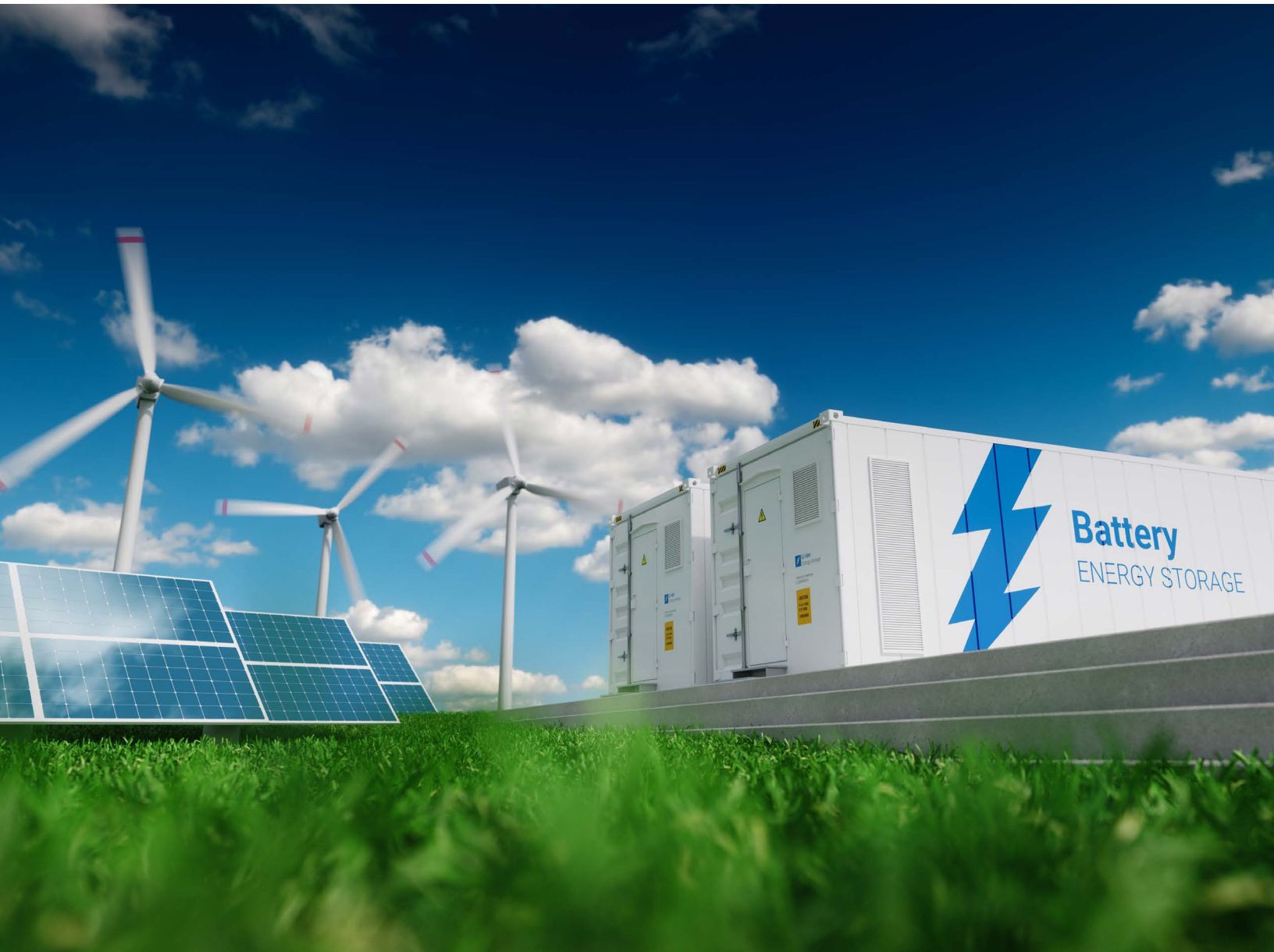
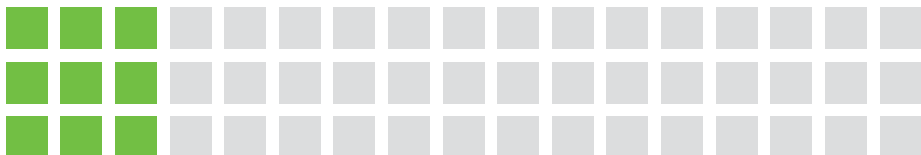


Application Considerations

An excerpt from the POWR-SPEED® Fuses Application Guide



SECTION 5.0



Expertise Applied | Answers Delivered

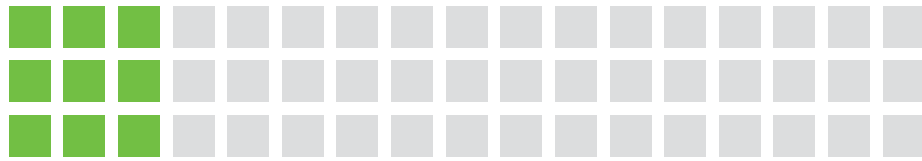
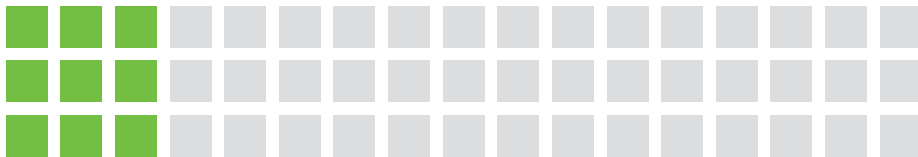


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For more insights, download the full
POWR-SPEED Fuses Application Guide at
[Littelfuse.com/powr-speed-application-guide](https://www.littelfuse.com/powr-speed-application-guide)





This document, which is excerpted from the POWR-SPEED Fuses Application Guide, reviews the application considerations when selecting high-speed fuses. Download complete, 52-page POWR-SPEED Fuses Application Guide at Littelfuse.com/powr-speed-application-guide for an in-depth look at high-speed fuse protection.

5.1 Protection of Power Conversion Devices

A typical application of high-speed fuses in a 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).

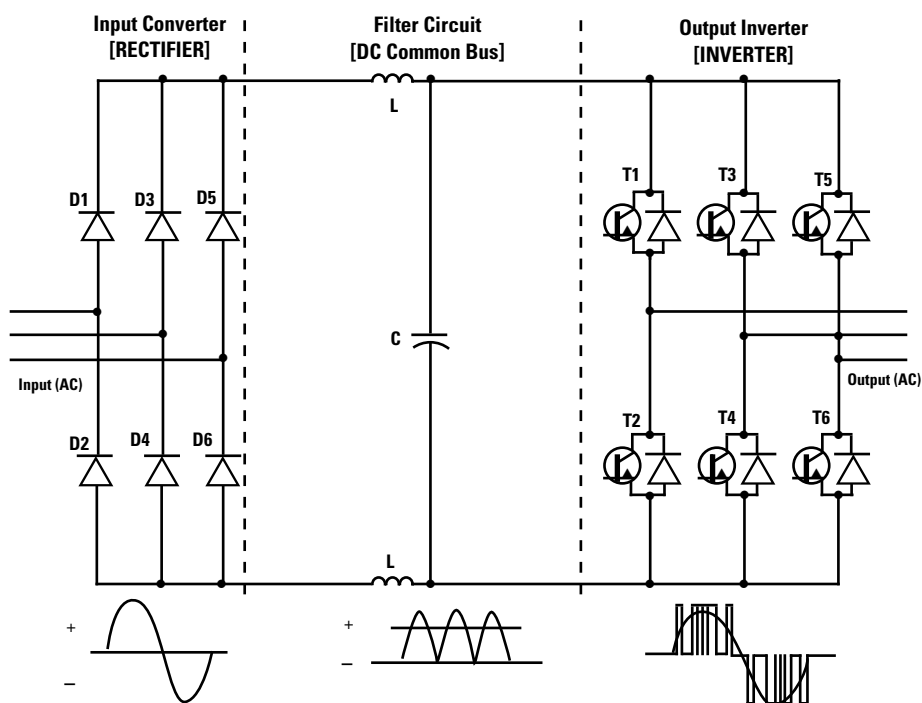


Figure 33. Typical three phase power converter circuit

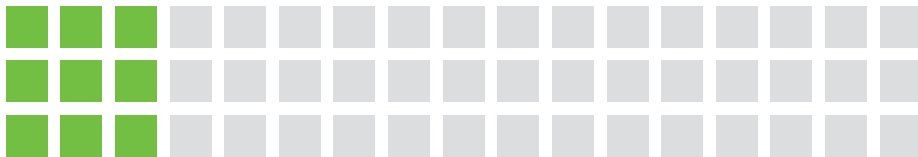
Protection requirements vary at each location, however the main purpose of the fuses in this circuit are to continuously allow the nominal load current and any permissible overload current to continue without any interruption. At the same time, the fuses are selected to interrupt any overcurrent fault 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 ac to 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.

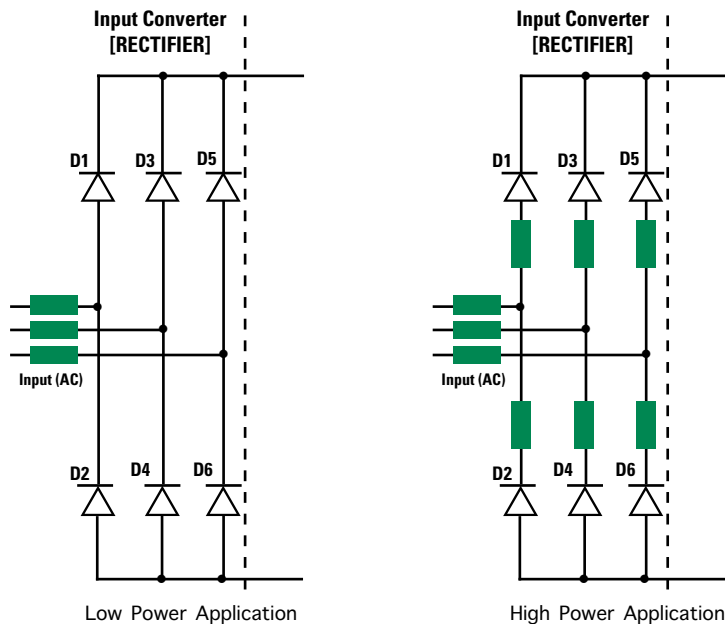


Figure 34. Location of high-speed fuses in rectifiers

5.1.2 Protection Consideration for Inverter Circuits

Power transistors (IGBTs and 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. 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.

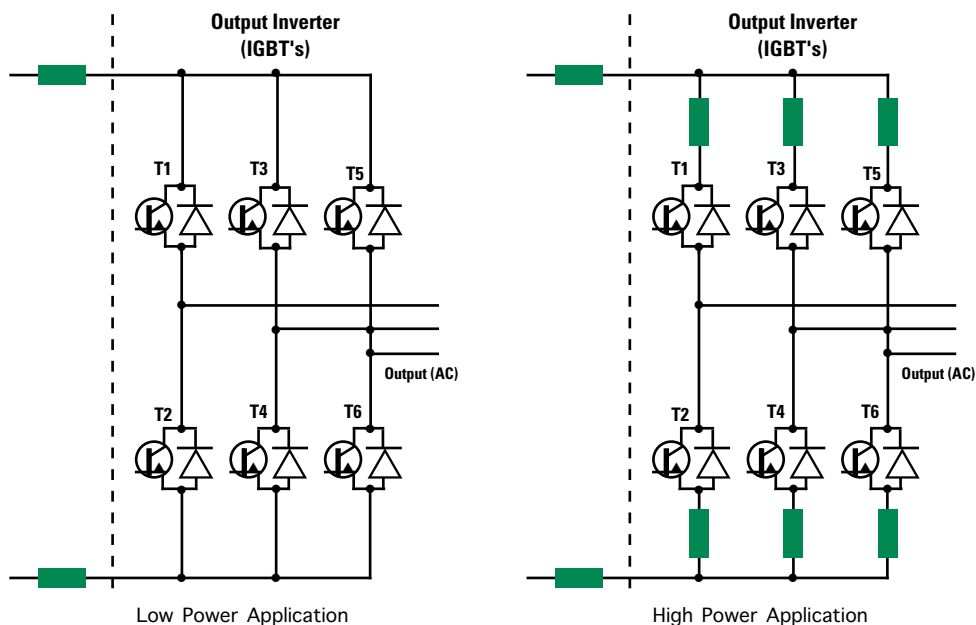
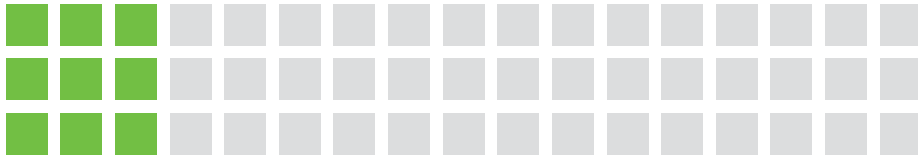


Figure 35. Location of high-speed fuses in inverters



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.

5.1.3 Protection Consideration for DC Bus

Depending on the application, requirements for the protection of the dc common bus, also known as dc bus, varies. DC bus configurations are generally found in group motor application (**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.

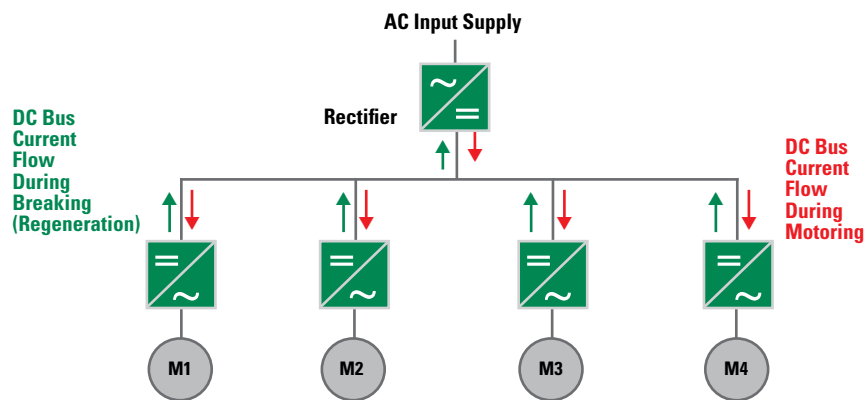


Figure 36. Dc bus configuration

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.

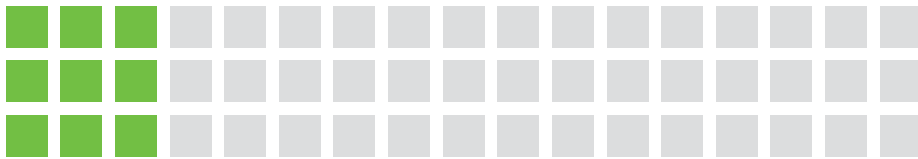
In general, while protecting the dc bus, high-speed fuses that are specially designed and tested to dc voltages with a dc time constant (L/R value) higher than the application specifications, are the right choice to offer the best level of protection. It is not recommended to use ac high-speed fuses while protecting the dc bus.

5.2 Protection for UL Motor Branch Circuits

There is a general perception that only UL Listed fuses (current limiting and with the proper rejection features) could be used for branch circuit protection per the NEC and general industrial practices. However, the NEC does permit the use of high-speed fuses for motor branch circuit protection under certain conditions.

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

Per the 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 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, on condition imposed by the 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 fuses can only be UL Recognized to the UL 248-13 standard and cannot be UL Listed.

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. Switching losses are prevalent in such circuits and designing 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.

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 means 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.

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 applications. These devices have a 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 limited, hence paralleling of one or more standard size high-speed fuses is widely practiced in the industry.

Paralleling of fuses has its own benefits and challenges¹. Some of the benefits include:

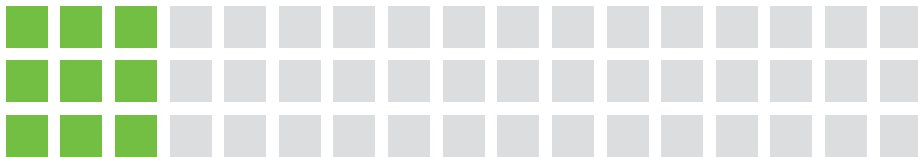
- Protection of high current and low withstand rating applications, where a single large fuse is not available to meet the requirement
- Maximizing heat dissipation and minimizing watt loss in power electronics applications
- Better inventory management for original equipment manufacturers (OEMs), distributors,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

*Reference:

¹ B. Gradwell, "Arc flash mitigation through the use of an engineered parallel high speed semi-conductor fuse assembly," IEEE/IAS 50th Industrial and Commercial Power Systems Technical Conf., Fort Worth, TX, USA, May 20–23, 2014, doi: 10.1109/ICPS.2014.6839162.



NEC Article 240.8 only allows fuses and circuit breakers to be connected in parallel if they are factory assembled in parallel and listed as a unit. T

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.

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
3. Selection of proper mounting arrangement and accessories to meet application requirements

5.4.1 Estimation of Theoretical Performance

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.

It is recommended that a de-rating factor (K_p) should be applied while estimating the nominal current rating of a paralleled fuse.

When two to four fuses are connected in parallel: $K_p = 0.9$

When more than four fuses are connected in parallel: $K_p = 0.8$

The nominal current rating for a paralleled fuse (I_{np}) is determined by the formula:

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

Example:

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

$$I_1 = 100A$$

$$I_2 = 100A$$

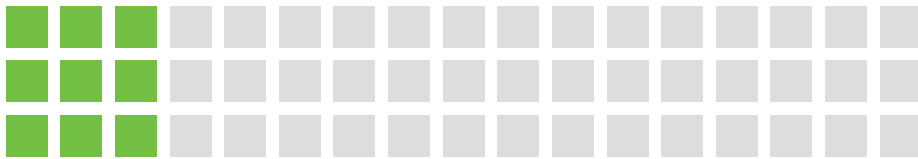
$$K_p = 0.9 \text{ (two fuses)}$$

$$I_n = (100+100) * 0.9 = 180A$$

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.

Time-Current Characteristic (TCC): 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. It is recommended to use the formula below for estimating the combined TCC curve (TCC_{np}) for fuses when connected in parallel.

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



Where:

TCC₁ = TCC curve of any fuse on 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.

Peak Let-Through Current: Peak let-through charts for parallel fuses are typically not available in the datasheet, unless it is factory assembled. It is recommended to use the formula below to estimate the peak let-through values for fuses connected in parallel (I_{N-PEAK}).

$$I_{N-PEAK} = I_{p1} * N^{2/3}$$

Where:

I_{p1} = Individual fuse peak let-through current

N = Number of parallel fuses connected

Ampere-Squared-Seconds (I₂t Value): I₂t 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 I²t_{np} value is determined by the formula:

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

Where:

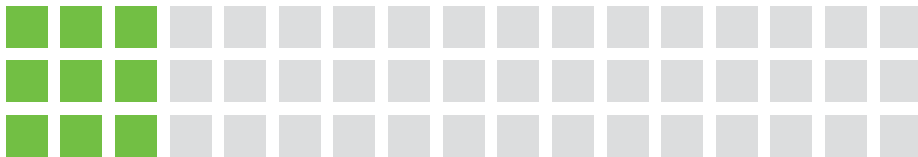
I²t₁ = Individual fuse I²t value

N = Number of parallel fuses connected

5.4.2 Validation of Application Conditions for Proper Sizing

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 and size
- Load conditions
- Available fault current
- Withstand rating (I²t) of semiconductor device
- Peak inverse voltage
- Frequency or time constant
- Vibration and shock



5.4.3 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.

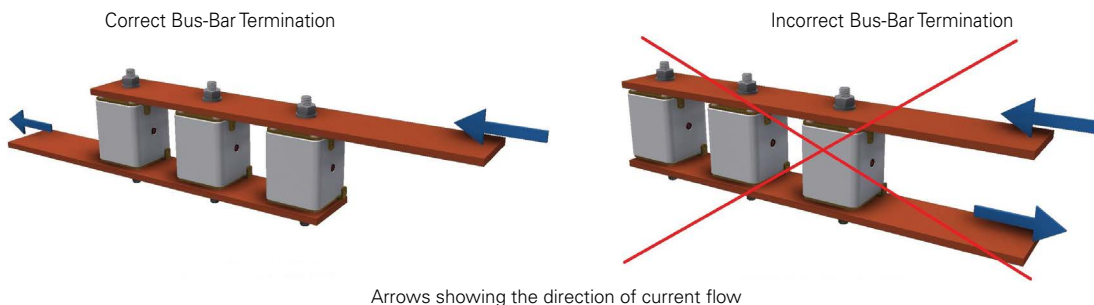


Figure 37. Paralleling two or more high-speed fuses

High-speed fuses run considerably hotter when compared to other fuses, so the distance between the fuses is critical when paralleling fuses. It is recommended to maintain 10 mm to 25 mm 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 37** illustrates the 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.

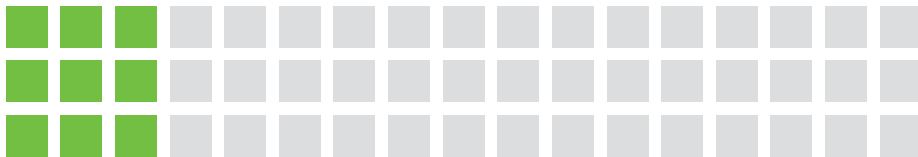
Using the proper stud size and applying the recommended tightening torque would ensure proper termination and help prevent any nuisance operations. Refer to the product’s datasheet for stud size and torque recommendations.

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 parallel fuses.

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 pre-arcing I^2t for all individual arm/leg fuses.

$$\text{Total Clearing } I^2t \text{ Line Fuse} < \text{Sum of Pre-arcing } I^2t \text{ of Leg or Arm Fuse}$$



DISCLAIMER

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.

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