Littelfuse®

Expertise Applied | Answers Delivered

POWR-*SPEED*®
FUSES

TECHNICAL APPLICATIONS GUIDE

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1. INTRODUCTION

Power Electronics is the technology that helps to run the modern world effectively and efficient. It is an interdisciplinary technology by which electric power (voltage, current and/or frequency) is converted, controlled and conditioned efficiently from one form to the desired output form using Power Semiconductor Devices.

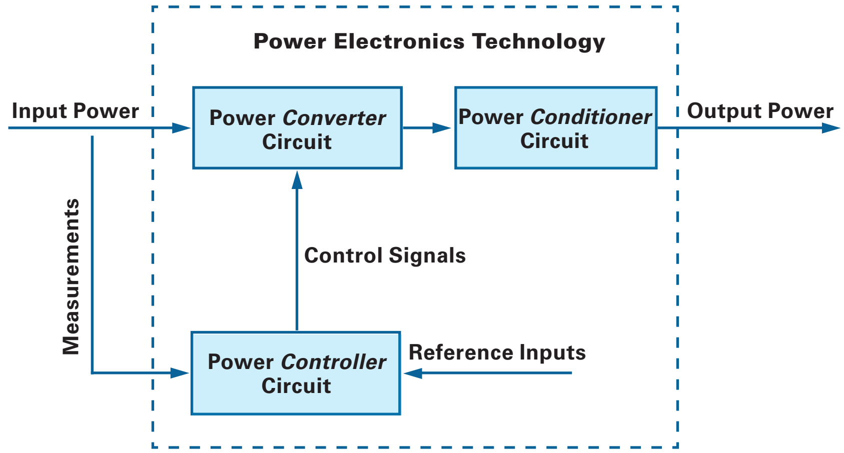


Figure 1: Power Electronics System Block Diagram

With demand for power consumption increasing due to advancements in electrical and electromechanical systems; there is steady rise in clean energy generation and consumption requirements. To meet all these growing demands, Power Electronics is the ultimate *'Go-to Technology'* and it plays a vital role to help run the world effectively and sustainably.

Figure 1 illustrates a typical block diagram Power Electronics System, where input power received is transformed from one form to another (AC-DC-AC) using a converter circuit. This conversion is based on control signals received from the controller circuit which are then filtered and provided as output using the conditioner circuit. This typical setup is found in most power electronics application

Power electronics technology today finds its use in wide market applications including renewable power generation, transportation, utility, industrial, commercial, consumer products/white goods, and medical.

Typical end-user equipment includes power conversion devices such as UPS and inverters, rectifiers, electric vehicle battery management systems, locomotive traction drives, industrial motor drives, factory automation systems, air conditioners, computers, telecom devices, battery chargers and many more.

All this equipment uses unique power semiconductor devices which provide the building blocks for the power electronics technology. To protect these very sensitive power semiconductor devices, they need an extremely fast acting and low energy let-through circuit protection device to protect them during an overcurrent fault. The only available device in the world to offer such superior levels of protection are ***Very Fast Acting (High-Speed) Semiconductor Fuses.***

The purpose of this Technical Applications Guide is to promote a better understanding of High-Speed Fuses, power semiconductor devices and their common application details within circuit design. These High-Speed Fuses being considered are current sensitive devices designed to serve as the intentional weak link in the electrical circuit. Their function is to provide protection of power semiconductor components, or of complete circuits, by reliably operating under current overload conditions.

Application guidelines and product data mentioned in this guide is intended for technical reference only. Fuse parameters and application concepts should be well understood to properly select a fuse for a given application. Application testing is strongly recommended and should be used to verify fuse performance in the circuit / application.

Littelfuse reserves the right to make changes in product design, processes, manufacturing location and literature information without notice. For additional questions, contact Littelfuse Technical Services Group at 1-800-TEC-FUSE or techline@littelfuse.com.

2. POWER SEMICONDUCTOR DEVICES

A power semiconductor device is a high power electronic device that is used as a switch for control and conversion of electric power. Use of power semiconductor devices came into existence when scientist R.N. Hall introduced the first power diode made from germanium in the year 1952. The ability of these devices to switch (turn ON/OFF) in an inductive circuit with minimum power loss is the key feature of this device.

Significant contributions were made by many researchers during the 1960s and 1970s which resulted in the introduction of many common power semiconductor devices which we use today. Key driving factors for the development of power semiconductor devices are their low material consumption per low cost and their high efficiency.

In the world of power electronics, a power semiconductor device is a combination of power semiconductor components and a driver circuit. Power semiconductor components are made from semiconductor materials such as silicon, germanium and gallium arsenide, which are used primarily for the switching application. The driver circuit is a low voltage electronic circuit that provides control signals to the power semiconductor components enabling it to turn ON/OFF.

Typical power semiconductor components that are broadly used in application include,

- IGBTs (**I**nsulated **G**ate **B**ipolar **T**ransistor)
- MOSFETs (**M**etal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor)
- SCRs (**S**ilicon **C**ontrol **R**ectifier, also known as Thyristors)
- GTOs (**G**ate **T**urn **O**ff) Thyristor
- IGCTs (**I**ntegrated **G**ate **C**ommutated **T**hyristors)
- Diodes

These power semiconductors devices are among the most complex devices used in modern day electrical systems, and by their very nature, are sensitive to over-temperatures, overloads, voltage spikes, surges and peak currents.

System designers have a most challenging task when selecting protection for semiconductor applications. At times, the most time-consuming task is obtaining the necessary detailed information about the system and associated semiconductors.

This applications guide contains a brief introduction to power semiconductor devices, listing the common power electronics applications and their protection scheme, with general guidelines to select High-Speed Fuse protection to such applications.

2.1 Power Semiconductor Device Classification

Power Semiconductor Devices are classified based on the number of terminals on each device. The most commonly used are two and three terminal devices.

Two Terminal Devices are those whose state depends on the external power circuit to which it is connected. PIN diodes and Schottky diodes are the most commonly available two terminal devices.

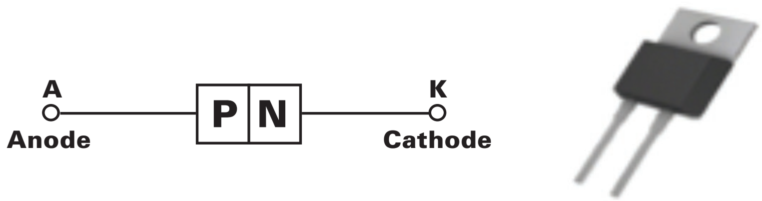


Figure 2: Two Terminal Power Semiconductor Device

Three Terminal Devices are those whose state is dependent on not only its external power circuit, but also the signal on its driving terminal (this terminal is generally referred as the 'Gate' or 'Base'). Power MOSFETs, JFETs, IGBTs, BJTs and SCRs are examples of common three terminal devices.

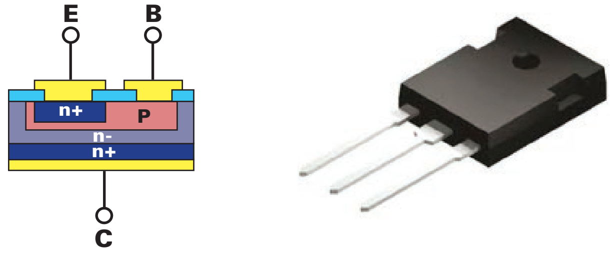


Figure 3: Three Terminal Power Semiconductor Device

With the addition of isolation circuitry to these power semiconductor devices and when packaged as a single unit, the device is called a Power Semiconductor Module or a Power Module. Figure 4 illustrates a typical Power Semiconductor Module Block Diagram.

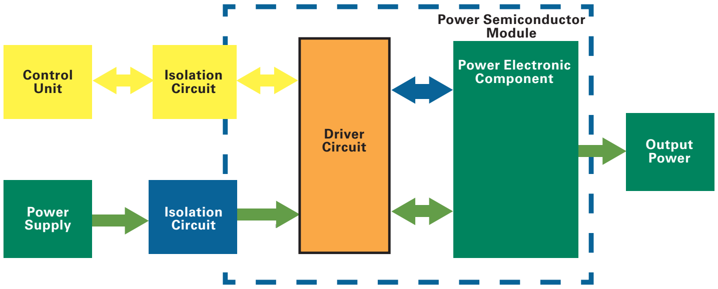


Figure 4: Power Semiconductor Module Block Diagram

2.2 Power Semiconductor Device Packaging

Power Semiconductor devices are packaged based on their current carrying capacity. Typically, they are available in three different packaging configurations:

- Discrete Packaging: Up-to a few hundred Amperes
- Module Packaging: 100A to 4000A
- Disc Packaging: 1000A to 6000A

Discrete **Modules** **Discs**

Figure 5: Power Semiconductor Device Packaging

2.3 Why Protection of Power Semiconductor Devices?

Power Semiconductor Devices are widely used due to the advantage of their high-power handling and fast switching capability in a small package size. Any reduction in their size impacts their ability to withstand overcurrent and overvoltage.

Additionally, these devices generate excessive heat during their nominal operation and have low thermal withstand capacity. This causes the devices to require additional arrangements such as heat sinks and/or forced air/liquid cooling to dissipate the heat and help them run cool.

Figure 6: Power Semiconductor Device

Performances of power semiconductor devices are also greatly affected due to the various stresses they handle during their operation such as electrical, mechanical, thermal, and environmental. When these stress levels exceed their withstanding limits, these devices tend to fail.

Thermal stress caused by various application conditions is identified as the major factor for semiconductor failure, and can result in catastrophic conditions such as case rupture, fire and explosion which can obviously cause extensive damage.

Very Fast Acting (High-Speed) Semiconductor Fuses have proven to be the protection device that offers the proper level of protection to these sensitive power semiconductor devices.

2.4 Specifications Required for Designing Circuit Protection

A clear understanding of the performance specifications and end application conditions of power semiconductor devices are key while designing the right circuit protection system.

Listed in this section are some of the key electrical and mechanical parameters that needs to be properly understood before recommending a High-Speed Fuse.

Performance Specifications

- Voltage Rating
- Current Rating (Steady RMS Current Rating)
- I^2t Rating (Withstand Rating)
- Peak Inverse Voltage Rating
- Peak Current Withstand Rating
- Watt Loss

Application Conditions

- Ambient Temperature
- Cooling
- Conductor Size
- Frequency
- Switching & Surges
- Overload (Current and Duration)
- Circuit Configuration

In Chapter 4 of this Technical Application Guide, a step-by-step approach to sizing and selecting High-Speed fuses is discussed in detail, based on these devices and application specifications.

3. HIGH-SPEED FUSEOLOGY

Understanding the protection requirements and selecting the right fuse for your application can be an overwhelming, time-consuming process even for a seasoned power-electronics design engineer. An important part of developing quality overcurrent protection is an understanding of system needs and overcurrent protective device fundamentals. In this Fuseology Selection section, fundamentals of overcurrent protection, construction and operating characteristics of High-Speed fuses are discussed.

3.1 Overcurrent Condition

An overcurrent is any current larger than what the equipment, conductor or device is rated to carry under specified conditions. All electrical systems eventually experience overcurrents. Unless removed in time, even moderate overcurrents quickly overheat system components, which in turn, can damage insulation, conductors, and equipment. Large overcurrents may melt conductors and vaporize insulation.

Very high currents produce magnetic forces that can bend and twist bus bars. These high currents can pull cables from their terminals and crack insulators and spacers. Too frequently, fires, explosions, poisonous fumes and panic also accompany uncontrolled overcurrents. This not only damages electrical systems and equipment, but may cause injury or death to personnel nearby.

3.2 Overcurrent Types

The term 'overcurrent' includes two types of fault conditions:

- Overload Fault Condition
- Short-circuit Fault Condition

Overload Fault Condition: Defined as an overcurrent that is confined to the normal current path, which if allowed to persist in the circuit, will cause damage to equipment and/or any connected wiring.

Overcurrent protective devices must disconnect circuits and equipment experiencing continuous or sustained overloads before any overheating occurs. Even moderate insulation overheating can seriously reduce the life of the components and/or equipment involved.

Typically, overcurrents less than 600% of the rated current of the device or application are termed as an 'Overload Fault Current'.

Overload conditions often arise in applications when temporary surge currents persist in the system due to mechanical obstruction or jammed equipment conditions.

Short Circuit Fault Condition: An overcurrent that flows outside its normal current path in the circuit is a Short-circuit Fault Condition. A short-circuit fault is most commonly caused by an insulation breakdown or a faulty connection.

When a short-circuit fault occurs, the current bypasses the normal load and takes a "shorter path," hence the term 'short-circuit'. Short-circuit faults are typically divided into three types: bolted faults, arcing faults, and ground faults.

Typically, overcurrents greater than 600% of the rated current of the device or application are termed as a 'Short-circuit Fault Current'.

Short-circuit conditions often arise in applications due to occurrences such as accidents, human error, dropped tools, misapplication, or insulation breakdown.

3.3 What are High-Speed Fuses? *(And how are they different from other fuses?)*

Fuses intended to protect solid-state power electronic components and power semiconductor devices from overcurrent condition are referred to as High-Speed Fuses or Very Fast Acting Fuses. Intentional time-delay features that are present in general industrial (time-delay) fuses are not available with these High-Speed fuses.

With specially designed element profile and body construction, these fuses offer all the necessary short-circuit characteristics required for protection of semiconductor devices such as low energy let-through (I^2t), low peak currents (I_{peak}), low arc voltage and high heat dissipation.

While High-Speed Fuses are known by many names in the electrical industry including rectifier fuse, ultra-fast acting fuse, ultra-quick fuse, and semiconductor fuse, the most commonly used term is High-Speed Fuses.

POWR-*SPEED*® is the brand name for the Littelfuse Industrial fuse series that are specially designed for High-Speed (semiconductor) device protection applications.

Littelfuse **POWR-*SPEED*®** fuses offer optimized circuit protection at extremely fast speeds required to protect highly sensitive power semiconductor devices. These **POWR-*SPEED*®** fuses are designed to provide balanced performance to extend longevity while lowering potentially damaging heat energy to the devices being protected.

The terms **POWR-*SPEED*®** Fuses and High-Speed Fuses are used interchangeably in this guide to represent the Littelfuse High-Speed range of products. The proper selection of High-Speed fuses is discussed in detail in sizing guidelines and application consideration sections later in this Technical Applications Guide.

3.4 High-Speed Fuse Construction

A *fuse* is a thermal current-controlled safety device used for electrical circuit protection. The term 'Fuse' or 'Fuse-link' are used synonymously throughout this document and refer to an overcurrent protective device consisting of one or more current carrying elements enclosed within a chamber. The chamber is fitted with contacts (also known as blade/end-bells or terminations) so that the fuse may be readily inserted into or removed from an electrical circuit.

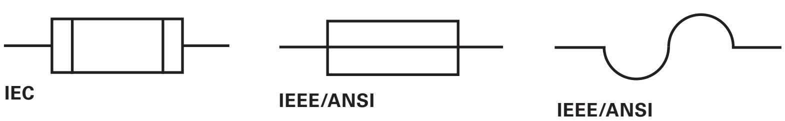


Figure 7: Representation of a fuse in an electrical circuit across various International Standards

The design and construction of High-Speed fuses are unique as is their size and terminations. This is done to avoid misapplication of these fuses to any other general industrial applications in the field.

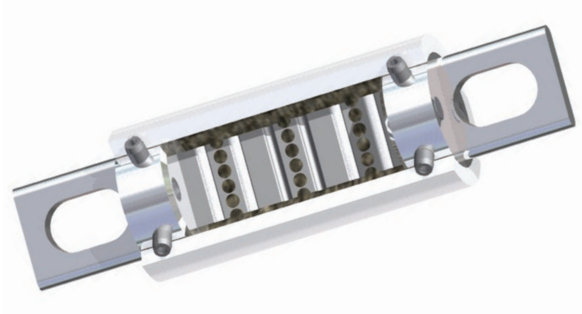


Figure 8: Cut-away of High-Speed Fuse

Superior grade materials are commonly used for High-Speed fuse construction. Listed below is a further description of each type used along with its physical properties and performance benefits.

Element: High-Speed fuses contain one or more current sensitive elements. Each element has a reduced cross section at one or more points. The reduced cross sections provide a measured resistance in each element.

The resistance of each element and the number of elements used in each fuse typically determines the current rating of the fuse. Littelfuse High-Speed fuses contain elements made of silver, silver-plated copper, copper or other suitable metals.

Body Material: The most common body materials used in High-Speed fuses are glass-reinforced melamine and high grade ceramics. Glass-melamine is strong and break resistant, whereas ceramic has higher heat dissipation and temperature withstand capabilities. Littelfuse High-Speed fuse are also made of these materials.

Mounting Terminals: Most of the Littelfuse High-Speed fuse terminals consist of a copper alloy material. Some lower ampere ratings are drawn-brass to provide proper stress relief. Terminals of these fuses are also typically plated to reduce corrosion and to provide low-resistance connections.

Filler Material: Fuses contain filler which is primarily used to help extinguish arcing that occurs during current interruption. High grade quartz silica crystal filler material is used which contribute to the fuse's current limiting ability. Additionally, fillers aid with heat balance within the fuse while provide stability to the elements. This stability allows for smaller element cross sections to be used which in turn, improves short-circuit performance.

3.5 High-Speed Fuse Styles

High-Speed fuse styles are broadly classified based on dimension, mounting and origin. The most common styles are:

- North American Traditional Round Body
- Square Body
- Cylindrical or Ferrule
- British Standard (BS88) Bolted

North American Traditional Round Body

Round-Body Bolted Style High-Speed Fuses are most common in North America for protecting power semiconductor devices. These fuses are made of premium grade glass-melamine bodies, copper terminals, high grade quartz silica filler and operating mechanism with 99.9% pure silver elements. Each of these components have unique features that offer unmatched degree for protection to power semiconductor devices.

Figure 9: North American Round Body Style Fuses

The glass-melamine body absorbs the heat dissipated by the fuse. Silver-plated copper terminals offer excellent electrical contact to the fuse holder or bus bar. High grade quartz silica quenches the arc produced during fuse operation. The silver elements are uniquely designed with reduced cross-section areas to carry the rated current continuously. During an overcurrent fault, the elements melt at those reduced sections much faster, thereby clearing the overcurrent fault and limiting energy let-through to any down-stream devices.

Square Body

Square Body Style High-Speed Fuses are widely used for protecting power semiconductor devices. These fuses are made with a premium grade ceramic body, silver plated copper terminals, high grade quartz silica filler, and operating mechanism containing 99.9% pure silver elements. These square body style fuses are available in different sizes to meet the wide range of electrical requirements demanded by modern power semiconductor devices.

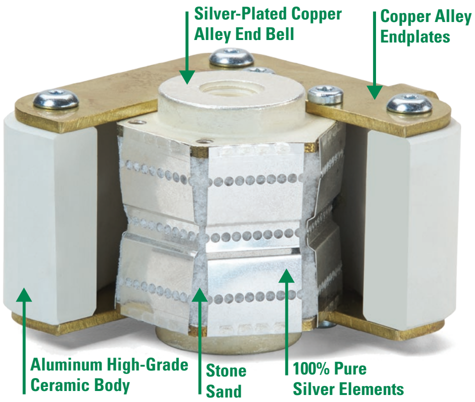


Figure 10: Square Body Style Fuses

The ceramic body has better heat withstand capabilities and offers higher resistance to arcing compared to the melamine material. The core in these square body fuses is made of multiple, parallel rows of specially designed silver or copper-silver elements that are designed to carry the rated current and melt during an overcurrent condition. The filler insider these square body fuses is high-grade quartz silica, however, unlike other fuses that have loose filler, this filler is in a solidified state referred to as 'stone sand'. This stone sand design offers superior arc quenching capabilities, low energy let-through and improved DC performance. The square body terminal style shown in Figure 10 is referred as 'Flush End', where the bus-bars are directly connected to the fuse.

Cylindrical or Ferrule Body

Cylindrical or Ferrule Style High-Speed fuses are widely preferred by users thanks to their compact size and ability to be mounted directly to the printed circuit boards. Typical applications of these fuses include power supplies and control circuits. These fuses are made of melamine or ceramic bodies, while the end caps are typically a plated copper material to provide better conductivity. The elements inside are pure silver and are filled with high grade quartz silica filler.

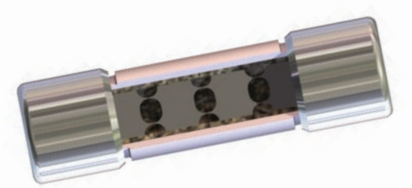


Figure 11: Cylindrical or Ferrule Style Fuses

Cylindrical High-Speed fuses are offered in standard case sizes including:

- 10.3mm x 38.1mm
- 14.3mm x 50.8mm
- 20.6mm x 50.8mm
- 20.6mm x 127.0mm

3.6 Fuse Operation

In terms of how a fuse operates, the fusible element inside a fuse simply melts to protect the downstream device to which it is connected. Thus, fuses are often referred to as the 'sacrificial device' or 'weakest link' in the circuit. Fuses are connected in series to the device intended to be protected. Within each fuse there are one or more fusible elements typically made of silver or copper, enclosed within a chamber made of ceramic or melamine, and connected to the application using copper or brass contacts or terminals. These fusible elements consist of one or more bridges or restrictions through which the electric current flow through.

Fusible elements are specially designed to carry a specified amount of current continuously without opening. This is referred to as the *rated current* of the fuse. When electric current flows through these element bridges or restrictions, heat is generated. Until there is a balance in heat transfer (where the heat generated equals the heat dissipated) the fuse element(s) continue to carry the current as intended.

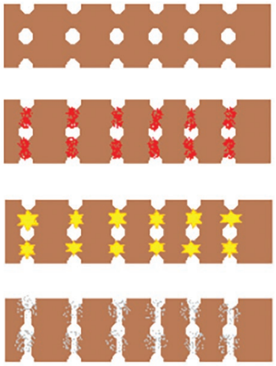


Figure 12: Changes to a fuse element during its operation

When there is an imbalance in heat transfer due to overcurrent conditions such as an overload or short-circuit occurrence, the amount of heat generated is greater than the heat dissipated. This causes a rise in temperature at the fusible element's restrictions or weak points.

When this rise in temperature reaches the melting point of the fusible element (1,984°F / 1,085°C for copper or 1,763°F / 962°C for silver), the element bridges start to melt and break, resulting in an interruption of current flow through the fuse to the circuit.

In the event of a short-circuit condition, the fusible element(s) will begin to melt and then separate in just a few milliseconds. Yet during this time, an arc is generated within the fuse which in turn, is quenched or extinguished by the quartz silica sand filler material. The graph below shows the performance of current and voltage within the fuse during its operation.

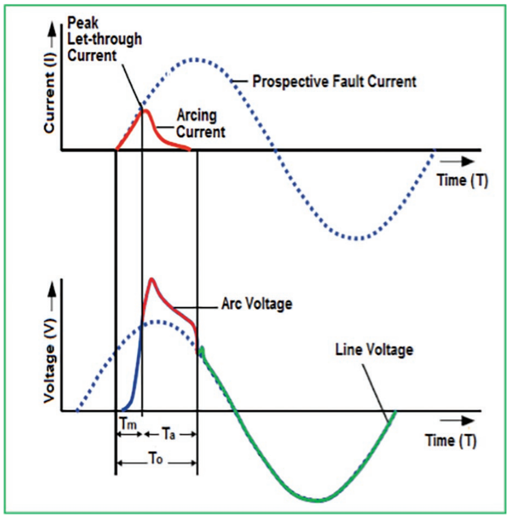


Figure 13: Performance of current and voltage inside a fuse during its operation

Thermal energy generated during the interruption of fault current by the fuse is usually expressed in *Joules* and commonly referred to as *Amperes Squared Time (A^2s or I^2t)*. It is proportional to the square of the current ('I' in amperes) during the operating time ('t' in seconds). The thermal energy generated is represented as Melting I^2t, Arcing I^2t and Clearing I^2t.

Melting I^2t is the heat energy passed by a fuse after an overcurrent occurs and until the fuse element melts. It equals the RMS current squared multiplied by the melting time (in seconds).

Arcing I^2t is the heat energy passed by a fuse during its arcing time. It is equal to the RMS arcing current squared, multiplied by the arcing time (in seconds).

Clearing I^2t (or Total Clearing I^2t) is the ampere-squared seconds (I^2t) through an overcurrent device from the inception of the overcurrent until the current is completely interrupted. Clearing I^2t is the sum of the Melting I^2t plus the Arcing I^2t.

3.7 Fuse Operating Characteristics

Fuses have inverse time characteristics; that is, the fuse opening time decreases as the magnitude of overcurrent increases. Time current characteristics determine how fast a fuse responds to overcurrents and are represented in the form of a Time Current (TC) Curve. Based on the fuse's response time, each fuse is classified as either a Time-Delay (*SLO-BLO®*) fuse, a Fast-Acting (*Normal-Opening*) fuse, or a Very Fast-Acting (*Semiconductor Protection*) fuse.

Time Delay (SLO-BLO®) Fuses: Time Delay Fuses have an intentional, built-in time delay when opening. When compared to fast-acting fuses, time-delay fuses have an increased opening time for low overcurrents. Time-delay characteristics are indicated on the fuse label by "Time-Delay", "T-D", "D", or other suitable markings.

Fast Acting (Normal-Opening) Fuses: Fast acting fuses have no intentional built-in time delay. The actual opening time is determined by the fuse class, the overcurrent, and other conditions. Fast-acting characteristics are indicated on the fuse label by "Fast-Acting", "F-A", "F", or other suitable markings.

Very Fast Acting (Semiconductor) Fuses: A fuse specifically designed to protect power semiconductor devices and/or components such as silicon-controlled rectifiers, thyristors, transistors, and AC-DC power converters is considered a Very Fast Acting High-Speed Fuse or more generally speaking…***High-Speed Fuse.***

Classification of High-Speed Fuses: Based on protection levels offered, High-Speed Fuses are classified into two broad categories: Full Range High-Speed Fuses and Partial Range High-Speed Fuses. The IEC 60269 Standard classifies fuse operating characteristics by utilization category, represented in the form of a two-letter alphabetical symbol/code (e.g. gG, aR, gR, aM, etc)

Full Range High-Speed Fuses offer protection to both overload and short-circuit overcurrent conditions and have an assigned utilization category symbol 'gR'. The first letter 'g' denotes full range protection while the second letter 'R' denotes 'semiconductor device application'.

Partial Range High-Speed Fuses offer protection to only short-circuit overcurrent condition and have an assigned utilization category symbol 'aR'. In this case, the first letter 'a' denotes partial range protection with the second letter 'R' again denoting 'semiconductor device application'.

3.8 High-Speed Fuse Characteristics Curves

Performance capabilities of High-Speed fuses are determined in the form of various characteristics curves, where two or more electrical performances are compared and represented graphically. Typical High-Speed fuse characteristics curves include,

- Time Current Curve
- Watt Loss Performance Curve
- Temperature Derating Curve
- Peak Let-through Current Curve
- Arc Voltage Curve
- I^2t Curve

Time Current Curve (TC Curve)

High-Speed fuse Time Current (TC) Curves are graphical representations or performance plots of the fuse's pre-arcing (melting) time at any given prospective symmetrical (fault) current. The TC Curves are generated based on standard test conditions and at an ambient temperature range of 20°C to 25°C.

The X-axis of a TC Curve represents the symmetrical RMS (fault) current (I_{fault}) in amperes. The Y-axis denotes the pre-arcing (melting) time ($T_{pre\text{-}arc}$) for the fuse. This is the time span from initiation of an overcurrent condition to the instant arcing begins inside the fuse.

TC Curves represent the inverse time-current relation characteristic of fuses, illustrating how the pre-arcing (or melting) time of a fuse decreases with the increase in prospective symmetrical (fault) current. TC Curves are used to determine a fuse's melting time for a given symmetrical (fault) current and to select the right fuse rating for an application.

To determine the 'time to melt' for a fuse, start by locating the symmetrical (fault) current on the X-axis (reference point A) as shown in the Figure 14. Extend a line from point A upward until it intersects the fuse TC Curve at point B. Then move to the left to identify the corresponding value on the Y-axis (referenced to as point C) which represents the fuse's pre-arcing (melting) time.

In the example in Figure 14, the symmetrical (fault) current available for this application is **2000A** which is identified in the X-axis as point **A.** Follow the line extending from point A up until it meets the TC Curve at point B. Them moving left to the Y-axis (at point C) determines the pre-arcing (melting) time for the fuse selected **= 0.004 seconds.**

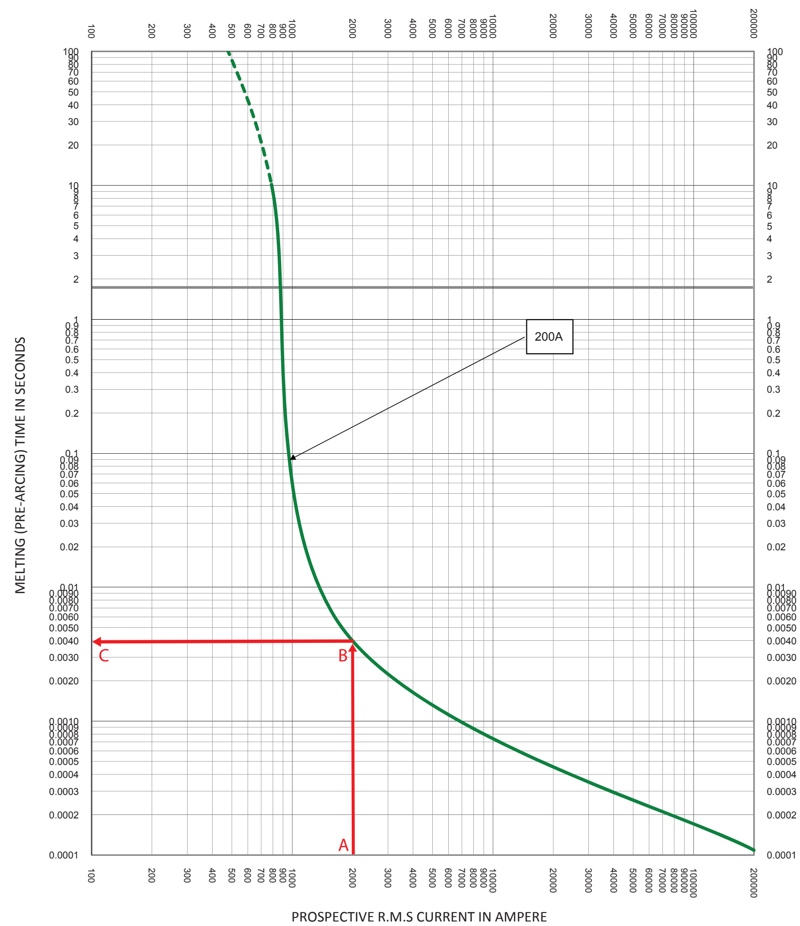


Figure 14: Time Current Characteristic Curve – Pre-arcing (Melting) Time determination

Unsafe Operating Region (TC Curve):

In a semiconductor device application, the common overcurrent fault condition that could occur would be a short-circuit fault. Thus, most High-Speed fuses are considered partial range fuses, offering only short-circuit protection and termed as ‘aR’ fuses.

There is limited full range High-Speed fuses available in the market offering both overload and short-circuit protection. These fuses are defined as ‘gR’/’gS’ fuses.

The short-circuit currents for which a High-Speed fuse offers protection is identified by a solid line on its TC Curve. Current ranges outside the fuse protection limits (typically the low overload fault currents) are represented by a dotted line on their TC curve. The intersection of the solid and dotted lines represents the minimum breaking current for the fuse.

Due to the thermal risk that prevails while applying High-Speed fuse at low overcurrents, it is not recommended that they be operated in this dotted line region.

Figure 15, is typical example of a partial range High-Speed fuse TC curve that has the solid and dotted line regions. The shaded zone identified at the top of the figure represents the unsafe operating region for this fuse.

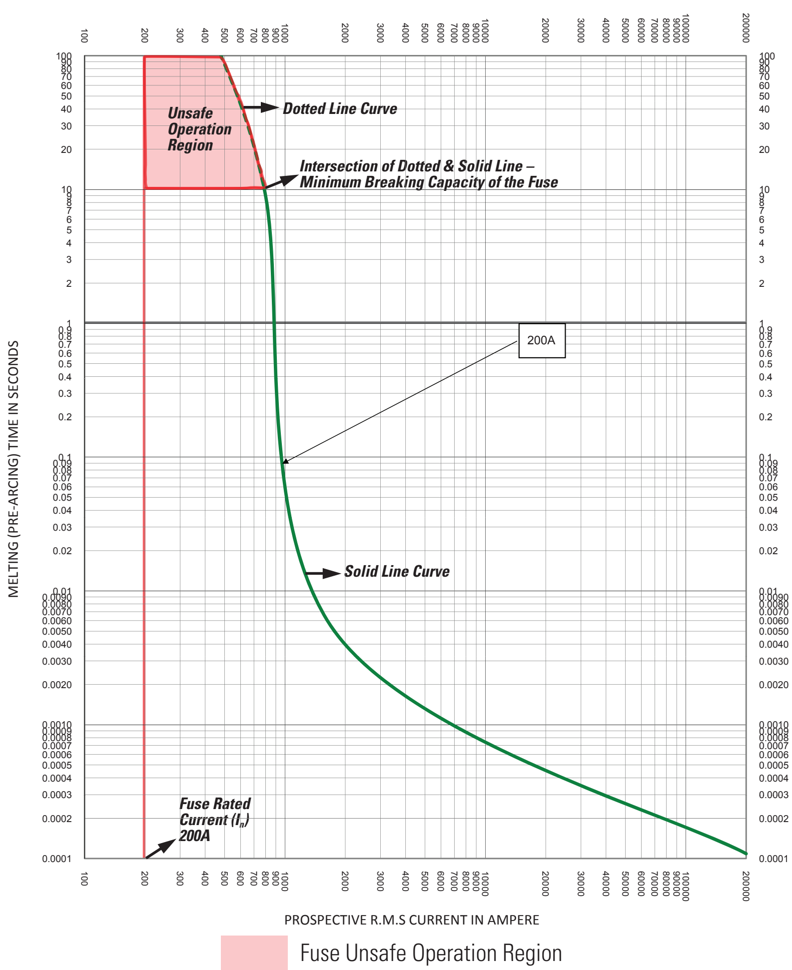


Figure 15: Time Current Characteristic Curve – Safe and Unsafe Operation Region Determination

While selecting High-Speed fuses for varying load current applications, care should be taken such that the load current of the application does not fall into the unsafe operation region of the fuse selected.

Watt Loss Performance Curve

The amount of energy consumed by a fuse during its nominal operation is referred to as the Energy Loss or Watt Loss of the fuse. Global standards require watt loss values to be furnished by the fuse manufacturer and tested at 100% of the rated current of the fuse.

In real world applications, semiconductor device protection fuses are typically not loaded up to 100% of their rated current, but are loaded anywhere between 60% and 80% of the rated current. Littelfuse publishes watt loss values for High-Speed fuses tested at both 100% and 80% of rated current. This data can be found in the form of an Electrical Characteristics table for each fuse in its datasheet, along with a Watt Loss Correction Factor re-rating curve that represents the watt loss performance of the fuse series between 30% and 100% of the rated current.

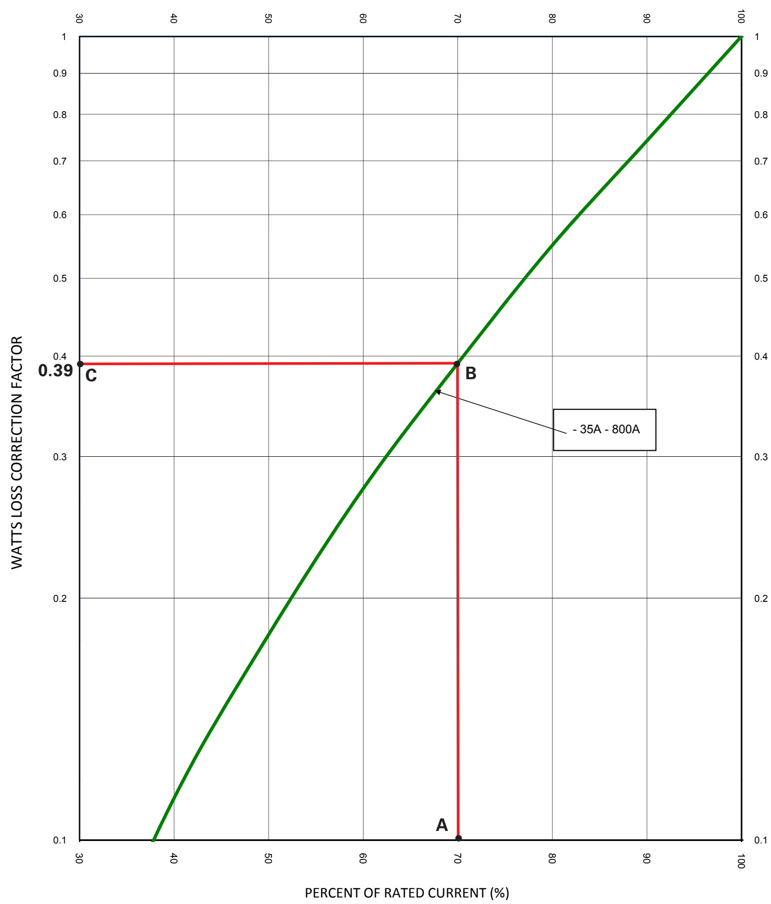


Figure 16: Watt Loss Correction Factor Curve

Figure 16 represents a typical Watt Loss Correction Factor Curve for a High-Speed fuse series. The X-axis of the curve represents the percentage of rated current, while the Y-axis shows the correction factor to be multiplied to the 100% Watt Loss value of the fuse being used.

Example:
Determine the watt loss value for a fuse when loaded at 70% of its rated current using the Watt Loss correction factor curve shown in Figure 16. The rated current watt loss from the fuse datasheet is 24W (watts).

Looking at Figure 16, start by locating the required percentage of 70% value on the X-axis (Point A) and extend a line upward until it meets the watt loss curve (Point B).

Then move to the left to identify the corresponding value on the Y-axis (Point C) which represents the watt loss correction factor to be multiplied to the 100%-watt loss values for the fuse selected.

The watt loss correction factor identified from the curve at 70% rated current is 0.39. Multiplying this factor to the 100%-watt loss value of the fuse results in,

24W x 0.39 = 9.36 W

This 9.36W is the mathematical derived approximate watt loss value for the fuse when loaded at 70% of its rated current.

Temperature De-Rating Curve

Fuses are thermally responsive devices and their current-carrying capacity depends upon the operating ambient temperature condition of the application where they are being used.

The current-carrying capacity of a fuse is reduced with an increase in ambient temperature, and vice-versa. A temperature de-rating curve can be used to determine this change in current carrying capacity across the operating temperature range of the fuse.

Temperature De-rating Curves are specific to fuse types and are based on the ambient air temperature that is surrounding and immediately outside the fuse (generally within a few inches from the fuse). If the fuse is mounted to an enclosed fuse holder, then the ambient is the air temperature immediately surrounding the fuse holder. Temperature de-rating curves show both the widest Ambient Temperature range (X-axis) within which the fuse can be safely operated (also known as Operating Temperature Range), as well as the corresponding de-rating factor to be applied to the rated current of the fuse.

To use the curve, first measure the ambient temperature for the application and locate that temperature on the X-axis (for example, reference point A1 as shown in Figure 17). Then extend a line upward from this reference point until it intersects with the de-rating curve. Then move left or right to find the corresponding percentage shown on the Y-axis. This identifies the necessary de-rating factor (uprating or downrating) to be applied to the rated current of the fuse rating selected for the application.

In the example shown here, the ambient condition of the application is 70°C, as represented by reference point A1 on the X-axis. Extend a line upward until it intersects the de-rating curve. In this instance, the de-rating curve is below the 0% part of the Y-axis so there will be a down-rating for this application. Extend the line to the Y-axis on the right side of the curve to identify 10% as the percentage factor of downrating necessary for the fuse selected for this application. In other words, the rated current of the fuse selected for this application should be reduced by 10%, with the calculated current value becoming the new current rating for the fuse.

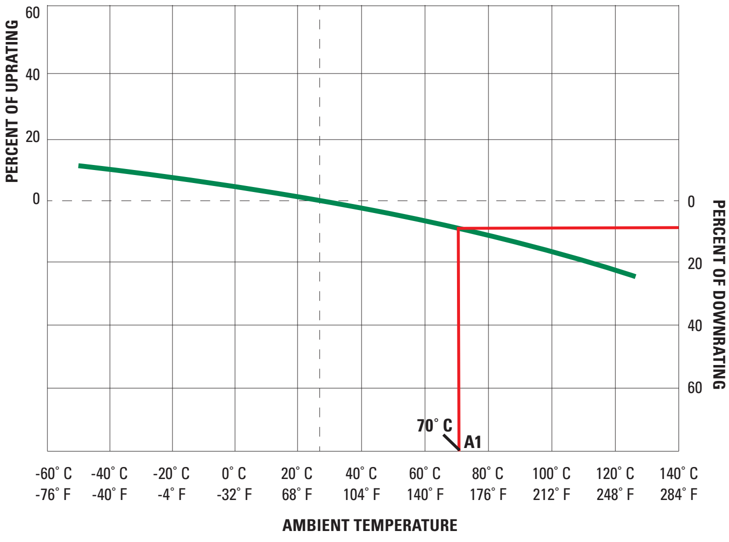


Figure 17: Temperature De-rating Curve (Temperature of Air Immediately Surrounding Fuse)

To complete the example, let's consider a 30A fuse for this application. Based on the 70°C ambient temperature involved a de-rating factor of **-10%** is now applied for this fuse. The new current rating of the fuse now becomes 30A – 10% = **27A.**

For Littelfuse High-Speed fuses, the typical storage temperature would range from **-20°C to 60°C** at a relative humidity of **75%.** The operating temperature range would be **-55°C to +120°C.**

Peak Let-through Current Curve

Peak Let-through Current Curves illustrate the maximum instantaneous current through the fuse during its total clearing time. This represents the current limiting ability of a fuse. Peak let-through curves for Littelfuse High-Speed fuses are available in individual fuse series datasheets. These curves are useful in determining whether a given fuse can properly protect a specific piece of equipment.

Fuses that are current-limiting open severe short-circuits within the first half-cycle after the fault occurs. Current-limiting fuses also reduce the peak current of the available fault current to a value less than would occur without the fuse. This reduction is shown in the Figure 18.

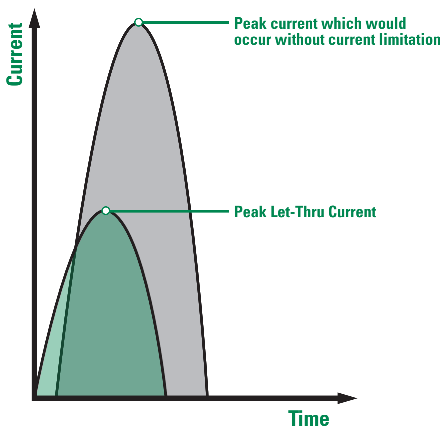


Figure 18: Current limiting effect of fuses

A fuse's current-limiting effects are shown graphically on Peak Let-through Curves as shown in Figure 19. The values across the curve's bottom represent the available (also referred to as potential or prospective) RMS symmetrical fault current. The values along the curve's left side represent the instantaneous available peak current and the peak let-through current for various fuse ratings.

In a circuit with a typical 15% short-circuit power factor, the instantaneous peak of the available current is approximately 2.3 times the RMS symmetrical value. This is represented by the A-B line on the curve that has a 2.3:1 slope.

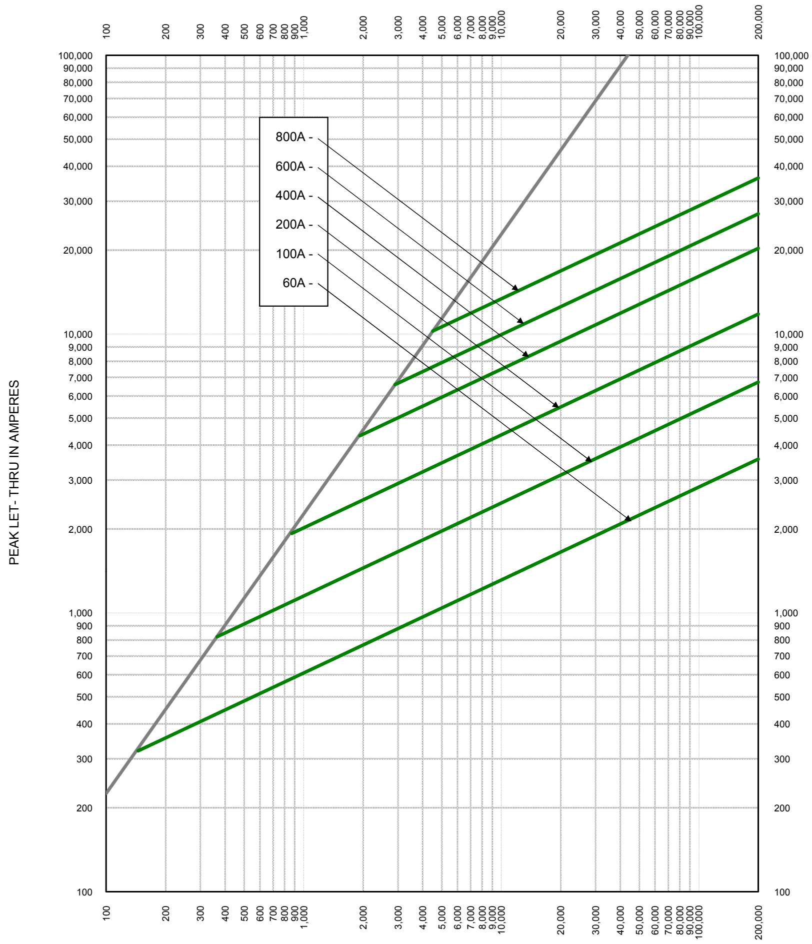


Figure 19: Peak Let-through Curves

The diagonal curves that branches off the A-B line illustrate the current-limiting effects of different fuse ampere ratings for a given fuse series.

A current limiting fuse which, when interrupting currents within its current-limiting range, reduces the current in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device was replaced with a solid conductor having comparable impedance.

This is important because the magnetic force created by current flow is a function of the peak current squared. If the peak let-through current of the current-limiting fuse is one-tenth of the available peak, the magnetic force is reduced to less than 1/100 of what would occur without the fuse.

Using Peak Let-through Curves "Up-Over-and-Down"

As an example, refer to Figure 20. For a given available fault-current of 100,000 RMS amperes, determine whether a 600A, 500V L50QS Series fuses can sufficiently protect equipment that has a 22,000A short-circuit rating.

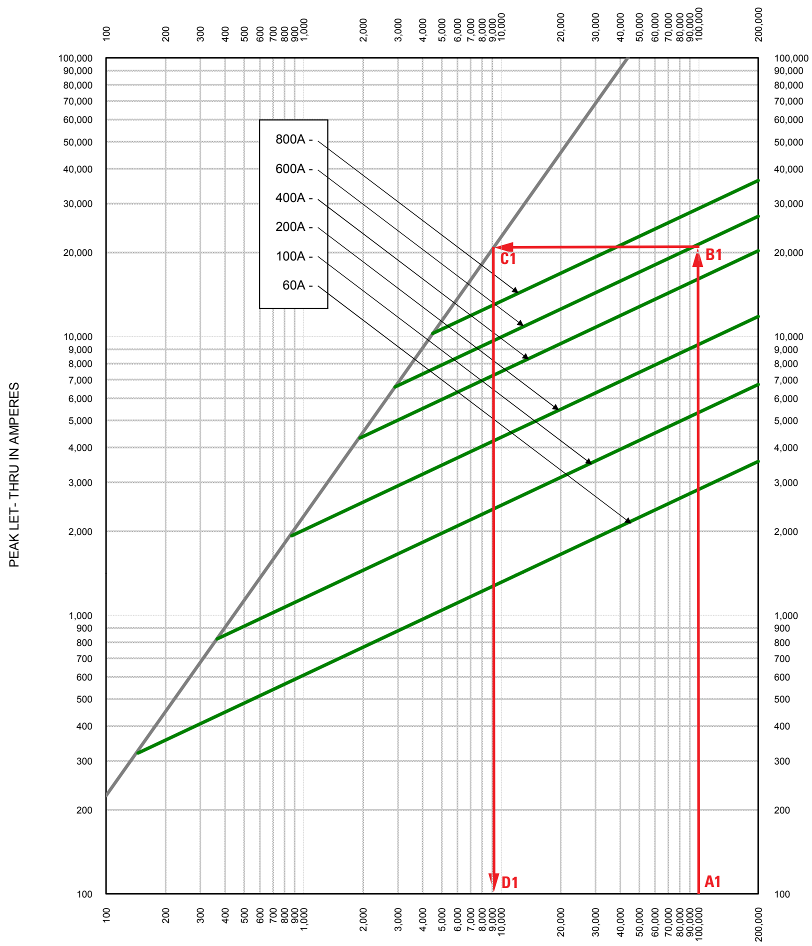


Figure 20: L50QS Series Peak Let-through Curve

Start by locating the 100,000A available fault-current on the bottom of the curve (Point A1) and follow this value upwards to the intersection with the 600A fuse curve (Point B1). Next, follow the point horizontally to the left to intersect with the A-B line (Point C1). Finally, read down to the bottom of the curve (Point D1) to read a value of approximately 8,000A (let-through current).

Based on this L50QS 600A High-Speed Fuse Peak Let-through analysis, the selected fuse has reduced the 100,000A available current to an apparent or equivalent 8,000A. This fuse can now be used to safely protect the connected piece of equipment in this application and its 22,000A short-circuit rating.

Arc Voltage Current Curve

Arc (arcing) voltage is a transient voltage that occurs across an overcurrent protection device during the arcing time. It is usually expressed as peak instantaneous voltage (V_{peak} or E_{peak})

When the bridges of the fusible element start to soften and melt during an overcurrent fault condition, arcing occurs inside the fuse. The arc produced inside the fuse conducts the flow of electrons or fault current until it is quenched by the filler media (silica sand). Other factors that affect the peak arc-voltage include the voltage rating and the power factor.

During this arcing process, the resistance of the arc causes a peak instantaneous arc voltage to appear across the fuse terminals that is greater than the system voltage. Arc voltage generated inside a High-Speed fuse will appear across the power semiconductor device that is connected in series to the fuse as instantaneous reverse voltage.

Peak Arc Voltage Curves for High-Speed fuse provide the different levels of arc voltage generated within the fuse at varying operating voltages below its rated voltage. These curves are based on the results when tested at a 15% power factor.

Figure 21 shows the level of peak arc voltage that may appear across the terminals of a 700Vac High-Speed fuse. For instance, consider a requirement to find the peak arc voltage for a 400A fuse at a 500V condition using the Peak Arc Voltage Curve. Start by locating the operating voltage (500V) on the bottom of the curve at point A on the X-axis. Then follow this value upwards until it meets the 225-800A curve at point B (which is the peak arc voltage curve of 400A rating). From there, follow the point horizontally until it meets the peak arc voltage at point C on the Y-axis. The corresponding value of 950V provides the peak arc voltage for a 400A rated fuse at an operating voltage of 500V.

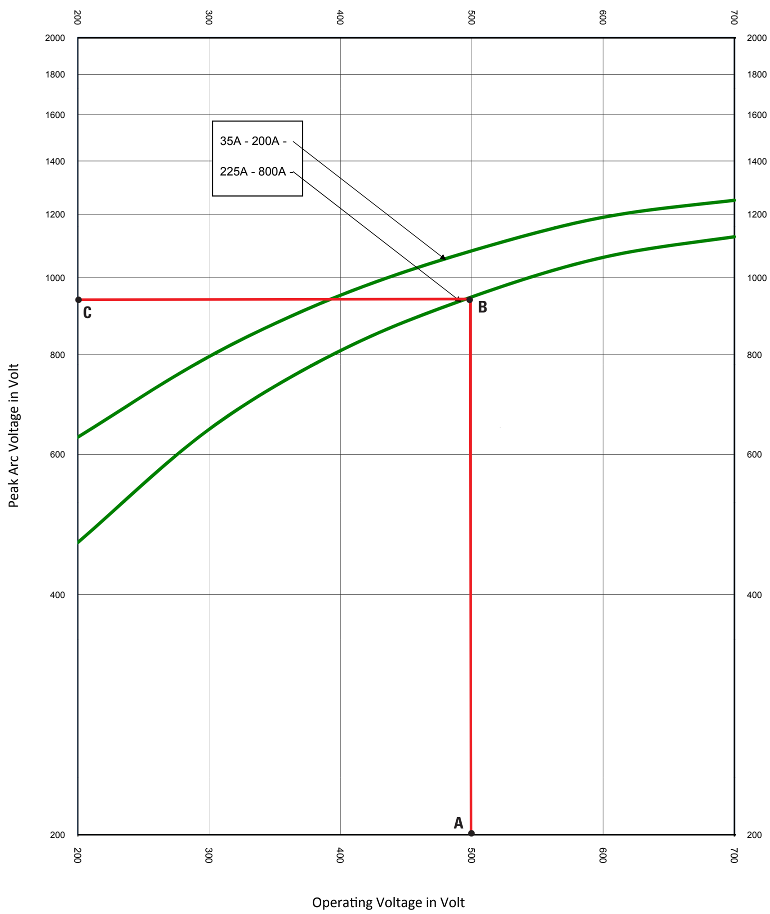


Figure 21: Peak Arc Voltage Curve for Littelfuse High-Speed fuse

Care should be taken during the fuse selection process to ensure that this peak arc voltage (also termed as 'reverse voltage') is less than the power semiconductor device peak inverse voltage (PIV) to avoid semiconductor device breakdown.

Consult the datasheet for each High-Speed fuse series to utilize the Littelfuse published peak arc voltage curves.

I^2t Current Curve

I^2t, also known as Ampere-Squared Seconds, is a means of describing the thermal energy generated by current flow. When a fuse is interrupting a current within its current-limiting range, the term is usually expressed as melting, arcing, or total clearing I^2t.

- **Melting I^2t** is the heat energy passed by a fuse after an overcurrent occurs and until the fuse link melts. It equals the RMS current squared multiplied by the melting time in seconds.
- **Arcing I^2t** is the heat energy passed by a fuse during its arcing time. It is equal to the RMS arcing current squared multiplied by arcing time in seconds. Arcing current is the current that flows through the fuse after the fuse link has melted and until the circuit is interrupted.
- **Clearing I^2t** (also Total Clearing I^2t) is the ampere-squared seconds (I^2t) through an overcurrent device from the inception of the overcurrent until the current is completely interrupted. Clearing I^2t is the sum of the Melting I^2t plus the Arcing I^2t.

Total Clearing I^2t = Melting I^2t + Arcing I^2t

Figure 22 shows the Melting I^2t and Total Clearing I^2t values of a typical High-Speed fuse. It's an older way of representing the I^2t values in graphical format where the X-axis of the curve represents the RMS prospective short-circuit fault current expressed in kiloamperes, and the Y-axis represents the I^2t value expressed in Ampere-Squared Seconds (A^2s). Melting and Clearing I^2t values at different prospective fault currents are plotted in this curve.

Melting I^2t and Total Clearing I^2t curves are higher for low levels of short circuit fault currents as it takes longer time to melt the fuse element. By comparison, for higher levels of short circuit, the fault current I^2t curve remains constant.

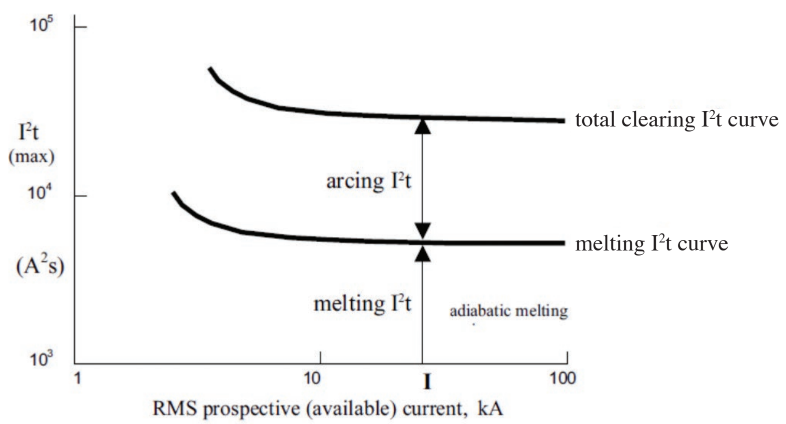


Figure 22: I^2t *Characteristic curve*

These curves are no longer published as it has become a general industrial practice to publish the Melting and Total Clearing I^2t when tested at rated voltage in table format. I^2t values for other voltages lower than the rated voltage are determined using an I^2t Correction Factor Curve.

Total Clearing I²t Correction Factor Curve

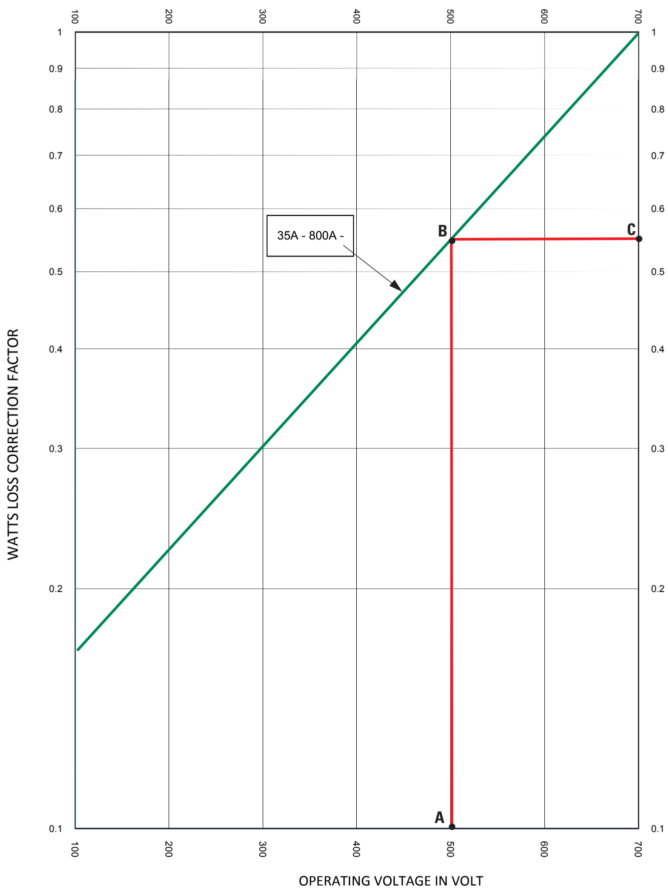


Figure 23: Total Clearing I²t *Correction Factor Curve*

Figure 23 shows the Total Clearing I²t Correction Factor Curve for Littelfuse L70S Series High-Speed fuse. The X-axis represent the application's operating voltage in volts, while the Y-axis represents the Total Clearing I²t correction factor, which is the ratio between the Total Clearing I²t values measured at a *reduced* voltage…to the total clearing I²t value at *rated* voltage.

Example:
Determine the Total Clearing I²t value of a L70S125 fuse at an operation voltage of 500Vac.

The total clearing I²t value at rated voltage (700Vac) from the respective fuse datasheet is **14700 A²s.**

Using the Total Clearing I²t correction factor curve, the correction factor at a reduced voltage of 500Vac can be obtained by locating Point A on the X-axis of the curve and following the voltage line until up it meets the correction factor curve at Pont B. The corresponding value on the Y-axis at Point C represents the correction factor, which is **0.55.**

Next, multiply the correction factor of 0.55 to the Total Clearing I^2t value of the rated voltage (in this example, 14700 A^2s) to determine the Total Clearing I^2t value. So for this example, at a reduced voltage of 500Vac, the L70S125 fuse has a total clearing I^2t value of:

14700 A^2s x 0.55 = 8085 A^2s

This I^2t Correction Factor curve greatly assists when selecting fuses for application wherein fuses are used at reduced or varying voltage environment.

During the fuse selection process, care should be taken such that the I^2t value of the fuse selected should be less than the withstand rating of the semiconductor device component in order to ensure proper fuse protection.

4. SIZING GUIDELINES

Designing the right circuit protection solution is critical to power semiconductor device applications that are vulnerable to catastrophic faults and failure. High-Speed fuses are the ideal choice by design engineers to protect such applications from failures.

The proper selection of High-Speed fuses involves greater understanding and consideration of its product specifications such as rated voltage, rated current, interrupting rating, and melting and total clearing I^2t ratings, and then sizing them appropriately to various application conditions. In this section, general industrial guidelines are discussed for sizing High-Speed fuse specifications based on these influencing application conditions.

4.1 Rated Voltage

Rated Voltage of a fuse is the maximum AC or DC voltage at which the fuse is designed to operate. Fuses may be rated for AC only, DC only, or both AC and DC. A fuse's voltage rating must equal or exceed the application voltage where the fuse will be installed.

The AC Voltage Rating on the fuse label is the maximum open circuit RMS voltage for which the fuse can be safely applied.

But it's also important to note that fuses used in DC circuits must be specifically rated for DC applications. The DC Voltage Rating on the fuse label is the maximum DC voltage where the fuse can be safely applied.

In some instances, and with certain limitations, an AC only rated fuse could be used on DC circuits. Please consult Littelfuse Technical Services to understand the safe DC voltage rating for applying such fuses. Most common application conditions that affect the rated voltage sizing of high-speed fuses are operating frequency, regenerative loads and adopted agency standards.

4.1.1 Effect of Operating Frequency (E_f)

The AC Voltage Rating of a fuse is determined by testing at a frequency between 45Hz and 62Hz per UL and IEC Standards. Typically, application frequencies (up to 1kHz) do not affect the performance of a fuse. However, at lower frequencies (below 45Hz), the circuit tends to perform more like a DC circuit which can significantly affect the fuse's ability to safely clear a fault current. In such applications, a fuse with a rated AC voltage higher than the application AC voltage would be recommended.

To determine the minimum rated AC voltage of a fuse at low frequency applications, the appropriate frequency correction factor (E_f) (see Figure 24 below) should be factored to the application AC voltage to determine the proper fuse voltage rating.

The minimum rated AC Voltage of a Fuse can be determined by:

$$E_n \geq \frac{E}{E_f}$$

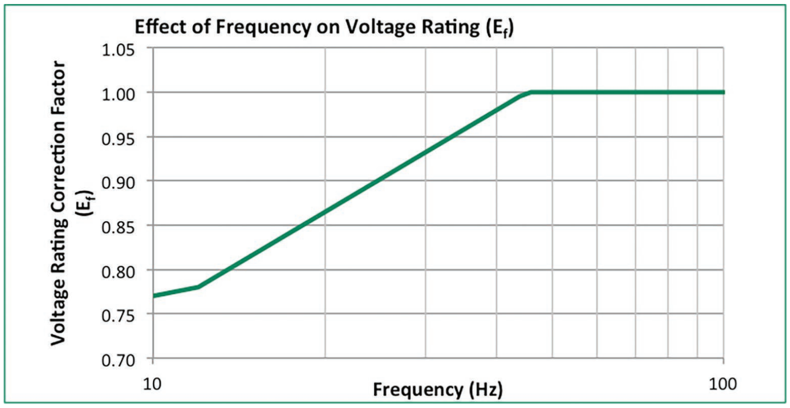


Figure 24: Frequency Correction Factor curve

Example:

Application Voltage Rating (E) = 480Vac

Application Frequency = 30Hz

Frequency correction factor (E_f) = 0.9

Min. Fuse AC Voltage $\mathbf{E_n} \geq \frac{\mathbf{E}}{\mathbf{E_f}} \geq \frac{480\text{Vac}}{0.9} \geq 533$ Vac

And thus, the recommendation would be to use a 550Vac or 600Vac rated fuse.

4.1.2 Effect of Time Constant (E_{tc})

The ability of a DC rated High-Speed fuse to safely interrupt DC overcurrents is influenced by the DC Time Constant (also known as the L/R ratio) of the circuit. In DC circuits, the inductance to resistance (L/R) ratio defines the rate of rise of fault current (di/dt). The DC circuit time constant is generally expressed in milliseconds (ms) and is the time it takes for the DC circuit to reach 63% of its final value.

The longer the time constant of the circuit, the more the burden on the fuse to safely interrupt the fault current. Littelfuse High-Speed fuses are tested in circuits with time constant (L/R) not less than 10milliseconds per the UL and IEC Standards requirements. When used in circuits with a time constant exceeding 10ms, High-Speed fuses requires additional rated voltage de-rating. Contact Littelfuse Technical Services for such applications.

4.1.3 Effect of Regenerative Loads (E_{reg})

When fuses are used in a regenerative power converter application where the mechanical energy of the motor and/or connected load is returned to the AC power source during braking, there is a chance of commutation fault. This is the worst-case fault in this circuit. During this fault, the application source AC voltage is superimposed upon the converter output DC voltage causing a sudden increase in system voltage. This affects the fuse's ability to safely clear the fault.

For a high-speed fuse to safely clear a commutation fault in a regenerative load application, a safety factor (E_{reg}) of 1.8 is applied to the application voltage rating (E) to determine the minimum rated voltage of the High-Speed fuse (E_n).

$\mathbf{E_n = E \times E_{reg}}$ or **En = E x 1.8**

For non-regenerative loads, the safety factor $\mathbf{E_{reg} = 1.0}$

4.1.4 Effect of Complying Fuse Standard

High-Speed fuses offered by Littelfuse are compliant to either UL, IEC, or in many cases, both standards depending on the fuse style. North American round body style fuses are compliant to the UL248-13 Standard. Per this standard, rated voltage testing is performed at 100% of the AC voltage of the fuse (printed on the fuse label).

In comparison, square body style fuses are tested to both IEC 60269-4 and UL 248-13 Standards. Per IEC, standard rated voltage testing is performed at 110% of the AC voltage of the fuse, to factor in any application overload conditions.

When applying North American round body style fuses in an IEC application, an additional safety factor of 0.9 should be factored to the application voltage to determine the rated voltage of the fuse.

Minimum High-Speed Fuse Rated Voltage $\mathbf{E_n = \frac{E}{0.9}}$

So in summary…the rated voltage of a fuse is determined using the formula

$$E_n = \frac{E \times E_{reg}}{E_f}$$

For North American Style fuses used in IEC applications, the rated AC voltage of a fuse is determined by

$$E_n = \frac{E \times E_{reg}}{0.9 \times E_f}$$

Where:
E, is the Application Voltage Rating
$\mathbf{E_{reg}}$, is the Regenerative Load Safety Factor
$\mathbf{E_f}$, is the Frequency Correction Factor

4.2 Rated Current

The Rated Current of a High-Speed fuse is defined as the continuous AC RMS current (and the DC steady-state current, when rated for AC and DC) that the fuse is designed to carry under specified conditions defined by the complying standard (UL and IEC).

The rated current printed on the fuse label is determined based on testing performed at standard test conditions.

- ***AC Circuits Conditions:*** Frequency range from 45Hz to 62Hz with an ambient temperature of 20°C ± 5°C
- ***DC Circuits Conditions:*** A time constant (L/R) of 10ms or less with an ambient temperature of 20°C ± 5°C

Typically, fuses are not always applied at standard test conditions; hence the sizing (or selecting) of the fuse's rated current is dependent on various application factors and conditions.

In this section a step-by-step approach to proper sizing (selection) of the rated current of High-Speed fuses will be discussed.

Step 1: Determination of normal full-load current (I_{AL}) through the fuses

High-Speed Fuses are typically used for protection of power electronics in power conversion devices (including inverters, rectifiers, soft-starters, and variable frequency drives) that convert power from AC to DC…or DC to DC…or DC to AC.

Depending on the location of the fuse in the power conversion circuitry (AC side or DC side), the load current through the fuse varies. In most cases this normal load current (I_{AL}) is generally available from the application design engineer.

For applications where normal full load current (I_{AL}) is not readily available, the value can be determined by calculating the RMS current (for AC Side fusing) or the steady-state current (for DC Side fusing).

In power conversion device/applications, the challenge remains in determining this AC RMS current and DC steady-state current (often stated as 'DC Average Current') due to the pulsating nature of the rectifier output current.

The mathematical relationship between AC RMS Current and DC Average Current is provided by the illustration below for a single phase unfiltered full-wave rectifier circuit.

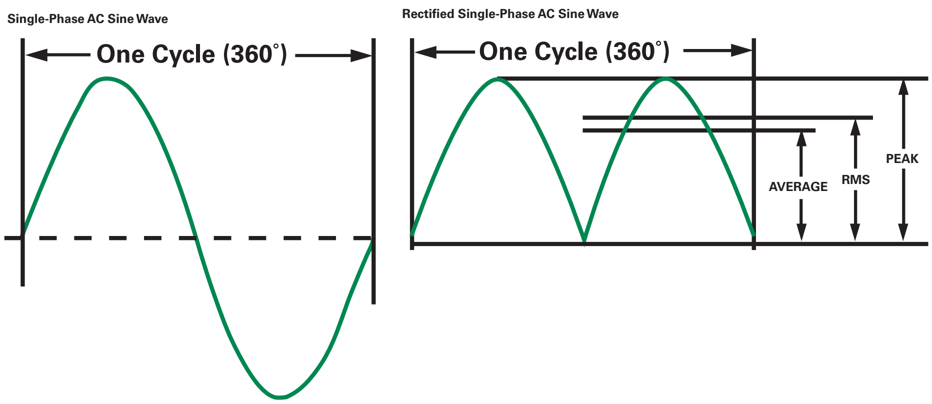


Figure 25: RMS Current Illustration

Where,
I_{PEAK} = Peak Current

I_{AVG} = DC Average (Output) Current

I_{RMS} = AC RMS Current

$I_{AVG} = 0.636 \times I_{PEAK} \longrightarrow I_{PEAK} = I_{AVG} / 0.636$

$I_{RMS} = 0.707 \times I_{PEAK}$

Thus, by substituting I_{PEAK} in the above equation,

$I_{RMS} = (0.707 / 0.636) \times I_{AVG}$

AC Side Normal Full-load Current (I_{AL}): $\mathbf{I_{RMS} = 1.11 \times I_{AVG}}$

-OR-

DC Side Normal Full-load Current (I_{AL}): $\mathbf{I_{AVG} = 0.9 \times I_{RMS}}$

Based on the illustration, the average DC current through the fuse is 0.9 times AC RMS current. In other words, fuses located in the AC side of the circuit will see an RMS current 1.11 times that of the DC average output current.

When multiple semiconductors (such as full-wave, parallel, three phase, or similar circuits) along with multiple fuses are used in a circuitry, current through each fuse depends on the location of the fuse in the circuit.

The examples below represent a few common rectifier circuit options with possible fuse placement locations shown along with the AC RMS current running through the fuse. (As calculated at 100% DC steady-state load current).

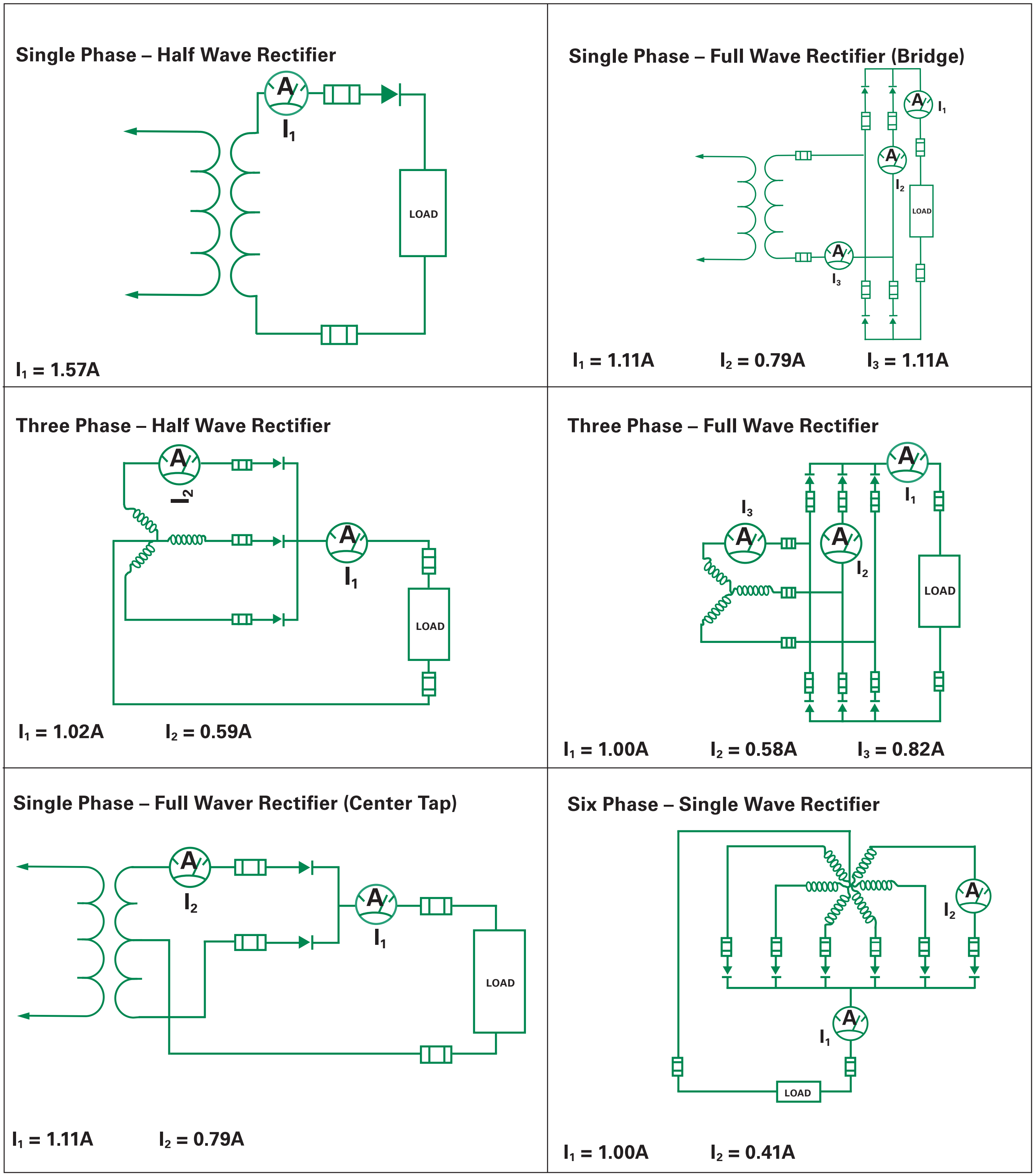


Figure 26: Typical Rectifier Circuits and Locations of High-Speed Fuses in the Circuitry

When the current through the fuse is constant and continues for one hour or more, then the calculated normal load current (I_{AL}) is similar to the AC RMS current or the DC steady state current per the illustrations above.

However, for applications involving varying load current, especially when subjected to inrush current or cyclic current (regular-repeating identical current cycles), the normal load current through the fuse (I_{AL}) is obtained by calculating the RMS current of one duty cycle, known as 'Adjusted Normal Load Current'.

Figure 27 shown below is a representation of a typical varying load cycle. The adjusted normal load current (I_{AL}) for this varying load cycles is provided by the formula,

$$I_{AL} = \sqrt{\frac{I_1{}^2 t_1 + I_2{}^2 t_2 + \cdots \ldots \ldots + I_n{}^2 t_n}{T}}$$

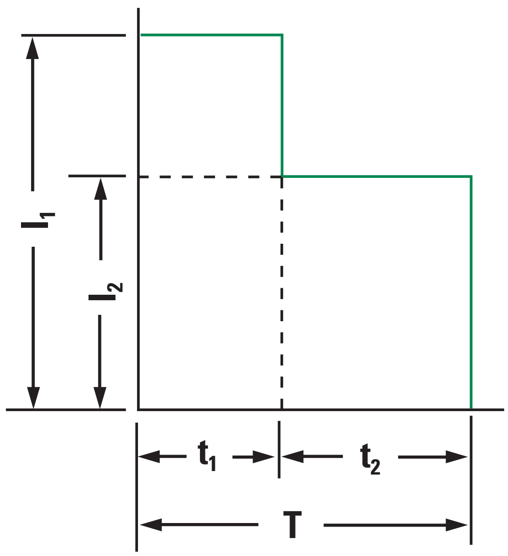
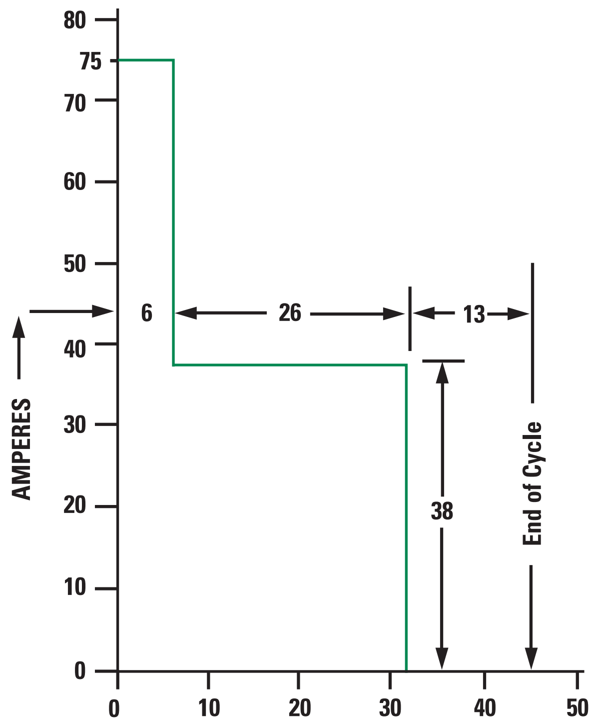


Figure 27: Varying Load Current (Cyclic Current)

Where,
I_1, I_2...I_n: Varying RMS Load Currents (Amperes)
t_1, t_2...t_n: Corresponding current cycle duration (seconds)
T: Total duration of one varying load current cycle (Including any OFF period)

Example:
Determine the adjusted normal load current for the cyclic current shown in the illustration shown in *Figure 28.*



Where,
I_1: 75A
I_2: 38A
t_1: 6 Seconds
t_2: 26 Seconds
T: 45 Seconds

$$\mathbf{I_{AL}} = \sqrt{\frac{{I_1}^2 t_1 + {I_2}^2 t_2}{T}}$$

$$= \sqrt{\frac{(75^2 * 6) + (38^2 * 26)}{45}}$$

$$\boldsymbol{I_{AL}} = \sqrt{1584} = \mathbf{40A}$$

For irregular current cycles, the adjusted load current must be calculated for a period of one hour, during which the largest effective surge current would occur.

Depending on the magnitude and duration of the surge current, the calculated 'adjusted normal load current' (I_{AL}) may be substantially less than the surges in the system.

Other common scenarios observed in Power Semiconductor applications would involve having multiple semiconductor devices connected in parallel (as shown in the Figure 29). In this scenario called a 'multi-parallel connection', each device is protected by an individual High-Speed fuse in each arm/leg of the power conversion circuit.

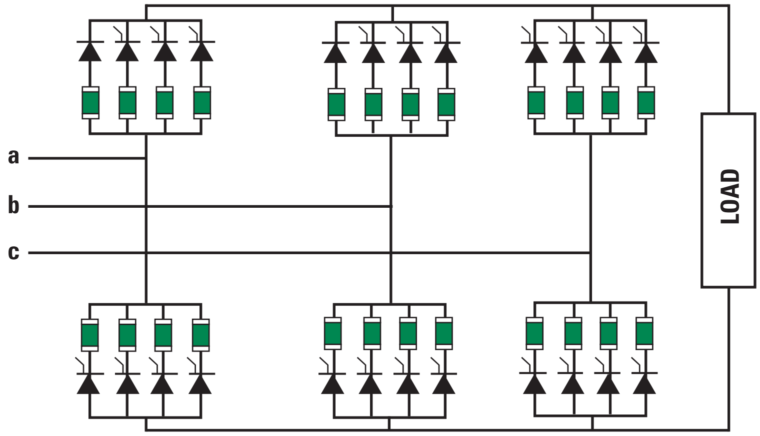


Figure 29: Multi-parallel connection in a rectifier circuit

In such situations, the load current through each arm/leg is shared between all parallel paths. However, load current sharing is typically not equal as upto 20% of uneven sharing is allowed. And consideration of continuous operation of this multi-parallel circuitry with one less parallel path (due to fuse operation on an internal fault) is possible. Thus, when determining the load current through the fuse in such multi-parallel circuits, both these conditions should be considered.

The normal load current (I_{AL}) through each fuse in a multi-parallel connection circuitry is determined by,

$$I_{AL} = \frac{I_{AL\ (LEG)}}{\left\{\frac{N}{(1+S)}\right\} - 1}$$

Where,
$I_{AL(Leg)}$, is the total RMS current in each arm/leg

N is the total number of parallel path in each arm/leg

S is the load current sharing factor (0%~20%)

The rated current of the High-Speed fuse being selected can be determined by applying rerating factors (computed in Step 2) to the normal load current (I_{AL}) determined from this section.

Step 2: Computation of rerating factors, based on various application conditions

As thermally sensitive devices, there are various application parameters that affect a fuse's operation (melting) characteristics of fusible elements. This, in turn, affects the overall current carrying capacity (rated current) of a fuse. Listed below are the application parameters, and their corresponding correction factors, that need to be considered while sizing High-Speed fuses.

Ambient Temperature

As mentioned earlier, fuses are thermally-responsive devices so their current carrying capacity is affected by the air temperature immediately surrounding the fuse during it operation. This temperature is known as the ambient temperature. Typically, High-Speed fuses are tested at standard test conditions of 20°C ± 5°C and can be applied at a wide operation temperature range of -50°C to +125°C. When fuses are operated at ambient temperatures outside their standard testing range, the appropriate 'Ambient Temperature Correction Factor needs be computed and factored to properly select the fuse rating. The Ambient Temperature Correction Factor (F_{AT}) is determined by the formula,

$$\mathbf{F_{AT}} = \sqrt{\frac{\mathbf{125 - T_a}}{\mathbf{125 - T_{std}}}}$$

Where,

$\mathbf{T_a}$, is the Application ambient temperature

$\mathbf{T_{std}}$, is the Standard Testing ambient temperature

Example:
Determine the Ambient Temperature Correction Factor for a fuse installed at a 55°C ambient temperature condition?

Per formula, it is calculated to be

$$F_{AT} = \sqrt{\frac{125 - T_a}{125 - T_{std}}} = \sqrt{\frac{125-55}{125-25}} = \sqrt{\frac{70}{100}} = \sqrt{0.7}$$

F_{AT} = 0.84

Forced Cooling

Due to their switching properties, power semiconductor devices typically produce large amounts of heat during normal operating conditions. When the heat produced exceeds their safe operating temperature limits, the devices will become inoperable.

Forced air cooling and liquid cooling are the two heat sinking methods commonly practiced in such applications. Fuses that are used to protect such devices are also subjected to such heat sinking methods and can directly affect (increase) the current carrying capacity of the High-Speed fuse.

The curve shown in Figure 30 determines the Forced (Air) Correction Factor (F_{FC}) that needs to be factored while sizing the rated current of the High-Speed fuse.

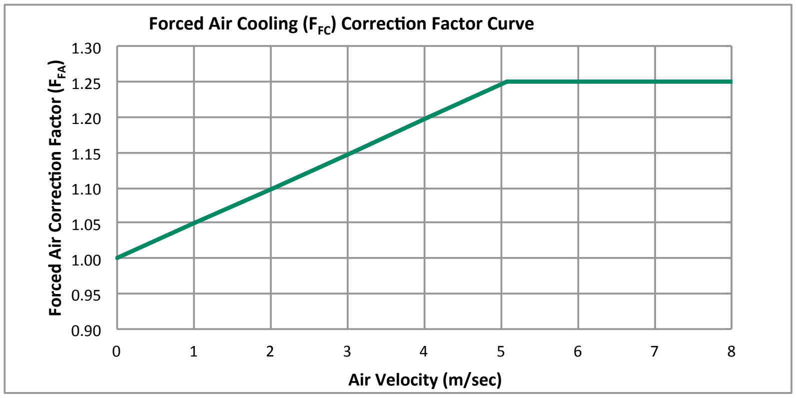


Figure 30: Forced (Air) Cooling Correction Factor (F_{FC}) Curve

Example:
Determine the forced air cooling correction factor for a fuse installed at an application with an air velocity of 4 m/sec.

Per the Force Air Correction Factor Curve,

For an air velocity of 4m/sec, $\mathbf{F_{FC} = 1.20}$

For applications with a liquid cooled bus-bar system (which may be used along with forced air cooling), the forced cooling correction factor of $\mathbf{F_{FC} = 1.25}$ can be considered when sizing High-Speed fuse's rated current.

Conductor Size (Wiring Connection Factor)

High-Speed fuses are connected to a system by means of copper conductors in the form of cable or bus-bar termination. The main purpose of the termination is to conduct power, but they also serve as a heat sinking device to remove heat from the fuse terminals and allowing it to operate efficiently.

The cross-section size of the conductor significantly impacts the current carrying capacity of a High-Speed fuse. The rated current of a High-Speed fuse is determined based on testing with recommended conductor sizes outlined in international standards. When applying these fuses in the field, any reduction in conductor size would require appropriate de-rating of the fuse rated current. In other words, fuse current ratings should be determined based on the cross-section size of the conductor.

Per IEC 60269-4 Standard Section 8.3.1, the current density of the copper conductor used shall be between 1.0A/mm2 (minimum) to 1.6A/mm2 (maximum) and vary with the rated current of the fuse. For ease of calculation, 1.3A/mm2 is considered as the reference value (100%) for conductor sizes. Based on this reference value and the application conductor size, the wiring correction factor (F_{WR}) for the application is determined from the curve shown in Figure 31 and factored in accordingly while sizing the rated current of High-Speed fuses.

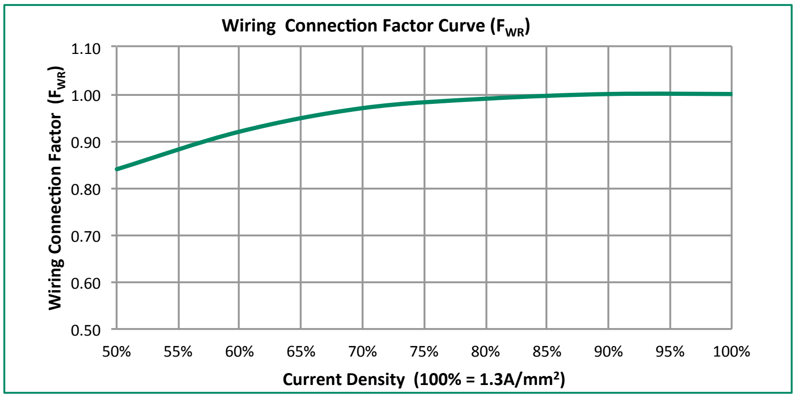


Figure 31: Wiring Connection Factor (F_{WR}) Curve

Example:
Determine the wiring connection factor for an application with a 400A load current using copper conductor with a cross-section of 185mm².

Load Current: 400A

Conductor Size used in application: 185mm²

Copper Current Density per IEC Standard = 1.3A/mm²

Recommended conductor size for 400A (per IEC Std.),

$$= \frac{400\text{A}}{1.3\text{A/mm}^2} = 308\text{mm}^2$$

Based on IEC recommended conductor size value determined; the application conductor size used is about

60% $\left(\frac{185mm^2}{308mm^2}\right)$ of the recommended size.

Applying the 60% value determined in the Wiring Connection Factor Curve, The Wiring Connection Factor for the application is, $\mathbf{F_{WR} = 0.92}$

Frequency

High-Speed fuses have one or more fusible elements connected in parallel configuration within their fuse body. When these fuses are subjected to high frequencies, and due to the electromagnetic property of alternating current (AC), the flow of current through the fuse is constrained to the outer layers of the fusible element, known as skin and proximity effect. This phenomenon causes unbalanced sharing of current between fusible elements resulting in increased heat, which significantly reduces the current carrying capacity of a fuse and could result in premature operation of a fuse.

Applications with a frequency above 500Hz are considered as very high frequency applications and require increased attention when sizing High-Speed fuses. Consult Littelfuse Technical Services for such high frequency applications.

The curve shown in Figure 32 determines the Frequency Correction Factor (F_{HZ}) to take into consideration when sizing the High-Speed Fuse rated current.

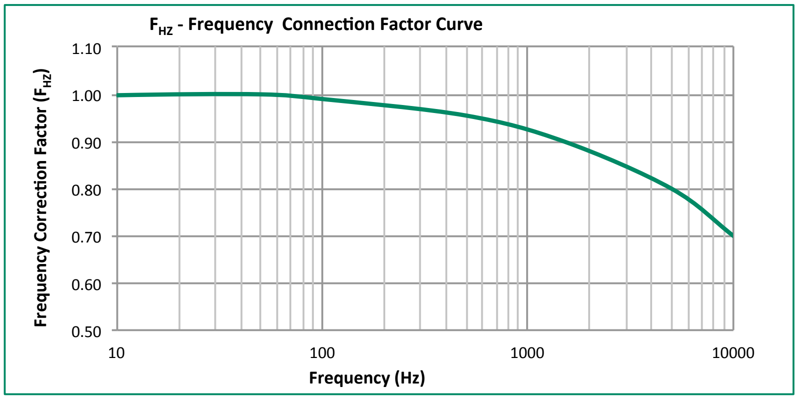


Figure 32: Frequency Correction Factor (F_{HZ}) Curve

Example:
Determine the frequency correction factor for an application with application frequency of 500Hz.

Application Frequency: 500Hz

From the frequency correction factor curve shown in Figure 31, the corresponding frequency correction factor for the application is $\mathbf{F_{HZ} = 0.96}$

Switching and Surges

In general, all electrical equipment is subjected to start-stop operations. The frequency of start (ON) and stop (OFF) operation and the associated surge in current during switching determines the aging effect on High-Speed fuses.

An ON-OFF operation induces heating and cooling effects on fuse elements. The higher the number of switching operations, the greater the impact on the fuse current carrying capacity over a period of time.

The Switching Correction Factor Table below provides the recommended switching de-rating factors (F_{ss}) to be considered for any frequent switching applications.

Switching Correction Factor (Fss) Table	
Frequency of Switching	**Switching Correction Factor (Fss)**
Less than 12 stops per year	1.00
More than one stop per month	0.95
More than two stops per week	0.90
More than one stop per day	0.85
Several stops per day	0.80

Table – Switching Correction Factor (F_{ss})Table

Rated Current of the High-Speed fuse

In Summary, the rated current of a High-Speed fuse can be determined using the following formula:

$$I_N = \frac{I_{AL}}{F_{AT} * F_{FC} * F_{WR} * F_{HZ} * F_{SS}}$$

Where,

I_{AL} = Adjusted normal full-load current

I_N = Rated current of High-Speed fuse for the application

F_{AT} = Ambient Temperature Correction Factor

F_{FC} = Forced Cooling Correction Factor

F_{WR} = Wiring Connection Factor

F_{SS} = Switching Correction Factor

Example:
Determine the suitable Littelfuse POWR-*SPEED*® North American round body fuse for a rectifier application with the following system details:

AC System Voltage: 600V

Frequency: 60Hz

Ambient Temperature (T_a): 65°C

Forced air cooling: 3m/s

Load Current: 100A

Available Short-Circuit Fault Current: 35kA

Load Condition: 15 stops per day

Overload condition: 200% for 10sec for every 3 minutes

Thyristor I^2t withstand rating: 20,000 A^2s

Rated Voltage of the fuse (E_N)

$$E_N = \frac{E}{0.9}$$

$$E_N = \frac{600}{0.9}$$

$$\mathbf{E_N = 667V \sim 700Vac}$$

Load Current

$$I_{AL} = \sqrt{\frac{{I_1}^2 t_1 + {I_2}^2 t_2}{T}}$$

$$= \sqrt{\frac{(100^2 * 180) + (200^2 * 10)}{190}}$$

$$\mathbf{I_{AL} = 107.6}$$

Ambient Temperature Correction Factor

$$F_{AT} = \sqrt{\frac{125 - 65}{125 - 25}}$$

$$\mathbf{F_{AT} = 0.775}$$

Forced Cooling Correction Factor

Forced Air cooling: 3m/s

Based on Forced Cooling Correction Factor Graph,

$\mathbf{F_{FC} = 1.15}$

Switching Correction Factor

Number of Stops per day: 15

Based on Switching Correction Factor Table

$\mathbf{F_{SS} = 0.8}$

Rated current of the fuse (I_N)

$$I_N = \frac{107.6}{0.775 * 1.15 * 0.8}$$

$$I_N = \frac{107.6}{0.713}$$

$$\mathbf{I_N = 150.9 \sim 150A}$$

Upon calculating the rated current including all of the factors involved, POWR-*SPEED*® Fuse part number L70QS150.V rated for 150A, 700Vac/dc, and 200kA I.R. could be considered for this application. This fuse has a Total Clearing I^2t value of 13,650 A^2s at 700Vac which is less than the thyristor device withstand rating of 20,000 A^2s, and meets the Voltage and Current Rating requirements of the application and thus can be recommended.

5. APPLICATION CONSIDERATIONS

5.1 Protection of Power Conversion Device

A typical application of High-Speed fuses in general industrial environment would involve the protection of power conversion equipment used in motor control systems (such as drives and soft-starters), power supplies and heating applications.

Figure 33 represents a typical circuit of a three-phase power converter circuit. There are three basic building blocks in this circuit, the input converter (also known as the 'Rectifier'), the filter and DC connection (also known as DC Common Bus) and the output inverter (or 'Inverter').

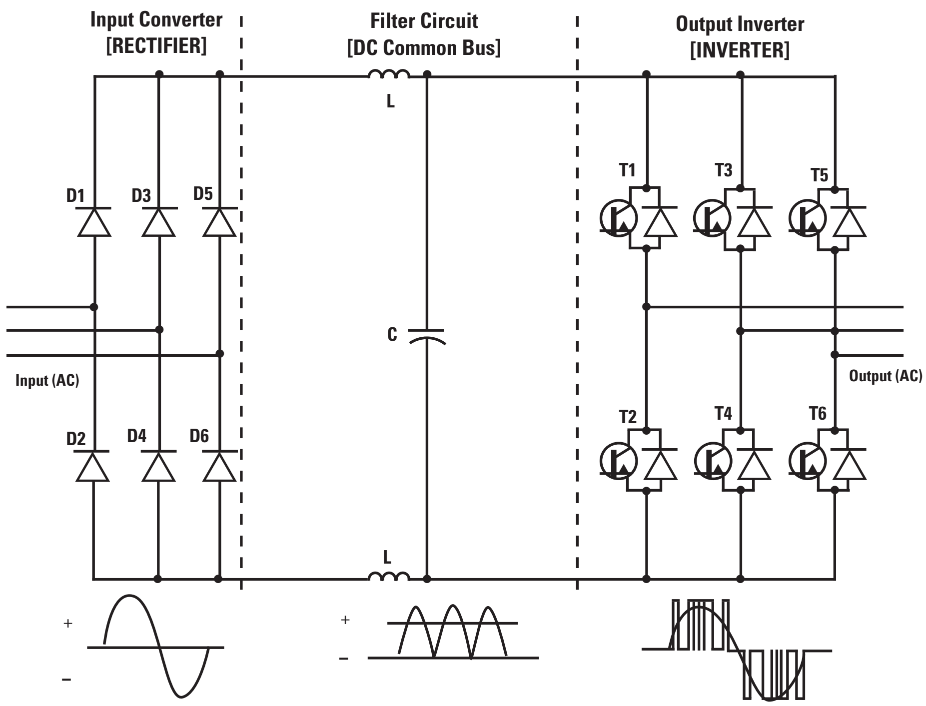


Figure 33: Typical Three Phase Power Converter Circuit

Protection requirements vary at each location, however the main purpose of the fuses in this circuit are to continuously allow the nominal load current and any permissible overload current to continue without any interruption. At the same time, the fuses are selected to interrupt any overcurrent fault caused during overload or short-circuit, with minimal let-through energy in order to protect the power semiconductor devices connected in the circuit.

5.1.1 Protection Consideration for Rectifier Circuits

Power semiconductor diodes are typically used for design of rectifier circuits, with the main purpose of this circuit being the conversion of alternating current (AC) to a direct current (DC) by allowing current to flow in only one direction. Rectifier circuits are found in a wide variety of applications, from small power supplier to large high-voltage DC power transmission systems.

The location of a High-Speed fuse in a rectifier circuit depends on the size of the system when considering power rating. Figure 34 illustrates the typical location of High-Speed fuses in a rectifier circuit.

For smaller power rated devices, High-Speed fuses are typically found only on the AC line side in a one fuse per phase arrangement.

For larger power systems, High-Speed fuses are typically located both on the AC line side as well as individually in series with each power semiconductor device on each arm of the rectifier circuit.

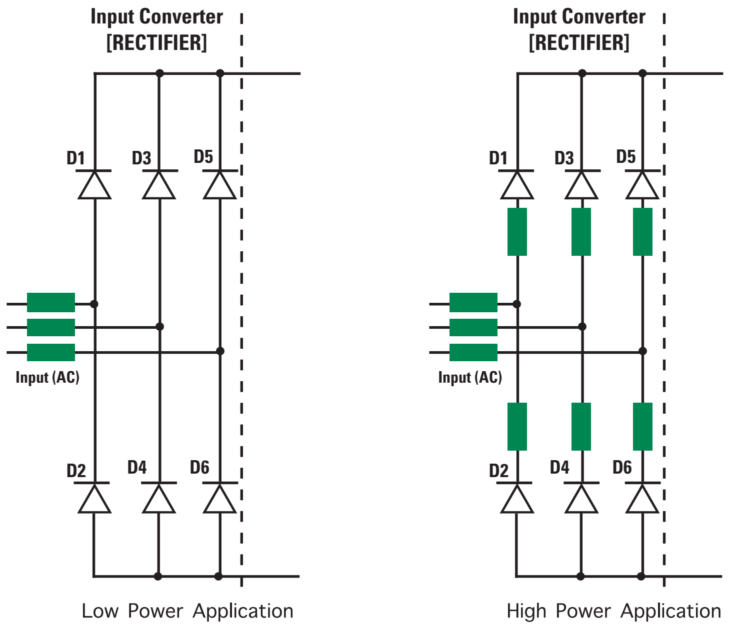


Figure 34: Location of High-Speed Fuses in Rectifiers

High-Speed fuse sizing guidelines discussed in Chapter 4 of this Technical Application Guide should be followed while selecting the fuses for rectifier circuits.

5.1.2 Protection Consideration for Inverter Circuits

Power transistors (IGBTs, MOSFETs) are typically used for the design of inverter circuits. These transistor devices are turned ON and OFF using gate pulses from the driver circuits to produce the required AC waveform from the DC source. Today, inverter circuits have a wide range of applications and can be found in electric motor adjustable speed drives, Uninterruptable Power Supplies (UPS), battery management systems, Flexible AC Transmission Systems (FACTS) and many more.

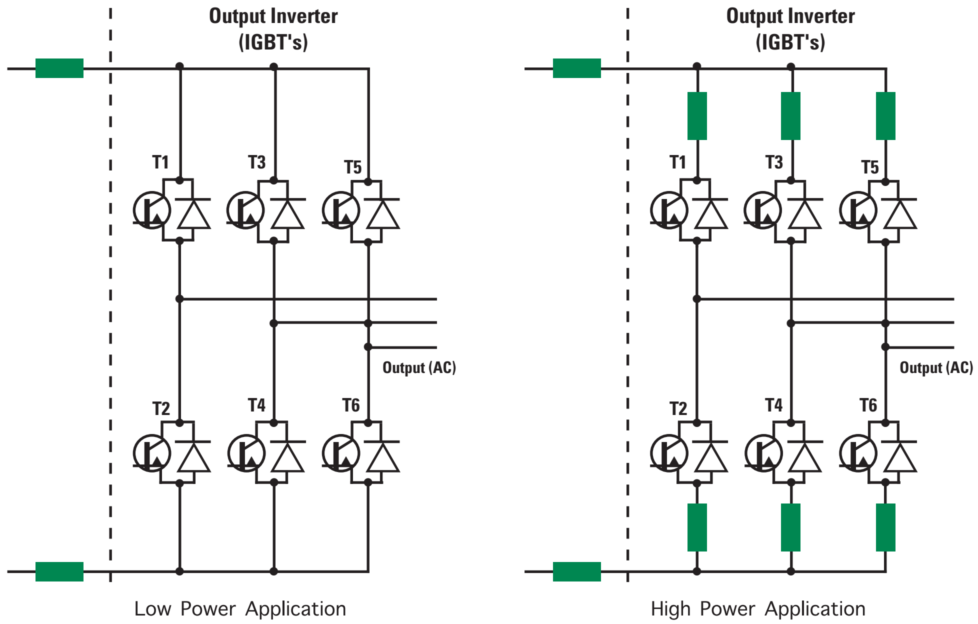


Figure 35: Location of High-Speed Fuses in Inverters

High-Speed fuses are used in inverter circuits to prevent line-to-line short circuit fault conditions. There are multiple ways this fault could be generated, with the misfiring of transistors being one of the leading causes. Depending on the power rating of the inverter circuit, the location and number of High-Speed fuses used in the circuit varies. For low power applications, the High-Speed fuses are typically designed only on the DC bus (one each on positive and negative). For higher power inverter circuits, fuse can be used both on the DC bus side and individually nearer (in series) to each transistor.

High-Speed fuse sizing guidelines discussed in Chapter 4 of this Technical Application Guide should be followed while selecting the fuses for inverter circuits.

5.1.3 Protection Consideration for DC Bus

Depending on the application, requirements for the protection of DC Bus (also referred to as DC Common bus) varies. DC common bus configurations are generally found in group motor application (shown in *Figure 36*), where multiple adjustable speed drives are fed from a DC common bus. This configuration offers the most efficient way to operate multiple motors in processing industries. A typical fault condition that could occur in this configuration would be a line-to-line DC short circuit fault which would require High-Speed fuse protection on both the positive and negative buses of the DC line to protect the drives connected to the DC bus.

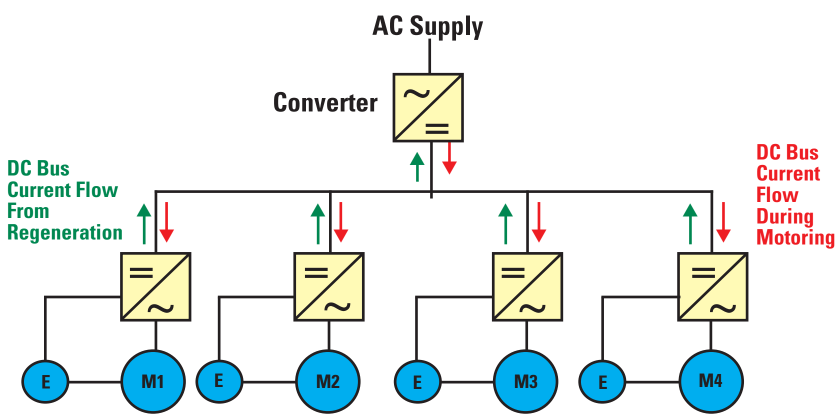


Figure 36: DC Bus Configuration

Protection of the DC bus is also required in standalone DC drives and common power conversion circuits nearer to the filter circuits that might be susceptible to insulation failure causing a line-to-line DC short-circuit fault condition. High-Speed fusing on both positive and negative bus is recommended in this application.

In general, while protecting the DC bus, High-Speed fuses that are specially designed and tested to DC voltages with a DC time constant (L/R value) higher than the application specifications, are the right choice to offer the best level of protection. Littelfuse offers a wide range of AC and DC High-Speed fuses, with information on DC performance characteristics being readily available on individual fuse datasheets.

5.2 Protection for UL Motor Branch Circuits

A question that is often asked by customers and motor control center manufactures is, "In UL installations, is it permitted to use a High-Speed fuse for motor branch circuit protection?"

It's a valid question, as the general perception that prevails is that "only UL Listed fuses" (current limiting and with the proper rejection features) could be used for branch circuit protection per National Electrical Code® (NEC®) and general industrial practices. However, not many are aware that NEC does permit the use of High-Speed semiconductor fuses for motor branch circuit protection under certain conditions.

NEC Article 430.52(C)(5) outlines the use of High-Speed semiconductor fuses for motor branch circuit protection in motor control system that use solid-state devices such as drives and soft-starters.

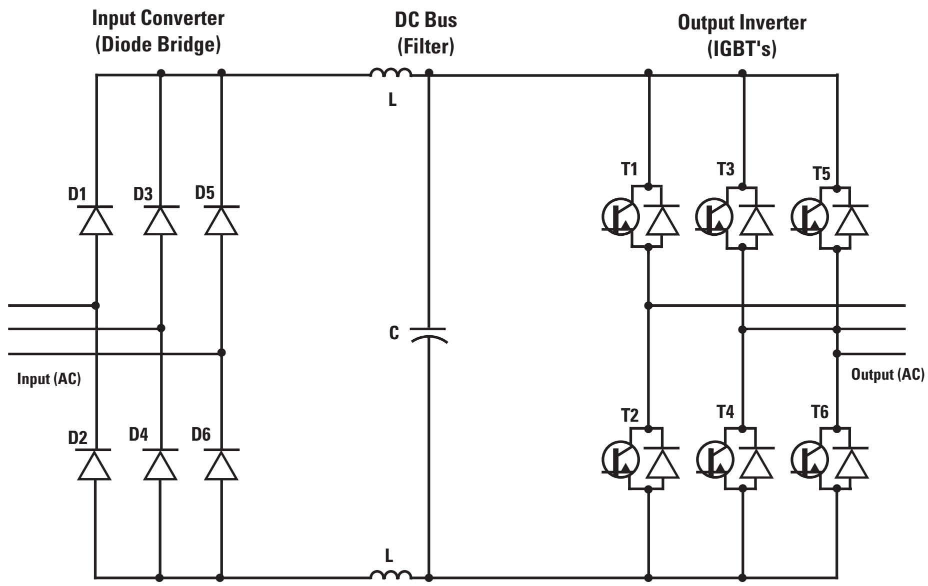
Per NEC, when the motor device is protected with built-in overload protection or overload protection is offered by a separate device connected in the same circuit, High-Speed semiconductor fuses can be used for branch circuit protection. (A typical example would be larger motor circuits using variable frequency drives or other power conversion devices where overload protection is built-in to the drives). Intended to prevent any misapplications, one condition imposed by NEC for users looking to utilize this exception/part of the Code is the requirement to provide markings for High-Speed fuse replacement (such as part number, make, etc.) adjacent to these fuse installations.

Due to the wide variety of shapes and sizes offered, High-Speed semiconductor fuses can only be UL Recognized to UL 248-13 standard and thus cannot be UL Listed.

So the answer to the question is "Yes", High-Speed semiconductor fuses that are recognized to UL 248-13 standard could be used to provide motor branch circuit protection in certain applications.

5.3 Protection of IGBT Based Devices

To achieve quality power output, high frequency devices such as IGBTs are typically used on the low inductance (or inverter) side of a power conversion circuit (Figure 37). Switching losses are prevalent in such circuits and de-signing them with minimal losses is a challenging task for engineers. Components used in these circuits including capacitors, bus-bar and fuses are designed with the inductance as low as possible.



<<High inductance Side | Low inductance Side>>

Figure 37: Typical Three Phase Power Converter Circuit

In general, IGBT modules cannot be protected from short-circuit faults using High-Speed fuses, whereas diodes and thyristors can be protected. The reason behind this is that IGBT modules available today can detect and turn off during a short-circuit instantly by mean of specially-designed driver circuits designed to function in micro (μ) seconds.

However, if the driver circuit fails to turn off the IGBT during a short-circuit fault condition, or if the internal conductors (thin aluminum wires) connected to the IGBT melt during a fault condition, there is a considerable rise in current and voltage. This leads to a melting and arcing situation inside the IGBT modules which results in vaporization of silicon material, likely causing a catastrophic case rupture failure such as the one shown in Figure 38.

Figure 38: IGBT Case Rupture During a Short-circuit Fault Condition

High-Speed fuses, when used in conjunction with IGBT devices, prevent such catastrophic events during a fault condition. High-Speed fuses can sense and operate during a short-circuit fault within a few milliseconds. By creating a complete open-circuit condition during its operation, High-Speed fuses limit any further flow of high currents into the IGBT module which prevents case-rupture.

Limited ranges of specially-designed IGBT fuses are available in the market today offering low inductance in high-frequency application. These devices have special design element profile that offers equal distribution of current between them, thereby offering minimal inverse proximity effect impact and better thermal profile. However, such special design IGBT fuses also do not protect the IGBT module, as they are designed to prevent case-rupture during a fault condition.

Properly sizing a standard High-Speed fuse to the application requirements could provide adequate protection to IGBT based device applications.

5.4 High-Speed Fuses Connected in Parallel

The need for high current application results in requirements for larger and bulkier High-Speed fuses. In most cases, the availability of such larger fuses is always limited, hence paralleling of one or more standard size High-Speed fuses is widely practiced in the industry.

Paralleling of fuses has its own opportunities and challenges. Some of the opportunities include:

- Protection of high current and low withstand rating applications, where a single large fuse is not available to meet the requirement
- Maximizing heat dissipation and minimizing watt loss in power electronics application
- Better inventory management for original equipment manufacturers (OEMs), distributors and end-users

Challenges faced while paralleling fuses include:

- Estimating the combined performance of fuses, when connected in parallel
- Selection of correct fuse combination for paralleling, depending on the load and application conditions
- Adapting the correct paralleling techniques to prevent misapplication

With minimal guidance, available in electrical codes and standards, the paralleling of fuses is certainly a demanding task for design engineers.

In North America, the National Electrical Code® (NEC®) does not permit paralleling of overcurrent protection devices in the field, although paralleling is permissible in a factory built assembly per NEC Article 240.8.

This section of the Technical Application Guide outlines the recommended practices and general design guidelines for paralleling Littelfuse **POWR-*SPEED*®** High-Speed fuses in a factory built assembly.

The first step in the proper paralleling of fuses starts with the selection of the correct fuse combination. The best practice followed in industry is to choose fuses with the same specifications for paralleling (i.e. same ampere rating, voltage rating, size, style, etc.); in other words, using the same part number.

Additionally, only fuses with approximately similar resistance values should be selected for paralleling in the field. With Littelfuse **POWR-*SPEED*®** products having each fuse's resistance value printed on the side of its label, it makes the fuse selection process easier.

Note: The performance of the fuse varies based on system conditions, so application testing is strongly recommended.

DESIGN CONSIDERATIONS

Application factors that design engineers should take into consideration while paralleling fuses include:

1. Estimation of theoretical (electrical and thermal) performance of parallel fuses,
2. Validation of application conditions for proper sizing of parallel fuses, and
3. Selection of proper mounting arrangement and accessories to meet application requirements.

Estimation of theoretical performance of parallel fuses

A. Nominal Current Rating (I_{np}):

When two or more fuses are considered for paralleling, the combined ampere rating of the paralleled fuses is always less than the numerical sum of individual fuse ampere ratings. The reduction in current carrying capacity is due to increased ambient thermal condition when fuses are placed near each other, and often there is unequal current distribution in paralleled fuses.

Littelfuse recommends that a de-rating factor (Kp) should be applied while estimating the nominal current rating of a paralleled fuse.

K_p = 0.9, when two to four fuses are connected in parallel

K_p = 0.8, when more than four fuses are connected in parallel

The nominal current rating for a paralleled fuse (Inp) is determined by the formula.

$$I_{np} = (I_1 + I_2 + \ldots + I_n) * K_p$$

Where,
I_1 to I_n are individual fuse's rated currents

K_p is the Parallel Fuse De-rating Factor

Example:
What is the estimated nominal current rating when two 100A fuses are connected in parallel?

I_1 = 100A

I_2 = 100A

De-Rating Factor (K_p) = 0.9 (two fuses)

In = (100+100) * 0.9 = 180A

B. Nominal Voltage Rating (V_{np})

The nominal (or combined) voltage rating for paralleled fuses is equal to the individual voltage rating of any one of the fuses in the combination.

C. Time-Current Characteristic (TCC)

How fast a fuse responds to overcurrent faults can be determined using time-current characteristic curves which are available in fuse datasheet. For fuses that are connected in parallel, it is challenging to publish TCC curves, as it varies with the number of fuses connected and various other application conditions. Littelfuse recommends using the formula below for estimating the combined TCC curve (TCC_{np}) for fuses when connected in parallel.

$$\mathbf{TCC_{np} = TCC_1 * N * K_p}$$

Where,
TCC_1 = TCC curve any fuse in the combination

N = Number of parallel fuses connected

K_p = Paralleling Fuse De-rating Factor

This formula can be applied by keeping the time axis constant and plotting the change in current values, for the specific fuse that is considered for paralleling.

D. Peak Let-through Current

Peak Let-through current, also known as cut-off current is the maximum instantaneous current that passes through the fuse during an overcurrent fault condition, and is represented graphically using Peak Let-through Charts.

Peak Let-through Charts for parallel fuse are typically not available in the datasheet, unless it is factory assembled. Littelfuse recommends using the formula below to estimate the peak let-through values for fuses connected in parallel ($I_{N\text{-peak}}$).

$$\mathbf{I_{N-peak} = I_{p1} * N^{\frac{2}{3}}}$$

Where,
$\mathbf{I_{p1}}$ = Individual Fuse Peak Let-through Current

N = Number of parallel fuses connected

E. Ampere-Squared-Seconds (I^2t Value)

When a fuse is interrupting an overcurrent fault, the thermal energy generated by the current flow is expressed in terms of Ampere-Squared-Seconds, also known as the I^2t value.

I^2t values for a fuse when tested at its rated voltage and when interrupting the circuit are published in the fuse's datasheet. When two or more fuses are connected in parallel, the combined I^2tnp value is determined by the formula:

$$\mathbf{I^2t_{np} = I^2t_1 * N^2}$$

Where,
I^2t_1 = Individual fuse I^2t value

N = Number of parallel fuses connected

Validation of application conditions for proper sizing of parallel fuses

The understanding of the application's conditions is critical while properly sizing fuses. The performance of the fuse is greatly affected by an application's system parameters.

The following typical application conditions should be considered when sizing High-Speed fuses:

- Ambient Temperature
- Forced Cooling
- Conductor Type & Size
- Load Conditions
- Available Fault Current
- Withstand Rating (I^2t) of semiconductor device
- Peak Inverse Voltage
- Frequency or Time Constant
- Vibration and Shock

Proper de-rating should also be applied to the current and voltage rating of the fuse selected based on the above application conditions. Be sure to refer to Chapter 4 of this Technical Application Guide for High-Speed fuse sizing guidelines recommended to achieve adequate protection.

Selection of proper mounting, arrangement and accessories

High-Speed fuses are available in different shapes, sizes and terminations, so selecting the proper style is critical when paralleling fuses. For reliable performance, the use of identical part numbers is recommended when paralleling.

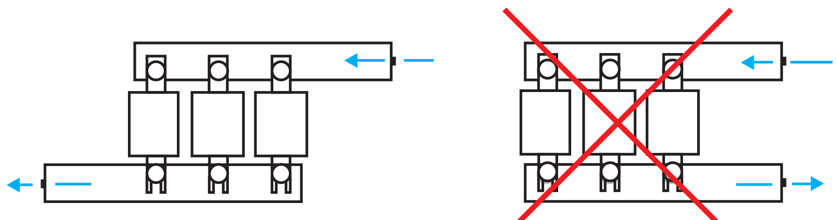


Figure 39: Paralleling Two or More High-Speed Fuses

High-Speed fuses run considerably hotter when compared to other fuses, so the distance between the fuses is critical when paralleling fuses. Littelfuse recommends 10mm to 25mm of spacing between two fuses connected in parallel. Also, when using high-speed fuses in parallel, bus-bar mounting is widely preferred to reduce mechanical stresses on the internal fuse elements.

Placement of bus-bar and direction of current flow is a critical factor while paralleling high-speed fuses. Figure 39 illustrates the Littelfuse-recommended arrangement for fuses connected in parallel in a bus-bar connection.

Fuses should be connected to the bus-bar such that the incoming current and outgoing current are not in opposite directions. When fuses are connected in an anti-parallel configuration (bus-bars are in parallel, but the currents are moving in opposite directions) additional bus-bar resistance ends up being added to the outermost fuse. It might also bend the bus bar due to the sizable magnetic forces involved.

Using the proper stud size and applying the recommended tightening torque would ensure proper termination and help prevent any nuisance operations. Refer to the product's datasheet for stud size and torque recommendations.

Littelfuse High-Speed Square Body Style fuses feature visual indication on them to represent the state of each fuse. An external indicator switch (Microswitch) for alarm signaling can be used on any one or more parallel fuses to represent the state of the (combination) parallel fuses.

Reference:
Gradwell, B., "Arc flash mitigation through the use of an engineered parallel high-speed semi-conductor fuse assembly," in Industrial & Commercial Power Systems Technical Conference (I&CPS), 2014 IEEE/IAS 50th , vol., no., pp.1-14, 20-23 May 2014 doi: 10.1109/ICPS.2014.6839162

5.5 High-Speed Fuses Connected in Series

Series connection of two High-Speed fuses is generally not recommended.

However, in power converter circuits that are designed to handle high-power levels (for example: a rectifier circuit using multiple power semiconductor devices per arm/leg), High-Speed fuses could be designed in a series configuration. In such situations, the voltage ratings of the fuses selected should be equal to the system voltage rating. In addition, to prevent nuisance operation, the total clearing I^2t value of the line side fuse should be less than the sum of pre-arcing I^2t for all individual arm/leg fuses.

$$\underset{\text{Line Fuse}}{\text{Total Clearing } I^2t} < \underset{\text{of Leg or Arm Fuse}}{\text{Sum of Prearcing } I^2t}$$

6. INSTALLATION GUIDELINES

The proper installation of High-Speed fuses is critical when designing circuit protection for power semiconductor devices. Thermal imbalance caused by the inadequate installation and maintenance of high-speed connections is the main reason there are nuisance operations in the field. The best practices for High-Speed fuse installation are discussed briefly in this section.

Conductor:

Copper conductors are generally preferred for connecting with High-Speed fuses. These connectors could be found in the cable or in bus-bar construction. Proper spacing between the connectors (meeting the requirements of the local electrical code adopted) is also recommended.

Termination/Connection:

The use of the Littelfuse-recommended screw type and size mentioned in the fuse's datasheet is ideal when installing High-Speed fuses. For the PSR Series square body fuse, instead of a bolted termination, a screw + nut assembly is preferred to prevent any damage to the internal fuse elements.

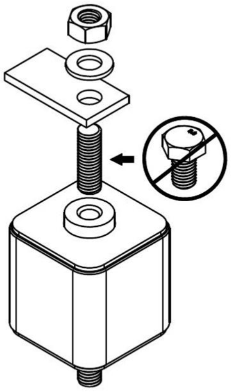


Figure 40: Recommended means for fuse termination

Tightening Torque:

The use of the Littelfuse-recommended tightening torque values mentioned in the fuse and fuse holder datasheets are ideal when installing High-Speed fuses. When applying the tightening torque and any counteracting forces, a general suggested practice as shown in Figure 41 could help ensure proper fuse termination.

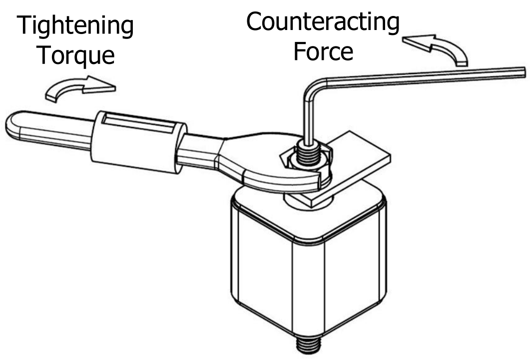


Figure 41: Recommended means to establish connection

Mounting Alignment:

Proper care should be taken during the tightening process to avoid any air gaps between the bus-bar and the fuse terminals. Such an air gap could lead to misalignment which could cause potential thermal stress or arcing issues.

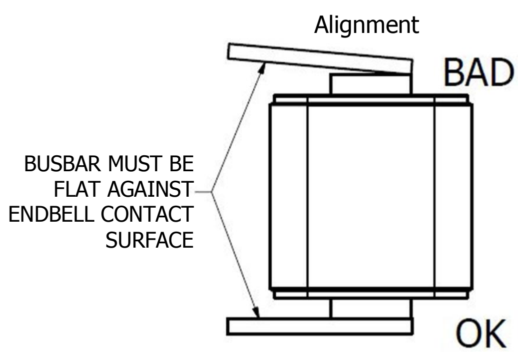


Figure 42: Recommended fuse mounting alignment

7. POWR-*SPEED*® Range

<table>
<tr><th>PSR Series</th><th>125A to 2000A</th></tr>
<tr><td rowspan="5"></td><td>550Vac to 1300Vac, 200kA or less</td></tr>
<tr><td>500Vdc to 1000Vdc, 150kA or less</td></tr>
<tr><td>UL 248-13, IEC 60269-4</td></tr>
<tr><td>c-UR-us, CCC, IEC, RoHS, CE</td></tr>
<tr><td>Power Converters, AC/DC Drives, Battery Management Systems, UPS, Inverters, Rectifiers, DC Common Bus.</td></tr>
<tr><th>L70QS Series</th><th>35A to 800A</th></tr>
<tr><td rowspan="5"></td><td>700Vac, 200kA</td></tr>
<tr><td>700Vdc, 50kA</td></tr>
<tr><td>UL 248-13</td></tr>
<tr><td>c-UR-us, RoHS, REACH, CE</td></tr>
<tr><td>Power Converters, VFDs, DC Bus</td></tr>
<tr><th>L50QS Series</th><th>35A to 800A</th></tr>
<tr><td rowspan="5"></td><td>500Vac, 200kA</td></tr>
<tr><td>500Vdc, 50kA</td></tr>
<tr><td>UL 248-13</td></tr>
<tr><td>c-UR-us, RoHS, REACH, CE</td></tr>
<tr><td>Power Converters, VFDs, DC Bus</td></tr>
<tr><th>L70S Series</th><th>10A to 800A</th></tr>
<tr><td rowspan="5">
</td><td>700Vac, 200kA</td></tr>
<tr><td>650Vdc, 20kA</td></tr>
<tr><td>UL 248-13</td></tr>
<tr><td>UR, CSA, RoHS, CE</td></tr>
<tr><td>AC/DC Drives, Heaters, Converters</td></tr>
</table>

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L50S Series	10A to 800A
	500Vac, 200kA
	450Vdc, 20kA
	UL 248-13
	UR, CSA, RoHS, CE
	AC/DC Drives, Heaters, Converters
L60S & KLC Series	**1A to 800A**
	600Vac, 200kA
	UL 248-13
	UR, CSA
	Power Supplies, Heaters
L25S Series	**1A to 800A**
	250Vac, 200kA
	250Vdc or less, 20kA
	UL 248-13
	UR, CSA
	Power Supplies, Power Converters, AC/DC Drives, DC Common Bus, Heaters, Inverters
L15S Series	**1A to 1000A**
	150Vac or less, 200kA or less
	150Vdc or less, 20kA
	UL 248-13
	UR, CSA
	Power Supplies, Heaters

8. ACCESSORIES

8.1 Microswitches

The Littelfuse MS Series microswitches offer remote indication features for the PSR Series square body fuses. These microswitches are three terminal devices (NO, NC and C) with the contact terminals being silver plated. The minimum operating voltage and current for these switches are 4 Volts and 1mA. In addition to electrical contacts, these microswitches have a 'Red Flap' for visual indication of the fuse's status.

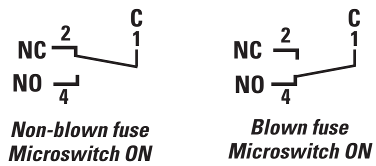

Figure 43: Circuit of MS Microswitch with NO-NC Contact

These microswitches can be connected directly to the fuse terminals using standard screws. The Terminal C contact in the microswitch is actuated upon the fuse blowing through a spring-loaded indication mechanism on the fuse body. This change in state of indication is permanent, and could be reset only by a manual reset operation of the 'Red Flap' on the microswitches.

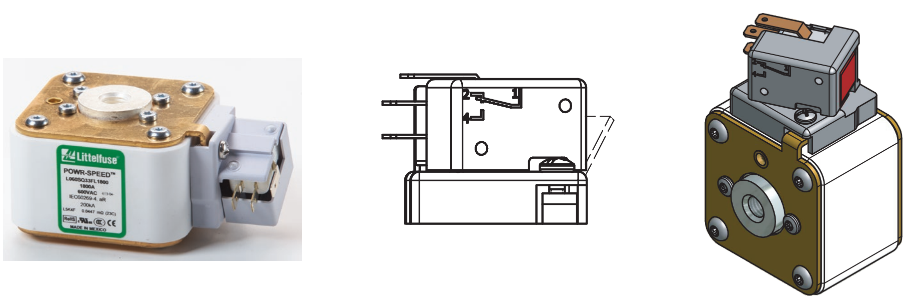

Figure 44: MS Series Microswitch for PSR Series Fuses

MS Series microswitches are available for all PSR Series Square Body Case Sizes.

- Microswitch part number MS3H1000C is suitable for use with Case Sizes 30, 31, 32 and 33.
- Microswitch part number MS7H1500C is suitable for use with Case Sizes 70, 71, 72 and 73.

The operating temperature range for these microswitches is between -60°C to +125°C at a relative humidity of 95%. For more information on these microswitches, refer to the product datasheet.

8.2 Stud Blocks

The use of stud mounting is widely adopted for North American Style round-body fuse (namely Littelfuse L70QS, L50QS, L25S Series fuses). Littelfuse LSCR Series stud blocks should be used for such requirements. Stud blocks get directly mounted to the panel board or equipment base plate, and wires are terminated to the screw on each end of the stud blocks.

Figure 45: LSCR Series Stud Blocks

Littelfuse LSCR Series blocks are available in both the 700V and 1000V range. The block selection guide table found on the LSCR Series datasheet should be followed to select the suitable LSCR part number based on fuse series and ampere rating. The recommended tightening torque mentioned in the datasheet is always preferred when mounting High-Speed fuses to these stud blocks.

9. TERMS & DEFINITIONS

Ampacity

The current in amperes that a conductor can carry continuously under the conditions of use, without exceeding its temperature rating. It is sometimes informally applied to switches or other devices. These are more properly referred to by their Ampere Rating.

Ampere Rating

The current rating, in amperes, that is marked on fuses or other equipment.

Ampere-Squared-Seconds (I^2t)

A means of describing the thermal energy generated by current flow. When a fuse is interrupting a current within its current-limiting range, the term is usually expressed as melting, arcing, or total clearing I^2t.

Arcing I^2t

Heat energy passed by a fuse during its arcing time. It is equal to the RMS arcing current squared, multiplied by arcing time.

Arcing Time (See Figure 1)

The time between the melting of a fuse link, until the overcurrent is interrupted.

Arc Voltage

Arc voltage is a transient voltage that occurs across an overcurrent protection device during the arcing time. It is usually expressed as peak instantaneous voltage (V_{peak} or E_{peak}), rarely as RMS voltage.

Clearing I^2t (also Total Clearing I^2t)

The ampere-squared seconds (I^2t) through an overcurrent device from the inception of the overcurrent until the current is completely interrupted. Clearing I^2t is the sum of the Melting I^2t and the Arcing I^2t.

Clearing Time

The time between the initiation of an overcurrent condition to the point at which the overcurrent is interrupted. Clearing Time is the sum of Melting Time and Arcing Time.

Continuous Current

An electrical load where the maximum current is expected to continue for three hours or more.

Current Limitation (Fuse)

A fuse which, when interrupting currents within its current-limiting range, reduces the current in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device was replaced with a solid conductor having comparable impedance.

Current Limiting Range

For an individual overcurrent protective device, the current-limiting range begins at the lowest value of RMS symmetrical current at which the device becomes current-limiting (the threshold current) and extends to the maximum interrupting capacity of the device.

Inductive Load

An inductive load is typically a motor load in which current waveform is lagging the voltage waveform. An inductive load pulls a large amount of current (an inrush current) when first energized. After a few cycles or seconds the current "settles down" to the full-load running current.

Interrupting Capacity (AIC)

The highest available symmetrical RMS alternating current (for DC fuses the highest direct current) at which the protective device has been tested, and which it has interrupted safely under standardized test conditions. The device must interrupt all available overcurrents up to its interrupting capacity. Also, commonly called **Interrupting Rating.**

Interrupting Rating (IR, I.R., AIR or A.I.R.)

The highest RMS symmetrical current, at specified test conditions, which the device is rated to interrupt. The difference between interrupting capacity and interrupting rating is in the test circuits used to establish the ratings.

Melting I^2t

The Heat energy passed by a fuse after an overcurrent occurs and until the fuse link melts. It equals the RMS current squared multiplied by melting time in seconds. For times less than 0.004 seconds, melting I^2t approaches a constant value for a given fuse

Melting Time

The time span from the initiation of an overcurrent condition to the instant arcing begins inside the fuse.

Overcurrent

Any current larger than the equipment, conductor, or devices are rated to carry under specified conditions.

Overload

An overcurrent that is confined to the normal current path (e.g., not a short-circuit), which if allowed to persist, will cause damage to equipment and/or wiring.

Peak Let-through Current

The maximum instantaneous current that passes through an overcurrent protective device during its total clearing time when the available current is within its current-limiting range.

Power Factor

The ratio of the actual electrical power dissipated by an AC circuit expressed in kilowatt (KW) to the product of the RMS values of current and voltage, and expressed as apparent power (kVA).

The difference between the two is caused by reactance in the circuit and represents power that does no useful work.

Recovery Voltage

Voltage measured across the fuse terminals after its operation.

Resistive Load

A resistive load, or resistive load bank, is a non-motor load in which current waveform is in phase with its voltage waveform. They are commonly used as heat generators.

RMS (Root Mean Squared) Current

Effective current value for a given alternating current (AC) wave obtained through mathematical method. The RMS value of AC is equivalent to the value of direct current (DC) which would produce the same amount of heat or power. The mathematical expression of RMS current corresponds to the peak instantaneous value of a AC waveform divided by the square root of two.

Semiconductor Fuse

A fuse specifically designed to protect power semiconductors devices such as silicon rectifiers, silicon-controlled rectifiers, thyristors, transistors, and similar components.

Short-Circuit

A current flowing outside its normal path. It is caused by a breakdown of insulation or by faulty equipment connections. In a short-circuit, current bypasses the normal load. Current is determined by the system impedance (AC resistance) rather than the load impedance.

Threshold Current

The minimum current for a given fuse size and type at which the fuse becomes current-limiting. It is the lowest value of available RMS symmetrical current that will cause the device to begin opening within the first 1/4 cycle (90 electrical degrees) and completely clear the circuit within 1/2 cycle (180 electrical degrees). The approximate threshold current can be determined from the fuse's peak let-through charts.

Time Constant

The inductance in a DC circuit limits the rate of current rise. The time required for the current to reach 63% 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 Henrys and R is resistance in ohms.

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Voltage Rating

The maximum RMS AC voltage and/or the maximum DC voltage at which the fuse is designed to operate. For example, fuses rated 600 Volts and below may be applied at any voltage less than this rating.

Note: There is no rule for applying AC fuses in DC circuits such as applying the fuse at one-half its AC voltage rating.
Note: Fuses used on DC circuits must have DC ratings.

Withstand Rating

Maximum current an unprotected electrical component can sustain for a specified period without any significant damage to its normal operation.

POWR-*SPEED*® FUSE CROSS REFERENCE GUIDE

10. CROSS-REFERENCE

This guide covers the most popular high-speed fuse types that Littelfuse has in stock and ready to ship! The cross reference is meant to serve as a guide for quick identification and product selection. We suggest you check all applicable specifications before making substitutions.

COMPETITOR	LITTELFUSE
170M	PSR
A_UD	PSR
A013F	L15S
A015F	L15S
A015R	L15S
A025F	L25S
A050F	L50S
A060F	L60S
A070F	L70S
A13X	L15S
A25X	L25S †
A50P (type 1 & 4)	L50S
A50QS	L50QS

COMPETITOR	LITTELFUSE
A60X	L60S
A70P	L70S
A70QS	L70QS
CHSF	L50QS
FWA	L15S † §
FWH	L50S † §
FWP	L70S * §
FWX	L25S * †
KAA	L15S
KAB	L25S
KAC	KLC
KBH	L50S
PC_UD	PSR

COMPETITOR	LITTELFUSE
PSC	PSR
RFA	L15S
RFC	KLC
RFL (750V)	L70S (700 V)
RFV	L50S
SF13X	L15S
SF25X	L25S
SF50P	L50S
SF60X	L60S
SF70P	L70S
XL25X	L25S
XL50F	L50S *
XL70F	L70S *

* Check specific mounting dimensions before substituting.
† Check characteristics and dimensions for application before substituting.
§ Verify voltage for DC applications.

Littelfuse reserves the right to make changes in product design, processes, manufacturing location and literature information without notice.
For more information or a complete listing of high-speed fuses offered visit Littelfuse.com/POWR-*SPEED* or call 1-800-TEC-FUSE.

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For more information, visit
Littelfuse.com/POWR-SPEED

Additional technical information and application data for Littelfuse protection relays, generator and engine controls, fuses and other circuit protection and safety products can be found on **Littelfuse.com**. For questions, contact our Technical Support Group **(800-832-3873)**. Specifications, descriptions and illustrative material in this literature are as accurate as known at the time of publication, but are subject to changes without notice. All data was compiled from public information available from manufacturers' manuals and datasheets.

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