Find the Right Fuse!

Selection Criteria for Correct Fuse Protection

Circuitry over-current protection rarely receives the attention it deserves. An inadequately thought out selection of fuses can lead to the breakdown of equipment and installation, resulting in high replacement costs and dissatisfied customers. This technical article focuses on the correct selection criteria for fuses and fuseholders, and should provide help for taking the more important aspects into consideration.

The function of a fuse is to interrupt an uncontrolled fault current or over-current before serious damage can occur such as the overheating of equipment. Because of its fusing element, a fuse is particularly suited for the reliable interruption of short-circuits. With moderate over-currents of up to 2x or 3x the rated current, a fuse is insufficiently accurate and as such, not so well suited. Other measures such as electronic protection, thermal overload elements or additional fuses are then necessary.

Normal operation after switching on is explained under point 1. This point should always be taken into consideration.

Point 2 is only necessary with capacitive loads when the charging of capacitors after switching on lead to high in-rush current peaks and where the rated current of the fuse is exceeded by many multiples.

Important facts with regard to fuseholders are given under point 3, where the correct selection of fuse and fuseholder combinations is explained.

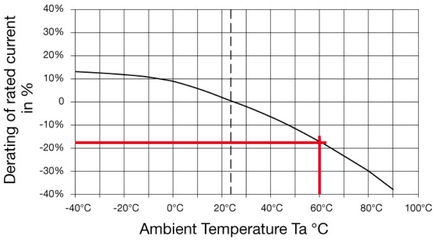

Fig.1 shows the derating curve of the time-lag SMD fuse UMT 250

Point 1: Normal Operation After Switching on

Under normal operating conditions, a fuse is subjected to a maximum operating current and a maximum operating temperature. A «derating» of the rated current is thus usually necessary since a fuse is rarely operated at 23 °C. As an example we will take a time-lag SMD fuse such as the UMT 250 from SCHURTER, which is operated at 60 °C. In accordance with fig. 1, this needs to be derated by 17%, i.e., when the operating current is 1 A @ 60 °C, then a rounded-up fuse value of 1.25A (1A / 0.83) is necessary.

Fuses can be dimensioned in accordance with IEC 60127 or UL 248-14. With this, the following difference with regard to rated current dimensioning should be observed: fuses in accordance with IEC 60127 may be operated continually at 100% of the rated current value, whereas fuses in accordance with UL 248-14 only at 75%. Typical for a fuse having a UL 248-14 characteristic is the minimum of 4h operating period at rated current (table 1).

Pre-Arcing Time

Rated Current In	1.0 x In min.	2.0 x In max.
0.375 A - 5 A	4 h	60 s

Table 1: Pre-arcing time of a fuse having a UL 248-14 characteristic

The self-heating effect of time-lag fuses is less than that for quick-acting. This can be seen from the typical values of voltage drop. For example, a 2-Ampere 5x20 mm glass fuse has a typical voltage drop of 60 mV with the time-lag, and 90 mV with the quick-acting version. This difference is evident by the thicker fuse element (higher melting value I^2t, see point 2) that is necessary for time-lag fuses. It should also be noted that fuses are heated by the current until a certain temperature has been reached when the fuse element melts (opens) and interrupts the circuit. All measures for cooling such as ventilation, heat sinks, large solder surfaces or heat accumulators (fig. 2) change the time/current characteristic of the fuse and should be thus avoided.

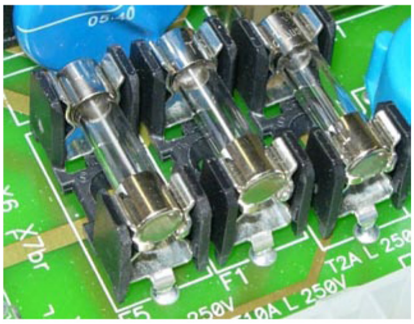

Fig. 2: Fuses mounted in holders and placed so close together as shown can influence each other reciprocally with regard to temperature.

Point 2: In-Rush Current Peaks

In-rush current peaks (fig. 3) arise through capacitors that are initially charged when switched on. These pulses can be many multiples of the rated current of the fuse, but are mostly, however, of a very short duration.

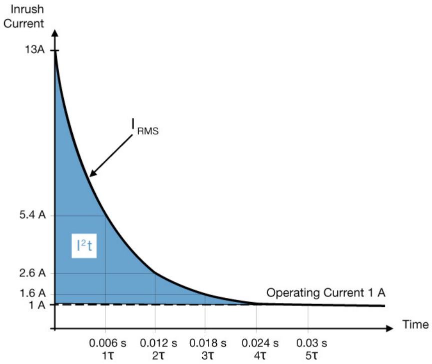

Fig. 3: Typical switch-on curve of a SMPS when capacitors need to be charged

The area beneath the curve is called the melting integral or I^2t value. The I^2t value is defined as that amount of energy necessary to heat up and melt a wire or fuse element. Generally this is an exponential curve having a peak current value of I_p over a period of time called τ, at which point the current has reached 37% of the peak current value. As an example we will take the time-lag SMD fuse UMT 250, 1 A. The I^2t-value can be calculated with the following formula using a peak current of I_p = 13 A and a τ = 6 ms:

$$I^2t_{Application} = 0.5 * I_p{}^{2} * \tau$$

$$I^2t_{Application} = 0.5*(13\ A)^2*6\ ms = 0.507\ A^2s$$

In addition, the number of pulses must be taken into account with the life of the equipment since fuse ageing is premature and this needs to be considered. With time-lag fuses, a factor of 0.29 is used for 10´000 pulses (see table 2).

$$I^2t_{min\_Fuse\_T} = I^2t_{Application} / F$$

$$I^2t_{min\_Fuse\_T} = 0.507\ A^2s / 0.29 = 1.748\ A^2s$$

For each type and rated current, the manufacturer gives the melting integral value in the catalogue, such as, for example, (table 3) with the IEC time-lag SMD fuse UMT 250. The 1 A rated current fuse has an I^2t value of 2.8 A^2s, that is, with an over-current (short-circuit) or an inrush current peak in excess of this value, the fusing element melts and interrupts the circuit. In our example the I^2t value of the fuse (2.8 A^2s) is higher than the calculated value (1.748 A^2s), that is, the selection would be correct for this application.

Variants

Order Number	Rated Current [A]	Rated Voltage [VAC]	Rated Voltage [VDC]	Breaking Capacity	Voltage Drop 1.0 In max. [mV]	Voltage Drop 1.0 In typ. [mV]	Power Dissipation 1.25 In typ. [mW]	Melting I^2t 10.0 In typ. [A^2s]	VDE	UL	cURus	PSE JET	CCC	K
3403.0155.xx	0.08	250	125	1)	1300	850	200	0.025	●		●			
3403.0161.xx	0.315	250	125	1)	750	343	500	0.27	●	●	●		●	●
3403.0162.xx	0.4	250	125	1)	700	290	500	0.4	●	●	●		●	●
3403.0163.xx	0.5	250	125	1)	600	257	500	0.54	●	●	●		●	●
3403.0164.xx	0.63	250	125	1)	500	216	500	1.1	●	●	●		●	●
3403.0165.xx	0.8	250	125	1)	400	190	500	1.4	●	●	●		●	●
3403.0166.xx	1	250	125	2)	300	164	500	→ 2.8	●	●	●		●	●
3403.0167.xx	1.25	250	125	2)	300	138	1000	4.5	●	●	●	●	●	●

Table 3: Versions of UMT 250 as an example with details of the melting integrals, voltage drops and power losses for every current rating

In-rush pulses, particularly then when they occur often, cause fuses to age prematurely. This can lead later to failures in the field, which should be avoided with this calculation. In order to obtain a high I^2t, time-lag fuses usually have a tin-plated melting wire. Over time, the tin diffuses in the wire, which leads to a change in the time/current characteristic of the fuse. In general, quick-acting fuses are more resistant to pulses than time-lag, but time-lag fuses need to be used because of their higher I^2t capability values than those for quick-acting.

	Time-lag	Quick-acting
100 pulses	0.5	0.6
10 000 pulses	0.29	0.49
1 Mio. pulses	0.19	0.42

Table 2: Factors for time-lag and quick-acting fuse types with different numbers of pulses

Point 3: Combination of Fuses and Fuseholders

The 5x20 mm fuses are used widely in industrial applications since they are easily available worldwide and can be replaced by the end customer or a service company. In applications such as these, a fuseholder is usually needed and for this the following points need to be observed: fuseholders approved to the IEC 60127-6 standard need to fulfil, amongst other requirements, the following: Rated power acceptance (e.g. 2.5 W / 10 A @ 23 °C), rated current (e.g. 10 A) and rated voltage (e.g. 250 V). For fuseholders approved to UL 512 and CSA C22.2 no. 39, only the rated current (e.g. 16 A) and rated voltage (e.g. 250 V) are specified.

The current with UL is usually higher than for IEC because of the following reasons:

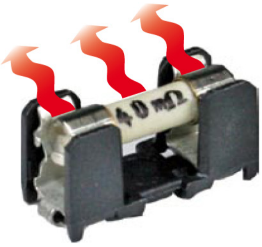

Fig. 4: IEC test with dummy fuse

IEC uses a dummy fuse, e.g., 40 mΩ = 4.0 W / (10 A)^2 (fig. 4). This dummy fuse and the contact resistance between fuse and clip generate heat. The fuseholder must withstand this condition for 500h and accessible parts is not allowed to exceed a temperature of 85 °C.

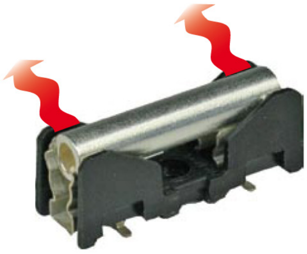

Fig. 5: UL/CSA test with silver tube

On the other hand, UL/CSA uses a silver tube having ≈0Ω (fig. 5). That means, heat is only produced by the contact resistance between fuse and clip. This leads to the fact that a fuseholder under UL/CSA condition can withstand a higher rated current than under IEC condition. Since every fuse has its own resistive value and is thus generating heat, the IEC consideration is closer to reality and should be taken into account when dimensioning. UL/CSA only tests the fuseholder itself, which is insufficient in practice.

The fuse standards (IEC 60127-2 to 4) check general electrical properties such as, for example, the minimum/maximum pre-arcing times. The standard for fuseholders (IEC 60127-6) checks thermal properties such as conditions of temperature at rated power and current over an operating period of 500h. Therefore, the cu-

stomer is obliged to carry out his own calculations and for this, the following approach is well tried and tested:
As example, we expect to have an operating current of 5 A @ 60 °C. Because of the increased temperature in the fuseholder, derating, as described under point 1, must also be taken into consideration here. In the example, the derating for standard fuses is around 20%, that means a rounded up current rating of 6.3 A (5 A / 0.8).
The fuse power dissipation is calculated with the rated current and typical voltage drop value (voltage level over the fuse at rated current) according to the catalogue. Ceramic fuses such as, for example SPT 5x20, 6.3 A have a typical voltage drop of 70 mV at rated current.

$P_{Fuse} = I_N{*}U_{VoltageDrop\_typ}$

$P_{Fuse} = 6.3\text{ A}{*}70\text{ mV} = 441\text{ mW}$

With a fuseholder, e.g. FPG1, having a rated power acceptance of 2.5 W @ 10 A, the recommended derating curve as shown in fig. 6 must be taken into account. At 60 °C and a rated current of 5 A, the curve I = << I_n, is used since the operating current is 5 A and the admissible current of the fuseholder under IEC is 10 A. In the example, this gives a maximum rated power acceptance $P_{Fuseholder}$ of 1.3 W.

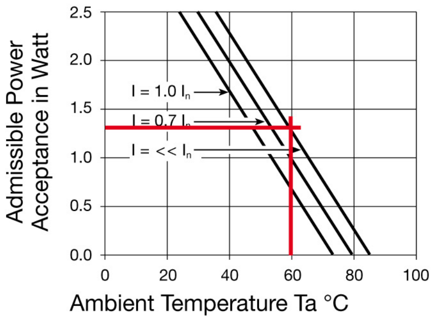

Fig. 6: Derating curve of a shock-safe fuseholder as e.g. FPG1

According to the IEC standard, the contact resistance R_c between fuse and clip is a maximum of 5 mΩ. Power dissipation can be calculated using the following formula:

$P_{Contact} = R_c{*}I_N^2$

$P_{Contact} = 5\text{ m}\Omega{*}(6.3\text{ A})^2 = 198\text{ mW}$

Correct dimensioning can be ascertained through the use of the following equation:

$P_{Fuseholder} = 1.3\text{ W}$

$P_{Fuse} + P_{Contact} = 441\text{ mW} + 198\text{ mW}$

$P_{Fuse} + P_{Contact} = 639\text{ mW}$

Combination is correct layed out, when
$P_{Fuseholder} > P_{Fuse} + P_{Contact}$

and this is the case in the example.

The following operational modes can be an additional burden to the fuseholder and must be specially evaluated: changes in electrical loads, continuous operation (>500h) at currents $>0.7{*}I_N$ and the effects of ventilation, cooling, heat accumulation, etc. Even after consideration of these selection criteria, extensive tests under worst-case conditions are indispensable in order to ensure secure operation in equipment and installations.

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