Overload Protection

Semiconductors are used today in many applications in power and control circuits. Their great advantage is in their capability to handle considerable power within a very small size. Unfortunately, because of their small mass, they are less able to withstand high-current overloads and overvoltages. Currents of many thousands of amperes may be caused by electrical faults (e.g., short circuits) in the circuit. The following pages describe the possibilities of protecting a semiconductor by fusing—when and how a fuse can be used and how much protection is afforded. Cases for which fuse protection is not possible, or for which only partial protection is feasible, are also discussed. Fuse selection methods are described.

FUSE BASICS

A fuse is a component that protects the semiconductor devices in a circuit against a failure of one or more of them as a result of a current overload. The fuse is connected in series with either the device to be protected or the load to be controlled.

The protection requirements of a fuse can be summarized as follows:

> A fuse must withstand the normal steady-state current, and interrupt overload current safely without permanently changing semiconductor performance.
>
> Therefore, a fuse must limit the amount of current allowed to pass through the semiconductor, limit the thermal energy to which a device is subjected (I^2t), and not produce an arc voltage greater than the semiconductor rating.

The protection can be either complete or for short-circuit only. In the first case, the fuse capability must be less than that of the semiconductor it is to protect over the overload time range. This type of protection is illustrated in Fig. 205.

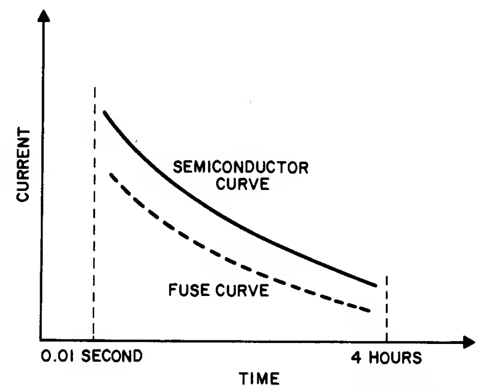


Fig. 205 - Complete protection of semiconductor by fuse.

The second case is the most common: a circuit breaker provides protection during long-duration overload, and the fuse works only for short-duration overloads. This type of protection is shown in Fig. 206. The following pages examine only the second type of protection.

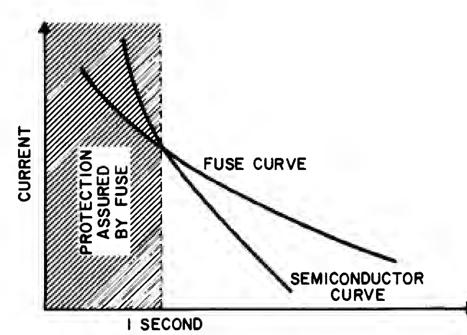


Fig. 206 - Semiconductor protected by fuse for short-circuit only.

Definitions

As shown in Fig. 207, a cartridge fuse consists of the fusing element (generally pure silver), the filling material, the body, and the terminals. Fig. 208 shows how the fuse is connected into the circuit; Fig. 209 shows the condition of the waveforms when a fuse interrupts an overload current.

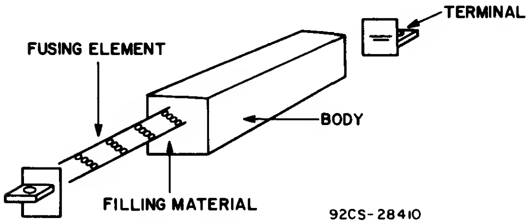


Fig. 207 - Cartridge fuse parts.

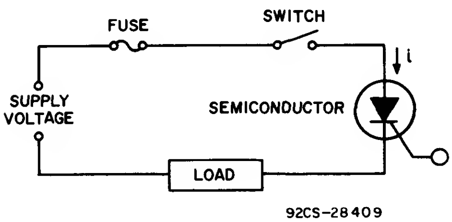


Fig. 208 - A fused circuit.

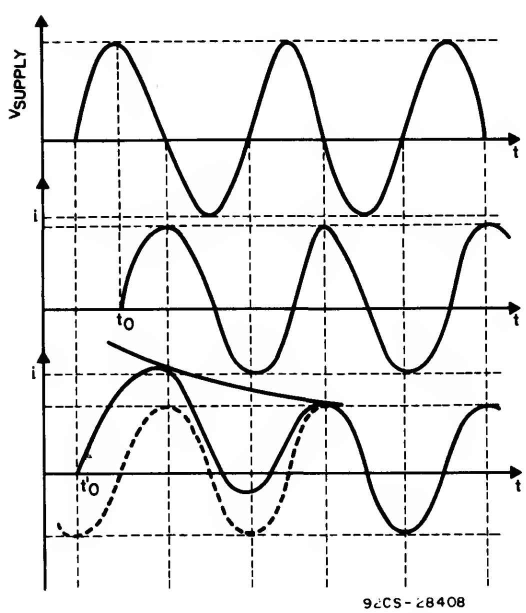


Fig. 209 - Current waveform for unfused circuit.

The shape of the current waveform depends on the time at which the overload occurs. Assume first that the overload occurs at the time that the switch (Fig. 208) is closed. If the switch is closed at t_o, the time of maximum supply voltage, the current waveform will be symmetrical, Fig. 209. If the switch is closed at another time, particularly at t'_o, the current waveform will be asymmetrical. This asymmetry is caused by the load parameter, $\cos\phi$ (generally, during fuse manufacture, $\cos\phi$ is chosen at 0.1). When an overload current is interrupted by a fuse, the short-circuit current shape is triangular, as shown in Fig. 210. Of course, this shape is fixed by the properties of the fuse.

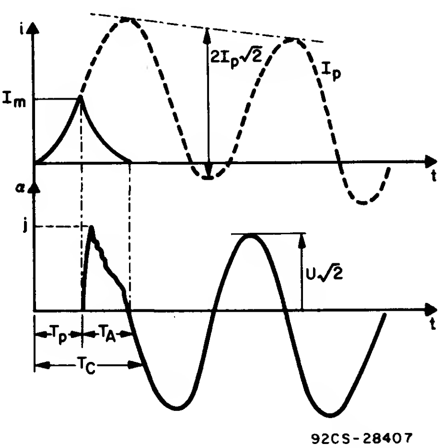


Fig. 210 - Voltage and current waveforms during action of a fuse.

Fuse Terminology

Voltage Rating, V_N:
Sinusoidal or continuous voltage value for which the cartridge fuse is built.

Current Rating, I_N:
Current from which characteristics are drawn. The fuse can withstand this current without damage.

Expected Current, I_p:
AC: Effective value of the ac current component.
DC: Continuous-current component value. This current would flow in the circuit if the cartridge fuse impedance were negligible.

Melting Time, T_p:
Time from the moment of overload until the fuse is melted. (Fig. 210)

Arcing Time, T_A:
Duration of arc. (Fig. 210)

Clearing Time, T_c:
$T_p + T_A$ (Fig. 210)

Peak Current, I_m:

Maximum instantaneous current value reached in the protected circuit. (Fig. 210)

Melting Energy, I^2t:

$$\int_{0}^{T_P} i^2 dt$$

Arcing Energy, I^2t:

$$\int_{T_P}^{T_C} i^2 dt$$

Clearing Energy, I^2t:

$$\int_{0}^{T_C} i^2 dt = \int_{0}^{T_P} i^2 dt + \int_{T_P}^{T_A} i^2 dt$$

Arc Voltage:
Maximum voltage across the cartridge fuse during its working time.

Working Voltage:
Effective voltage value across the fuse after the current stops. It is less than or equal to the maximum rated voltage, V_N.

Breaking Capacity:
Maximum current that can be passed by the fuse.

Fuse Characteristics

The following fuse characteristics typically supplied by the manufacturer are shown in Fig. 211.

Time/current characteristics
Maximum value of total operating energy
Actual total operating time
Voltage drop
Arc voltage
Cutoff characteristics

An example of how these characteristics are used is given below.

Fuse Position

There is no well-established theoretical method for determining the correct location of a fuse in a circuit; only practical examples can be given: rectifier circuits, inverters, dimmers—all in the small- or medium-power range. More detailed methods concerning the protection of high-power circuits through the use of several semiconductors in parallel can be found in the literature. Three types of protection are discussed in the following paragraphs:

- External
- Internal
- Total

Fig. 212 summarizes these types of protection. When only external protection is required, the fuse is connected at the output of the circuit, just before the load. When internal or total protection is required, fuses are placed either at the circuit input or internal to it.

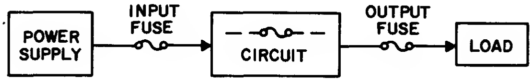


Fig. 212 - Fuse placement.

EXTERNAL PROTECTION

The characteristic curve of the protection system must cover the same time range as the device curve. When the circuit is protected by a fuse only, fuse and device curves cover the same time range, Fig. 205. When a circuit is protected by a circuit breaker and a fuse with a short time characteristic, the current-time capacity of the fuse must be less than that of the semiconductor, Fig. 206.

INTERNAL PROTECTION

Bridge Rectifier

When internal protection is to be provided, the fuses can be connected in series with the semiconductors or the phase lines. For example, Fig. 213 illustrates the case of the protection of a Greatz bridge. The in-line fuse rating is equal to the fuse rating in the bridge multiplied by $\sqrt{2}$. Fig. 214 gives voltages and currents at different locations of several rectifier bridges. This information aids in calculating fuse ratings.

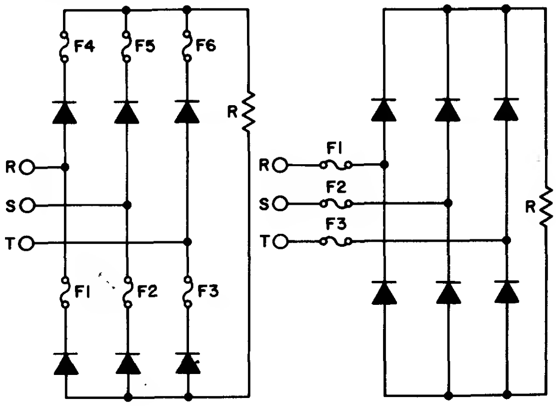


Fig. 213 - Three-phase-bridge fuse protection.

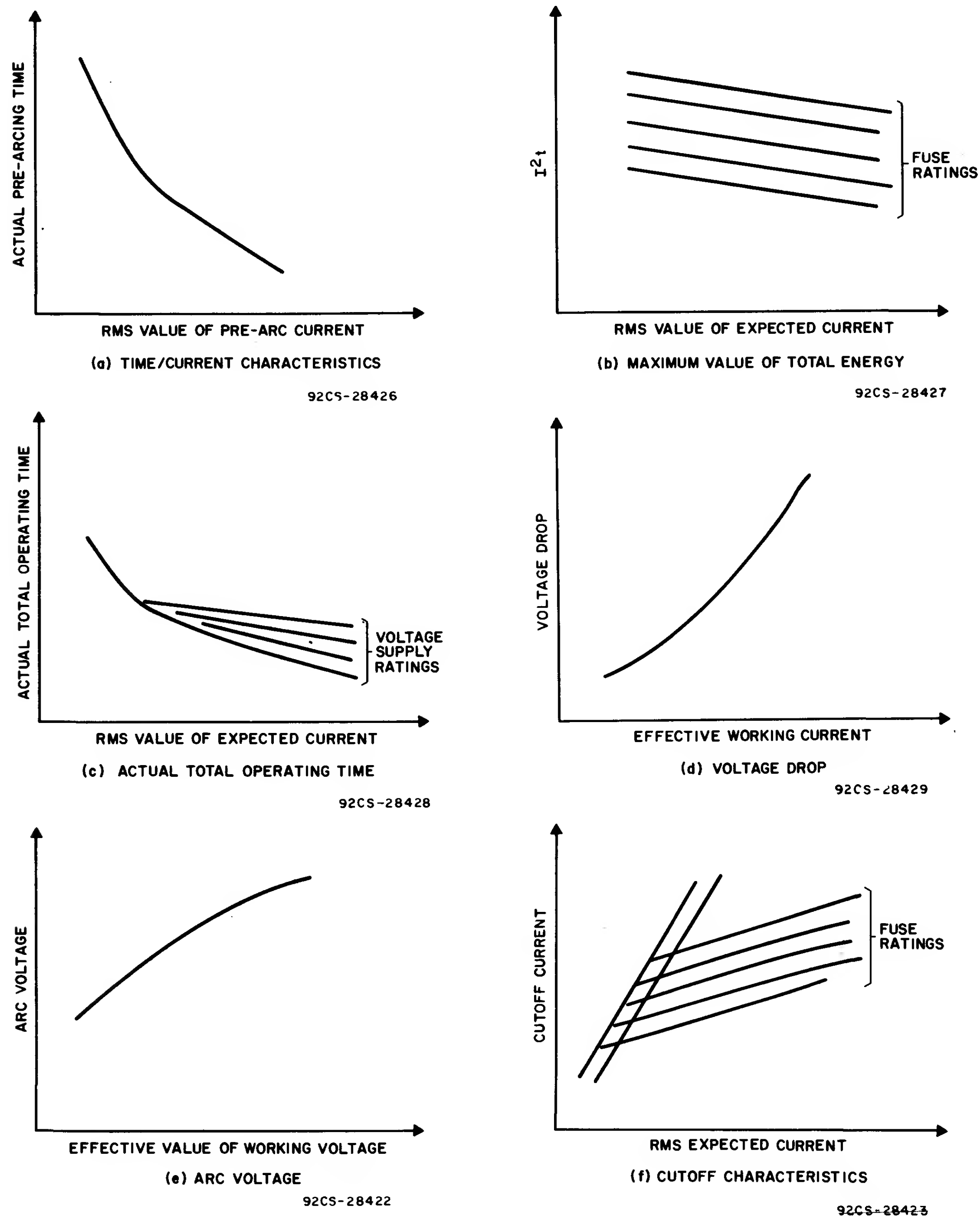


Fig. 211 - Fuse characteristics typically supplied by the manufacturer.

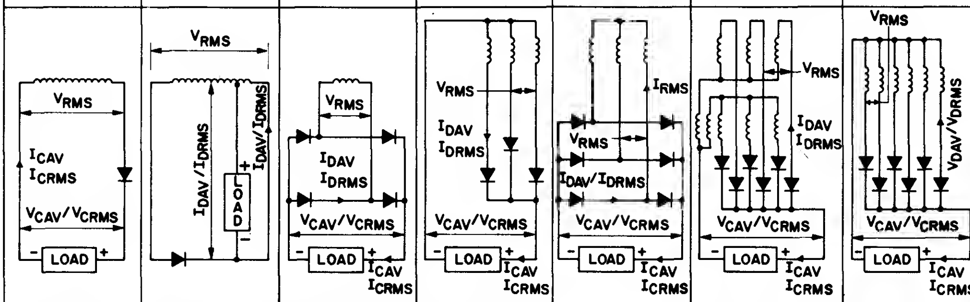
In inverter circuits, it is recommended that the fuse be placed in series with each device.

Fuse Choice

Fuse choice consists of four steps:

- Type of fuse
- Working voltage
- Fuse rating
- Fuse arc voltage

The type of fuse, slow or fast, depends on the type of semiconductor to be protected; a



SINGLE PHASE HALF WAVE	SINGLE PHASE FULL WAVE	SINGLE PHASE BRIDGE	THREE PHASE HALF WAVE	THREE PHASE FULL WAVE	DOUBLE START CONNECTION WITH INTERPHASE TRANSFORMER	HEX -BRIDGE
$I_{CRMS} = \frac{\pi}{2} I_{CAV}$	$I_{CRMS} = \frac{\pi}{2\sqrt{2}} I_{CAV}$ $I_{DAV} = \frac{1}{2} I_{CAV}$ $I_{DRMS} = \frac{\pi}{4} I_{CAV}$	$I_{CRMS} = \frac{\pi}{2\sqrt{2}} I_{CAV}$ $I_{DAV} = \frac{1}{2} I_{CAV}$ $I_{DRMS} = \frac{\pi}{4} I_{CAV}$ $I_{RMS} = \frac{\pi}{2\sqrt{2}} I_{CAV}$	$I_{CRMS} = \frac{\pi}{3} I_{CAV}$ $I_{DAV} = \frac{1}{3} I_{CAV}$ $I_{DRMS} = \frac{\pi}{3\sqrt{3}} I_{CAV}$	$I_{CRMS} = \sim I_{CAV}$ $I_{DAV} = \frac{I_{CAV}}{3}$ $I_{DRMS} = \frac{I_{CAV}}{\sqrt{3}}$ $I_{RMS} = \sqrt{\frac{2}{3}} I_{CAV}$	$I_{CRMS} = \sim I_{CAV}$ $I_{DAV} = \frac{I_{CAV}}{2 \times 3}$ $I_{DRMS} = \frac{I_{CAV}}{2\sqrt{2}}$	$I_{CRMS} = \sim I_{CAV}$ $I_{DAV} = \frac{I_{CAV}}{6}$ $I_{DRMS} = \frac{I_{CAV}}{\sqrt{6}}$
$V_C = \frac{\pi}{2} V_{CAV}$ $V_{PK} = \pi V_{CAV}$ $V_{RMS} = \frac{\pi}{\sqrt{2}} V_{CAV}$	$V_{CRMS} = \frac{\pi}{2\sqrt{2}} V_{CAV}$ $V_{PK} = \frac{\pi}{2} V_{CAV}$ $V_{RMS} = \frac{\pi}{2\sqrt{2}} V_{CAV}$	$V_{CRMS} = \frac{\pi}{2\sqrt{2}} V_{CAV}$ $V_{PK} = \frac{\pi}{2} V_{CAV}$ $V_{RMS} = \frac{\pi}{2\sqrt{2}} V_{CAV}$	$V_{CRMS} = \frac{\pi}{3} V_{CAV}$ $V_{PK} = \frac{2\pi}{3} V_{CAV}$ $V_{RMS} = \frac{2\pi}{3\sqrt{2}} V_{CAV}$	$V_{CRMS} = V_{CAV}$ $V_{PK} = \frac{\pi}{3} V_{CAV}$ $V_{RMS} = \frac{\pi}{3\sqrt{2}} V_{CAV}$	$V_{CRMS} = V_{CAV}$ $V_{PK} = \frac{2\pi}{3} V_{CAV}$ $V_{RMS} = \frac{2\pi}{3\sqrt{2}} V_{CAV}$	$V_{CRMS} = V_{CAV}$ $V_{PK} = \frac{2\pi}{3} V_{CAV}$ $V_{RMS} = \frac{\pi}{\sqrt{6}} V_{CAV}$

C = CONTINUOUS STD
D = DIODE

TRANSFORMER VOLTAGE DROP AND DIODE FORWARD-VOLTAGE-DROP NEGLECTED.

92CL-28454

Fig. 214 - Voltages and currents at various locations of several rectifier bridges.

fuse must operate before semiconductor degradations occur.

The working voltage of the fuse must be in agreement with the supply voltage. Often, to decrease fuse energy dissipation, a higher working voltage than needed is chosen.

The current rating of a fuse must be at least the value of the rms current flowing through the device. But most of the time that value is not large enough and, occasionally, some fuses may fail under the normal steady-state conditions for the device being protected. The fuse manufacturers specify a correction factor, F, which allows the user to calculate the fuse rating as follows:

Fuse Rating=F · I_{RMS}

The factor F depends on the following parameters:

- Permanent current: AC current with T < 100 milliseconds
  DC current without interruption or with interruption limited to within 10 milliseconds
- Temperature
- Forced cooling
- Effect of the current variation on the fuse life
- Current waveshape
- Random current overload expected

The fuse arc voltage is an important parameter; the speed of the fuse and the arc voltage are interdependent. The faster the fuse, the higher the arc voltage. Because this arc voltage is applied between the semiconductor main terminals, it should be smaller than the maximum voltage rating of the semiconductor. The extent to which the arc voltage limits the use of fuses in semiconductor protection is covered in the following paragraphs.

Fig. 215 describes the arc voltage as a function of rms supply voltage. The arc voltage is never more than 2.2 V_N, the sinusoidal or continuous voltage value for which the fuse is designed. In the worst case then, one must select a fuse so that 2.2 V_N does not exceed the maximum rated voltage of the device to be protected.

For additional information on Fuses, refer to RCA Application Note, AN-6452, "A New Practical Fuse-Thyristor Coordination Method."

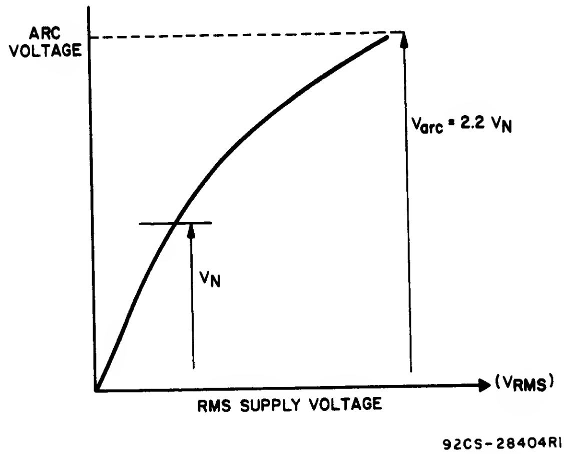


Fig. 215 - Arc voltage as a function of V_{RMS} supply curve.