FAST-ACTING FUSES FOR SEMICONDUCTOR PROTECTION

POWER ELECTRONICS NOTE 3

BY JEAN-FRANÇOIS DE PALMA

With the birth of semiconductors in the 50s and their use in power converters the need of protection with fuses came along. Fuses for the protection of semiconductor, known as semiconductor fuses, 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, and IGCT for drive application as well as large diodes 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.

INTRODUCTION TO FUSES

Like power semiconductor devices, fuses are technical devices backup by years of development and testing. When selecting semiconductor fuses, 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 602694, like body and terminal temperatures rise, arc voltage as well as customer application requirements, energy let thru by the fuse, commonly known as I^2t, 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.

GLOSSARY

- **I^2t:** Image of energy let go by a fuse while clearing the current.
- **di/dt:** Current rate of rise.
- **UL/CSA/IEC:** National and International Standards.

CONTACT

USA
374 Merrimac Street, Newburyport, MA 01950
T 978 462 6662 | F 978 462 0181
info.nby@mersen.com

CANADA
6200 Kestrel Road, Mississauga, ON L5T 1Z1
T 905 795 0077 | F 905 795 2508
technicalservices.mis@mersen.com

BASIC FUSE DESIGN TECHNOLOGY

A typical semiconductor fuse consists of one or more silver or copper or thrulay (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 performance. 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 terminal. 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 to 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.

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 I^2t needed to melt the fuse element; in another words the energy you need to deliver to the fuse to melt the reduced section path. Under sustained overcurrent, the fuse element generates heat at a faster rate than the filler can conduct it away from the element. If the overcurrent 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 preacing time is launched you are only pat way to final fuse opening.

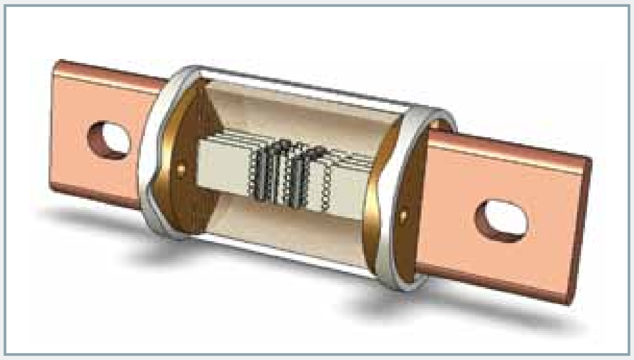

Figure 1: The numbers of notches in series will define the fuse operating voltage and the total cross section of paralleled element will define the rating of the fuse

FUSE I^2T PARAMETERS

Once the end of the pre-arcing time is reached the fuse switches to the arcing mode. The fuse will develop an arc voltage, higher than the source

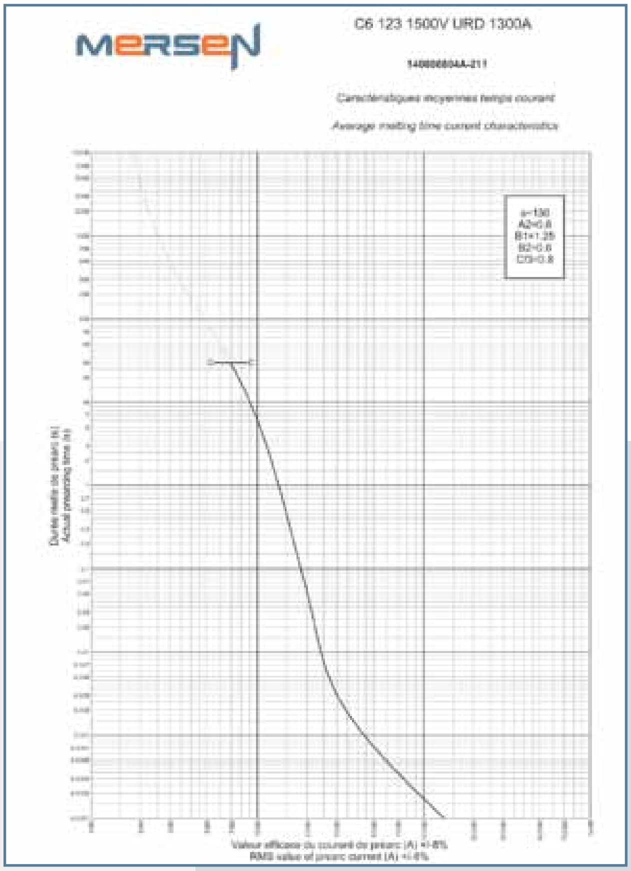

Figure 2: The fuse time current curve

Expertise, our source of energy

voltage thus will force the current to go down to zero. This period is call the arcing time. During this period fuse will have to dissipate the energy supplied by the source as well as the energy stored in the circuit, mainly ½ LI2. The total energy let through by the fuse, or known as total I^2t, is the result of the sum of the prearcing I^2t plus the arcing I^2t. Those values are supplied for our fast acting semiconductor fuses. The normal condition for shortcircuit protection is that the total I^2t integral let through by the fuse when clearing the fault must be less than the I^2t which produces system damage. For example, for the IGBT's the appropriate value is the level of I^2t which causes case rupture.

EXAMPLE OF APPLICATION

Shortcircuit faults in power electronics equipment will cause excessive damage, or in worst case, explosion. Electronic protection against overloads and shortcircuits is normally embedded in the new power electronic semiconductors but backup 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 semiconductors shoot through the capacitor bank will discharge through 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.

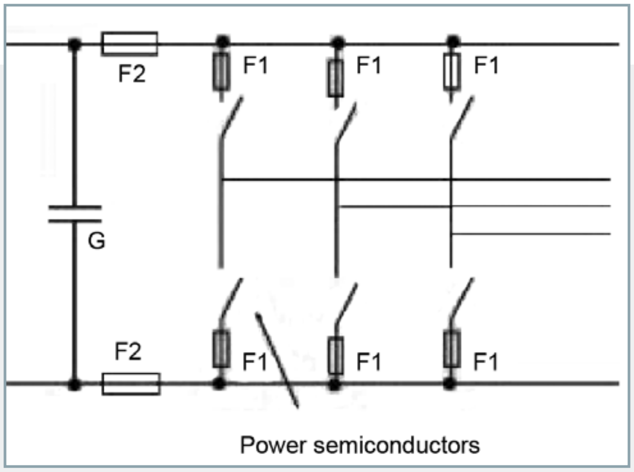

Figure 3: Typical inverter circuit for generation of a 3-phase variable frequency supply

HIGH VOLTAGE SEMICONDUCTOR FUSE

Increase of voltage for IGCT and IEGT protection, demand for lower I^2t for IGBT protection and large rectifier protection have lead 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 figure 4). Fault simulation will help to calculate the melting duration, and will give the total I^2t to be compared with the semiconductor housing I^2t. If needed for demanding applications our capacitor discharge lab will backup simulation/calculation by true testing. Also Mersen'a High Power Test Lab can be used to determine the semiconductor true housing I^2t 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 Tech topic has too briefly introduced the semiconductor fuse and much more needs to be shared. I invite all readers to know and understand fuses better.

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