Input Fuse Selection

Application Note

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Introduction

A fuse is recommended at the input of a DC/DC converter to protect the input circuitry from damage in case of a catastrophic failure of the DC/DC converter. The fuse must be used if it is specified in the "Conditions of Acceptability" section of the DC/DC converter safety report.

Besides providing protection, the fuse also isolates the failed DC/DC converter from the rest of the system, allowing the system to continue operating. The fuse should be installed in the ungrounded lead to preserve the integrity of the system grounding under fault conditions.

1. Fuse Selection Checklist

Proper selection of an input fuse for a DC/DC converter involves thorough consideration of the following factors:

1. Current rating
2. Voltage rating
3. Temperature derating
4. Melting integral
5. Maximum fault current of the circuit
6. Required agency approvals
7. Mechanical considerations

While items 2, 6, and 7 are derived from system specifications, a number of measurements and calculations needs to be performed to determine items 1, 3, 4, and 5.

2. Current Rating

The minimum current rating of a fuse 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 the equation below:

$$I_{input\_max} = \frac{P_{out\_max}}{V_{in\_min} \times h}, (1)$$

Where P_{out_max} is the maximum output power of the DC/DC converter expected in the application; V_{in_min} is the minimum input voltage on the input pins of the DC/DC converter; and η is the efficiency of the DC/DC converter at P_{out_max} and V_{in_min}. The efficiency can be found from the DC/DC converter's datasheet.

The magnitude of the input current also can be found from the input characteristic similar to the one in Figure 1. Note that the input current values are measured at the maximum rated output current. Therefore, using the value from the curve below will result in an oversized fuse if a DC/DC converter is not fully loaded.

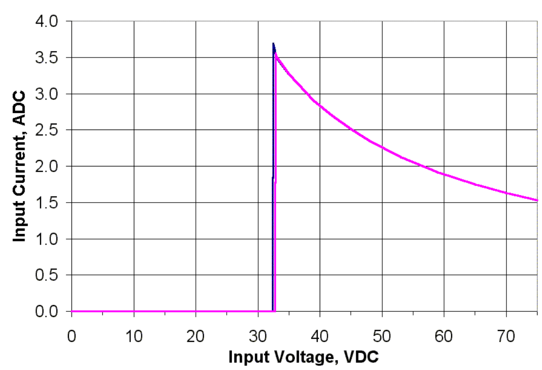

Fig. 1 HLS30ZE (3.3V) Input Characteristic

To satisfy various safety agency requirements, the actual continuous operating current of a fuse at room temperature should not exceed 70% of the rated current of the fuse. The derating is required because of the differences between lab test conditions utilized by the agencies and real world applications. This factor compensates for the input voltage fluctuations, enclosed fuseholders, airflow, variances in wire and solder pad dimensions, and differences in contact resistances.

3. Voltage Rating

The voltage rating of a fuse must be equal to or greater than the maximum voltage expected in the application. Since fuses are insensitive to voltage changes, the proper voltage rating selection is strictly a safety issue. Fuses can operate at any voltage below their rated voltage.

4. Temperature Derating

If a fuse is intended to operate at an ambient temperature exceeding the standard 23°C ambient temperature, its operating current should be derated further. Conversely, operating at an ambient temperature lower than the standard allows the operating current to increase. Typical fuse derating curves are shown in Figure 2.

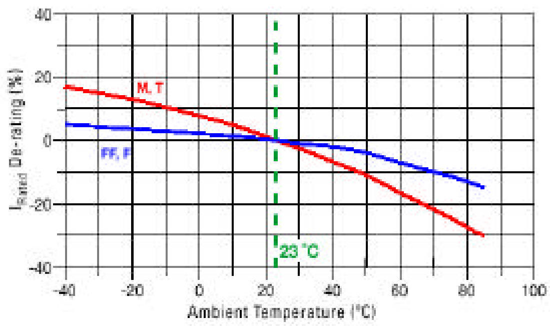

Fig. 2 Derating curves published by Wickmann.

The red curve is for slow blow fuses; the blue curve is for fast-acting fuses.

Then, the fuse rating is determined by the equation below:

$$I_{rated} = \frac{I_{input\_\max}}{0.7 \times K_{temp}}, \quad (2)$$

where I_{input_max} is the current determined from (1) or a DC/DC converter datasheet, 0.7 is a derating factor required by safety agencies, and K_{temp} is the temperature derating factor determined from Figure 2. Note, that K_{temp} is less than 1.0 for temperatures exceeding 23°C and more than 1.0 for temperatures lower than 23°C.

The lowest suitable fuse rated current is obtained by rounding up the calculated value to the standardized rating values shown in the fuse catalog. The selected rating needs to be lower than the fuse rating used to conduct safety testing of the DC/DC converter. The rating of that fuse can be found either in the converter's datasheet or in the "Conditions of Acceptability" part of the DC/DC converter's safety report.

5. Melting Integral

When a DC/DC converter is connected to the input voltage source, it causes an inrush current. A similar phenomenon occurs during hot swapping. The peak inrush current of a DC/DC converter can be significantly greater than the steady state current.

Periodic inrush currents sufficiently powerful to warm the fuse element but not strong enough to melt it cause significant thermal stress of the element. Cyclical expansions and contractions of the fuse element can lead to mechanical fatigue and its premature failure. Selecting the appropriate fuse involves choosing the appropriate melting integral rating.

The melting integral is a measure of the thermal energy required to melt the fusing element. The melting integral is measured in A^2s and is represented in catalogs as I^2t. The I^2t for a particular fuse is a function of the melting element construction and material and is independent of both temperature and voltage.

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. It will guarantee that the fuse will not cause a nuisance opening during the transient conditions. To ensure reliable operation of the system for the required number of turn-on cycles, the following condition must be met:

$$I^2t_{PULSE} \le I^2t_{FUSE} \times K, \quad (3)$$

where I^2t_{PULSE} is energy of a current pulse, I^2t_{FUSE} is the melting integral of a fuse, and K is the factor determined by the number of current pulses the fuse must withstand.

I^2t_{FUSE} can be found in a fuse datasheet. Make sure that the value used in (3) is either the minimum or nominal melting integral of a fuse, not its maximum melting integral. The condition (3) also determines the type of a fuse that is suitable for the application. We recommend starting with a fast-acting fuse. If it does not meet (3), a slow blow fuse should be considered. Slow blow fuses have an inherent thermal delay that makes them capable of withstanding large current pulses.

The factor K is determined from the chart in Figure 3.

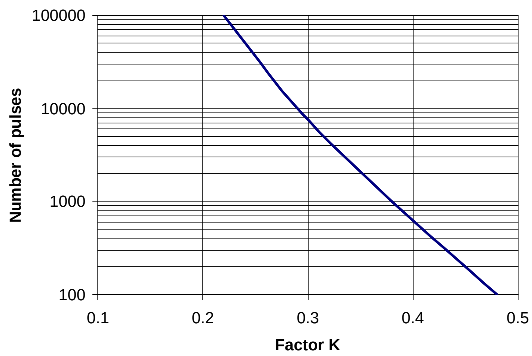

Fig. 3 Number of pulses a fuse can withstand as a function of the ratio of the I^2t_{PULSE} to I^2t_{FUSE} (published by Littelfuse).

Note that the chart can be used only when the time interval between current pulses is sufficient enough for the fusing element to cool down to its normal operating temperature. Typically, the interval is between 10 and 30 seconds. If the time interval is shorter than that, contact the fuse manufacturer for appropriate curves.

5.1 Pulse Energy

To calculate current pulse energy, it is necessary to determine the magnitude and duration of the current pulse. The parameters depend on many factors, such as the input voltage, the source and supply line impedance, internal input inductance and resistance, as well as capacitance and ESR of the internal input filter of the DC/DC converter. Some of the factors depend on a system design and layout and are difficult to calculate. The most accurate way to determine parameters of a current pulse is to measure them in the application.

Make sure that the current sensor used to measure a current pulse does not change its parameters. Non-invasive sensors such as Hall sensors are recommended for the measurements.

Equations for current pulse energy of the most common waveforms are shown in the table below.

Waveform	Equation
Rectangle	$I^2t_{PULSE}=Ip^2 \times t_P$
Sine	$I^2t_{PULSE}=0.5 \times Ip^2 \times t_P$
Triangle	$I^2t_{PULSE}=0.33 \times Ip^2 \times t_P$

Where Ip is the amplitude of the current pulse and t_p is the duration of the pulse.

However, the most common waveform of an inrush current pulse is not a perfect geometrical shape.

Figure 4 shows the inrush current of a Power-One DC/DC converter model HLS030ZE, connected to the 48V source via a 1' cable. A 100µF aluminum electrolytic capacitor was connected across the input pins of the converter to simulate typical power distribution scheme.

For the purposes of the note, no attempts have been made to limit the magnitude of the inrush current. In real world applications, the inrush current is limited by special circuitry. See the application note "Inrush current control" on www.power-one.com for details on design of the current limiting circuits.

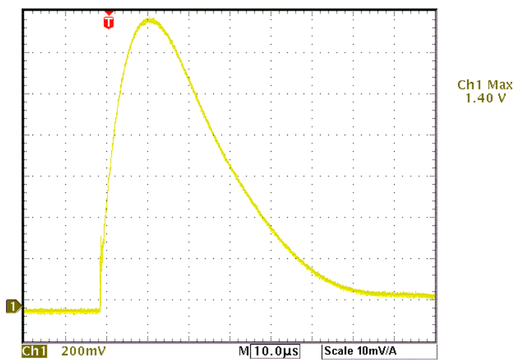

Fig. 4 Inrush current of HLS030ZE with an external 100µF electrolytic capacitor

The following equation is used to determine energy of the inrush current pulse:

$$I^2t_{PULSE} = I_p^2 \times (0.72 \times t_h - 0.39 \times t_r), \quad (4)$$

where I_p, t_h, and t_r are determined from Figure 5.

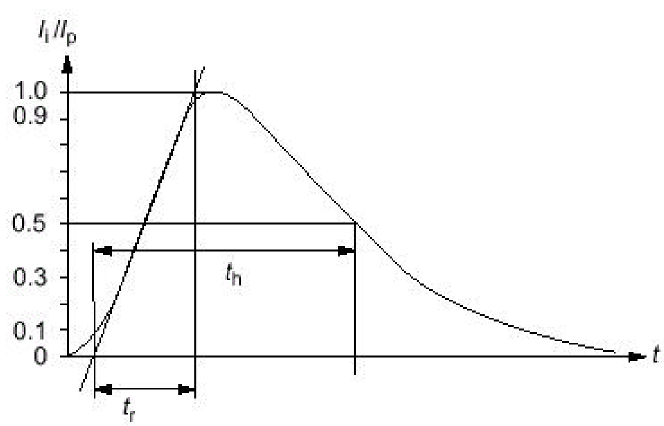

Fig. 5 Parameters of the inrush current pulse

6. Agency Approvals

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

- Current rating of the fuse does not exceed the rating of the fuse used for safety testing of the DC/DC converter it is intended to protect. The information can be found in the "Conditions of Acceptability" section of the DC/DC converter safety report.
- Fuse has a published DC rating.
- Fuse is installed in the ungrounded line. It will ensure uninterrupted ground connection in case of the fuse opening.
- Both input traces and the chassis ground trace (if used) are capable of conducting a current of 1.5 times the rated current of the fuse.
- The fuse is approved by your company's safety department.

It is important to understand that the purpose of the fuse is to protect the internal circuitry and not to provide safety disconnect.

7. Design Example

Given: DC/DC converter – HLS30ZE
Iout=30A
Vin=48V
Tambient=50°C
Inrush current – Figure 4
Number of turn-on cycles - 10,000

Solution:

Power-One recommends using the smallest fast-acting fuse suitable for the application. In our internal testing, Littelfuse NANO series 451 fuses are used. They feature a compact package, SMT mounting, and a DC rating up to 125V. To select a particular fuse, the following calculations need to be performed:

1. Minimum current rating:

From Fig. 1, the HLS30ZE input current at Iout=30A and Vin=48V is 2.3A.

From (2), $I_{rated} = \dfrac{2.3}{0.7 \times 0.96} = 3.42A$

2. Maximum current rating

According to the safety test report, the HLS30 series converters were tested with a 10A fuse.

3. Melting integral

From Figure 3, K=0.29

From Figure 4 and (4),

$$I^2 t_{PULSE} = 140^2 (0.72 \times 30ms - 0.39 \times 10ms) = 0.35A^2 s$$

From (3), $I^2 t_{FUSE} = \dfrac{0.35A^2 s}{0.29} \geq 1.21A^2 s$

4. Select the fuse catalog #R45103.5, Irated=3.5A, nominal I^2t_{FUSE}=2.47A^2s.

5. To ensure proper selection of the fuse, always perform testing under normal and fault conditions. If the fuse is going to be subjected to multiple inrush current pulses, life testing should be performed as well.

Bibliography

1. Wickmann. "Fuseology Application Bulletin"
2. Power-One. "Inrush Current", Technical article, 2000
3. Littelfuse. "Fuseology"