Although features and functionality attract the most attention for new electronic products, whether consumer, industrial, or medical, their reliability depends on protecting their power systems from overcurrent events. Internal, external, and nuisance threats can affect circuit and system reliability. Through proper fuse selection, you can minimize risks and failures so that an electronic product retains its competitive edge.

Fuses are overcurrent devices that protect electrical and electronic devices by melting and opening a circuit to prevent excessive current from causing damage or starting fires. Fuses serve two main purposes:
1. To protect components, equipment and people from risk of fire and electric shock
2. To isolate sub systems from the main system.

The fusing action begins when the circuit current is high enough to heat the fuse element and starts it to melt. Once melting begins, a gap is created that the current will “arc” across. Melting continues and the gap grows wider until it is too wide to
sustain the arc. At that point, current ceases to flow and the overcurrent event is “cleared,” opening and making the circuit safe.

1. There are two types of overcurrent events:
   1) Overload - simply drawing excessive current beyond the designed capacity of the circuit,
   2) Short-circuit, or fault current.

Regardless of the overcurrent event, fuses are designed and specified to be a circuit’s “weakest link.” These “thermally operated” devices typically employ a metal wire or strip element in their construction.

**Fuse Types**

Fast-acting fuses open very quickly when their current rating is exceeded. This action is needed when speed is important for sensitive electronics and for many dc power applications. They are generally used in resistive loads with low inrush current levels.

Time-delay fuses have a time-delay mechanism. They are designed to open only on an excessive current draw for a defined period of time and are typically used to protect inductive and capacitive loads that experience heavy current draws upon initial powering. The time delay action prevents the fuse from needlessly blowing during a temporary heavy current draw or surge. Time-delay fuses tolerate higher inrush currents than fast-acting fuses and are often ideal for dc-dc converter input protection, as most converters have an input capacitor that draws a large amount of current when initially charged.

Selecting the right fuse is critical in all electronic and electrical system designs. Catastrophic system failure can be prevented with the proper fuse on the dc-dc converter input. In the event the converter’s internal circuitry can no longer withstand an overload condition, the fuse will prevent fire or further damage to the board, the converter, or neighboring components. Most dc-dc converters are protected from short-circuits on their outputs by either circuit-sensing current limit and/or thermal overload circuits. Fuses are required to protect against a catastrophic component failure (e.g., MOSFET failure) or if a component failure creates a short-circuit on the input side of the dc-dc converter.

Proper selection of an input fuse for a dc-dc converter involves understanding and consideration of the following factors:

1. Voltage Rating
2. Current Rating
3. Interrupting Rating
4. Temperature Derating
5. Melting Integral (I²t)
6. Maximum Circuit Fault Current
7. Required Agency Approvals
8. Mechanical Considerations

**Voltage Rating**

Fuses are first rated by the ac and/or dc circuit voltage into which they can be safely applied. A fuse installed in an AC circuit performs differently than when installed in a DC circuit. With AC circuits, the current is crossing the zero potential at 60 or 50 cycles a second. This helps in breaking the arc that forms when the fuse element melts and creates a gap. In dc circuits, the voltage does not go to a zero potential, making it more difficult to suppress the arc in the melting element’s gap.

Generally, fuse ac voltage ratings coincide with the utility supply, e.g., 110V, 240V, 415V, etc. This means that a fuse is suitable for use with these nominal voltages and is tested for voltage levels at least 15% higher than the nominal rating. This is not true with dc voltage ratings, which are normally maximum ratings and should not be exceeded. More specifically, the voltage rating of a fuse must be equal to or greater than the maximum voltage expected in the application.

Fuses are insensitive to voltage changes within their ratings so selecting the proper voltage rating is strictly a safety issue. Fuses can operate at any
voltage below or equal to their rated voltage.

CURRENT RATING
Although some power supplies are designed for constant current output regulation, most typical DC-DC converters are designed as constant power devices. This means that as the input voltage drops, the input current must increase to uphold the constant output power relationship of \( P = V \times I \).

The fuse’s minimum current rating is determined by the maximum input current of a DC-DC converter. Typically, the maximum current consumption occurs at the maximum output load and the minimum input voltage. The magnitude of the input current can be determined from:

\[
I_{\text{INPUT(MAX)}} = \frac{P_{\text{OUT(MAX)}}}{V_{\text{IN(MIN)}} \times \text{Efficiency}} \tag{1}
\]

Where:
\( P_{\text{OUT(MAX)}} \) = Maximum dc-dc converter output power.
\( V_{\text{IN(MIN)}} \) = Minimum input voltage on the dc-dc converter input.
Efficiency = Efficiency of dc-dc converter at \( P_{\text{OUT(MAX)}} \) and \( V_{\text{IN(MIN)}} \); can be determined from the dc-dc converter’s datasheet.

To prevent damage to converter components, the fuse current rating is selected with a large enough current capability so that the fuse will not open under steady state conditions, yet will open during an abnormal (excessive) overload or short-circuit condition. Usually this results in selecting a fuse to be 150% to 200% percent of the maximum steady state input current at maximum load and minimum line input voltage.

INTERRUPTING RATING
The fuse interrupting rating is the maximum amperage at rated voltage the fuse can safely interrupt. This rating must exceed the maximum fault (short-circuit) current the circuit can produce. Interrupting ratings for AC and DC currents are different and the fuse data sheet should be consulted before selection.

TEMPERATURE DERATING
When a fuse is applied in an ambient temperature exceeding the standard 23°C, the fuse current rating should be derated (a higher amp rating with higher temperatures). Conversely, operating at an ambient temperature lower than the 23°C standard allows using a lower fuse amp rating. Fig. 1 shows a typical fuse derating curve. The fuse rating is determined by:

\[
I_{\text{RATED}} = \frac{I_{\text{INPUT(MAX)}}}{K_{\text{TEMP}}} \tag{2}
\]

Where:
\( I_{\text{INPUT(MAX)}} \) = Current determined from Equation (1) or a dc-dc converter datasheet
\( K_{\text{TEMP}} \) = Temperature derating factor determined from Fig. 1.

The lowest suitable fuse rating is obtained by rounding up the calculated value to the next higher current rating shown in the fuse datasheet.

MELTING INTEGRAL
The DC-DC converter peak inrush current is usually significantly greater than the steady state current. Additionally, periodic inrush currents can be sufficiently powerful to warm the fuse element. Though not large enough to melt the element, it can still cause significant thermal stress to the element. Cyclical expansions and contractions of the fuse element can lead to mechanical fatigue and premature failure.

Selecting the appropriate fuse involves choosing the appropriate melting integral. The melting integral of a fuse, termed melting \( I^2t \), is the thermal energy required to melt a specific fuse element. The fuse element construction, materials and cross sectional area will determine this value.

The task of a system designer is to select a fuse with the minimum \( I^2t \) greater than the energy of the inrush current pulse. This rating ensures that the fuse will not cause a nuisance opening during transient conditions. For reliable system operation for the required number of turn-on cycles, the following condition must be met:

\[
I^2t_{\text{(FUSE)}} = I^2t_{\text{(PULSE)}} \times F_P \tag{3}
\]

Where:
\( I^2t_{\text{(PULSE)}} \) = Energy of a current pulse
\( I^2t_{\text{(FUSE)}} \) = Melting integral of a fuse
\( F_P \) = the pulse factor (dependent on fuse element construction in Table 1)

\( I^2t_{\text{(FUSE)}} \) can be found in fuse datasheets. Do not use

<table>
<thead>
<tr>
<th>TABLE 1. PULSE FACTOR FOR SOLID MATRIX CONSTRUCTION</th>
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<tbody>
<tr>
<td>Number of Surge Pulses</td>
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<td>------------------------</td>
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<td>1 to 100,000</td>
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<th>TABLE 2. FUSE PULSE FACTOR</th>
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<tr>
<td>Pulse Factor for Wire-in-Air Construction</td>
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<tr>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>Number of Surge Pulses</td>
</tr>
<tr>
<td>------------------------</td>
</tr>
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<td>1,000</td>
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the fuse’s maximum melting integral in Equation (3), and use either the minimum or nominal melting integral of the fuse.

**MAXIMUM CIRCUIT FAULT CURRENT**

Other selection considerations include start-up (inrush) currents and transient load conditions. When a dc-dc converter is initially powered, the input bulk capacitors of dc-dc must be charged. Current flowing into the input terminals of a dc-dc converter is approximately \( I = \frac{V}{R} \) for typical power supplies with charge times less than 10 milliseconds. When \( V \) is the input voltage change, and \( R \) is a combination of wiring resistance, your source’s resistance under start-up, and the Equivalent Series Rating (ESR) of the converter’s input bulk capacitors.

Larger dc-dc converters often use a large capacitor with very low ESR inside the converter. This inrush current can have a significant effect on the fuse’s life. Size the fuse properly to allow these inrush current pulses to pass without nuisance openings or degrading the fuse element as discussed in melting integral.

To calculate current pulse energy, one must first determine the magnitude and duration of the current pulse. The most accurate way to determine parameters of a current pulse is to measure this current in the application under minimum and maximum voltage conditions.

Note that the melting \( P_t \) values of the fuse must be calculated at the condition where the product of the peak current squared and time the peak occurs is maximum. For example, the steady state current is maximum at low line so a transient load surge needs to be added to the low line current to establish the maximum peak current for an operating condition. But the inrush current is usually maximum at the highest input voltage. The fuse’s melting \( P_t \) must be evaluated at the condition with the highest calculated \( P_t \) to ensure that the fuse will not open during these “normal” operating conditions.

The pulse factor is dependent on the construction of the fuse element (see pulse factor tables under Melting Integral).

The patented solid matrix construction used in the Cooper Bussmann® 0603FA, 3216FF, CC12H and CC06 fuse series provides excellent cycling and temperature performance while significantly reducing nuisance openings from high inrush currents. It also provides protection against unanticipated current surges from the system. The small physical size allows maximum protection without oversizing the fuse rating. Solid matrix construction reduces heating from repeated surges that would normally cause a fuse to open at lower current levels.

Wire-in-air construction, as in the 3216TD and new S505H series, and many traditional ferrule fuses, provides high inrush withstand. Wire-in-air technology makes a smaller fuse possible without sacrificing \( P_t \), temperature or operating voltage range. Using a fuse with high surge-withstand capability means fewer open fuses during momentary overloads.

**AGENCY APPROVALS**

North American UL/CSA and IEC standards for overcurrent protective devices require significantly different Time-versus-Current characteristics. UL rated fuses are tested to open at 135% of rated current while IEC fuse ratings are tested to carry 150% of rated current. Be aware of these differences as the fuses are tested and specified differently between these standards for products sold in different parts of the world.

The physical dimensions and materials for both UL and IEC fuses are similar. However, fuses made to different standards are not interchangeable. Their element melting and opening times will differ when subjected to the same magnitude of current. The circuit designer must consider that different world markets may require different fuse agency standards.

To select a fuse that ensures system and agency compliance the following conditions must be met:

- Fuse current rating does not exceed the rating of the fuse used for safety testing of the dc-dc converter it is intended to protect.
- Fuse is installed on the ungrounded side of the circuit to ensure uninterrupted ground connection in case the fuse opens.
- The input traces and chassis ground trace (if used) are capable of conducting a current of 1.5 times the fuse current rating.

**MECHANICAL CONSIDERATIONS**

There are numerous physical sizes of fuses for electronics, including subminiature fuses. The most common ferrule designs are 5x15mm, 5x20mm and 6.3x32mm (¼ in. x 1¼ in.). Ferrule fuses are generally mounted in fuse clips or holders with some available with axial leads for soldering directly onto a PCB. Subminiature fuses are often used when board space is limited. For applications of this type, there are through-hole and surface mount devices available. Standard package sizes for surface mount fuses are 0402 (1005), 0603 (1608), 1206 (3216), 6125, and 1025.
By selectively removing these fuses, the various converters can be powered separately, or the PFC operated with an external load. In addition to facilitating testing of the different power sections during product development, the fuses can aid troubleshooting in production and in the event the product needs to be repaired.

Fuses applied to overcurrent protection points of Fig. 2 include F1 providing primary overcurrent protection. Use ac line voltage rated fuses located on the transformer primary side (typically 125Vac / 250Vac line voltage)
- SR-5 / SS-5 radial fuses
- S501-2-R fast-acting fuse
- C310T Series (coming soon)
  3.6x10mm axial-leaded, time-delay, ceramic tube fuse (Fig. 3)
- 5mm or ¼ in. ferrule fuses

Fuses F2 and F3 that provide secondary overcurrent protection. Use 400Vdc or higher rated fuses on the secondary side of the transformer or on battery powered applications (ac or dc, typically lower voltages, but not always).
- PC-Tron® (up to 2.5A) (Fig. 4)
- S505H Series (coming soon)
  400Vdc/500-600Vac, time-delay, 5x20mm (Fig. 5)

These sizes are standard throughout the electronic industry. Through-hole axial and radial leaded products allow fuses to be PCB mounted. For example, Cooper Bussmann offers electronic fuses ranging from 32V to 450V. Voltage ratings can and do vary inside a fuse family or series, as well as interrupting ratings, I²t and agency approvals. Always consult data sheets for the ratings that apply to the desired voltage and amp rating of the application.

**TYPICAL FUSE LOCATIONS IN POWER SUPPLIES**

Product safety standards require fuses for primary ac power protection and secondary protection against any catastrophic failure in the input filter capacitors, Power Factor Correction (PFC) boost module, output capacitors, or within the dc-dc converters where fuse F1 in Fig. 2 is a typical ac fuse location. The fuse is placed near the input connector so that all other components are downstream and protected.

The PFC boost module usually does not contain overcurrent protection. If a short-circuit is applied across the PFC output terminals, there is no internal circuit opening device to safely interrupt the power. The fuse in the AC input line (Fuse F1 in Fig. 2) protects the PFC boost converter.

Although the primary input line fuse will eventually open, dc fuses positioned right at the input to the dc-dc converters will limit the energy delivered by the hold-up capacitors and prevent failure to the PFC boost module. DC fuses between the PFC and dc-dc converters protect against a catastrophic failure in the dc-dc converter (Fuses F2 and F3 in Fig. 2). Fusing each dc-dc converter will allow the converter not subject to a fault to continue operating by isolating the failed converter.

Fuses F2 and F3 have an added benefit during product development.

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**Fig. 5. The S505H Series of time delay fuses**

By selectively removing these fuses, the various converters can be powered separately, or the PFC operated with an external load. In addition to facilitating testing of the different power sections during product development, the fuses can aid troubleshooting in production and in the event the product needs to be repaired.