

Fast Acting Fuse for Semiconductor Protection

Protect IGBT, IEGT, IGCT for drives as well as large diode and thyristor

With the birth of semiconductor in the 50's and their use in power converters the need of protection with fuse came along. Fuses for the protection of semiconductor, known as semiconductor fuse, have grown in demand and performances. Applied for diode and thyristor protection in the early age of power electronics, new fuses have been developed and are currently in service for the protection all power semiconductors like IGBT, IEGT, IGCT for drive application as well as large diode and thyristors for very high current rectifier applications. The goal of this article is to introduce to all readers the fuse basic performances and features.

By Jean-François de Palma, Power Electronics Specification Engineering Manager, Mersen PE Newburyport, MA, USA

Introduction to fuse

Like power semiconductor devices, fuses are technical devices backed up by years of development and testing. When selecting semiconductor fuse, one will have to answer opposite deliverables. We want, during normal operation, low watts, unlimited life time expectancy, low body and terminal temperatures, of course low cost but we also need the fuse to operate as fast as possible, with the minimum let through energy and arc voltage when everything else have failed. As well, power semiconductor fuses are designed to meet a given set of performances specified by international standards like UL, CSA and IEC 60269-4, like body and terminal temperatures rise, arc voltage ... as well as customer application requirements, energy let thru by the fuse, commonly known as I2t, life cycle expectancy, connection, fuse operation indicators etc. Many of these fuse performance requirements conflict with each other. Nevertheless new fuse designs as well as new manufacturing processes have helped resolved these conflicting requirements. Furthermore, new simulation tools in addition to Mersen specification field engineers have shorten the fuse selection for demanding power electronic applications like drives and rectifiers.

Basic fuse design technology

A typical semiconductor fuse consists of one or more silver or copper or thulay (series of silver and copper in a same fuse element) elements enclosed by a fuse body. The elements are either welded or soldered to the fuse contacts/ terminal. The figure 1 depicts a typical fuse technology valid for round or square body designs. The element will be typically surrounded by silica sand commonly called filler. The sand plays a major role in fuse performances. It quenches the arc by absorbing the energy during arcing time and it serves as fuse element cooler during normal operation. The sand conducts the heat away from the element, through the fuse body and to the medium surrounding the fuse. Short fuse will transfer heat more thru the ter-

minal. Long fuse will transfer heat through fuse body. The fuse "savoir faire" is how well you manage the fuse element thermal equilibrium. Running element hot will make the fuse fast to open but subject to premature opening. Running the element at lower temperature will lead a long lasting fuse but when needed, will it protect? Fortunately, we current rate fuses to give the best trade off between clearing, operation and cycle performances.

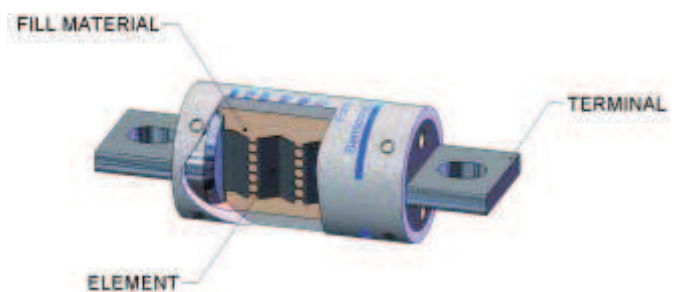


Figure 1: The numbers of notches in series will define the fuse operating voltage and the total cross section of paralleled element will define the rating of the fuse

Basic fuse performances

The fuse is a calibrated current carrying device designed to open under specific conditions. In the figure 1, note the reduced cross-section areas in the element, also called notches. The numbers of notches in series will define the fuse operating voltage and the total cross section of paralleled element will define the rating of the fuse. The element material, mass and notch configuration, along with the surrounding materials, all contribute to the fuse performance. Reduced section path for the current will lead to higher current density thus to higher heat generated at the notches. The total notches cross section will define the pre-arcing I2t needed to melt the fuse element, in

another word the energy you need to deliver to the fuse to melt the reduced section path. Under sustained over-current, the fuse element generates heat at a faster rate than the filler can conduct it away from the element. If the over-current persists, the element at the notches will reach its melting point. The fuse time current curve, figure 2, is the fuse thermal response undergoing fault current, it gives the fuse melting time versus the fault r.m.s. current. Once the end of the pre-arc time is launched you are only part way to final fuse opening.

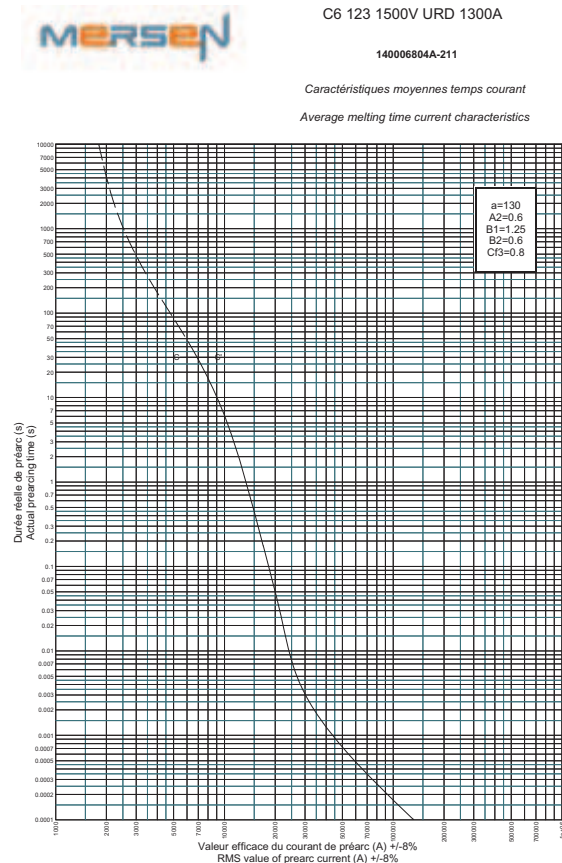


Figure 2: The fuse time current curve

Fuse I²t parameters

Once the end of the pre-arc time is reached the fuse switches to the arcing mode. The fuse will develop an arc voltage, higher than the source voltage thus will force the current to go down to zero. This period is called the arcing time. During this period the fuse will have to dissipate the energy supplied by the source as well as the energy stored in the circuit, mainly $\frac{1}{2} LI^2$. The total energy let through by the fuse, or known as total I²t, is the result of the sum of the pre-arc I²t plus the arcing I²t. Those values are supplied for our fast acting semiconductor fuses. The normal condition for short-circuit protection is that the total I²t integral let through by the fuse when clearing the fault must be less than the I²t which produces system damage. For example, for the IGBT's the appropriate value is the level of I²t which causes case rupture.

Example of application

Short-circuit faults in power electronics equipment will cause excessive damage, or in worst case, explosion. Electronic protection against overloads and short-circuits is normally embedded in the new power electronic semiconductors but back-up fuse protection is still needed to ensure safety in the event of failure of these systems or the device itself.

Generic inverter circuit

Figure 3 shows the layout of a typical inverter circuit for generation of a 3-phase variable frequency supply. The capacitor bank is typically several thousands of mF, fed from a DC source. The inductance in the inverter leg can be less than 1mH. In case of semiconductor shoot through the capacitor bank will discharge thru the short circuit path and generate a large fault current that will be cleared by fuses. Alternative locations for the fuses are shown at F1 and F2. Location F1 is the preferred option as the r.m.s. current is lower. This permits smaller current rated fuse size to be used leading to a faster operating protection. However in many circumstances location F2, which requires fewer fuses, may also be satisfactory.

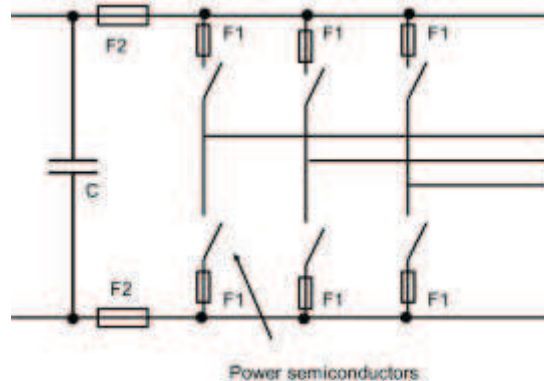


Figure 3: Typical inverter circuit for generation of a 3-phase variable frequency supply



Figure 4: Semiconductor fuses rated at 10kV - 1000 A with low inductance

High voltage semiconductor fuse

Increase of voltage for IGCT and IEGT protection, demand for lower I²t for IGBT protection and large rectifier protection have led to new rating and new fuse performances. It is not rare anymore to see semiconductor fuses rated at 10kV - 1000 A with low inductance see in figure 4. Fault simulation will help to calculate the melting duration, and will give the total I²t to be compared with the semiconductor housing I²t. If needed for demanding

applications our capacitor discharge lab will backup simulation/calculation by true testing. Also Mersen high power AC lab can be used to determine the semiconductor true housing I²t value.

Conclusion

Cost is always a driving factor when selecting a fuse but what is a fuse cost versus containing the fault inside the semiconductor instead of spreading it throughout the entire inverter with the catastrophic risk of explosion. This article has introduced too briefly the semiconductor fuse and much more needs to be shared. I invite all readers to know and understand fuses better. I would like to thank Cindy, Jean-Louis and Kevin that have contributed to the making of this article.

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