

High Speed Fuses

The protection needs for solid-state power equipment often differ from electrical equipment; hence, the high speed fuse evolved. The protection of power diodes and SCRs requires ultra current-limiting short circuit fuses; semiconductor devices cannot withstand heavy short-circuit current. The circuits in which fuses are installed place certain requirements upon high speed fuses. These requirements are generally more stringent than the fuse requirements for typical 60 cycle AC power distribution systems in commercial buildings or industrial plants.

The diodes or SCRs are at the heart of the solid-state power equipment. These semiconductor devices have relatively low short-circuit current withstand capabilities. The thin silicon chip imbedded in the semiconductor device package has a very low transient thermal capacity. The heating effect produced by low, moderate and high fault currents can quickly cause permanent damage to the device. Damage to a semiconductor device can occur in a very short time period; the current-limiting fuse protection is one of the fastest protection means available. Under fault conditions, restricting the short circuit energy by a high speed fuse is essential to the protection of SCRs, diodes, and other semiconductor devices in the system.

NEC® 430.52 recognizes the use of these types of fuses in motor applications; see the section motor circuits with adjustable speed drives in this bulletin.

There are several criteria that can be used to judge the performance of high speed fuses (also referred to as semiconductor fuses). Among these are the current-limiting short circuit capability and DC interrupting capability. From a design standpoint, I^2t is most often used to evaluate the current-limiting short circuit performance. I^2t (RMS amps- squared seconds) is a parameter that indicates the heating effect associated with a current pulse. Typically the

semiconductor data sheet specifies a maximum I^2t withstand for a semiconductor device. To offer short circuit protection to the semiconductor device, the fuse selected should have an I^2t let-through less than the I^2t withstand rating of the semiconductor device. High speed fuses have excellent current-limiting ability, as indicated by their low I^2t let-through and peak current let-through.

High speed fuses are often applied where DC interrupting capabilities are required. Some high speed fuses have been designed and rigorously tested in developing their excellent DC characteristics.

The type circuits often employed require specialized knowledge. Included in the following data are the current and voltage relationships for many of the common circuits.

Ratios of Circuit Currents (Diagrams on next page)

Circuit Diagram* No.	Relative Circuit Currents			
	I_{1RMS} $I_{1average}$	I_{2RMS} $I_{2average}$	I_{3RMS} $I_{3average}$	I_{2RMS} I_{1RMS}
1	1.57	—	—	—
2	1.11	0.79	—	0.71
3	1.11	0.79	1.11	0.71
4	1.02	0.59	—	0.58
5	1.00	0.58	0.82	0.58
6	1.00	0.41	—	0.41
7	—	—	—	0.71
8	—	—	—	0.71

*For example, in Diagram No. 1: $\frac{I_{1RMS}}{I_{1average}} = 1.57$



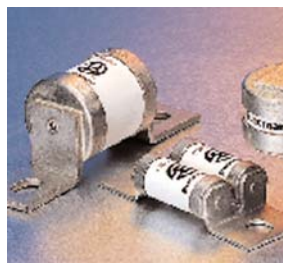
North American

FWA, FWX, FWH, KAC, KBC, FWP, FWJ
1 to 4000A, 130V to 1000V, 200,000AIR AC, UL Recognized

Cooper Bussmann offers a complete range of North American blade and flush-end style high-speed fuses and accessories. Their design and construction were optimized to provide:

- Low energy let-through (I^2t)
- Low watts loss
- Superior cycling capability
- Low Arc Voltage
- Excellent DC performance

Medium power applications. While there are currently no published standards for these fuses, the industry has standardized on mounting centers that accept Cooper Bussmann fuses.



British Style BS 88

LET, LMMT, CT, FE, FM, MT

6 to 900A, 240V to 690V, 200,000AIR AC, UL Recognized
Designed and tested to BS 88:Part 4 & IEC 60269:Part 4

Widest range of British style semiconductor fuses and accessories. Use innovative arc quenching techniques and high grade materials to provide:

- Minimal energy let-through (I^2t)
- Excellent DC performance
- Good surge withstand profile

Found in equipment manufactured in the United Kingdom or British Commonwealth countries. North American manufacturers have begun to specify British style fuses - particularly in UPS applications at 240 volts or less - to take advantage of their size, performance and cost benefits.



Square-Body

170M####

10 to 7500A, 690V to 1250V, 200,000AIR AC, UL Recognized, Designed and tested to IEC 60269:Part 4
Complete range of Square Body style high-speed fuses and accessories. Easy to provide custom products.

High power applications which require a compact design with superior performance. Different end fittings options include:

- DIN 43 653
- DIN 43 620
- Flush End (Metric/U.S.)
- French Style
- US Style



Ferrule

FWA, FWX, FWH, FWC, FWP, FWK, FWJ, FWL, FWS
1 to 100A, 150V to 2000V, 200,000AIR AC, UL Recognized

Designed and tested to IEC 60269:Part 4

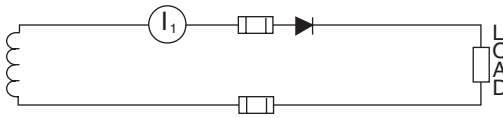
Cooper Bussmann offers a full line of ferrule style (cylindrical and clip-mounted) high-speed fuses, designed and tested to meet standards and requirements in various locations around the world. Their unique design and construction provide:

- Superior cycling
- Low energy let-through (I^2t)

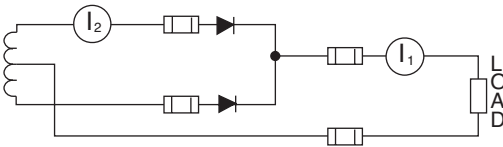
Ferrule high-speed fuses provide an excellent solution for small UPS, small AC drives and other low power applications where space is at a premium.

High Speed Fuses

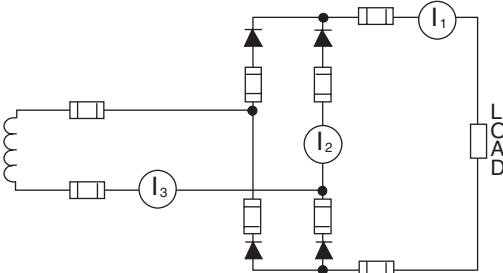
Typical Circuits



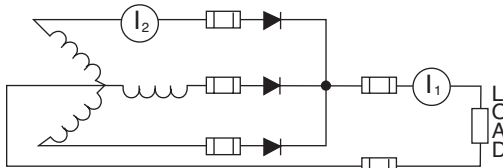
1. Single-Phase, Half-Wave.



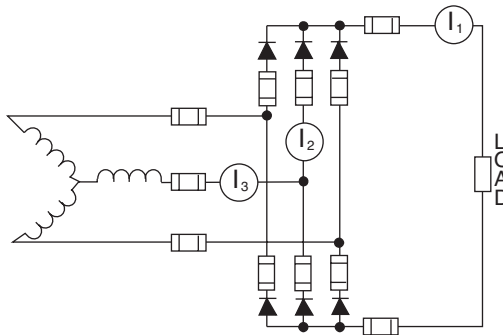
2. Single-Phase, Full-Wave, Center-Tap.



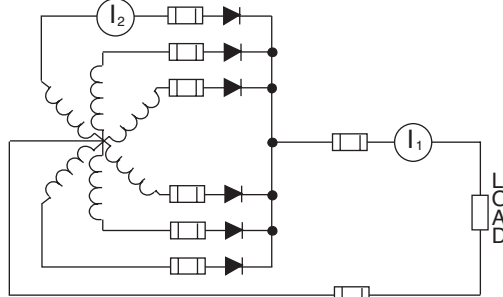
3. Single-Phase, Full-Wave, Bridge.



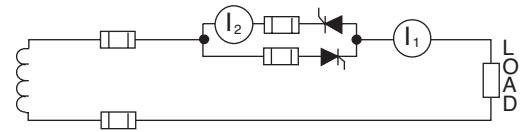
4. Three-Phase, Half-Wave.



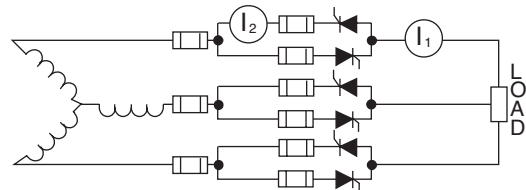
5. Three-Phase, Full-Wave.



6. Six Phase, Single Wave



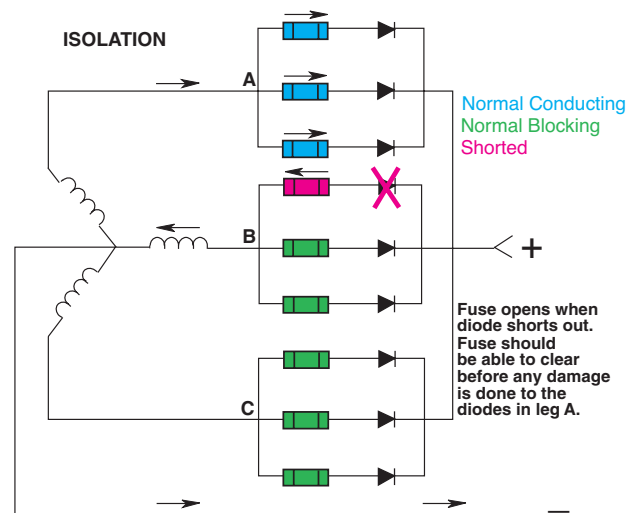
7. Single-Phase, Anti-Parallel, AC Control.



8. Three-Phase, Anti-Parallel, AC Control.

Not all systems are designed to have the fuse provide full protection for a diode or SCR. There are several degrees of protection:

1. Prevent Device Rupture—Fuse merely needs to interrupt current before SCR or diode ruptures.
2. Isolate Failed Device—Typically, used only where three or more diodes or SCRs (devices) are used per conduction path. An individual fuse is not intended to protect an individual device. Rather, the purpose of the fuse is to remove the diode or SCR after it shorts out and permit the overall circuit to continue operating. At this level, the fuse must be able to protect the diodes or SCRs that are splitting the fault current in another leg, as illustrated in the following diagram.



3. Protect The Device (Short Circuits)—In this case the fuse is selected to protect the diode or SCR against short-circuits external to the SCR or diode. Typically, the fuse has to be selected to give a much lower let-through current than that required in applications (1) or (2) above.

For more information on high speed fuses, see Motor Circuits With Power Electronic Devices section.

Motor Circuits With Power Electronic Devices

Power Electronic Device Circuit Protection

Variable frequency drives, soft starters, and other power electronic devices are becoming increasingly more common in motor circuits. These power electronic devices are much more sensitive to the damaging effects of short-circuit currents and therefore require a level of protection that may not be provided by circuit breakers or conventional fuses. In the past, manufacturers of these devices provided internal protection in the form of high speed fuses, which are much more current-limiting than conventional branch circuit fuses. However, as drives and soft-starters have grown smaller and smaller, the internal fuses have been omitted by starter manufacturers in favor of short-circuit testing to UL standards with external protection.

Now, in many cases, drives are shipped without fuses, and it is the responsibility of the installer or owner to provide this protection. During the design and installation stages, it is important to check the data sheets, label, or manual of the power electronic device to understand the short-circuit protection options. With the proper fuse selection, a safer installation may result, with better power electronic device protection. This can result in more productive operation and higher short-circuit current ratings.

Short Circuit Testing

UL 508C, the standard to which drives and soft starters are listed, provides at least two levels of short-circuit protection. The Standard Fault Current test is mandatory to be listed, and there is an optional High Fault Current test which can be performed during the listing of the device.

UL also provides an "Outline of Investigation", UL 508E, which can be used to verify Type 2 (no damage) protection when protected by a specific current-limiting overcurrent protective device.

1. The Standard Fault Current tests evaluate the drives at rather low levels of fault current, and significant damage to the drive is permitted – i.e. the drive does not have to be operational after the testing. Examples of the level of fault currents are 5000 amps for 1.5 to 50Hp drives and 10,000 amps for 51 to 200Hp drives.

The drive must be marked with the maximum short-circuit current rating (at which it was tested). It does not have to be marked with the type overcurrent protective device if it has followed certain procedures. However, the manufacturer can list the drive with fuse protection only and then the label will be marked to identify that branch-circuit protection shall be provided by fuses only (either high speed or branch circuit types).

2. The High Fault Current tests can be at any level of short-circuit current above the standard fault current tests. Significant damage to the drive is permitted – i.e. the drive does not have to be operational after the testing.

The drive must be marked with the short-circuit current rating at which it was tested. In addition it must be marked with the type overcurrent protective device(s) that were used for the test. If current-limiting branch circuit fuses (such as Class J, T, CC, etc.) are used, then the tests are conducted with special umbrella fuses. Umbrella fuses have energy let-through levels greater than the UL limits for various classes and amp rated fuses. These umbrella fuses have energy let-through levels that are greater than commercially available fuses.

A drive can be listed and marked for either fuses or circuit breakers or both. Typically the drives are marked for protection only by fuses since current-limitation is necessary to meet the requirements set forth in the product standard. If the unit is marked for fuse protection only, then only fuses can be used for protection of that drive unit and the proper type and size must be used. Some drives will be marked for protection by a specific amp and class fuse (for branch circuit fuses).

3. Type 2 (no damage) is the best level of protection. With this protection, the drive cannot be damaged, and the unit is tested and marked with a high short-

circuit current rating. It must be able to be put into service after the fault has been repaired and the fuses replaced.

A clear understanding of semiconductor device types is needed when considering Type 2 coordination with variable speed drives. Only silicon controlled rectifier (SCR), gate turn-off thyristor (GTO) and diode based devices can achieve Type 2 protection, and it is only possible with properly selected high speed fuses. Thyristor type devices can effectively share energy equally across the PN junction. They have short-circuit energy withstand levels that are lower than conventional branch circuit fuse let-throughs, however, Type 2 protection can be achieved with properly selected high-speed fuses.

Equipment that use insulated gate bipolar transistors (IGBT) high frequency devices cannot presently achieve Type 2 protection levels. IGBTs do not have enough surface area contact with the actual junction to help share energy evenly. IGBTs share energy very well during long duration pulses, but during short duration, high amplitude faults most of the energy is being carried by an individual bonding wire or contact. Current fuse technology cannot effectively protect the bonding wires of IGBT based equipment from overcurrent conditions, and therefore Type 2 no damage protection is not possible. However, current high speed fuse technology can protect IGBTs from case rupture under short-circuit conditions.

Protecting Drives and Soft Starters

There are two important considerations when selecting protective devices for drives and soft starters:

1. The device must be able to withstand the starting current and duty cycle of the motor circuit without melting.
2. The device must be able to clear a fault quickly enough to minimize damage to the drive or soft starter.

The melting time current characteristic curve can be used to verify a fuse's ability to withstand starting currents and duty cycle, while clearing I^2t at the available fault current can be used to verify the various levels of protection described earlier. For more information on proper sizing of high speed fuses, please see the High Speed Application Guide, available on www.cooperbussmann.com.

There are two types of faults that can occur with drives and soft starters – internal faults and external faults. Internal faults are caused by failures of components within the drive or soft starter, such as failure of the switching components (SCRs, thyristors, IGBTs, etc.) External faults occur elsewhere in the circuit, such as a motor winding faulting to the grounded case.

Most soft starters utilize either silicon-controlled rectifiers (SCRs) or gate turn-off thyristors (GTOs) for power conversion. These devices depend on high speed fuses for protection from both internal and external faults. If high speed fuses are properly selected, Type 2 protection may be achieved.

Modern adjustable speed drives often utilize insulated gate bipolar transistors (IGBTs) as the main switching components. IGBTs have drastically lower energy withstands than SCRs and GTOs, which makes protection of these components very difficult. For external faults, drives using IGBTs incorporate electronic protection that shut off the switching components when fault currents are detected. However, over time, transient voltage surges can lead to the electronics' inability to shut off the IGBT switching. This can lead to internal faults as the IGBTs fail and rupture. The violent rupture of IGBTs can cause additional faults to adjacent components as a result of the expelling of gases and shrapnel. High speed fuses may not be able to prevent the IGBT from failing, but properly selected high speed fuses can prevent the violent rupture of IGBT devices and the resultant additional faults and safety hazard.

Large adjustable speed drives often include internal high speed fusing in order to protect against rupturing of components. However, small drives (below

Power Electronic Device Circuit Protection

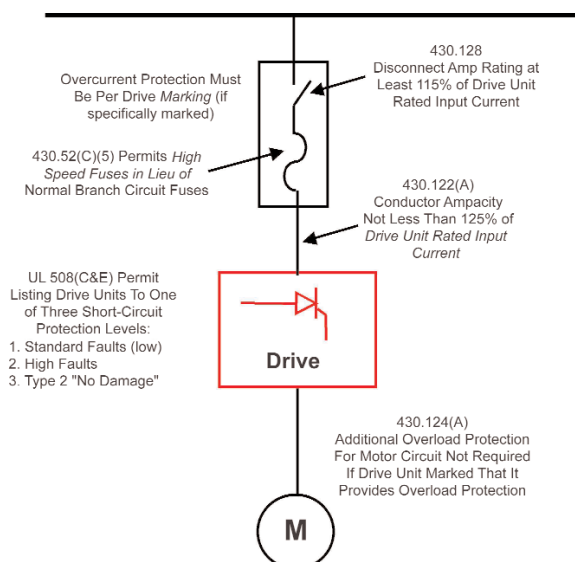
200Hp) often do not include internal fusing, so the user must supply protection. It is important to note that Type 2 or "no damage" protection of devices utilizing IGBTs is not possible with current fuse technology. However, with properly sized and applied high speed fuses, repair, replacement and lost productivity costs will be minimized.

Fuses for Specific Drives

Selection tables for various manufacturers' drives with Cooper Bussmann fuse recommendations by specific drive model / part # are available on www.cooperbussmann.com.

Complying with the NEC®

Traditional high speed fuses come in many different shapes and sizes. They can be recognized to UL and CSA standard 248-13. This standard does not contain requirements for overload performance or dimensions, therefore, these fuses are not considered branch circuit protection per the NEC®. However, NEC® article 430, which covers motor circuits, does allow high speed fuses to be used in lieu of branch circuit protection when certain conditions are met.



The use of high speed fuses for protection of power electronic devices in lieu of normal branch circuit overcurrent protective devices is allowed per NEC® 430.52(C)(5), which states that "suitable fuses shall be permitted in lieu of devices listed in Table 430.52 for power electronic devices in a solid state motor controller system, provided that the marking for replacement fuses is provided adjacent to the fuses." Please note that this only allows the use of high speed fuses in lieu of branch circuit protection.

Per NEC® 430.124(A), if the adjustable speed drive unit is marked that it includes overload protection, additional overload protection is not required. NEC® 430.128 states that the disconnecting means for an adjustable speed drive system shall have a rating not less than 115% of the rated input current on the drive unit. This means that the disconnect required in front of each drive unit must be sized in accordance with the drive unit rated input current, not the motor current. When connecting conductors between the disconnecting means and the drive, NEC® 430.122(A) states that "Circuit conductors supplying power conversion equipment included as part of an adjustable speed drive system shall have an ampacity not less than 125% of the rated input to the power conversion equipment." This means that the conductors shall be sized to the rated current on the conversion unit nameplate and not the motor rating.

New: Cooper Bussmann Series DFJ (Class J) Drive Fuse

The Cooper Bussmann Drive Fuse (Series DFJ) provides the performance of a high speed fuse for protection of semiconductor devices and meets UL listing requirements for Class J fuses. Unlike traditional high speed fuses, the Cooper Bussmann DFJ Drive Fuse is suitable for branch circuit protection (per the NEC®), and fits in standard Class J fuse clips, holders and disconnects.

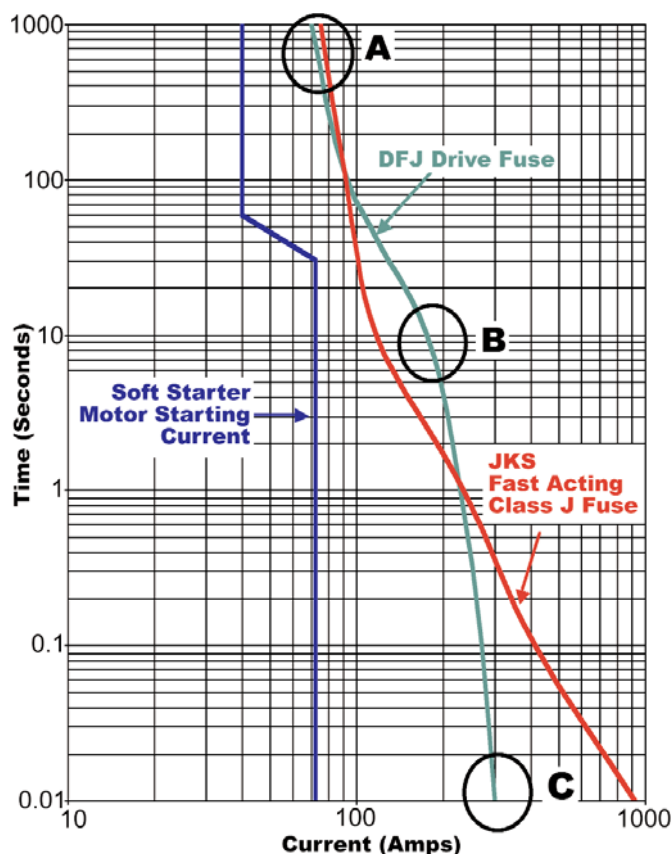


Figure 1 - The above comparison of time-current characteristics shows the superior performance of the Cooper Bussmann DFJ Drive Fuse at three critical performance points.

Figure 1 represents the typical starting parameters of an AC drive, as well as the melting characteristics of a traditional, non-time delay, Class J fuse and the new DFJ Drive Fuse from Cooper Bussmann. There are three critical performance points that are shown:

- A: Continuous Region (Amp Rating)** – The continuous current-carrying capacity of the DFJ Drive Fuse is identical to the traditional Class J fuse. This is key to meeting UL branch circuit opening time requirements.
- B: Overload Region** – Traditional, non-time delay Class J fuses have far less overload withstand than the new DFJ Drive Fuse from Cooper Bussmann. This extended withstand allows for more reliable protection without nuisance openings.
- C: Short-Circuit Region** – The DFJ Drive Fuse has far lower required melting current and clearing I^2t than the traditional Class J fuse, allowing for greater current limitation and lower energy let-through.

Motor Circuits With Power Electronic Devices

Power Electronic Device Circuit Protection

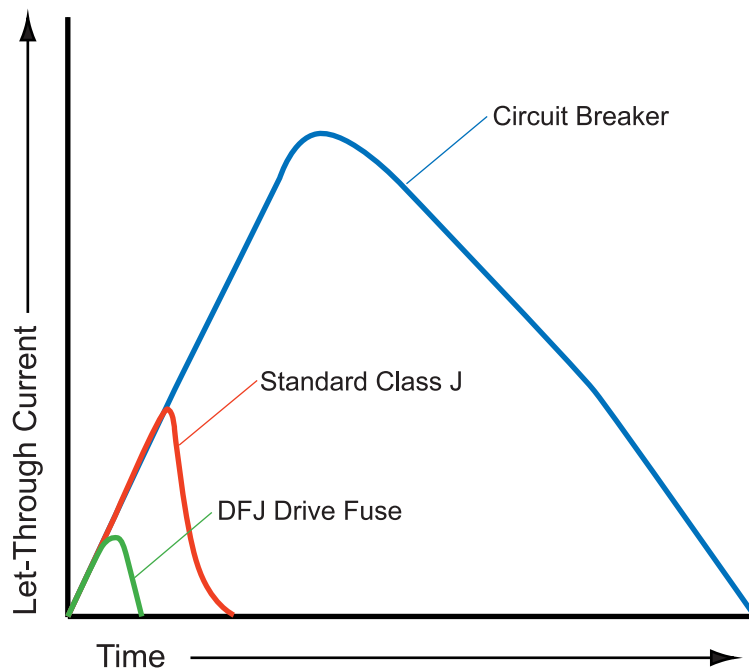


Figure 2 – The graph shown above is a representation of the energy let-through by a circuit breaker, a standard, non-time delay Class J fuse, and the new Cooper Bussmann DFJ Drive Fuse during the same magnitude fault.

Under fault conditions, the DFJ Drive Fuses clear the fault much faster, and are much more current-limiting, than circuit breakers and standard, non-time delay Class J fuses. The DFJ Drive Fuse has high speed fuse performance under fault conditions, which means high speed fuse protection for power electronic devices.