text{ A} \end{aligned}$$



## E: Determining fuse amp ratings

While a 200 A fuse may be sufficient, a safety factor check (B) is needed to ensure that the pulse keeps a sufficient safety distance from the fuse's melting curve. This is obtained from the Rule 2  $I_{\text{pulse}}$  equation in Part 3, using Figure E6 for a given total time period  $T = 17$  minutes, then  $B = 0.32$ .

Given a  $t_{\text{pulse}}$  of two minutes for the cyclic loading condition,  $I_t = 440$  A can be found from the time current curve for the 200 A fuse (Figure E8).

$$\begin{aligned} I_{\text{pulse}} &< I_t \times B \\ &< 440 \text{ A} \times 0.32 \\ &< 141 \text{ A (150 A requirement not met!)} \end{aligned}$$

The result of less than 141 A concludes that the application  $I_{\text{pulse}}$  of 150 A exceeds the fuse's melting curve and a higher, 250 A fuse rating should be selected.

### Fuses in parallel

There are many applications that use fuses in parallel.

As the surface area of two smaller fuses is often greater than a larger, equally rated fuse, the cooling effect is also greater. The result may provide a lower  $I^2t$  solution, providing closer device protection or a lower power loss (watts loss) solution.

Only fuses of the same part number and rating should be used in parallel (fuses of the same basic part number and rating, but one with indicator as the only difference is considered the exception).

The fuses must be mounted to allow equal current and heat flow to the connections. In large installations, best practice is to install parallel fuses as close as possible with equal cold resistance values.

The  $I^2t$  value of parallel fuses is given by:

$$I^2t \times N^2$$

Where:

$N$  = The number of fuses connected in parallel

Mountings should ensure at least 5 mm (0.2") distance between adjacent fuses.

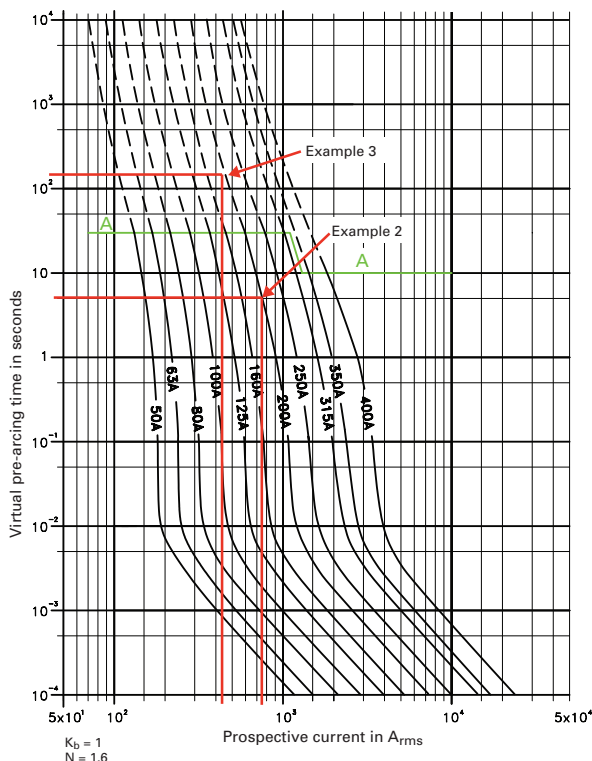


Figure E8. Example 2 and 3, time-current curves.

## F: High speed fuse applications

Power semiconductors protected by high speed fuses are used in many applications such as AC drives, DC drives, traction, soft starters, solid state relays, electrolysis, induction furnaces and inverters. The power source for these may be supplied by the grid, local generator or batteries.

The circuit configurations for these applications vary a lot. Some of the most typical circuits are illustrated on the following page along with information on how to find relevant RMS and load current levels for the fuse installation.

All of these circuit examples may operate at just a few amps or at many thousands of amps. Regardless, the circuit operating principles are usually the same. However, the protection levels involved depend on multiple needs including protection against:

- Accidents
- Injuries to personnel
- Integrity of semiconductors and other components, etc.

Some aspects of the example circuits and their protection are common to many applications. These will be covered here with more specific details covered in following sections.

Applications are broadly grouped into AC and DC current, with many in modern circuits using both AC and DC currents.

The applications that utilize DC to AC inverters (variable speed AC drives and Uninterruptible Power Supplies (UPS)) can usually have their fusing requirements considered in two parts. First the AC to DC converter and then the inverter section. This guide will describe the AC part first and consider the DC rectifier systems and switches second.

### RMS currents in common bridge arrangements

The most common circuits involve rectifiers that convert alternating current (AC) into direct current (DC).

There are a number of ways in which the supply transformers and rectifying devices may be configured. For the purposes of these schematic examples, the semiconductor devices are represented by diodes (although these could also be thyristors or GTOs that would give control over the output voltage or current).

There are common places to apply high speed fuses in rectifier circuits. The RMS current at these circuit locations varies depending on the amount of cyclic current that will be flowing. This is described for diodes, but for controlled circuits (with thyristors or GTOs), these values may be different. However, they will not exceed those shown, as this is the same as the controlled device being constantly in the ON state.

The most common arrangements are shown here.

The pros and cons of applying high speed fuses in the designated locations will be considered in detail later.

Circuit 1 is not often encountered in power electronics systems. The half wave output would be inefficient with much distortion reflected to the supply.

### Typical rectifier circuits

Fuses are RMS devices and based upon 100 percent average DC load current output, the relevant RMS load currents  $I_1$ ,  $I_2$  and  $I_3$  can be found.

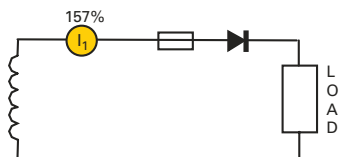


Figure F1. Single-phase, half wave

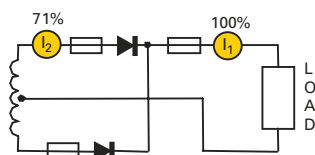


Figure F2. Single-phase, full wave, center tap

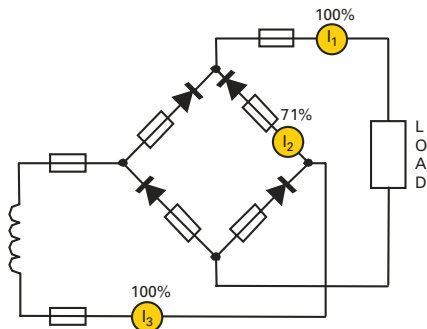


Figure F3. Single-phase, bridge

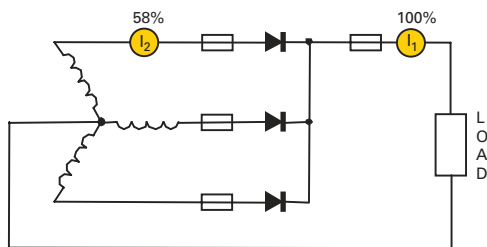


Figure F4. Three-phase, Wye

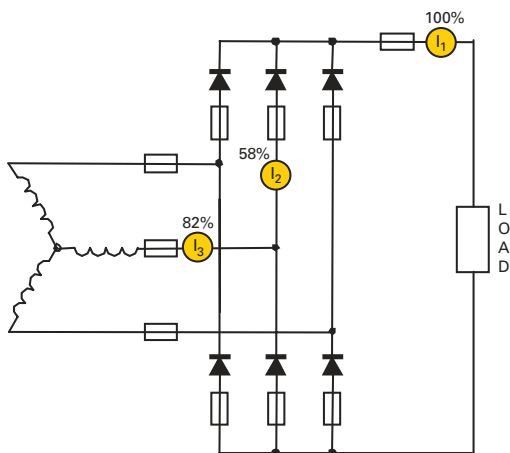


Figure F5. Three-phase, bridge

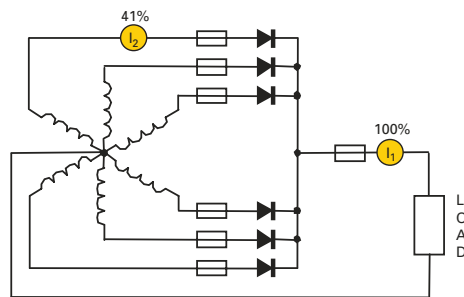


Figure F6. Six-phase, star

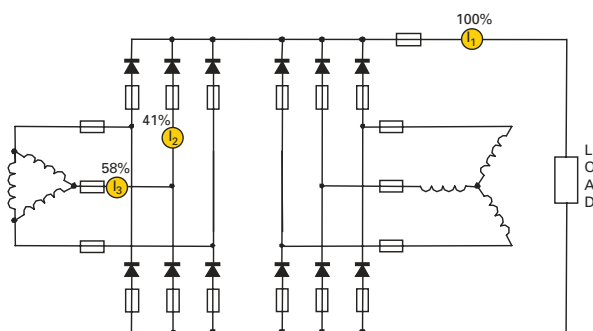


Figure F7. Six-phase parallel (without IPT)

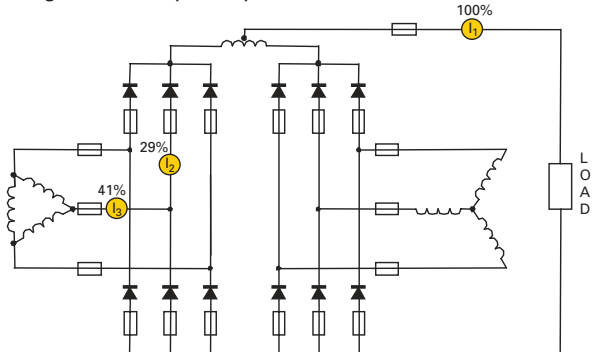


Figure F8. Six-phase parallel (with IPT)

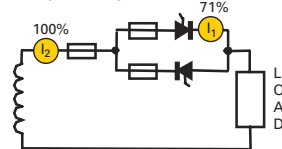


Figure F9. Single-phase, anti-parallel, AC control

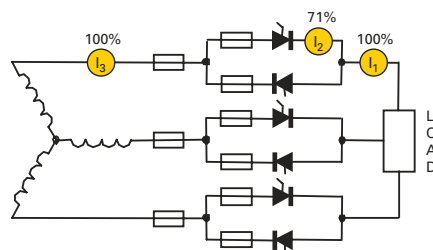


Figure F10. Three-phase, anti-parallel, control

## G: Fuse protection for rectifiers

In principle, a fuse should carry all the application's required continuous current and any expected, transient overloads. When a short-circuit occurs, the fuse should limit the energy passing through the semiconductor device so that it remains undamaged.

### Internal and external faults — high power/high current rectification

As can be seen in the schematics on the previous page, fuses may be placed in different circuit locations. Fuses may be connected in series with the semiconductor devices, in the supply lines, and sometimes in the output lines. Only the fuses in the bridge legs (or arms) will allow maximum semiconductor steady state current carrying capacity as the minimum fuse RMS current is in this location.

In the design of high power rectifier equipment, there are two types of short-circuits that must be accounted for:

- **Internal faults** — a short-circuit of an individual rectifier cell. Failure to open in the circuit of a silicon power rectifier is rare. However, this type of short-circuit can be ascertained by the use of detection circuitry (see Figures G1 and G2).
- **External faults** — a short-circuit or excessive load at the output terminals of the equipment (see Figure G3)

### Protection from internal faults

In order to protect healthy rectifier cells in the event of an internal fault, fuses should be connected in series with each rectifier cell.

#### Consideration for rectifiers with parallel paths

It's important to note that in designing high power, high current rectifier equipment, continuity of supply in the event of an internal fault is often a desired feature. The equipment must be designed to provide the required output under all load conditions with one or more non-operating semiconductor devices according to the manufacturer's specification. This can be done when each arm consists of having multiple rectifier cells (see Figure G1).

To ensure continued operation and output with an internal fault, the fuse connected in series on the faulted rectifier cell of the arm must open and clear without opening the fuses connected in series with other, functioning rectifier cells within the faulted arm.

In order to satisfy this condition, the total clearing  $I^2t$  of the single fuse must be less than the combined pre-arcing  $I^2t$  of all the fuses in one arm of the equipment's bridge, expressed as:

$$I^2t_2 < I^2t_1 \times n^2$$

Where:

$I^2t_2$  = Total clearing  $I^2t$  of the cell fuse faulted

$I^2t_1$  = Pre-arcing  $I^2t$  of each fuse in the arm

$n$  = the number of parallel paths in each bridge arm of the equipment  
More precisely, to allow for non-uniform current sharing in the parallel paths,  $n$  should be replaced by  $n/(1 + S)$  where  $S$  is the uneven sharing, usually between 0.1 and 0.2 (10 and 20 percent).

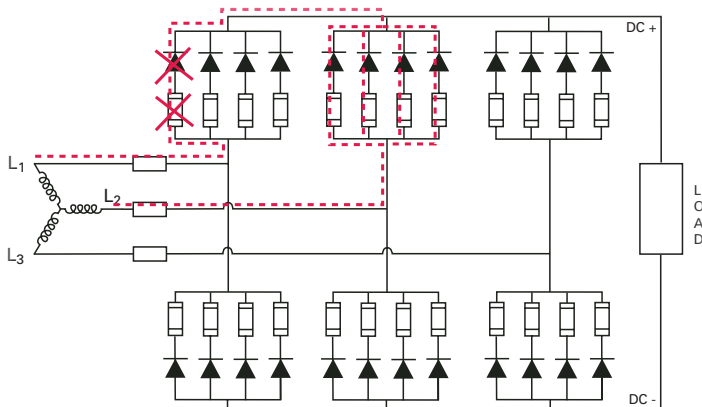


Figure G1. Internal fault.

Additionally, should the equipment design specify that supply continuity must be maintained in the event of one or more semiconductor devices failing, the "n" in the above formula must be replaced by (n - x), where x is the required number of failed semiconductor.

Experience has shown that where "n" is less than four (4) (see Figure G2), protection of the above nature is often difficult to achieve. In applications utilizing both line and individual device fuses, a check must be made to ensure that when an internal fault occurs, the device fuse selectively coordinates with the line fuse (i.e., the total clearing  $I^2t$  of the cell fuse must be less than the pre-arcing  $I^2t$  of the line fuse):

$$I^2t_2 < I^2t_1$$

Where:

$I^2t_2$  = Total clearing  $I^2t$  of cell fuse

$I^2t_1$  = Pre-arcing  $I^2t$  of line fuse

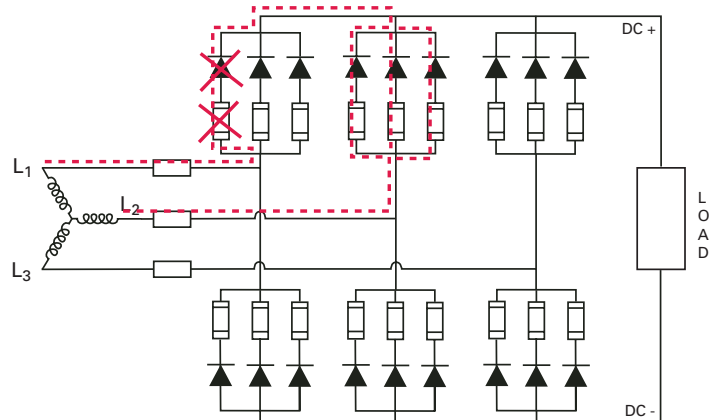


Figure G2. Internal fault, fewer parallel paths.

### Protection from external faults

In the event of an external fault, it is undesirable to have all the rectifier's individual fuses open. Therefore, it's a good practice to include a fuse, in series, with the supply line (see Figure G3).

To ensure the line fuse clears before the individual device fuse, the total clearing  $I^2t$  of the line fuse must be less than the combined pre-arcing  $I^2t$  of the cell fuses used in one bridge arm of the equipment, expressed as:

$$I^2t_1 < I^2t_2 \times n^2$$

Where:

$I^2t_1$  = Total clearing  $I^2t$  of the line fuse

$I^2t_2$  = Pre-arcing  $I^2t$  of each cell fuse

$n$  = Device fuses connected in parallel

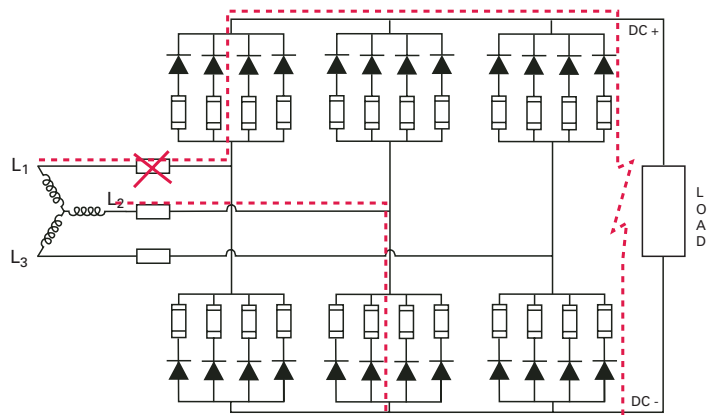


Figure G3. External fault.



### Service interruption upon device failure

The majority of faults in low and medium power rectifying and converting equipment fall into this category. Fuses connected in series with the semiconductor devices, or in the supply lines, are used to protect against internal and external faults in these common applications:

- Variable speed motor drives
- Heater controls
- Inverters
- Low power rectifiers

With inverter circuits, care must be taken that correct DC voltage ratings are chosen for each application. DC faults can also occur upon device failure in bridge circuits when other power sources feed the same DC bus, or when the load consists of motors, capacitors or batteries. Example 1 in the worked examples section illustrates the protection of a typical DC thyristor drive.

### Continued service upon device failure

Service interruptions cannot be tolerated in large-scale rectifying applications such as DC supplies for electrochemical operations.

As discussed earlier, these applications employ several parallel paths ( $n > 4$ ) in each arm of the rectifier. Each of these parallel paths are individually fused to isolate faulty devices (see worked example section).

In applications where many fuses are used, detecting an individual open fuse is made easier by using indicating fuses that can actuate microswitches for remote monitoring and warning.

## Fuse protection in DC systems

The inductance in a DC circuit limits the rate of current rise. The time required for the current to reach 63 percent of the final value is called the "time constant," and often referred to in terms of  $L/R$  (Figure H1).

The rate of current rise influences the energy input rate that melts the fuse's element. This influences both the fuse's melting time-current characteristic and the peak let-through current. For long operating times (greater than 1 second) the heating effect of an AC current is the same as DC current and the characteristics will merge. Figure H2 shows a typical AC peak let-through and time-current curve (red) along with DC peak let-through and time current curve at time-constants of 25 ms (green) and 80 ms (blue). Note that higher DC time constants make the curves shift up for the peak let-through, and right for the time-current curves.

Many circuits have a time constant ranging between 10 ms and 20 ms. As such, IEC specifications require testing between these values. Time constants longer than 20 ms are not often encountered outside of traction third rail applications, where long rail lengths give extremely high inductance-to-resistance ratios. For short-circuit considerations, the value of the circuit time constant under short-circuit conditions should be used. This may be different than the time constant for normal operating conditions.

In many rectifier circuits (even under fault conditions), a fuse will be subjected to an alternating voltage. The voltage will reduce to zero (or close to zero) on a regular basis as defined by the supply line frequency. Under these conditions, extinguishing the arc inside the fuse, under fault conditions, is assisted by the voltage periodically reducing to zero.

When a fuse is applied in a purely DC application, extinguishing the fuse arc will not be assisted by the reducing voltage or the zero voltages of alternating current. The inductance in the circuit stores electrical energy. This influences the manner in which the fuse arcing process reduces the current in the circuit and is beyond the scope of this guide.

The voltage under which the fuse can safely operate is dependent on circuit time constants. It should be noted that when the time constant is short, it may be possible for the DC voltage rating to be greater than the AC voltage rating (to IEC or UL). However, for most fuses, the DC voltage rating is 75 percent or less than the AC voltage rating, with the DC rating further decreasing as the circuit time constant increases.

The arc voltage generated by the fuse during operation will also vary with respect to the system voltage. The arc voltage variation with respect to applied voltage will be different between AC and DC systems. However, in most cases, it is acceptable to use the data provided for AC conditions.

Unless special design features are included, fuses should not be called upon to clear low overcurrents in DC circuits. The performance in this area may be a limiting factor on fuse selection.

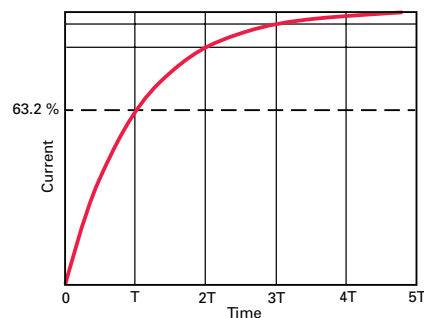


Figure H1. Time constant ( $L/R$ ) in DC circuits is 63 percent.

### DC fed systems

The vast majority of applications involving DC have an AC supply that's rectified to supply a load. This load may be passive such as an electrolysis cell or as complex as a regenerative drive.

There are a number of circuit types requiring special consideration. These include circuits with batteries, capacitors and those where the motor drive is regenerative. In large electrolysis systems there are often considerations of parallel devices and fuses. Circuits with batteries and capacitors are covered elsewhere in this guide, as are regenerative drives.

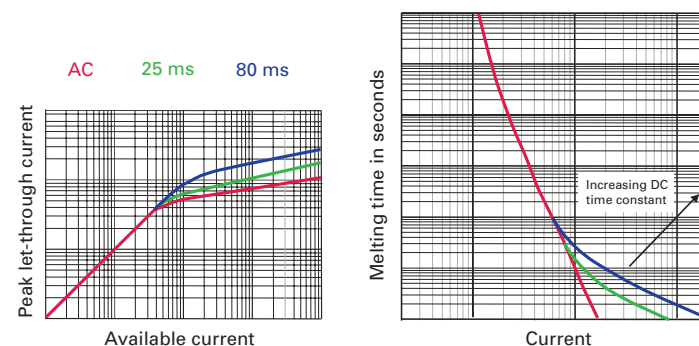


Figure H2. AC and DC operating characteristics will merge for operating times greater than 1 second.

### Battery as a load

In principle, battery-charging circuits are similar to electrolysis systems.

Standard bridge configurations are commonly used for these systems. Fuses may be located in the AC line, arm or the DC line.

The use of arm fuses not only provides the closest semiconductor device protection, but also protects the bridge against internal bridge faults and faults in the DC system.

In high current circuits, regulating the amount of current is often by phase control using thyristors. In lower power systems, the fault current may be limited only by the impedance of the transformer's secondary side and the rectifier will consist only of diodes.

In systems that regulate current by phase control, high fault currents can occur if the control to the thyristors fails. Selection of fuses for this type of circuit is like that for a DC drive (detailed elsewhere in this guide).

However, in a diode-only system, in the event a battery is connected in reverse polarity, the fault current will pass directly through the diodes. The resulting fault current will only be limited by the internal impedance of the battery. Fast isolation is required to protect the diodes and to limit the  $I^2t$  in the diode.

Attention must also be paid to the possible pulse duty a battery charger may be called upon to perform. Many controlled charger circuits have a high charge rate for a short time before a lower, continuous charge rate is applied. Guidance on this is given in the section on cyclic loads.

#### Battery as only source

The use of batteries is vast and increasing due to the demands for renewable energy where they are common and essential as power storage devices.

Protecting a battery (or batteries) is particularly difficult under fault conditions due to their characteristics. The problem is made more difficult by the large number of manufacturers and battery types.

Due to their superior current limiting effect, high speed fuses can be a good choice for protecting batteries under short-circuit conditions.

However, for a high speed fuse to effectively operate, it requires the fault current to be high enough to quickly melt the fuse element. The fault current's rate of rise (time constant) has to be fast enough to allow the fuse to clear the DC arc that's generated during fault clearing. DC fault conditions are difficult to properly fuse, and misapplication can, in some cases, cause a fuse stress failure. Fault current under short-circuit conditions is severely limited by a battery's internal impedance and state of charge. If a battery is fully charged there may be sufficient energy to operate the fuse, but as the battery's charge reduces, it could be to a level well under that required by the fuse to open.

As with long time constants typically greater than 15 ms, insufficient fault current could cause a similar failure of the fuse. Fault currents applied to the fuse that are above the A-A line (the dotted line area) of the time current curve would be of major concern.

It is essential that all the possible battery parameters are known before attempting to select a fuse. Details of the battery and data sheets should be obtained from the manufacturer. It may be required that the selected fuse can only be used when the batteries are maintained at or above a certain state of charge, and the manufacturer can guarantee a short-circuit time constant in the event of a short-circuit.

A high speed fuse will, of course, only provide short-circuit protection. For cable protection, a more general purpose fuse should be applied that is able to operate under low overload conditions. This causes other problems as branch and supplemental fuses are often not able to handle DC voltages to the same degree as high speed fuses. A sustained low current overload at high DC voltage may require a fuse that's specifically designed for DC applications and will provide safe reliable fuse protection.

Contact Application Engineering at FuseTech@eaton.com.

The following information applies specifically to the 660, 690, 1000 and 1250 Vac standard Typower Zilox fuses when they are applied in DC applications. These fuses have not specifically been proven and have not been specifically assigned a DC voltage capability.

These fuses may be used in circuits where DC faults occur and caution must be taken in their selection. It's recommended to validate the fuses after following this selection process (this is only a guideline — end users must validate fuse selection for their application).

The interrupting capability of the fuse depends on a combination of:

- Applied DC voltage
- Circuit time constant (L/R)
- Minimum prospective short-circuit current ( $I_{pmin}$ ) of the circuit
- Pre-arcing  $I^2t$  of the selected fuse

To correctly apply a fuse, a factor (F), relating to the melting  $I^2t$  to the prospective current, must be used.

In order to determine factor F in Figure I3, use the curves in Figure I1 or I2 that show the dependency of the maximum applied DC voltage on L/R, with 3 levels of  $I_p$  as a parameter indicated as 1, 2, and 3. Select the curve 1, 2 or 3 by choosing the curve above the point from the known available voltage and circuit time constant.

If no curve exists above the voltage-L/R point, then a fuse with a higher AC rating than 1250 V must be chosen. Contact Application Engineering for assistance at FuseTech@eaton.com.

Factor F is found in Figure I3 as a function of the circuit time constant L/R and the selected curve 1, 2, or 3 as parameter.

To check if the minimum level of available current ( $I_{pmin}$ ) in the actual DC circuit is in accordance with the selection made in Figure I1 or I2, the following condition must hold true:

$$I_{pmin} \geq F \times \sqrt{I^2t} [A]$$

Where  $I^2t$  is the pre-arcing integral (from cold) in A<sup>2</sup>s of the fuse in question and, importantly, it's capable of interrupting this minimum current.

In Figure I4, the fuse's worst case peak arc-voltage can be found as a function of applied DC voltage.

**Note:** Where fuses have a reduced AC voltage capability, the DC voltage capability will be reduced by a similar percentage. E.g., a 690 V, 2000 A Size 3 fuse has an AC voltage rating of 550 Vac, so the DC voltage rating will be reduced by 20 percent to 440 Vdc.

\* These fuses have not specifically been validated and have not been specifically assigned a DC voltage capability.

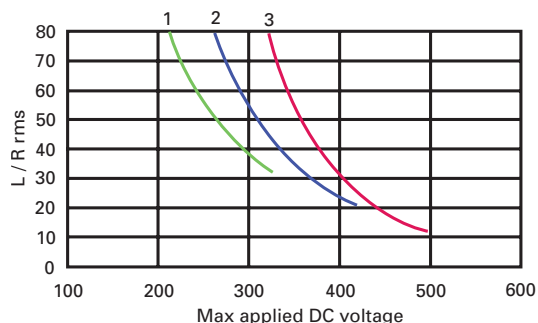


Figure I1. 660-690 Vac Typower Zilox maximum applied DC voltage.

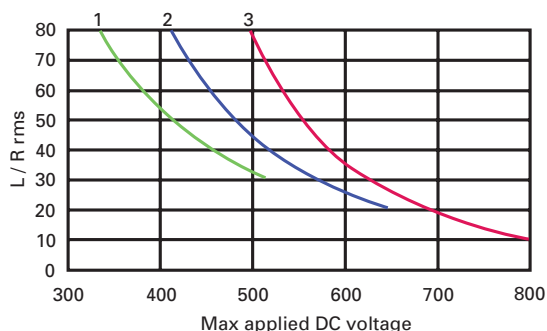


Figure I2. 1000-1250 Vac Typower Zilox maximum applied DC voltage.

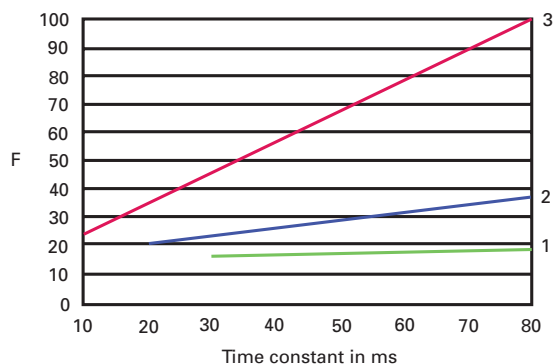


Figure I3. Factor F based upon circuit time constant in Figures I1 and I2.

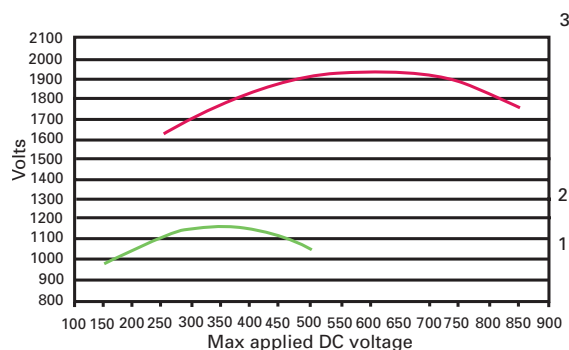


Figure I4. Worst case peak arc voltage.

## Calculation example

Typower Zilox 170M6149 is:

- 1250 Vac
- 1100 A
- Size 3/110
- 575,000 A<sup>2</sup>s (I<sup>2</sup>t pre-arcing integral)

The applied voltage  $E = 500$  Vdc

First, the prospective short-circuit current and time constant (L/R) should be determined based upon the circuit parameters shown in Figure I1 and the above ratings for the Typower Zilox 170M6149 fuse.

Prospective current ( $I_p$ ):

$$\begin{aligned} I_p &= E/R \\ &= 500 \text{ V}/16 \text{ m}\Omega \\ &= 31.3 \text{ kA} \end{aligned}$$

Where:

$E = 500$  Vdc applied voltage

$R = 16 \text{ m}\Omega$  circuit resistance in Figure I5

Time constant (L/R):

$$\begin{aligned} L/R &= 0.64 \text{ mH}/16 \text{ m}\Omega \\ &= 40 \text{ ms} \end{aligned}$$

Where:

0.64 mH = circuit inductance from Figure I5

16 m $\Omega$  = circuit resistance from Figure I5

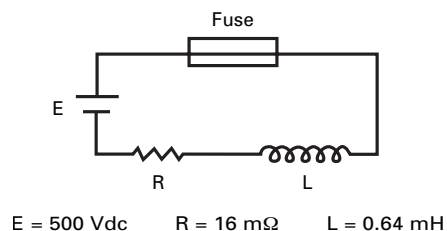


Figure I5. Calculation example circuit.

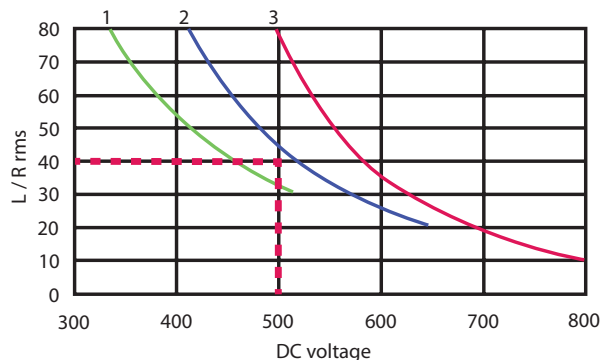


Figure I6. Maximum applied DC voltage.

Using Figure I6, at an applied voltage of 500 Vdc and a time constant (L/R) of 40 ms, Curve 1 has been passed, meaning that, to be on the safe side, Curve 2 must be used.

From Figure I7, we find factor  $F = 26.5$  based upon initially calculated  $L/R = 40$  ms and Curve 2 selected from the step above. Together with the pre-arcing  $I^2t = 575,000 \text{ A}^2\text{s}$  of the selected fuse, this calls for a minimum prospective current ( $I_{pmin}$ ) of:

$$\begin{aligned} I_{pmin} &= 26.5 \times \sqrt{575,000} \\ &= 20094.62 \\ &= 20.1 \text{ kA} \end{aligned}$$

Checking with the actual circuit parameters, it can be seen that the interrupting rating of the selected fuse is sufficient for the circuit having the following main parameters fulfilled:

- The maximum applied DC voltage is 500 Vdc (up to 280 Vdc could be allowed at the calculated time constant)
- The time constant L/R is 40 ms (up to 46 ms could be allowed at the given maximum applied DC voltage)
- Minimum  $I_p$  of 20.1 kA is needed (actual prospective current is 31.3 kA)

The fuse's peak arc voltage can be found in Figure I8 to be lower than 1900 V.

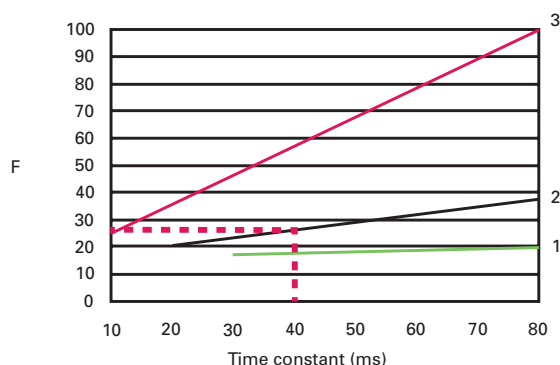


Figure I7. Time constant.

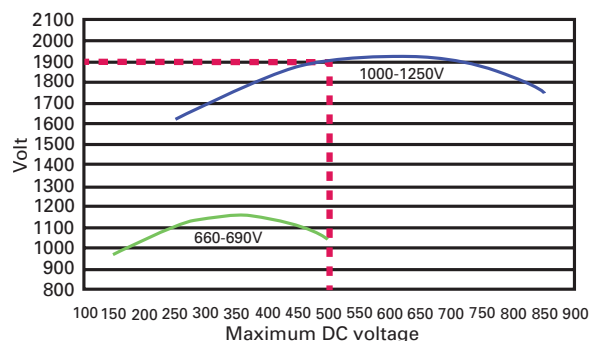


Figure I8. Worst case arc voltage.

In principle, the fuse should carry all the required continuous current and any expected transient overloads. When a short-circuit occurs the fuse should limit the energy passing through the semiconductor so that it remains undamaged.

To start, the types of faults that can occur in the equipment must be known before selecting the rated fuse voltage.

Fuses could be applied at circuit location F2 only (Figure J1), or at circuit locations F1 + F3.

In rectifier operation there are three possible fault types: internal faults, cross-over faults and external faults (Figures J1-J3).

## Conclusion on the rectifier mode

With internal, cross-over and external faults, the short-circuit current will pass through two fuses in series. This means that the two fuses will normally help each other in clearing the fault. Nevertheless, for safety, at a minimum the rated fuse voltage  $U_N$  has to be higher than the RMS AC supply voltage ( $U_N \geq U_{AC}$ ) (pay attention to the commutation fault situation). When it comes to protecting the semiconductor and the  $I^2t$  calculation, it is an advantage to have two fuses in series.

In the short-circuit path, if the prospective current is very large, the  $I^2t$  can be calculated with almost equal sharing of the fault voltage. At smaller fault current levels it is not considered safe to use total equal voltage sharing. Normal procedure is to use 1.3 as a safety factor. Hence, the  $I^2t$  values are found at an RMS AC supply voltage of:

$$\begin{aligned} \text{Sizing } I^2t \text{ voltage} &= U_{AC} \times 0.5 \times 1.3 \\ &\approx U_{AC} \times 0.65 \end{aligned}$$

There can also be three fault types while operating in the regenerative mode (Figures J4-J6).

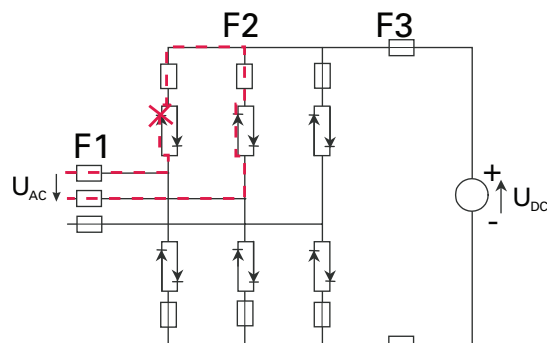


Figure J1. Internal fault — rectifier mode.

This fault is due to a thyristor losing its blocking capacity, leading to an AC line-to-line short-circuit.

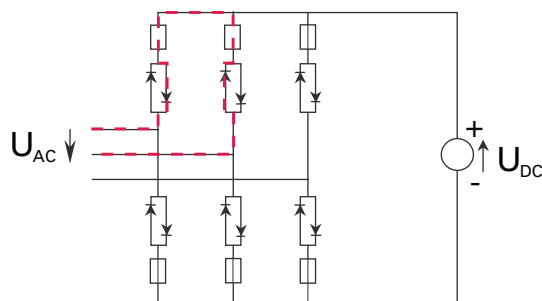
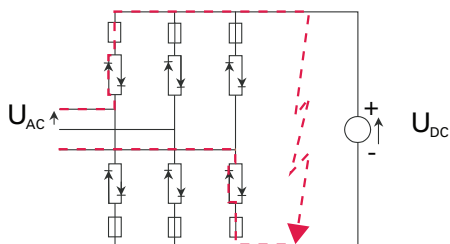


Figure J2. Cross-over fault — rectifier mode.

This fault occurs when a misfiring of one of the thyristors in the inverter bridge results in an AC line-to-line short-circuit.

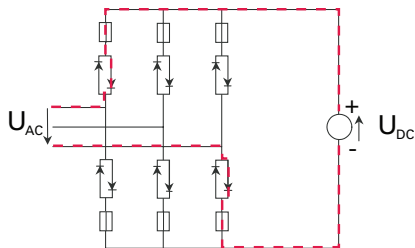


## J: Fuses protecting regenerative drives



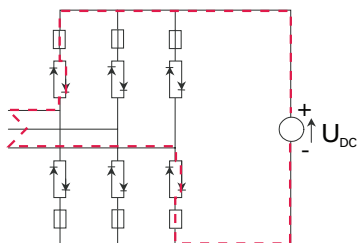
**Figure J3. External fault — rectifier mode.**

This fault is due to a short-circuit on the DC output side (motor flash-over for example). The applied fault voltage is again equal to the AC line-to-line voltage.



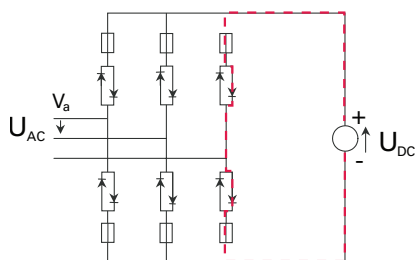
**Figure J4. Commutation fault — rectifier mode.**

This fault is due to a thyristor losing its blocking capability while there is a direct line-to-line voltage across it. This leads to a short-circuit where the AC voltage is superimposed on the DC voltage.



**Figure J5. Loss of AC power — regenerative mode.**

If the AC voltage fails, a short on the motor acting as a generator occurs through the thyristors and the transformer.



**Figure J6. DC shoot-through — regenerative mode.**

This fault occurs due to one thyristor misfiring and leads to a DC short-circuit.

### Conclusion on the regenerative mode

As it can be seen from the fault circuit diagrams (Figures J4-J6), there will also be two fuses in series, but the fault voltage greatly differs.

During the commutation fault, the fault voltage is the AC voltage added to the DC voltage. In the worst case (assuming a minimum firing angle of 30 degrees), the peak voltage will be:

$$\begin{aligned} \text{Peak fault voltage} &= 0.866 \times 1.35 \times U_{AC} + U_{DC} \times \sqrt{2} \\ &\approx 2.58 \times U_{AC} \end{aligned}$$

Where:

$U_{AC}$  = RMS AC line-to-line supply voltage

As a general rule, the fault voltage is half a sine wave at a lower frequency. The RMS value of the fault voltage will be:

$$\begin{aligned} \text{RMS fault voltage} &= 2.58 \times U_{AC} \times 1/\sqrt{2} \\ &\approx 1.8 \times U_{AC} \end{aligned}$$

Though this type of fault is very rare, it will require derating the fuse's rated voltage. This means the rated fuse voltage should be in accordance with:

$$U_N \geq 1.8 \times U_{AC}$$

Where:

$$U_N = \text{Fuse voltage rating}$$

If an  $I^2t$  calculation is needed (mainly for internal fault only), the sizing  $I^2t$  voltage having two fuses in the same short-circuit path will give:

$$\begin{aligned} \text{Sizing } I^2t \text{ voltage} &= 1.8 \times 0.5 \times 1.3 U_{AC} \\ &\approx 1.2 \times U_{AC} \end{aligned}$$

For the other three inverter fault types, the fault voltage will be a pure DC voltage and the maximum DC fault voltage will be:

$$\begin{aligned} U_{DC} &= 0.866 \times 1.35 \times U_{AC} \\ &\approx 1.1 \times U_{AC} \end{aligned}$$

A normal AC fuse can operate under DC conditions with some limit to the line voltage, the minimum available fault current and the time constant.

Please refer to the section AC fuses in DC circuit applications.

During the DC shoot-through fault (Figure J6), the only impedances in the circuit are in the motor and inverter branch. The minimum prospective fault current is normally very large and the time constant in the circuit is small (e.g., 10 to 25 ms). Under this condition, having two fuses in series, the  $I^2t$  value is normally equal to the value obtained under an AC sizing  $I^2t$  voltage of:

$$\begin{aligned} \text{Sizing } I^2t \text{ voltage} &= U_{DC} \times 1/\sqrt{2} \times 0.5 \times 1.3 \\ &= 1/\sqrt{2} \times 1.1 \times 0.5 \times 1.3 \times U_{AC} \\ &\approx 0.5 \times U_{AC} \end{aligned}$$

In order to be certain, all data should be available for the motor and other impedance in the circuit.

In case of a reduced or total loss of the AC power, the condition is worse (Figure J5). The fault current level can be very low and the impedance of the transformer gives large time constants.

In order to select fuses that can function under these conditions it is necessary to have information not only on the motor and the inverter impedance, but also on the transformer.

### Summary of voltage selection for regenerative drives

Combination of line voltage and load voltage requires:

Fuse voltage  $U_N \geq 1.8 \times U_{AC}$  (line-to-line) — e.g.:

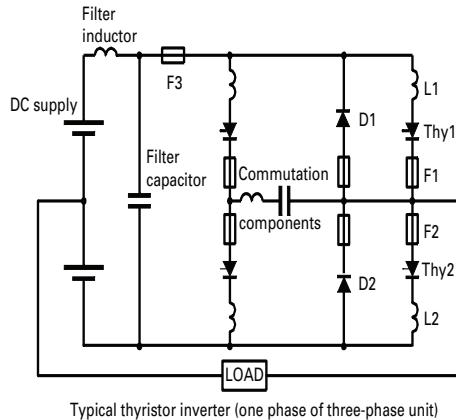
- 110 V system: 200 V fuse
- 380 V system: 690 V fuse
- 690 V system: 1250 V fuse

For further guidance, please contact Application Engineering at [FuseTech@eaton.com](mailto:FuseTech@eaton.com).

## K: Fuses protecting inverters

There are many inverter types. Some simply convert DC current to AC current (e.g., PV inverters) or AC current to DC current (this may also be accomplished with a rectifier) or that convert AC current to DC current and back to AC current (e.g., VFD variable speed motor drives and UPS uninterruptible power supplies).

VFD and UPS inverters work by switching DC current ON and OFF in a predetermined manner. Early inverters using thyristors were often of the McMurray form (Figure K1). Once turned ON, thyristors continue to pass current until the voltage across them is reversed using numerous components to commutate the devices. The commutation thyristors also require protection.



**Figure K1. McMurray inverter.**

Even with fuse protection in the DC circuit at fuse location F3, it is best to use device protection for the thyristors at fuse positions F1 and F2. To ensure protection in these circuits, it is essential to use the fastest fuses available (and still meet all the current sizing) which are also rated with a DC voltage capability at least as high as the DC circuit voltage.

The key to fuse selection for inverters is to select the highest speed available that will meet the current and voltage sizing requirements.

### Voltage selection

Fuses in the inverter must have a DC voltage rating of at least the supply circuit voltage. Even though in most fault conditions there will be two fuses in series, these will not share the voltage equally. Also, in some fault situations the voltage on the DC circuit may exceed the nominal value for a short time by up to 30 percent.

### Current selection

As shown in the inverter circuit schematics, there are several locations to place fuses. As with DC drive circuits, the use of DC line fuses results in the highest current rating and closest protection is determined by where individual fuses are located in the circuit.

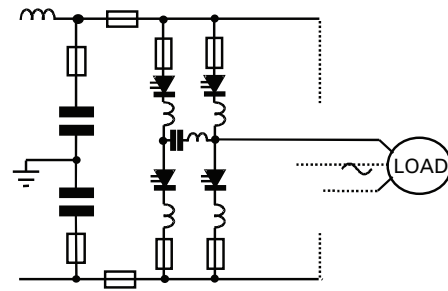
As inverter circuits contain high frequency components to carry the current, and the physical arrangements are compact, proximity effects may influence the fuses, and further allowance must be made for current carrying capability.

### I<sup>2</sup>t selection

Due to the magnitude of the fault current from the capacitor and small inductance in the circuit, the current rise rate may be very high. Selection of suitable I<sup>2</sup>t criteria is not easy. Device data may not be available for times below 3 ms, nor fuse information for these conditions. Fuse performance will also vary slightly depending on the capacitor size, the circuit inductance and resistance, and DC link voltage.

To ensure device protection a fuse selected for lowest I<sup>2</sup>t that will meet the current sizing requirements will be the best way. Even if device protection is not ensured, this fuse selection will certainly limit the damage to all the circuit components.

It is especially important to select a low I<sup>2</sup>t fuse if the capacitor is a low value. When a short-circuit occurs in the inverter, the current rises rapidly to a peak and will then decay, displaying a waveform that is classical of capacitor discharge. It is important that the fuse has opened and cleared before the voltage on the capacitor has decayed to a low value. If the fuse was to operate at a low voltage on the capacitor, the fuse may not have developed sufficient insulation resistance to withstand the DC circuit voltage when it is replenished from the supply.



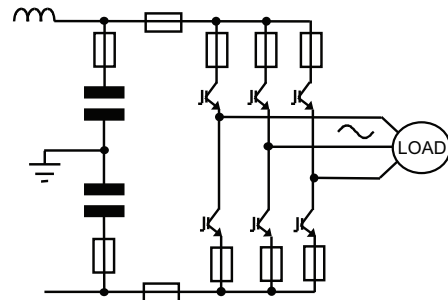
**Figure K2. GTO inverter.**

With the development of Gate Turn-Off thyristor (GTO), it was possible to switch the DC current OFF without the use of commutation components (as required in the McMurray inverter using thyristors). It should be noted that by reducing the complicated trigger (firing) circuits, considerable space and costs savings were made and energy losses were reduced, too.

Although GTOs are more expensive than thyristors, the additional cost is more than offset by the component reduction. In terms of protection, there is little difference in the selection parameters between an inverter using thyristors and one using GTOs. However, the GTO circuits are inherently more reliable with fewer power components to protect.

### IGBT as switching device

The advent of the Insulated Gate Bipolar Transistor (IGBT) as a switching device has made control circuits much easier and power dissipation in the power switching sections reduced. The higher switching frequency capability and ease of control allows more efficient use of the pulse width modulation techniques, as well as improved quality of the output waveform. However, the IGBT circuit poses different protection problems.



**Figure K3. IGBT inverter.**

To reduce switching losses, the inductance of the filter capacitor and IGBTs has to be as low as possible. This is achieved by careful busbar arrangements that often preclude using fuses.

## L: Worked examples

Due to the silicon switching element design, an IGBT module can limit current for a short period. In addition, it is often possible to detect fault currents and switch the IGBT OFF before damage occurs. However, if the IGBT is not switched OFF before the device is damaged, the silicon will melt and vaporize.

There is another failure mode with plastic IGBT modules that occurs before the silicon melts. The internal conductors to the IGBTs and other components are thin aluminum wires. These wires melt and arc under fault conditions, causing the module case to become detached from the base. Therefore, fuse protection must also include protecting the wires and the module case as well as the devices. Unfortunately, there is often no  $I^2t$  data provided for IGBT modules.

### Protecting drive circuits

If damage is caused to the IGBT device or connecting leads, the gate control circuits may become involved with the high voltage and current of the power circuit. To avoid, or limit, damage to the control circuits, miniature fuses with a high interrupting rating should be used in the drive circuits. Low interrupting capacity glass tube fuses are not suitable.

### Bipolar power and Darlington pair transistors

It is difficult to protect power transistors with fuses. The power transistor usually operates extremely close to its power limits of current and voltage. Only a short excursion beyond the safe operating area will damage the functional aspect of the transistor and even a high speed fuse will not react fast enough to protect the device. However, like IGBTs, when the function of the transistor is lost the current is limited only by the damaged silicon's low resistance. This results in very high currents. These will melt any connecting wires and will, in the case of a press pack configuration, eventually melt the silicon. The resulting arcs will cause the packaging to fail with catastrophic results. Even though device protection cannot be offered by fuses, it is still essential to use fuses to prevent case rupture and isolate the circuit.

## Worked examples

The previous information can be best understood by studying typical examples for selecting an appropriate Bussmann series fuse that meets the protection requirements.

### Example 1: DC Thyristor drive

Basic information

**Note:** no cyclic loading details are included for this example.

- 500 Hp VFD
- Motor: nominal voltage 660 Vdc, maximum current 600 A DC
- Supply transformer 750 kVA, 5% impedance.
- Supply voltage - 480 Vac RMS.
- Overload protection is provided by a current limit circuit (direct control of thyristor firing) with a response time of 25 ms
- Maximum 40°C/104°F ambient, convection ventilation
- The circuit is a 3-phase thyristor bridge, one thyristor per leg
- Thyristor particulars:
  - $I^2t$  120,000 A<sup>2</sup>s
  - Peak reverse voltage withstand ( $U_{rrm}$ ) 1600 V

### Basic design

For optimal protection, device protection with six fuses will be considered (one per thyristor).

Since the fuses are for short-circuit protection only, this is simply a question of coordinating the  $I^2t$ , peak current and maximum RMS fuse current ratings. Maximum RMS current through each thyristor is given by the appropriate factor for the circuit layout, multiplied by the DC load current (see Typical rectifier circuits, Figure F5, circuit location  $I_2$ ):

$$= 0.58 \times 600 \text{ A}$$

$$= 348 \text{ A}$$

For this example a fuse from the square body fuse type is required. From the catalog for a square body, 690 V, 400 A and size 00, the Bussmann series 170M2621 fuse is initially selected. From the temperature rating graph, Figure E1 in the section *Determining fuse amp ratings*, a derating to 90 percent is required at 40°C/104°F. No other thermal derating factors will be required.

$$0.9 \times 400 \text{ A} = 360 \text{ A}$$

As shown above, the maximum current through each thyristor is 348 A and the maximum permissible current rating for the selected fuse would be appropriate.

Next, the fuse  $I^2t$  has to be confirmed to be less than the  $I^2t$  withstand of the device.

For the Bussmann series 170M2621 fuse selected above, the total  $I^2t$  is 125,000 A<sup>2</sup>s at 660 V. By observing the factor for  $I^2t$  with respect to applied voltage on the data sheet the adjusted  $I^2t$  at 480 V (Figure L1) can be found to be less than the  $I^2t$  withstand of the thyristor:

$$\begin{aligned} I^2t \text{ at } 480 \text{ V} &= K \times I^2t \text{ at fuse voltage rating} \\ &= 0.7 (70\%) \times 125,000 \text{ A}^2\text{s} \\ &= 87,500 \text{ A}^2\text{s (well below the thyristor withstand)} \end{aligned}$$

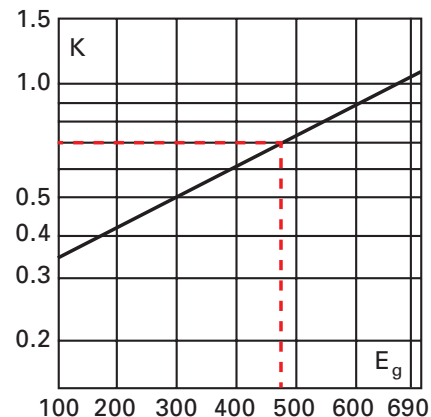
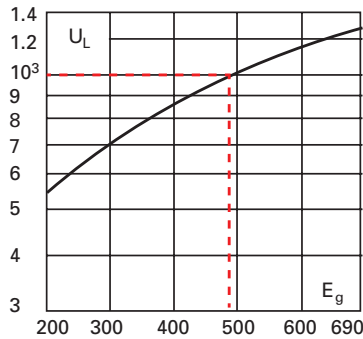


Figure L1. Reference: Bussmann series product data sheet no. 720013, total clearing  $I^2t$  at rated voltage.

## L: Worked examples

A check of the arc voltage shown on the graph in Bussmann series data sheet 720013 (Figure L2) confirms that the fuse arc voltage of 1000 V will be below the 1600 V peak reverse voltage rating of the thyristor:



**Figure L2. Reference: Bussmann series product data sheet no. 720013, peak arc voltage at applied voltage.**

Thus the Bussmann series 170M2621 fuse is confirmed to work in this application. If the power dissipation (watts loss) of the equipment is critical and there are no physical space constraints, it may be possible to utilize an alternative solution.

By selecting a fuse with a higher current rating and using it at a current well below its capability, the power dissipation (watts loss) will be considerably lower. For this example we can choose a square body, 690 V, 500 A Size 2, fuse (Bussmann series 170M5010 fuse for example). Although the  $I^2t$  is 145,000 A<sup>2</sup>s at 660 V, this will be reduced to 101,000 A<sup>2</sup>s at 480 V, which is also below the  $I^2t$  withstand of the device.

The power dissipation (watts loss) of the Bussmann series 170M2621 fuse, 400 A fuse applied at 348 A is calculated below:

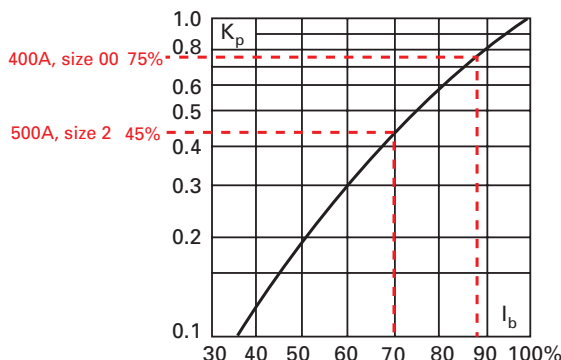
$$\begin{aligned}\% \text{ Load current} &= \text{load current/current rating} \times 100 \\ &= 348 \text{ A}/400 \text{ A} \times 100 \\ &= 87\%\end{aligned}$$

$$\begin{aligned}\text{Watts loss at 87\%} &= K_p \times \text{Watts loss at 100\% fuse current rating} \\ &= 0.75 (75\%) \times 70 \text{ W (Figure L3)} \\ &= 53 \text{ W}\end{aligned}$$

If the 500 A, square body, Size 2 fuse is used at 348 A, then the actual watts loss calculated below will be reduced to below the adjusted power loss found for the 400 A, Bussmann series 170M2621 fuse:

$$\begin{aligned}\% \text{ Load current} &= \text{load current/current rating} \times 100 \\ &= 348 \text{ A}/500 \text{ A} \times 100 \\ &= 70\%\end{aligned}$$

$$\begin{aligned}\text{Watts loss at 70\%} &= K_p \times \text{Watts Loss at 100\% fuse current rating} \\ &= 0.45 (45\%) \times 75 \text{ W (Figure L3)} \\ &= 34 \text{ W}\end{aligned}$$



**Figure L3. Reference: Bussmann series product data sheet no. 720013, 720014, watts loss at % load current of rated current.**

As six fuses are used in this example, the total power saved by using the physically larger, Size 2 fuses will be:

$$\begin{aligned}&= (53-34) \times 6 \\ &= 114 \text{ watts}\end{aligned}$$

### Example 2: High power/high current DC supply with redundant diodes

A rectifier is to provide a 7500 A, 80 Vdc supply from a 50 Hz source

Basic information

- Nominal 80 Vdc voltage supply
- Maximum 7500 A current output
- 3-phase diode bridge with six parallel diodes per leg
- 200% overload for 1 minute, once a month
- Maximum 55°C/131°F ambient with 4 m/s forced air cooling
- Busbars based on 1 A/mm<sup>2</sup>
- Diode rating:
  - Maximum mean rating (free convection, specified heat sink) 1000 A
  - $I^2t$  rating, 10 ms, 1,000,000 A<sup>2</sup>s, peak reverse voltage withstand ( $U_{rm}$ ) 500 V
  - Maximum prospective AC fault current = 125,000 A RMS symmetrical

Protection requirements

Fuses must protect the diodes from internal faults and isolate faulty diodes without interrupting the power supply.

Design details

Protection requirements for this application requires device fuses and the equipment design specifies continuity in the event of one semiconductor device failing in one leg of the bridge. Maximum RMS current through each arm of the bridge is given by the appropriate factor for the circuit layout, multiplied by the DC load current (see Typical Rectifier Circuits, Figure E5, circuit location  $I_2$ ):

$$\begin{aligned}&= 0.58 \times 7500 \text{ A} \\ &= 4350 \text{ A (per arm of bridge rectifier)}\end{aligned}$$

The maximum RMS current through each diode (or fuse) in one leg of the rectifier can now be calculated allowing for one defective diode, non-uniform current sharing of 10 percent, and six parallel diodes per leg of the bridge:

$$\begin{aligned}&= 4350 \text{ A} / ((n-1) / (1+s)) \\ &= 4350 \text{ A} / ((6-1) / (1.0+0.1)) \\ &= 966 \text{ A (per diode of each arm of bridge rectifier)}\end{aligned}$$

The selected fuse must have a current rating above 966 A after thermal deratings (to account for the high ambient temperature and forced air cooling) are applied. From the section on *Determining fuse amp ratings* (page 11) we find the following correction factors based on the given application information:

$$\begin{aligned}K_e &= 1 \text{ (at 1 A/mm}^2 \text{ current density, no adjustment is needed)} \\ K_t &= 0.85 \text{ (Figure E1 at ambient temperature of 55°C/131°F)} \\ K_v &= 1.2 \text{ (Figure E3 at 4 m/s forced air flow)}\end{aligned}$$



## L: Worked examples

The selected fuse's rated current ( $I_n$ ) must be greater than:

$$\begin{aligned} I_n &\geq I_{rms} / (K_g \times K_t \times K_v) \\ &\geq 966 \text{ A} / (0.85 \times 1.2 \times 1) \\ &= 947 \text{ A} \end{aligned}$$

For this low voltage application, with a low peak reverse voltage diode, a fuse from the low voltage UL branch or supplemental or British range is required.

Based on a power source of 950 A, 240 Vac a UL or British fuse series would require using three, 350 A fuses in parallel (Note: NEC 240.8 precludes field installation of parallel fusing). To avoid parallel fusing, the Bussmann series FWA North American style high speed fuse should be chosen. It's this fusing option that will be considered for the overload considerations.

### Overload

The selected fuse must also withstand a 200 percent (twice the continuous load current) overload for 60 seconds, once a month. Using Table E1 from Part 2 on page 12 of this application guide, it should be possible to select a fuse up to 80 percent of the time-current curve at the 60 second operating time:

$$\begin{aligned} I_{max} &< 80\% \times I_t \\ &< 80\% \times 3000 \text{ A} \\ &< 2400 \text{ A} \end{aligned}$$

Or

$$\begin{aligned} I^t \text{ at } 60 \text{ sec} &> I_{rms} \times 2 / 80\% \\ 3000 \text{ A} &> 2415 \text{ A} \quad \text{TRUE!} \end{aligned}$$

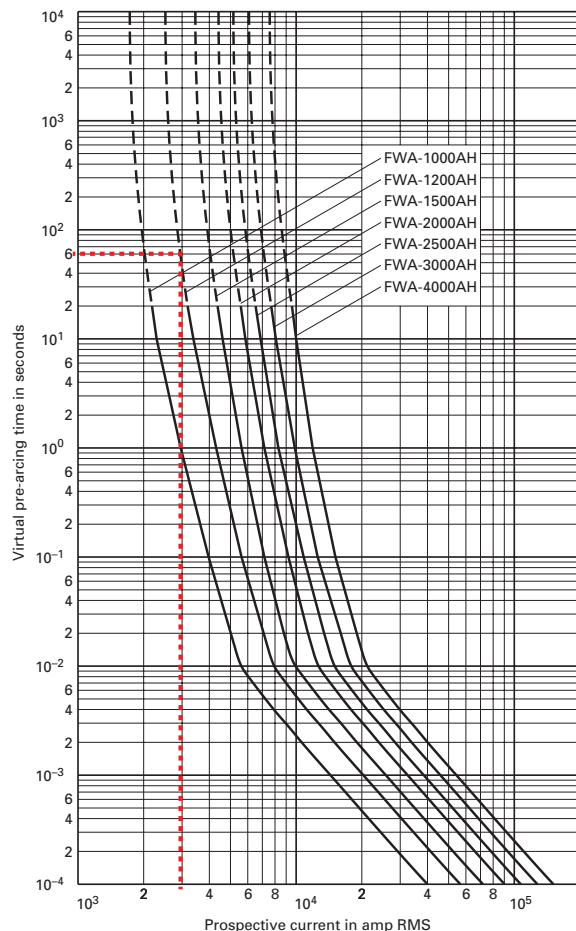


Figure L4. Reference: Bussmann series product data sheet 35785301, time-current curve; 60 second operating time.

### Arc voltage

From the Bussmann series FWA-1200AH data sheet, (Figure L5) the arc voltage of 190 V can be seen to be less than the 500 V reverse voltage capability of the diodes chosen.

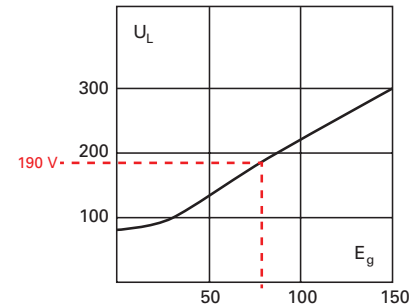


Figure L5. Reference: Bussmann series product data sheet no. 720001, arc voltage at applied voltage.

### Short-circuit protection

The Bussmann series FWA-1200AH fuse  $I^2t$  is 730,000 A<sup>2</sup>s at 130 V, which will reduce in the following manner (see Figure L6):

$$\begin{aligned} I^2t \text{ at } 80 \text{ V} &= K \times I^2t \text{ at fuse voltage rating} \\ &= 0.75 (75\%) \times 730,000 \text{ A}^2\text{s} \\ &= 548,000 \text{ A}^2\text{s} \text{ (well below the thyristor withstand)} \end{aligned}$$

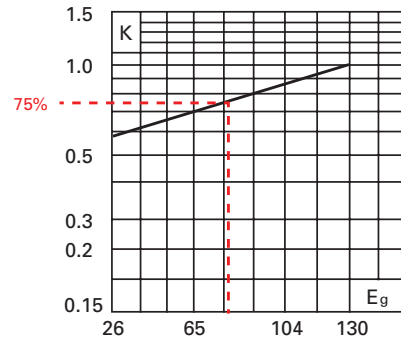


Figure L6. Reference: Bussmann series product data sheet 720001, total clearing  $I^2t$  at applied voltage.

To ensure continuity of supply when a device fails, the total clearing  $I^2t$  of the fuse in series with the faulty device must be less than the combined pre-arcing  $I^2t$  (270,000 A<sup>2</sup>s each) of all the six fuses in series with the fault (in a different arm of the bridge):

$$\begin{aligned} I^2t \text{ clearing} &< I^2t \text{ pre-arc} \times n^2 \\ 548,000 &< 270,000 \text{ A}^2\text{s} \times 6^2 \\ &< 9,720,000 \text{ A}^2\text{s} \end{aligned}$$

This confirms the selected fuse will protect the devices suggested.

### Example 3: Regenerative drive application

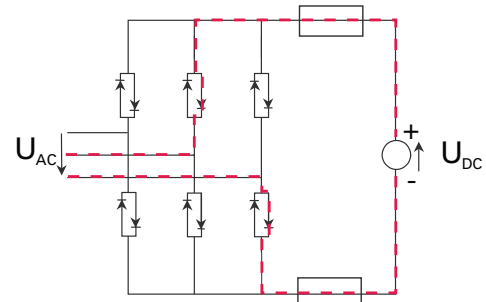


Figure L7. Regenerative drive circuit example (see Figures J1 to J6 on pages 20 to 21).

## Basic information (Figure L7)

- High inertia drive, 500 Hp DC motor
- Motor: 500 Vdc nominal voltage, maximum current 750 A DC
- Power is supplied from a 380 Vac\* three-phase grid
- The busbars are rated between 1 and 1.6 A/mm<sup>2</sup>
- An air cooled system with ambient temperature of 35°C/95°F with no forced air cooling

Although expected overloads will be cyclic, regenerative drives would not be cost effective if the load was not regularly stopped.

For simplicity, the cyclic loading details will not be included in this example. In practice, the rules for cyclic loading explained in this guide should be followed and applied to the current rating as well as the ratings described in this example. A 380 Vac supply will give a nominal DC voltage of 500 V (typically 135 percent of the RMS line voltage) from a six-pulse bridge.

To maximize the degree of protection in this application, the best place to install the fuses is in series with each semiconductor (device or arm fusing). The maximum RMS current through each arm of the bridge is given by the appropriate factor for the circuit layout, multiplied by the DC load current (see Typical rectifier circuits, Figure F5, circuit location I<sub>2</sub>):

$$= 0.58 \times 750 \text{ A}$$

$$= 435 \text{ A}$$

The only consideration for permissible maximum continuous current will be ambient temperature derating where we find K<sub>t</sub>, which adjusts the minimum fuse current rating:

$$K_t = 0.94 \text{ (Figure E1 at ambient temperature of 35°C/95°F)}$$

$$\begin{aligned} I_n &= I_b / K_t \\ &= 435 / 0.94 \\ &= 462 \text{ A} \end{aligned}$$

The next rating available fuse above this should be chosen. In most product ranges this will be 500 A.

## Voltage rating consideration

The worst case voltage rating in a regenerative drive results from a commutation fault. Therefore, the fuse will require an AC voltage rating of at least:

$$\begin{aligned} &= (0.866 \times 1.35 \times \text{Vac} + 1.414 \times \text{Vac}) \times 1/\sqrt{2} \\ &= 1.8 \times 380 \text{ Vac} \\ &= 684 \text{ Vac} \end{aligned}$$

For this we would select a 690 Vac fuse.

See section on *Fuses protecting regenerative drives* on page 20.

Selection of fuse is then based on mounting arrangements, physical constraints and approvals required, etc.

## Note on voltage rating

If a drive system is to align with the international standard voltage (not the old voltages) the drive should be rated for a 400 Vac supply with the DC voltage maintained at the same voltage using phase-angle control of the bridge devices. In this case, using a higher voltage fuse may be required.

For many years high speed fuses did not have any international standards. As more manufacturers produced these fuses, many dimensional arrangements became commonplace. High speed fuses are now a mature product with international standards covering test methods and dimensions.

## In the United States

Common dimensions became an “industry norm” but until they were included in EN 60269, they were not a part of any published standard. Testing was performed to either customer requirements, or when a UL Recognized fuse was required and the tests performed would be similar to those of other UL standards.

The UL Standard 248-13 now defines test conditions and methods. Although these UL and EN (IEC) standards are similar, there are some small differences that are beyond the scope of this guide.

The major difference between the UL and IEC standards is voltage rating. This difference is common to many electrical specifications and is based upon a long historical background. Briefly, European standards require voltage testing at some tolerance above the fuse's rated voltage, thus providing a safety margin. Practice in the United States requires fuse testing at the rated voltage. Hence, it is design practice to use the maximum voltage available for determining the rated voltage of components.

## In Europe

The test requirements of BS88 Part 4 (1976) are the same as IEC 60269-4, with dimensions included for high speed fuses in common use in the UK. IEC 60269-4 included test conditions for AC and DC circuits that are more suitable for high speed fuses than fuses for industrial circuits. The German VDE specification 0623 Part 23 is specific to the testing of high speed fuses. Dimensions are included in DIN 43620 (the same as industrial fuses) and DIN 43653 (European high speed square body). Cylindrical fuses are usually dimensioned to French NF C63211.

The latest version of EN 60269-4 includes dimensions from all previous European and United States high speed fuse standards and includes standardized testing for fuses used in voltage sourced inverters (VSI). This standard now supersedes all previous standards.

## Bussmann series product range

Various fuse constructions originate from different parts of the world. As a result, Bussmann series high speed fuses can be grouped in four world-recognized standards:

- US Style — North American blade and flush-end style
- European standard — square body
- British Standard — round body BS88
- Ferrule fuses — cylindrical

## US Style — North American blade and flush-end style

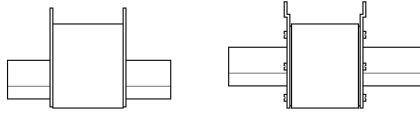


Over the years, the North American market has adapted its own mounting styles for high speed fuses. Although no published standard exists for these as yet, the industry has standardized on mounting centers that accept Eaton's Bussmann series fuses.

## Appendix 1: International standards

In many ways, US Style fuses are similar to the European Style. They are made in both blade and flush-end versions, but with two major differences: US Style fuses are usually made in mineral fiber tubes and the fixing centers will vary depending on both rated voltage and rated current.

### European standard



DIN 43620 — bladed fuse



DIN 43653 — bottled tag fuse

In Europe, outside of the United Kingdom, two mounting types are preferred for high speed fuse applications - blade type and flush-end.

### Blade type fuses

In Europe, two German standards cover most fuse mounting for normal styles of Bussmann series blade type high speed fuses.

They are:

- The DIN 43620 style is used for gG fuses (previously referred to as gL). It is also used for high speed fuses. However, a high speed fuse typically reaches a higher temperature during continuous operation than a normal gG fuse. As a result, the DIN 43620 style high speed fuse cannot get a sufficient rating if its holder temperature limits are not to be exceeded. Knives with holes for mounting fuses directly on the busbar are the solution to this issue.
- The DIN 43653 standard came in 1973 with the possibility of mounting the fuse directly on the busbar. New holders also appeared at the same time. For the most common voltage ratings, fuses with blades according to DIN 43653 will always have fixing centers of 80 mm or 110 mm.

### Flush-end contact type



Like the DIN 43653 style, the flush-end style has become a very efficient and popular high speed fuse style due to its installation flexibility. This style is also selected because the current carrying capacity is the most efficient of all fuse types. This is now an industry standard style and is included in the international standard IEC 60269-4-1.

### British Standard — BS88



Not surprisingly, this mounting type has found its use mainly, but not exclusively, in the United Kingdom and British Commonwealth countries. Also, North American manufacturers have begun to specify British style fuses (particularly in applications like UPS equipment with voltages of 240 V or less) due to their size, performance and cost advantages. The dimensions given in the BS88 Standard for high speed fuses are not physically interchangeable with industrial fuse standard.

### Cylindrical/ferrule fuses



Often referred to as ferrule fuses, this style is internationally used and accepted. In most cases, the Bussmann series cylindrical high speed fuses have dimensions that meet IEC Standard 60269. These fuses have proven very popular for applications with ratings up to 660 V/100 A, due to their easy installation. The standard dimensions are 8x31 mm, 10x38 mm, 14x51 mm and 22x58 mm, and can be installed in available Bussmann series fuse blocks and holders.

## Appendix 2: Fuse reference system

With the many Bussmann series high speed fuse varieties, our reference system is complex. The use of one reference system in Europe (outside the UK), another one in the UK and a third in the US has become a fact of life. Discussions have been held on replacing them all with one. However, all reference systems are so well established in their respective markets, the decision was made to maintain the existing systems.

The following describes the Bussmann series reference systems in detail.

### European high speed fuses

A typical fuse from the Bussmann series range of European square body fuses could have a catalog number like 170M3473. However, this will not give any guide to what ratings or mounting this fuse has. Here, the user will first need to know the ratings. However, the mounting is also of interest, so we use a Type Description to determine what style is in question. Fuses according to the German DIN 43620 standard are always listed by size. For example, DIN 3, DIN 00, etc. For other fuses, according to DIN 43653, flush-end types or special types, this description will reveal the actual type in question. For the reference given above, the type designation will be the following:

1\*BKN/50

To interpret this Type Code we have made the following general guideline, that will cover most of the European fuses.

Fuse type code positions						
1	2	3	4	5	6	7
	1*		B	K	N	/80
Primary code	Body size	Optional	Mechanical fixing	Indicator type	Indicator position	Center distance

The following tables show the various options for all characters in the above Type Code:

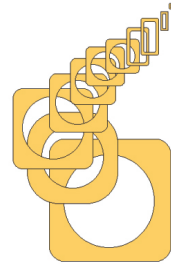
#### Position 1 — Primary code

The primary code can be one of the following values:

None	DIN 43653 or other style	3KN/110	
DIN	DIN 43620	DIN 3	
2//	Two fuses in parallel connected with fish joint	2//3BKN/100	
2	Two fuses in parallel integrated between plates	24BKN/85	

#### Position 2 — Body size

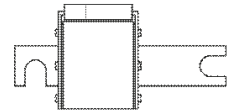
0000	17×17mm	0000U/80
000	21×36mm	000/80
00	30×47mm	DIN 00
0	35×45mm	0S/55
1*	45×45mm	1*BKN/90
1	53×53mm	DIN 1
2	61×61mm	2TN/110
3	76×76mm	2//3SBKN/55
4	105×105mm	4PKN/150
4+	115×115mm	24+BKN/55
5	159×159mm	5BKN/65



#### Position 3 — Optional

Over the years, many square body fuses have been adapted to specific customer needs. Therefore, a lot of special, customized fuses are now a part of the product offering. Position 3 in the Type Code might therefore be an S for special. For all such references, please consult the Bussmann Division for a mechanical drawing, if this is not already at your disposal.

S Customised fuse 2SKN/210



#### Position 4 — Mechanical fixing

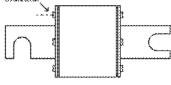
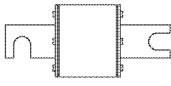
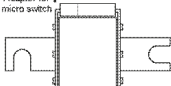

None	Slotted blade type DIN 43653	2TN/110	
F	US or BS 88 blade style	1*EKE/78	
B	Flush-end version — metric thread	3BKN/50	
G	Flush-end version — US thread	1GKN/50	
D	Double bolt, flush-end version — metric	3DKN/65	
E	Flush style blades	1EKN/86	
P	Press pack	3PKN/85	
H	Blade, without slots (not DIN 43620)	3SHT	



## Appendix 2: Fuse reference system

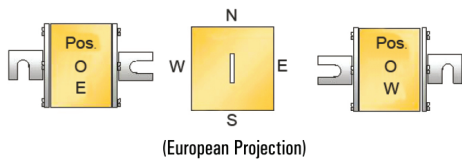
### Position 5 — Indicator type

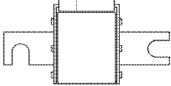
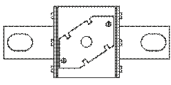
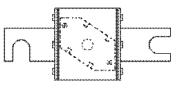
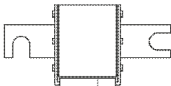
Often a fuse will have an indicator to show if it has opened. Some indicators are built in and some have to be externally fitted. Indicators may also trigger optional microswitches for remote indication. On the indicator Position 5 in the Type Code, the following options are standard:

None	Standard visual indicator	1/80	
U	No indicator	2U/110	
K	Adaptor type indicator mounted on the fuse prepared for microswitch	3KN/100	
T	Tag-type indicator prepared for microswitch	2TN/110	

### Position 6 — Indicator position

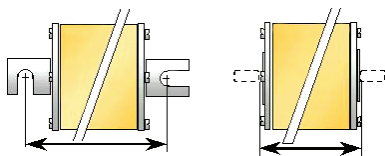
The indicator position may vary from fuse to fuse. Standard mounting is the so called Position N (North) and alternative positions are E (East), W (West), and S (South):



N	North position (standard fixation)	2KN/110	
E	East position	1FKE/78	
W	West position	2KW/110	
S	South position	2SKS/110	

### Position 7 — Center distance

Indicates center distance for mounting, or overall length of fuses with flush-end contacts, stated in millimeters.



### BS88 high speed fuses

Since fuses were first produced in the dimensions that became standardized in BS88 Part 4, fuse technology has improved. It is now possible to manufacture fuses with many different operating characteristics. In these dimensions, Bussmann series high speed fuses are available in two speed ratings: T range and F range. Fuses can be selected according to the following codes.

#### For T range fuses


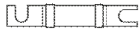

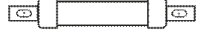
#### BS88 fuse code positions

1	2	3	4
80	L	E	T
Current rating	Voltage or style	Body size	T Range

#### Position 1 — Current rating

The continuous current rating in amps.






#### Position 2 — Voltage or style

L	Voltage rating 240 volts. Fixings as BS 88 part 4	80LET	
A	Voltage rating 660 volts. Fixings 80mm	80AET	
C	Voltage rating 660 volts. Fixings 110mm	250CMT	
None	Voltage rating 660 volts. Fixings as BS 88 part 4	20CT	

#### Position 3 — Body style

In BS88 Part 4, fuses have three diameters. The letter in Position 3 indicates the fuse's diameter. To achieve a greater fuse current rating, it is possible to place two fuses in parallel. With such fuses, and to indicate that two fuse barrels are used, the letter indicating the diameter is repeated (e.g., two M diameter fuses in parallel is LMMT).

## Appendix 2: Fuse reference system

C	8.4mm	6CT	
E	18mm	35LET	
M	38mm	315LMT	
EE	2 × 18mm	140EET	
MM	2 × 38mm	710LMMT	

### Position 4 — “T Range”

The Bussmann series T range fuse has a “T” in the fourth position. Some special purpose fuses in “standard” dimensions or with special fixing arrangements may have an alternate letter in this position. For example, 80LET is an 80 amp, 240 volt fuse, 18 mm diameter. 160AEET is a 160 amp, 660 volt fuse with two 18 mm diameter barrels and 80 mm mountings.

### For F range fuses

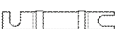


BS88 fuse code positions

1	2	3	4
80	A	F	E
Current rating	Voltage or style	F Range	Body size

### Position 1 — Current rating

The continuous current rating in amps.

### Position 2 — Voltage or style

A	Voltage rating 660 volts. Fixings 80mm	20AFE	
C	Voltage rating 660 volts. Fixings 110mm	250CFM	
No mark	Voltage rating 660 volts. Fixings as BS 88 part 4	80FE	






### Position 3 — F Range

The Bussmann series F range fuse (these are faster acting than the T range) has an F in the third position.

### Position 4 — Body style

In BS88 Part 4, fuses have three diameters. The fuse diameter is indicated by means of a letter in Position 4. To achieve additional fuse current ratings, it is possible to place two fuses in parallel. To indicate that two fuse barrels are used, the letter indicating the diameter is repeated (e.g. two FM fuses in parallel is FMM).

For example, 80FE is an 80 amp, 660 volt fuse, 18 mm diameter.

C	8.4mm		
E	18mm	35FE	
M	38mm	200FM	
EE	2 × 18mm	180FEE	
MM	2 × 38mm	630FMM	

### US high speed fuses

Like the European square and round body fuses, US fuses also have descriptive part numbers. While there is no recognized US dimensional standard for high speed fuses, there are accepted industry standards that Bussmann series fuses meet.

The following tables show the various options for all positions in the Type Code.

### Standard fuses — Type FW

Fuses can be selected by the following codes:

Fuse type FW code positions

1	2	3	4	5	6
FW	X	-	1000	A	H
Primary code	Voltage rating	Current rating	Technical revision	Fixing style	Indicator type

### Position 1 — Primary code

All Bussmann series US style high speed fuses in the standard program are designated by the prefix FW.

### Position 2 — Voltage rating

The AC voltage rating of the fuse.

Letter code	Volts	Example
A	130 or 150	FWA-80A
X	250	FWX-1A14F
H	500	FWH-175B
C	600	FWC-12A10F
P	700	FWP-15A14F
K	750	FWK-5A20F
J	1000	FWJ-20A14F
L	1250	FWL-20A20F
S	1500	FWs-15A20F

## Appendix 2: Fuse reference system

### Position 3 — Current rating

For Bussmann series high speed fuses this is usually the continuous current rating.

### Position 4 — Technical revision

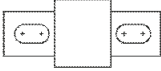








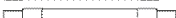
Resulting from continuous improvement, Bussmann series FW fuses also represent a consolidation after several acquisitions. When this occurs, it is necessary to distinguish each technical revision without changing the existing part numbers. In common with the semiconductor industry, a letter code is used for this purpose. For technical reasons, it may be necessary to maintain more than one of these revisions for some applications, but most applications should use the latest revision.

Position 4	Description
No mark	The first version of this product
A, B, C, etc.	Later improved version

### Position 5 — Fixing style

Most of the FW fuses have center blades with mounting holes. However, flush end mounting (often called a “Hockey Puck”) are common and so are the cylindrical or ferrule types.

Note: Where F is in Position 5, the first version of the product will be designated with an A

Empty	Standard blade	FWX-90A	
H	Flush end fixings — UNC thread	FWX-1000AH	
BB	Flush end fixings — metric thread	FWA-2000ABB	
**F	Cylindrical bladeless (ferrule) where ** is the diameter in mm of the end cap	FWH-30A6F	
		FWC-20A10F	
		FWH-30A14F	
		FWA-35A21F	
		FWP-100A22F	
		FWK-25A20F	
		FWK-60A25F	

### Position 6 — Indicator

As standard, the Bussmann series FW fuses do not have visual indication of fuse operation.

Position 6	Description
Empty	Standard product
I	Indication by additional external type TI (Trip Indicator) indicating fuse that also takes the MAI or MBI type microswitches (see BS style accessories)
SI	Indication by external indicator that also takes the 170H0069 microswitch

### Special fuses - Type SF and XL

In addition to the standard FW fuses, special purpose fuses are offered along with higher speed versions as an alternative to some of the FW range. These special fuses can be selected by the following codes.

Fuse type SF and XL code positions						
1	2	3	4	5	6	7
SF	75	X	1000		H	I
Primary code	Voltage rating	Style	Current rating	Technical revision	Fixing style	Indicator type

### Position 1 — Primary code

Bussmann series US style high speed and special purpose fuses are designated by the prefix SF or XL.

### Position 2 — Voltage rating

Generally, this is one tenth of the AC voltage rating of the fuse. For special purpose fuses, please check with Application Engineering at FuseTech@eaton.com.

### Position 3 — Style

Position 3	Description
F	High speed performance. This often also means good DC voltage performance
X	Slow speed, often for traction applications

This is only an indication of the letters used; others may also be used.

### Position 4 — Current rating

On standard high speed fuses this is usually the continuous current rating. For special types, this position may only be an indication of capabilities, as many of these designations are agreed upon with OEMs for special applications.

### Position 5 — Technical revision

When a technical revision occurs with products outside our main fuse offerings, it is necessary to distinguish each technical revision without changing the existing part numbers. In common with the semiconductor industry, a letter code is used for this purpose. For technical reasons it may be necessary to maintain more than one of these revisions for some applications while most applications should use the latest revision.

Position 5	Description
Empty	The first version of this product
A, B, C, etc.	Later improved version

### Position 6 — Fixing style

Most of the SF and XL type fuses have center blades with mounting holes.

Position 6	Description
Empty	Standard blade
HP	Flush end fixings — unified thread
BB	Flush end fixings — metric thread
Others	Agreed with OEM

### Position 7 — Indicator

Position 7	Description
Empty	Standard product
I	Indication by additional external type TI (Trip Indicator) indicating fuse that also takes the MAI or MBI type microswitches (see BS style accessories)
M	Microswitch fitted

## Appendix 3: Installation, maintenance, environmental and storage

High speed fuses are highly sophisticated and require proper installation and maintenance. Doing so will help ensure reliable performance throughout the fuse's life. This section will cover the following topics:

- Tightening torque and contact pressure
- Mounting alignment
- Surface materials of contacts
- Resistance to vibration and shock
- Service/maintenance
- Environmental issues

### Tightening torque and contact pressure

High speed fuses are electromechanical devices. Their proper function depends on the contact quality between the fuse and the connecting cables/busbars, or between the fuse and fuse holder. This is not only important for proper electrical contact, but also heat dissipation because high speed fuses generate a lot of heat that is partially removed via thermal conduction through the fuse's connections. A poor thermal connection can result in the fuse overheating and a reduced service life. Therefore it is important to apply the right tightening torque when mounting fuses.

### Flush-end contact fuses

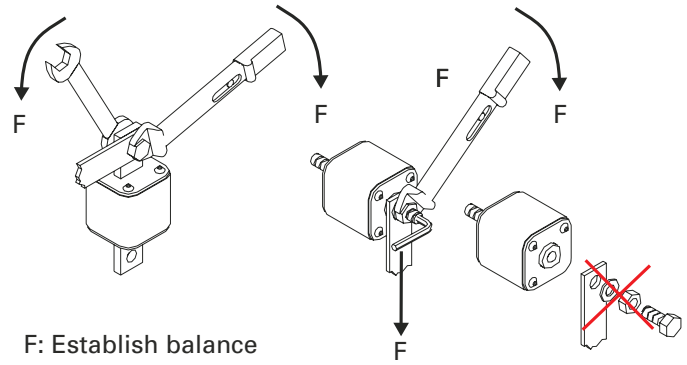
For all kinds of flush-end fuses, grade 8.8 steel socket set screws according to ISO 4026/DIN 913 or ISO 4029/DIN 916 are recommended. The studs must be tightened carefully applying a torque of 5-8 N•m. As a rule, the torque on the nuts relates to the threaded hole dimension in the fuse contact. A calibrated torque wrench with a tolerance of maximum  $\pm 4$  percent is recommended. The following provides the recommended nut tightening torques:

Size/type	Thread hole		Torque N•m	
	mm	Inches	Ungreased	Greased <sup>†</sup>
00B	M8	—	20	10
1*B – 1*G	M8	5/16	20	10
1B – 1G	M8	5/16	20	10
2B – 2G	M10	3/8	40	20
3B – 3G	M12	1/2	50	40
23B – 23G	2 × M10	2 × 3/8	40	20
4B – 4G	4 × M10	4 × 3/8	40	20
24B – 24G	3 × M12	3 × 1/2	50	40
5B – 5G	5 × M12	5 × 1/2	50	40
FWX, FWA, KBC	—	3/8	40	20

† Greased with Rhodorsil paste 4.

### Special flush-end types

Special types like 4SB or 24SB normally have threaded holes in only one end and a plate on the other for mounting on (water cooled) busbars. In such cases, the screw-in studs and nuts for the threaded hole use the values in the torque table while the plate is mounted on the busbars with 50 N•m of torque.



F: Establish balance

### Fuses with contact knives

Generally this fuse type is divided into two main groups: fuses with slotted knives according to DIN 43653 for mounting directly on busbars (or in special fuse holders) and fuses with solid knives according to DIN 43620 for mounting in spring-loaded fuse holders.

#### DIN 43653 bolted tag fuses on busbars

Fuses for mounting on busbars are to be tightened with the largest possible bolts/studs, nuts and washers. Use of washers is recommended. The bolts/nuts are tightened with a torque appropriate to their size and tensile strength. E.g., M8 Type 8.8 30 N•m (with lubricant) or 50 N•m (without lubricant).

#### DIN 43653 bolted tag fuses in blocks

Fuses mounted in special-made fuse blocks must be tightened according to the specification provided with the blocks.

Maximum tightening torque for some Bussmann series blocks are given below:

Catalog number	Torque N•m (lb-in)	
	Bolts for holder*	Bolts for cables/fuses
170H1007**	4 (35) — M6	—
170H3003 – 170H3006**	10 (88) — M8	—
	Conductor set screw	Fuse mounting bolt
1BS101	13 (120)	8 (70)
1BS102	31 (275)	13 (120)
1BS103	31 (275)	19 (170)
1BS104	42 (375)	19 (170)
BH-1, 2, 3	—	—

\* Thread greased with Rhodorsil paste 4 (Rhône-Poulenc), etc.

\*\* For 170Hxxxx holders, the above values can be increased by 25 percent if no plastic parts are stressed.

### DIN 43620 bladed fuses in blocks

This kind of holder is equipped with one or more springs to provide the correct contact pressure on the fuse's blades. No tightening is possible or recommendations given. When mounting Bussmann series holder 170H3040-47 onto the equipment, use a maximum tightening torque of 10 N•m to mount it. Note: a fuse holder amp rating may not always match up with the fuse amp rating. In some cases you might be able to match the fuse's rated watts loss and maximum permissible load current to arrive at the correct holder.

### Press Pack fuses

Some of the most common semiconductors can be stack-mounted under an applied clamping force. A range of so-called “Press Pack” fuses in body type 3P and 4P are available, and allow the user to reduce the required number of components. This can be achieved by clamping the semiconductor and the fuse together with a water cooling box in a single mounting arrangement. The maximum clamping force a fuse can withstand depends on many factors such as:

- Fuse body length and cross section area
- Temperature gradient between the fuse contacts
- Electrical load conditions

When clamping a fuse into an application, these requirements need to be considered:

- The maximum clamping force applied to a press pack fuse should not exceed the stated value (see table below) as this may damage the ceramic body
- To ensure safe electrical and thermal contact between fuse contact and the water cooling box or busbar, a minimum force of 2 N/mm<sup>2</sup> needs to be applied to the contact area of the fuse
- A maximum for of 15 N/mm<sup>2</sup> can be applied to the minimum contact area of the fuse, to ensure safe thermal contact pressure (note that the total pressure should not exceed the amounts stated in the table below)

#### Example maximum clamping force values

Size	Single-sided cooling kN	Double-sided cooling kN
3P/55	22	30
4P/60	40	50
3P/80	30	40
4P/80	50	60

**Note:** Greater permissible clamping force can be applied on some press pack fuses, please consult Application Engineering at FuseTech@eaton.com.

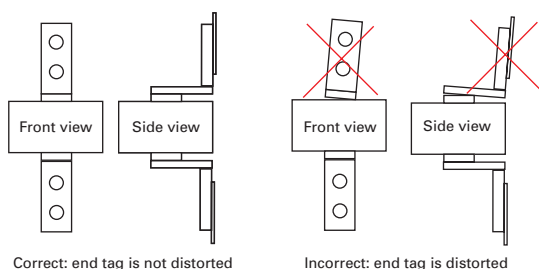
If a Press Pack fuse is water cooled at one end and not at the other, there will be a temperature difference (thermal gradient) between each contact end. If the difference in temperature at each end is greater than 55°C then the clamping values in the above table are invalid. For fuses that use double-sided water cooling, the temperature difference between the fuse contacts is expected to be negligible, and the above table values remain valid.

There are Bussmann series double body Press Pack fuses (24B and 24+B). Consult Application Engineering (FuseTech@eaton.com) when using these fuses in your application.

### Mounting alignment

Bussmann series high speed fuses are generally supplied in a ready-to-install condition.

The fuses are not meant as mounting isolators. Excessive tension, compression and torque from misalignment between fuse blades and busbars (see example below) should be avoided. If possible, mounting should start with the fuse followed by the necessary adjustment and tolerance utilization of busbar components.



### Surface material

The electrical conducting parts of Bussmann series high speed fuses are usually plated to maintain an acceptable surface condition. Tin is the most common material for the fuse contacts.

### Tin-plated contacts

	Concentration – duration PPM – h	According to standard
H <sub>2</sub> O	12.5 ppm – 96 h	IEC 68-2-43 Kd
SO <sub>2</sub>	25 ppm – 504 h	IEC 68-2-42 Kd

Most Bussmann series high speed fuse contact surfaces are electroplated with a 5 µm layer of tin. This plating provides an excellent electrical and thermal interface with holders or cables/busbars of either pure copper or copper/aluminum plated with tin/nickel or silver.

Many tests and more than 30 years of experience have shown that a tin, nickel or silver-plated surface is both mechanically and electrically stable in the entire high speed fuse operating temperature range (typical maximum temperature rise of 130°C/266°F).

### Vibration and shock resistance

High speed fuses should not be submitted to excessive vibration. However, standard high speed fuses can withstand vibration with a maximum 5 g magnitude for a long-time basis and 7 g for short periods (shocks). Before using fuses in applications with stronger vibration, consult Application Engineering at FuseTech@eaton.com.

### Service and maintenance

The following points should be observed and checked during maintenance of electrical cabinets and switchgear:

- Check tightening torques and examine ceramic fuse bodies for visible cracks. Tighten or replace as needed.
- Check all fuse indicators. In case of any fuse opening, replace all opened AND unopened fuses that have been subjected to the same fault current or any part of it. Even if the resistance (Ω) of the unopened fuses is unchanged, the fuses may be damaged by the fault current and must be replaced to avoid nuisance openings.

### Environmental issues

Generally, high speed fuses are made from the following materials:

- Ceramic
- Fiberglass
- Silver
- Copper
- Brass
- Steel
- Silica sand

Accessories like microswitches and fuse holders are partly made of various plastic materials. For further information on fuse materials, contact Application Engineering at FuseTech@eaton.com.

### Storage

Fuses should be stored in their original boxes under typical warehouse conditions for electromechanical products (free from any dirt and dust). Storage conditions should be no more than 70 percent relative humidity and in the -40°C to +85°C (-40°F to +185°F) range.



# Glossary

## Arcing $I^2t$

Value of the  $I^2t$  during the arcing time under specified conditions.

## Amp (Ampere)

The measurement of intensity of rate of flow of electrons in an electric circuit. An amp is the amount of current that will flow through a resistance of one ohm under a pressure of one volt.

## Amp rating

The current-carrying capacity of a fuse. It is given in amps RMS (root mean square, also called the effective value).

## $I^2t$ (amp squared seconds)

The measure of heat energy developed within a circuit during the fuse operation.  $I$  stands for effective let-through current (RMS), which is squared, and  $t$  stands for time of opening, in seconds. It can be expressed as Melting  $I^2t$ , Arcing  $I^2t$  or the sum of them as Clearing  $I^2t$ .

## Arcing time

The amount of time from the instant the fuse has melted until the overcurrent is safely interrupted (cleared).

## Arc voltage

This is the voltage, which occurs between the terminals of a fuse during operation. The size of the arc voltage for a given fuse is supply voltage dependent.

## Breaking capacity

This is the maximum value of prospective current, RMS symmetrical, which a fuse is capable of interrupting at stated conditions.

## Class of fuses/fuse class

National and international standards have developed basic physical specifications and electrical performance requirements for fuses with voltage ratings that pertain to specific countries.

The fuse class refers to the designed interrupting characteristic of the fuse. The following fuse class found in IEC 60269 applies to high speed fuses.

- aR - Partial-range interrupting capacity (short-circuit protection only) for the protection of power semiconductors (IEC Utilization category).

Other classes are:

- gG (gL) — Full-range interrupting capacity (overload and short-circuit protection) for general applications (IEC Utilization category).
- gM — Full-range interrupting capacity (overload and short-circuit protection) for the protection of motor circuits (IEC Utilization category).
- aM — Partial-range interrupting capacity (short-circuit protection only) for the protection of motor circuits (IEC Utilization category).
- gR — Full-range interrupting capacity (overload and short-circuit protection) for the protection of Power Semiconductors (pending).
- gPV — gPV – Full-range interrupting capacity (overload and short-circuit protection) for the protection of Photovoltaic (PV) systems" below gR class.

## Clearing (total operating) time

The total time between the beginning of the overcurrent and the final opening of the circuit at system voltage. Clearing time is the total of the melting time and the arcing time.

## Commutation fault

A fault that occurs on a regenerative DC drive due to a thyristor losing its blocking capability while there is a direct line-to-line voltage across it, which leads to a short-circuit where the AC voltage is superimposed on the DC voltage.

## Continuous current rating

The current level that causes the fuse to operate in a time of four hours is called the continuous current rating.

## Current-limitation

A fuse operation relating to short-circuits only. When a fuse operates in its current-limiting range, it will clear a short-circuit before the first peak of the current. Also, it will limit the instantaneous peak let-through current to a value substantially less than that obtainable in the same circuit if that fuse were replaced with a solid conductor of equal impedance.

## Cut-off current/peak let-through current

The maximum value reached by the fault current during the interrupting operation of a fuse. In many cases the fuse will be current-limiting.

## Electrical load

That part of the electrical system which actually uses the energy or does the work required.

## Fast-acting fuse

A fuse which opens on overload and short-circuits very quickly. This type of fuse is not designed to withstand temporary overload currents associated with some electrical loads, when sized near the full load current of the circuit.

## Fulgurite

In the context of fuses, the non-conductive, rock like substance that forms during a fuse's short-circuit interruption when the element material vapor fuses with the quartz sand fill.

## Fuse

An overcurrent protective device with a fusible link that operates and opens the circuit on an overcurrent condition.

## Fusing factor

The ratio of minimum fusing current to the rated current.

## High speed fuses

Fuses with no intentional time-delay in the overload range and designed to open as quickly as possible in the short-circuit range. These fuses are often used to protect solid-state devices.

## $I^2t$

Also referred at as the Joule integral,  $I^2t$  is the integral of the square of the current over a given time interval. Pre-arcing  $I^2t$  is the  $I^2t$  integral extended over the pre-arcing time of the fuse. Operating  $I^2t$  is the  $I^2t$  integral extended over the operating time of the fuse.

## IEC

IEC stands for the International Electrotechnical Commission. It is a non-profit, non-governmental international standards organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology."

## Inductive load

A load which has inductive properties. Common forms are motors, transformers, wound control gear. This type of load pulls a large amount of current when first energized.

## Interrupting capacity/rating

Refer to breaking capacity.

## Melting time

The amount of time required to melt the fuse element during a specified overcurrent. (See arcing time and clearing time.)

# Glossary

## Ohm

The unit of measure for electric resistance. An ohm is the amount of resistance that will allow one amp to flow under a pressure of one volt.

## Overload

This is a condition in which an overcurrent exceeds the normal full load current of a circuit that is in an otherwise healthy condition.

## Peak let-through current

The instantaneous value of peak current let-through by a current-limiting fuse, when it operates in its current-limiting range.

## Power factor

The ratio of active power (kW) to apparent power (kVA) drawn by a load. It corresponds to the cosine of the phase angle between the voltage and current (cos).

## Power losses/watts losses

The power released in a fuse when loaded according to stated conditions.

## Pre-arcing time

The time taken from the initiation of the fault to the element melting

## Prospective short-circuit current

This is the current that would flow in the fault circuit if the fuse was replaced by a link with an infinitely small impedance. Normally it is given as symmetrical RMS value, also called  $I_p$ .

## Recovery voltage

This is the voltage which can be measured across the fuse connections after operation.

## Resistive load

An electrical load which is characteristic of not having any significant inductive or capacitive component. When a resistive load is energized, the current rises instantly to its steady-state value, without first rising to a higher value.

## RMS current

Also known as the effective value, it corresponds to the peak instantaneous value of a sinusoidal waveform divided by the square root of two. The RMS value of an alternating current is equivalent to the value of direct current which would produce the same amount of heat or power.

## Semiconductor fuses

Fuses used to protect solid-state, semiconductor devices. Commonly referred to as high speed fuses or less commonly  $I^2t$  fuses. See high speed fuses.

## Short-circuit current

Can be classified as an overcurrent which exceeds the normal full load current of a circuit by a factor many times.

## Short-Circuit Current Rating (SCCR)

The maximum short-circuit current an electrical component can sustain without the occurrence of excessive damage when protected with an overcurrent protective device.

## Threshold current

The symmetrical RMS available current at the threshold of the current limiting range, where the fuse becomes current limiting when tested to the industry standard. This value can be read off of a peak let-through chart where the fuse curve intersects the A-B line. A threshold ratio is the relationship of the threshold current to the fuse's continuous current rating. This current is used during testing to UL specifications

## Time constant

The inductance in a DC circuit limits the rate of current rise. The time required for the current to reach 63 percent of the final value at rated voltage is called the "time constant," and is often referred to in terms of  $L/R$  where  $L$  is inductance in Henries and  $R$  is resistance in ohms.

## Time-current characteristics

These are the time and current levels needed for a fuse element to melt and open. They are derived using the same test arrangement as the temperature rise test, with the fuse at ambient temperature before each test.

## Time-delay fuse

A fuse with a built-in delay that allows temporary and harmless inrush currents to pass without opening, but is so designed to open on sustained overloads and short-circuits.

## Total clearing time

Also referred to as total clearing  $I^2t$ , it is the total measure of heat energy developed within a circuit during the fuse's clearing of a fault current. Total clearing  $I^2t$  is the sum of the melting  $I^2t$  and the arcing  $I^2t$ .

## Virtual melting time

Is a method of presenting melting times in a manner independent of the current waveform. It is the time that it would take a DC current equal to  $I_p$  to generate the melting  $I^2t$ . For high speed fuses, the virtual melting time ( $t_v$ ) is used and plotted down to 0.1 ms. The formula for determining time-current characteristics is:

$$t_v = \int \frac{i^2 d_t}{I_p^2}$$

Where:

$t_v$  = Virtual pre-arcing time

$i^2$  = Applied fuse current squared

$d_t$  = Change in time

$I_p$  = Prospective short-circuit current

## Total operating (Clearing) $I^2t$

The total operating  $I^2t$  value is the total of the pre-arcing and the arcing  $I^2t$  values under specified conditions.

## UL

UL stands for Underwriters Laboratories, Inc., an independent, non-profit, and non-governmental organization focusing on product safety. UL issues standards, and provides third party testing mainly for US markets.

## Voltage rating

The maximum open circuit RMS voltage in which a fuse can be used, yet safely interrupt an overcurrent. Exceeding the voltage rating of a fuse impairs its ability to clear an overload or short-circuit safely.

## Withstand rating

The maximum current that an unprotected electrical component can sustain for a specified period of time without the occurrence of extensive damage. See short-circuit current rating (SCCR).

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