ULTRA QUICK

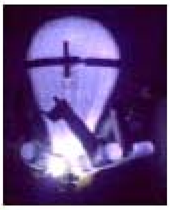
Application guide

FUSES FOR PROTECTION OF SEMICONDUCTORS

ETI POWER NEEDS CONTROL

Historical survey

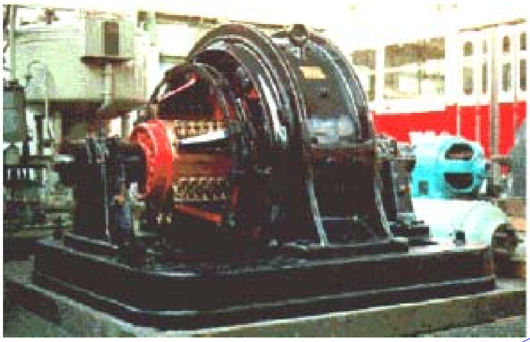
Following the discovery of the transistor, diode, in 1948 in the Bell Laboratories, a rapid development of semiconductors commenced. As far back as at the end of the fifties, the need for the first semiconductor protection fuses emerged, because the ordinary fuses couldn't fulfill the protection requirements. Semiconductor element is a square silicon chip with a size of several mm, inserted into a casing (metallic or plastic), connected to connection terminals, and appropriately encapsulated. Due to the small size of the silicon chip it has low thermal capacity with short time intervals under 100ms, without possibility of heat transfer from the silicon chip to the environment. For this reason the protection elements must be very fast-acting in order to prevent destruction of the semiconductor. Protection device with a silver fuse link was the right answer to these requirements. At the beginning the semiconductor elements were very sensitive with very low Joule integral value. The first types of NV fuses for semiconductor protection were M-shaped knives. Because of their poorer electrical and thermal conductivity, a new standard appeared in 1973 with S-shaped knives (M shape plus a notch for screw fixation). In the subsequent years the need arised for G-shaped terminals (screw connection).

Mercury rectifier, vacuum tube rectifier, inignitron

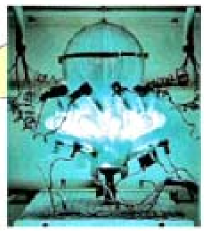
1960:
Power diode, Thyristor

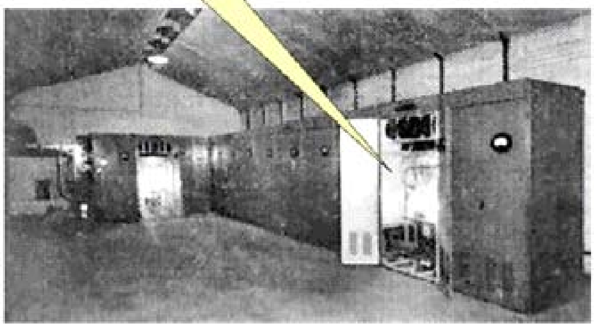
1985:
MOS-FET, IGBT, GTO



In the beggining

Not so far

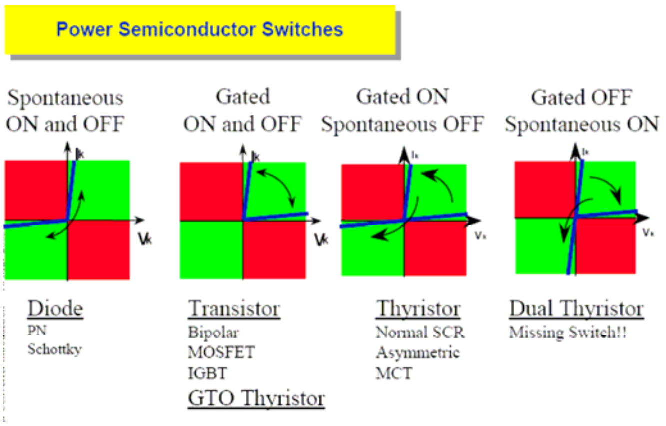




Still now

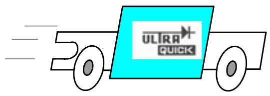
Introduction

The fuse links of ULTRA-QUICK type are used for the protection of power semiconductors, such as



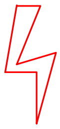
diodes, thyristors, triacs...IGBT transistors. These elements are due to their low thermal capacity very sensitive to over-loads, therefore a normal protection with fuse links for installation protection is not enough, because they are too slow. The fuse links for semiconductor protection must fulfill a series of requirements, the most imortant of them are:

- Fast acting in the overload and short-circuit range



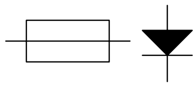
- Extremely low value of the operating Joule integral (I^2t)

- Low switching overvoltage at circuit opening

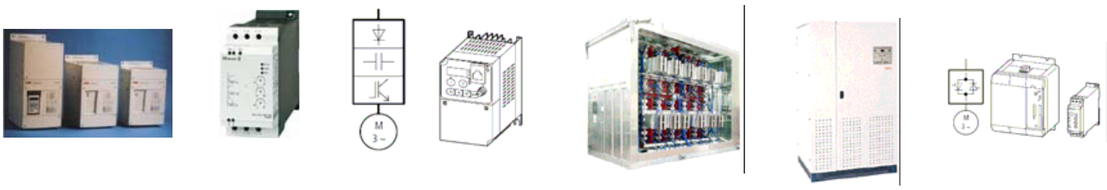


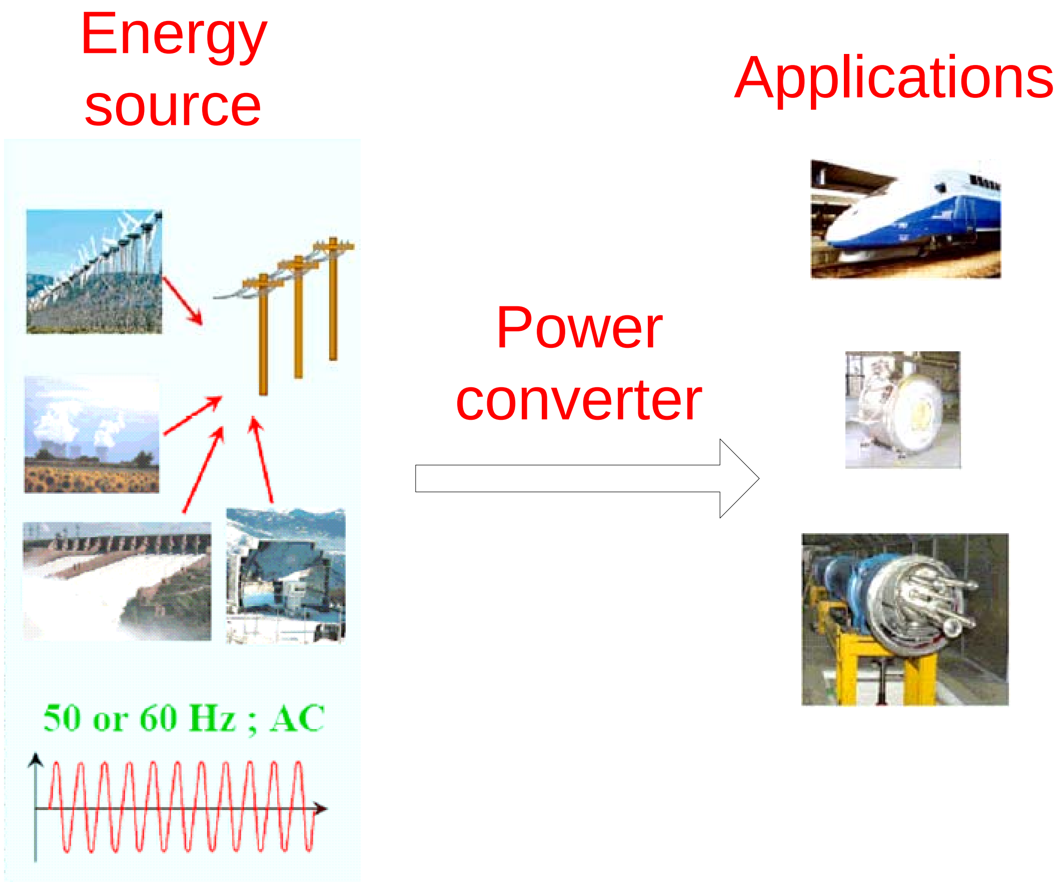
- Low power dissipation (P_d)

Some of these requirements are contradictory, therefore are ULTRA – QUICK fuse links the required product. At high inductivities L the overvoltage can destroy a semiconductor. Inter alia, they are distinguished by their low sensitivity to ageing, which was achieved by the use of pure silver for the fuse element. The fuse links ULTRA-QUICK meet all the requirements of DIN 57636/VDE 0636. Dimensionally, they are equal to the fuse links of standard programs D0, D, BS, C in NV-NH. Externally they are differ from them by the mark ULTRA-QUICK, and the fuse symbol for semiconductor protection



This Technical information is intended to be used as an instruction for the use of the ULTRA-QUICK catalogue program, it is an aid in designing, and represents a basis for dimensioning optimum power semiconductor protection in your converter, soft-starter, UPS, freqency converter, solid state relays, power regulator...





Characteristic electrical values

Rated values

U_N- Rated voltage of a fuse element (link) is an effective (root-mean-square) value of a sine alternating current with a frequency of 45-60 Hz. The fuse elements have been tested at that voltage increased by a factor of 1.1. At a higher voltage a risk of the fuse failure at circuit opening exists (damages of the ceramic body). Therefore the operating voltage must not exceed the rated voltage.
The rated voltages for AC and DC are different, which is apparent from the label on the fuse link (D, D0, U, U-N), and from the catalog data. For UQ1, UQ 2, UQ 01, UQ02 there is no separate data for DC voltage. In the event of an error (the most unfavourable case), a voltage can appear in the invertor equaling the sum of the energizing DC voltage at output and AC mains voltage. The effective value of that voltage can amount to 1.8 x voltage at AC side, and that is the value the fuse links in the invertor have to be dimensioned to.

I_N- Rated current of a fuse link is an effective value of a sine alternating current with a frequency of 45-60 Hz. This is the current a fuse link can be permanently loaded with under the following conditions:

- ambient temperature (20±5) °C
- without additional cooling (e.g. by means of a fan)
- section and length of the connecting wires complying with IEC 269 and VDE 0636

I_1- Rated breaking capacity is the highest value of the expected short-circuit current the fuse element will reliably cut off. The fuse elements have been tested with that current. The rated breaking capacity can be separately indicated for AC (I_1~) and DC (I_1=). It is indicated in the ULTRA

QUICK catalog and on the fuse link bases (D, D0, U, U-N). On the fuse links UQ1, UQ2, UQ01, UQ02 is indicated the rated breaking capacity for alternative current.

Values during the fuse link blowing

The figure below shows a characteristic switch-off at AC and DC short-circuit current.

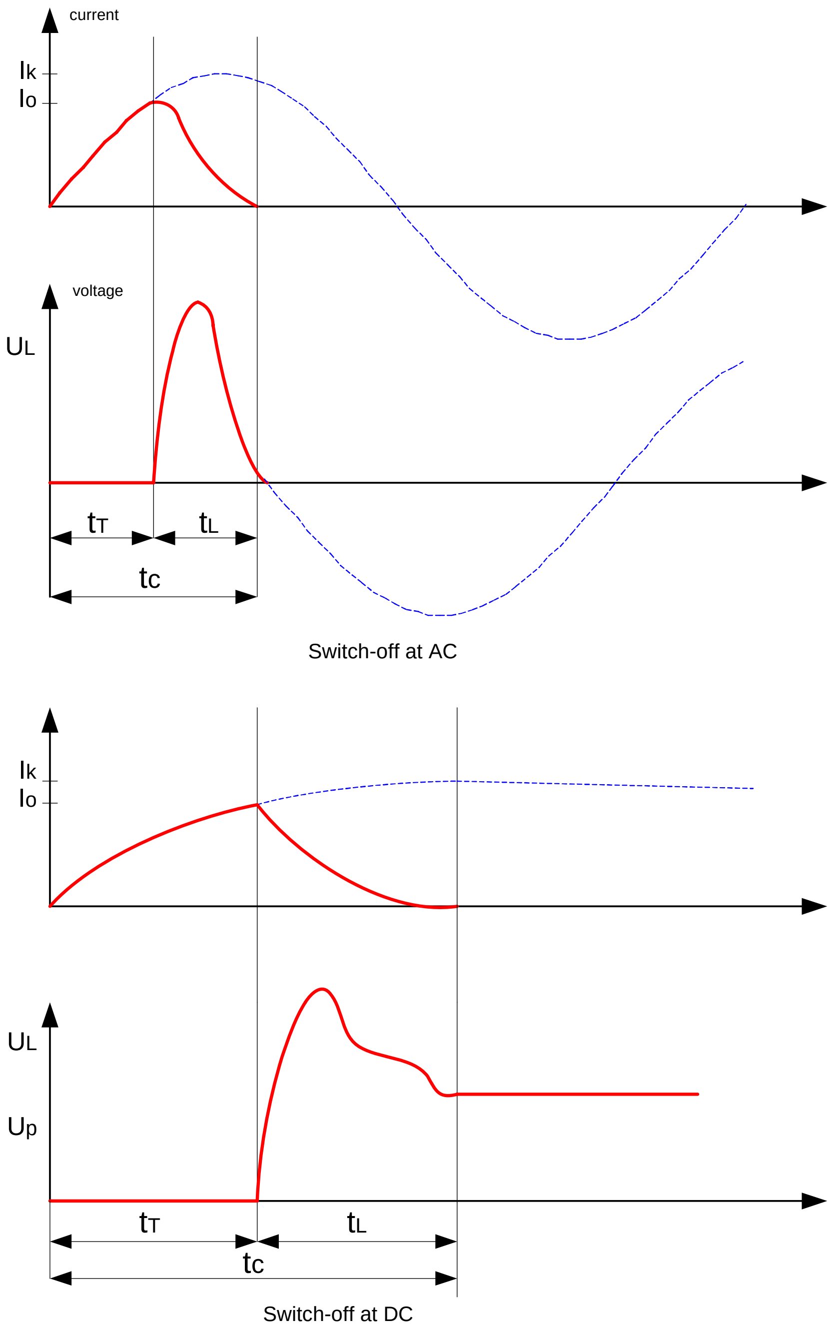


Figure 1

I_K- is the peak value of a short-circuit current which would flow through the circuit in the case when the fuse would have been replaced by a circuit with a negligebly low impedance. It is a sum of the DC and AC components of the short-circuit current pulse ($\chi\sqrt{2}\,I_K$).

I_O - cut-off current, maximum instantaneous current flowing through the fuse
U_L - arc voltage (switching voltage) is peak value of the voltage at the fuse terminals during the breaking process
t_T - fusing time – time interval between switching-in sufficient current to melt the fuse element, and arc appearance
t_L - arc time is time interval between arc appearance and its final breaking
t_C - overall breaking period of the fuse element, $t_C = t_T + t_L$

Short-circuit current during the melting phase (within t_T time) causes breaking of the fuse element. At the breaking moment an arc voltage U_L appears on the fuse terminals. Due to the circuit inductivity the current is not interrupted immediately, but passes to electric arc which is extinguished in time t_L. After the time t_C, which is the sum of the fusing time t_T and arc time t_L, the fuse will definitely break, and, after some transient oscillations, on its terminals will be established the connected voltage U_P.

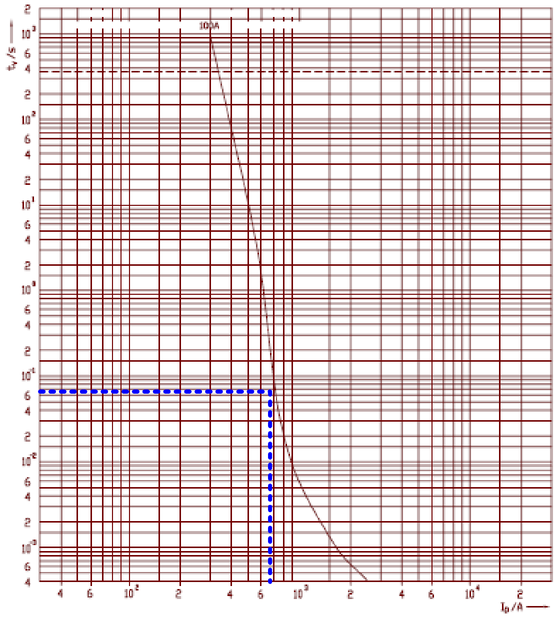


Figure 2

Fusing characteristics

The fusing characteristics of fusing elements graphically represent fusing time t_T dependence of the load current I_P effective value. Owing to the large currents and times span they are drawn on a net with double logarithmic scale. The fusing characteristics are measured using alternative current with a frequency of 50Hz from cold state, whereas in warm state the fusing times are reduced.

Example: Figure 2 shows the fusing characteristics of a fusing element with I_N =100A. For a selected current of 700A we draw a perpendicular up to the fusing characteristics, and at their intersection a horizontal line; on the time ordinate we can read the fusing time, 65ms in this example. The fusing characteristics of the fusing elements ULTRA QUICK are shown in the catalog.

Fusing characteristics gR and aR.
From the fusing characteristics we can see whether the fusing element provides protection over the whole range, or only within the short-circuit area. The classification corresponds to DIN 57636/VDE 0636.

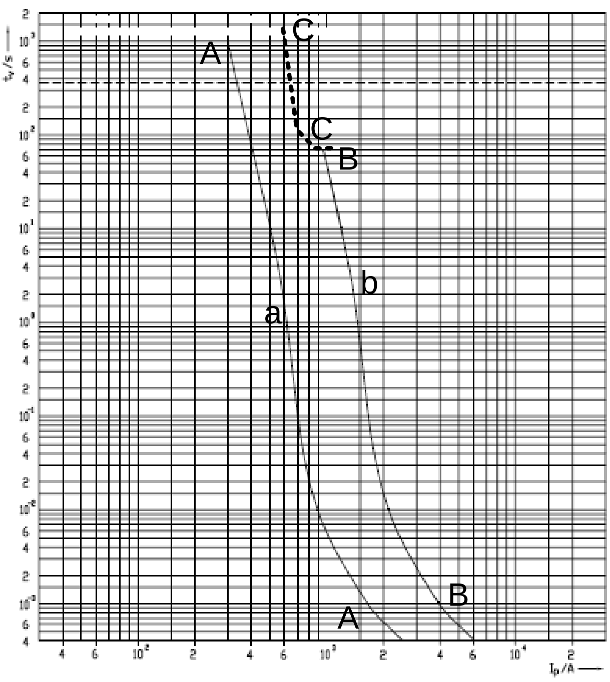


Figure 3

The gR characteristics designates protection of semiconductor elements over the entire current range. Fuse elements with that characteristics are able to permanently conduct currents up to their rated current, and reliably interrupt all currents from the lowest fusing current up to the rated breaking capacity. The fusing characteristics is an unbroken curve over the whole AA area.

The aR characteristics designates protection of semiconductors within the current domain mentioned. Fuse elements with that characteristics are able to permanently conduct currents up to their rated current, and reliably interrupt all currents from some rated current multiple up to the rated breaking capacity. The area of reliable breaking is represented by the curve BB, within the range of lower loads, whereas the line CC designates a limit above which the fuse elements should not be loaded. Fuse elements with that characteristics are only intended to protect semiconductor elements against short circuits, whereas lower loads above the CC curve are taken over by some other protection element, e.g. thermal overcurrent switch or circuit breaker, electronic protection within a converter's control circuit... Loading a fuse element above the CC curve, owing to excessive thermal emission, in spite of the use of high-quality materials, could cause cracking of the fuse element casing, and thereby unreliable breaking.

Unless otherwise stated in the catalogues, the fuse links ULTRA QUICK are manufactured up to I_N = 100A with a fusing characteristics gR, and for higher rated currents I_N > 100A with a fusing aR. This is valid for fuse links U, U-N. UQ01, UQ1 have aR characteristics, and UQ2 mostly gR.

Cut-off currents characteristics, breaking capacity

Cut-off Currents Characteristics
An important property of fuse elements is short-circuit current limiting. The fuse will limit the short-circuit current if it has operated before the peak current of an expected short-circuit current has been reached. This property of fuse elements substantially reduces the requirements for dynamic strength of devices protected by the fuse elements, and makes possible the use of semiconductor elements with lower permissible impulse current I_{TSM}. An example of cut-off currents characteristics is shown in Figure 4. This characteristics, too, is drawn in a double logarithmic scale. From the circuit data an effective value of the expected short-circuit curent I_K (e.g. 4kA) is calculated.
At that value on the abscissa a perpendicular is drawn. At the intersection of the perpendicular and cut-off current characteristics of a selected fuse element (e.g. I_N = 100A) a horizontal line is drawn, and the value of the cut-off current (I_O=1,5kA) can be read on the ordinate. At the intersection of the perpendicular and the straight line $I_K\sqrt{2}$ a horozontal line is drawn, and the peak value of the prospective short-circuit current can be read on the ordinate for the example χ = 1 (I_K=6kA). In the same way can be obtained peak value of the prospective short-circuit current for the example χ = 2 (I_K=11kA).

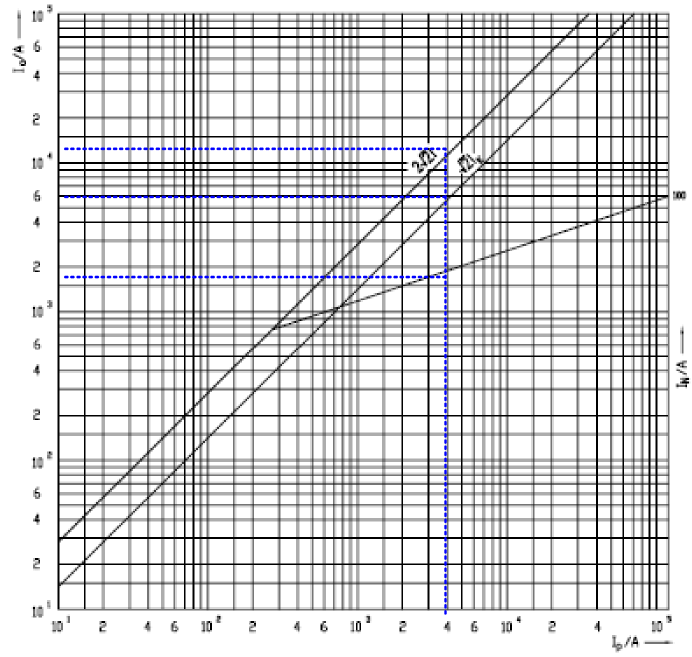


Figure 4

Peak value of a short-circuit impulse current amounts to $\sqrt{2}\ \chi\ I_{K}$, χ being impulse coefficient with a value between 1 and 2, depending on the magnitude of DC component of the impulse current. It depends on the moment when short circuit arose, and on the shorted circuit impedance.
In the example shown in Figure 4 we have seen that the fuse element with I_N = 100A limited the short-circuit impulse current to the value of 1.5kA, which otherwise, unless the fuse was inserted, would have reached in the most unfavourable case 11 kA. The characteristics of cut-off currents for ULTRA QUICK fuse links are described in the catalogue.

Breaking capacity

Breaking capacity of a fuse element means that the fuse element is capable to reliably break all the currents, from the lowest current causing melting up to the rated breaking capacity I_1. The latter is indicated on every fuse element (link), and in the ULTRA QUICK catalog as well. Calculated breaking capacity for UQ1,UQ01,UQ02 is 200kA AC, measured and on the label is 100kA AC.

I^2t values

The form of current during the breaking process of the fuse element is shown in Figure 2. I^2t value, i.e. the Joule integral, is a measure for the energy that flows through the fuse, and also through a semiconductor element protected by the fuse. A proportion factor represents internal resistance of the fuse element or semiconductor. I^2t values are given in A^2s units. The indication of Joule integrals makes sense only for very short fusing times (under 100ms), when not yet larger thermal passage from the fuse or semiconductor to surroundings has occurred.

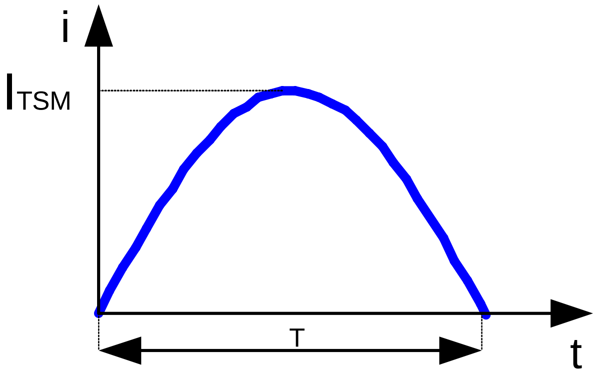
The value $\int_0^{t_T} i^2 dt$ is called pre-arcing integral, and depends on the fuse element construction.

The value $\int_{t_T}^{t_L} i^2 dt$ is called arc(ing) integral, and depends on:

- input voltage
- circuit impendance (cos φ or τ)
- short-circuit current value
- instantaneous switching-on of the short-circuit current

Sum of the pre-arcing and arcing integrals is the operating integral. The permissible value I^2t for a semiconductor element should not be compared with a pre-arcing integral of fuse elements, but with the operating integral for the provided circuit data. Value of the operating integral for a fuse element must be lower than the permissible integral of the protected semiconductor element. The values of integrals for fuse elements are indicated from their cool state. Some semiconductor manufacturers indicate permissible integrals for their products both from cool (25ºC) and warm (125ºC) state. With which of those data should the value of the fuse element integral be compared?

Because I^2t value of the fuse element by increasing the temperature or by the growth of preliminary load diminishes faster than I^2t value of semiconductors, the comparison »cool semiconductor -» cool fuse« will be sufficient.
Some semiconductor manufacturers don't indicate I^2t value, but maximum permissible impulse (surge) current for the duration of one half cycle (10ms) - I_{FSM} or I_{TSM} . In this case the I^2t value of a semiconductor can be calculated from the integral – Figure 5.



$$\int_0^T i^2 dt = \int_0^T (I_{TSM} \sin \omega t)^2 dt = \frac{I_{TSM}^{\;2}}{2} T$$

$$\int_0^T i^2 dt = \int_0^T (\sqrt{2} I_p \sin \omega t)^2 dt = i_p^{\;2} T$$

Figure 5

In catalogue of the ULTRA QUICK program are in tables indicated values of fusing integrals for fuse elements from the cool state, and the values of overall integrals for several different input voltages.
The values of overall integrals for intermediary voltages can be obtained by interpolation.

Power dissipation

Fuse elements for semiconductor protection have higher power dissipation than fuse elements for installation protection. That is why they heat up more at rated current than traditional fuse elements for instalation protection. When ULTRA QUICK fuse links are installed into a rectifier housing, this additional heating must be taken into consideration for dimensioning of cooling. A load lower than the rated one will cause, of course, lesser voltage drop, and thereby lower power dissipation. In the ULTRA QUICK catalog are provided power dissipation diagrams at rated currents for fuse elements.

Switching voltage

During the breaking process of a fuse an arcing voltage will on its terminals, i.e. switching voltage. For successful arc extinction the latter must be higher than source voltage. The arcing voltage will also appear on semiconductor elements as reverse voltage, and must not exceed their maximum permissible peak reverse voltage.

The ULTRA QUICK fuse links are designed to ensure quick and reliable breaking at relatively low arcing voltage. The switching voltage primarily depends on input voltage and circuit power factor cosφ.
The maximum peak blocking voltage of semiconductors must be higher than arcing voltage of the fuse elements used. With larger semiconductor systems for transformation of electric energy the use of overvoltage protection for semiconductors is recommended.

Insertion of Ultra Quick fuse links into semiconductor systems for electric energy transformation, and examples of possible defects

Insertion of fuses into a circuit
Fuses can be included into the circuits of semiconductor rectifiers, inverters, DC to DC converters and AC to AC converters, such as:

1. line fuses in individual phases of a secondary circuit
2. individual fuses for protection of individual semiconductor elements
3. fuses in a DC circuit

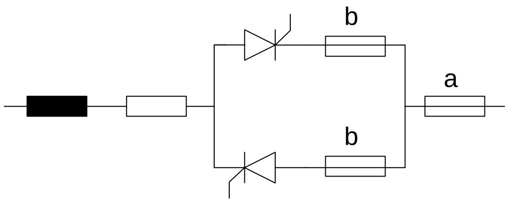


Figure 6

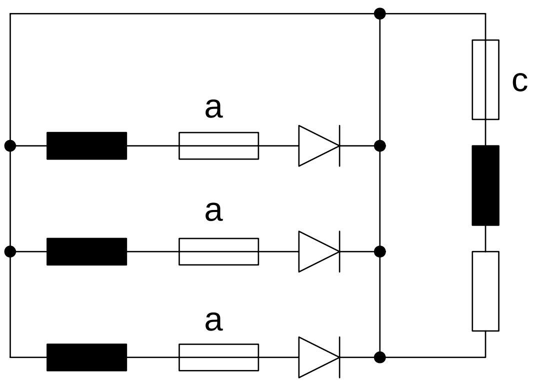


Figure 8

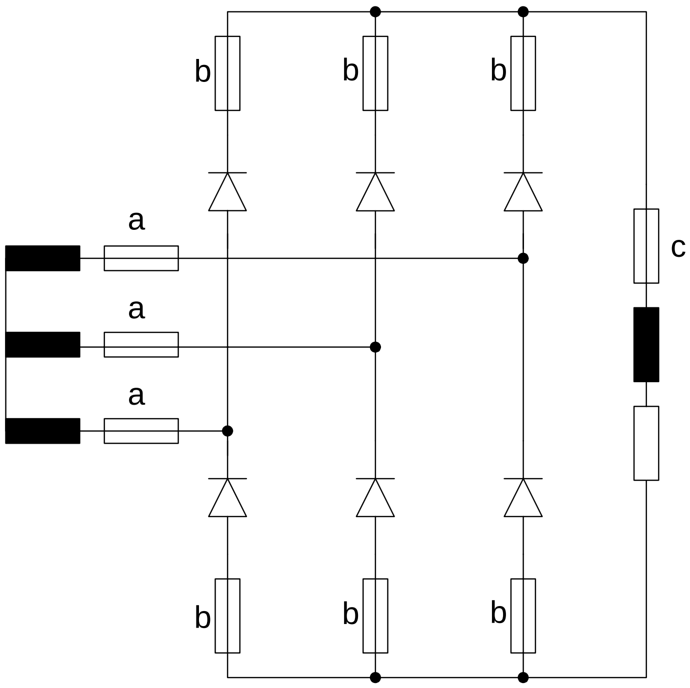


Figure 7

Examples of such insertions are shown in Figures 10,11,12.

Most frequently used rectifier and inverter circuits:

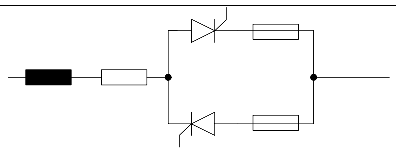
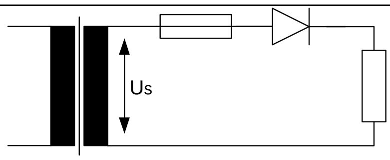
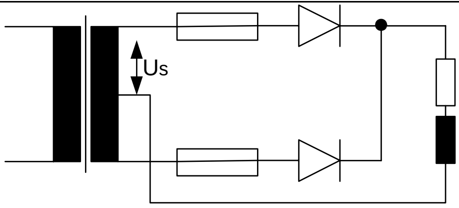
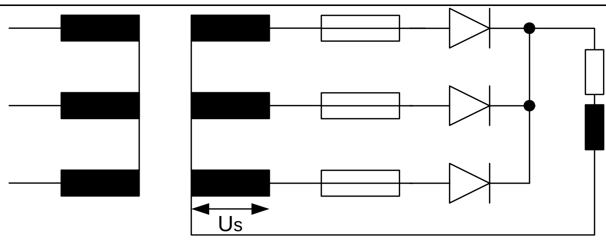
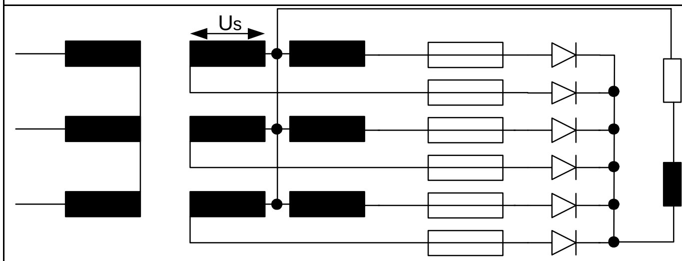
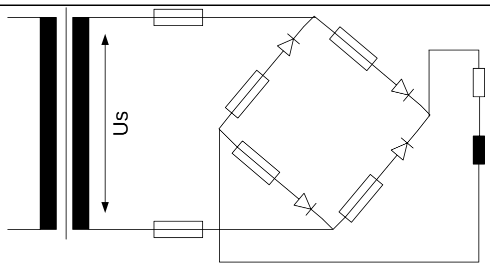
In the table in Figure 13-22 are represented today most frequently used circuits of rectifier and inverter devices, together with data needed for dimensioning fuse elements:

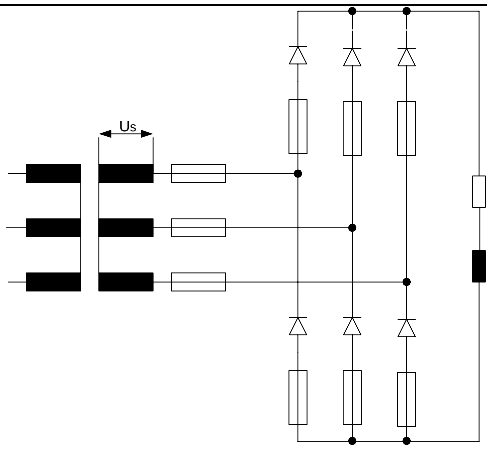
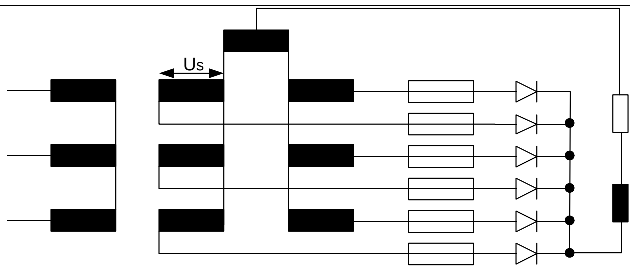
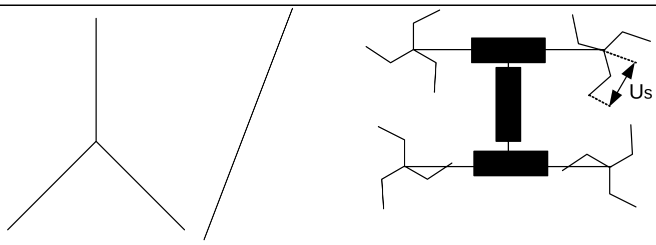
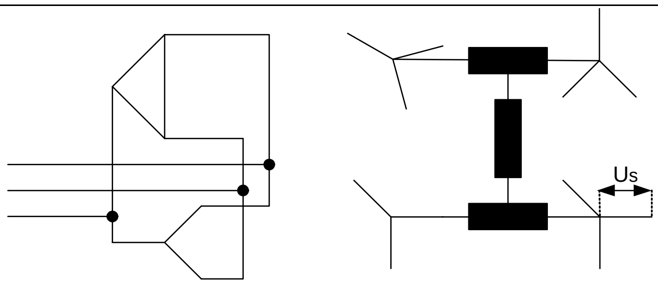
$\frac{I_{SF}}{I_=}$ effective (rms) value of the current through a line fuse as a multiple of the mean value of direct current.

$\frac{I_S}{I_=}$ effective value of the current through an individual fuse as a multiple of the mean value of direct current.

$\frac{U_R}{U_S}$ maximum value of reverse voltage on a semiconductor element as a multiple of the transformer secondary voltage.

$\frac{U_S}{U_=}$ effective value of the fuse input voltage as a multiple of idle running DC voltage.

circuit	connection description	$I_{SF}/I_=$	$I_S/I_=$	U_R/U_S	$U_S/U_=$
 **Figure 9**	aternating current control	1,00	0,50	1,41	-
 **Figure 10**	one-phase half wave	1,57	1,57	1,41	2,22
 **Figure 11**	one-phase full wave	0,71	0,71	2,83	2,22
 **Figure 12**	three-phase half wave	0,58	0,58	2,5	1,48
 **Figure 13**	three-phase full wave	0,41	0,41	2,83	1,48
 **Figure 14**	one-phase bridge	1,11	0,71	1,41	1,11

 **Figure 15**	three-phase bridge	0,82	0,58	2,50	0,74
 **Figure 16**	three-phase double star with a balance coil	0,29	0,29	2,50	1,48
 **Figure 17**	twelve pulsed with a balance coil	0,14	0,14	2,5	1,48
 **Figure 18**	/	0,14	0,14	2,5	1,48

Possible faults in electric energy transformation devices

In electric energy transformation devices with power semiconductors could arise several types of faults against which the fuse elements should protect semiconductor elements. For selective and efficient protection the following possible fault examples have to be considered:

1. External short circuit: a load fault causing short circuit at the device output terminals (e.g. breakdown in a DC machine). A fuse in DC circuit with selective breaking will prevent individual fuses from breaking. A prerequisite is that the operating integral of the fuse element in DC circuit be lesser than the melting integral of a preceding fuse.
2. Internal short circuit: A semiconductor element in the circuit loses its blocking capability, and causes short in the circuit.

3. Inverter's control fault due to an overload or AC voltage drop causing conduction path between DC and AC circuits.

An example of dimensioning rectifier circuits protection.

A three-phase bridge rectifier circuit has been dimensioned for maximum permissible direct current with mean value of 150A. Idle running (no-load) DC voltage amounts to 500V. Select line fuses, individual fuses, and DC circuit fuses.
Required data for the given circuit can be read from the table:

$$\frac{I_{SF}}{I_=}=0{,}82 \quad \frac{I_S}{I_=}=0{,}58 \quad \frac{U_R}{U_S}=2{,}5 \quad \frac{U_S}{U_=}=0{,}74$$

Current passing through individual fuse is:

$$I = I_= \frac{I_S}{I_=} = 150 \times 0{,}58 = 87A$$

We must select the closest higher standard rated current of the fuse element I_N=100A.

Current through the line fuse amounts to:

$$I = I_= \frac{I_{SF}}{I_=} = 150 \times 0{,}82 = 123A$$

We shall select the fuse element with I_N =125A.

For a fuse element in DC circuits with maximum current of 150A, we shall select I_N=160A.
If a selective protection is required, the operating integral of that fuse element must be smaller than melting integral of a line fuse or individual fuse.

In addition, we have to determine the rated voltage of line and individual fuses.

$$U = U_= \frac{U_S}{U_=} = 500 \times 0{,}74 = 370V$$

For line and individual fuses we shall take fuse links with U_N>370V (400 or 500V).

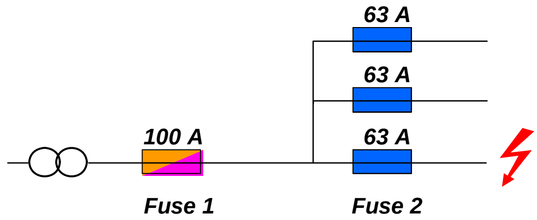
Selectivity

There is partial selectivity if series-connected fuses are selective in overload phase for 1,1 to 1,6 x In. Within this domain is important I/t characteristics (observe tolerance of 10%). A complete selectivity can be achieved by taking into account the Joule integral as well!!! The operating Joule integral of the fuse must be smaller than the fusing integral of a preceding fuse.

SELECTIVITY:

Important: Selectivity is ensured when orange surface is bigger than blue

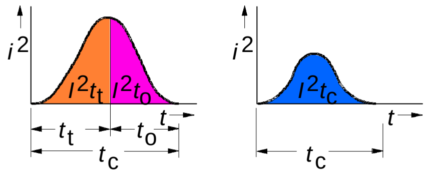
Rules: Fuse-links are selectivity when nominal current are given in the rate 1:1,6



Rules :

Pre-arc integ. $I^2t_S = f(I_p)$

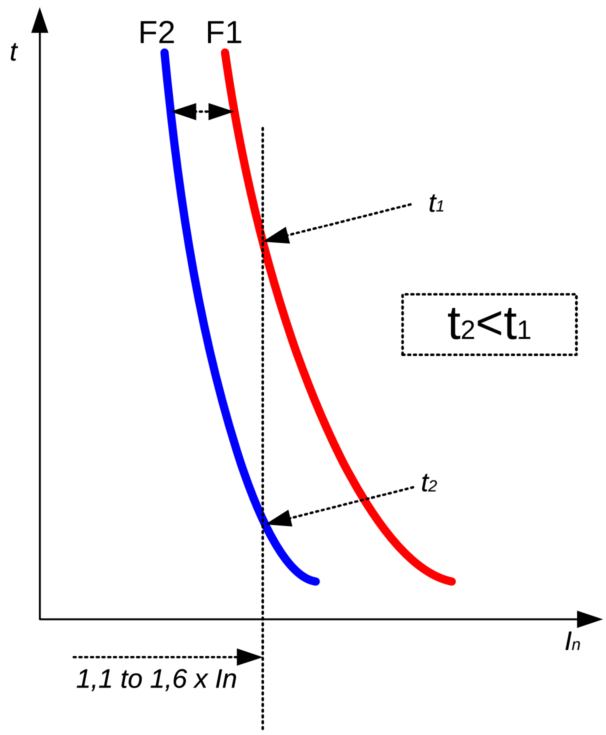
Arc int. $I^2t_L = f(I_p, U_n, \cos\varphi)$



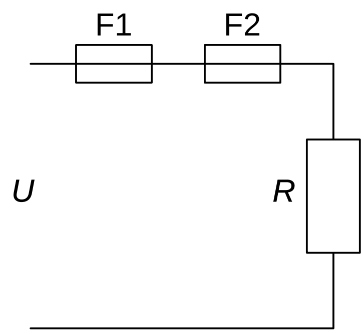
Pre-arcing integral Fuse 1	>	Operating integral Fuse 2
I^2t_t (Fuse 1)	>	I^2t_c (Fuse 2)

Case :

100 A	63 A
$I^2t_t = 24000\ A^2 s$	$I^2t_t = 7700\ A^2 s$
	$I^2t_o = 10300\ A^2 s$
	$I^2t_c = 18000\ A^2 s$



overload



10%
characteristics tolerance

Series and parallel circuit of ULTRA QUICK fuse links

Series circuit

Series fuse circuit is used at connection voltages higher than standard U_N of fuse elements. Such a connection should be avoided in most cases. When series circuit can not be avoided due to higher voltage, specific conditions must be met. So connected fuse elements may only break currents higher than ten times the rated current, or fusing times must be shorter than 10ms.

In addition, series circuit is only allowed for fuse elements of the same type, same rated current, and as equal internal resistance as possible.
If these conditions are not met, the risk exists of uneven voltage distribution, non-simultaneous breaking of series-connected fuse elements, and final destruction of the fuse element which was extinguishing an arc for the longest time. For series connection of two fuse elements the values given in the catalog must be doubled.

Parallel circuit

At very high load currents fuses can be connected in parallel. Care should be taken for approximately equal distribution of currents through fuse elements, which can be achieved by using fuse elements of the same type and same rated current. Owing to minor differences in internal resistance, check whether the current through the most strained fuse doesn't exceed its rated current. At parallel connection the value of operating integral will quadruple the value of one single fuse element, and the cut-off current will increase its value by 1.6 times.
The voltage rating must also be reduced by 10-15% for certain fuse designs.
The Joule integral of two fuses connected in parallel equals the square of the number of fuses connected in parallel multiplied by the Joule integral of the fuse:

I^2t (fuses connected in parallel) = $I^2t \times N^2$

When two fuses are connected in parallel, the common surface is then larger than the surface of only one equivalent fuse, which contributes to reducing the Joule integral. In order to ensure appropriate cooling, distance between the fuses must be at least 5mm.

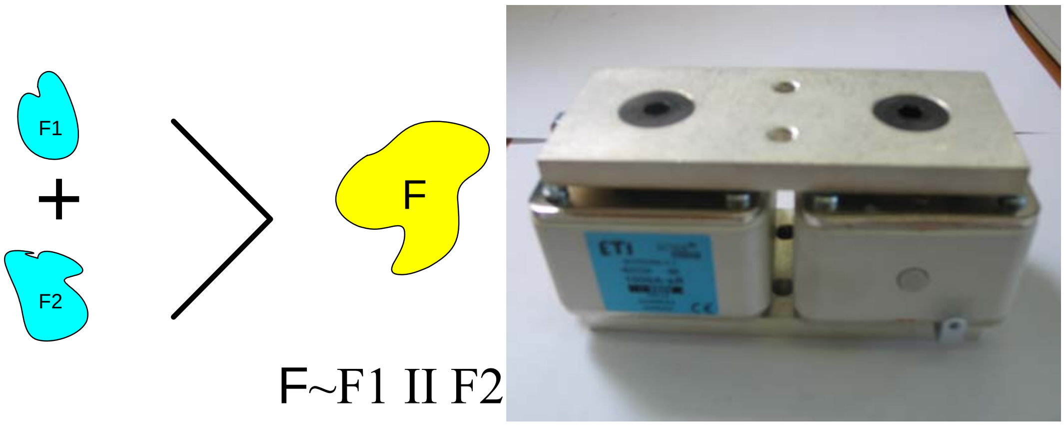


Figure 19

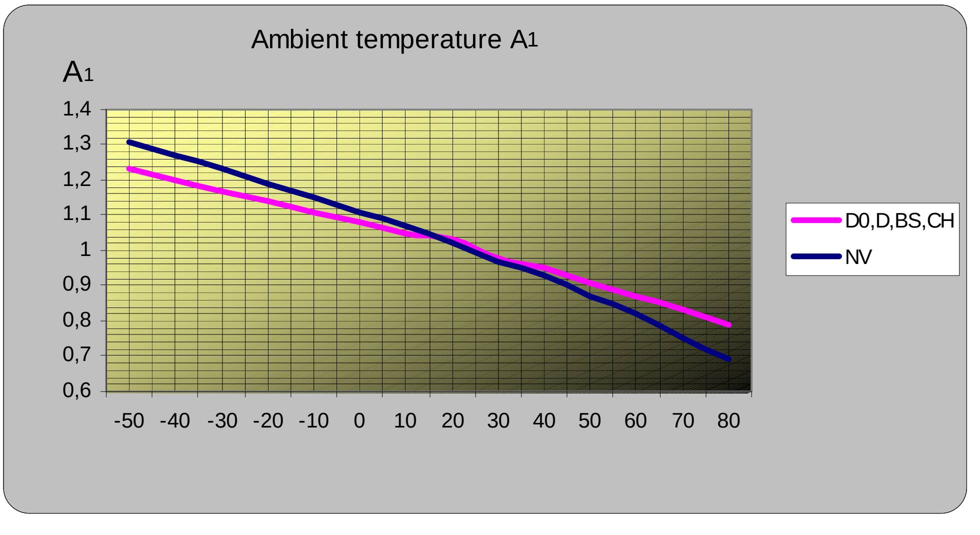
Fish-connection

It is used for 'GREAZ' bridge circuit.

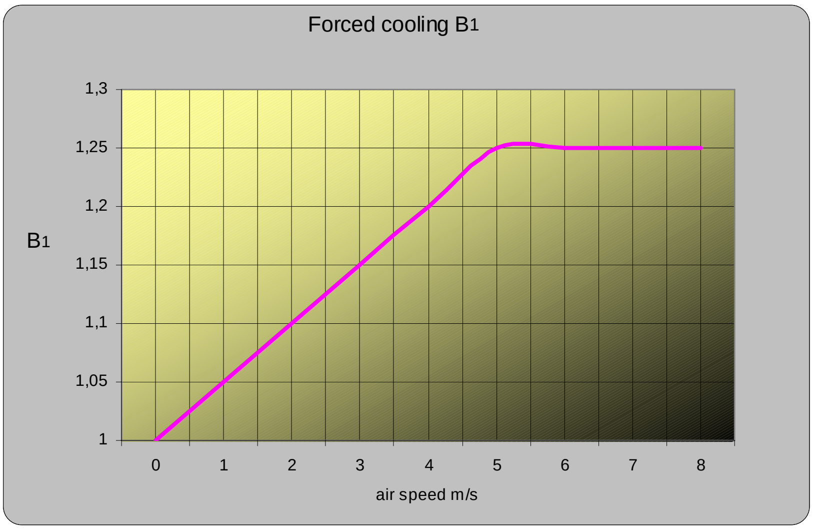
Calculation coefficient of thermal and other Influences

The rated data for ULTRA-QUICK fuse links apply to their operation in normal conditions. In practice are these conditions rarely ensured, therefore must be permissible loadability of fuse elements under different installation conditions reduced or increased. Various installation conditions define the calculation coefficients A1, A2, B1, C1 and C2.

$$I_n^* = I_n \times A_1 \times B_1 \times C_1 \times C_2 \times A_2$$



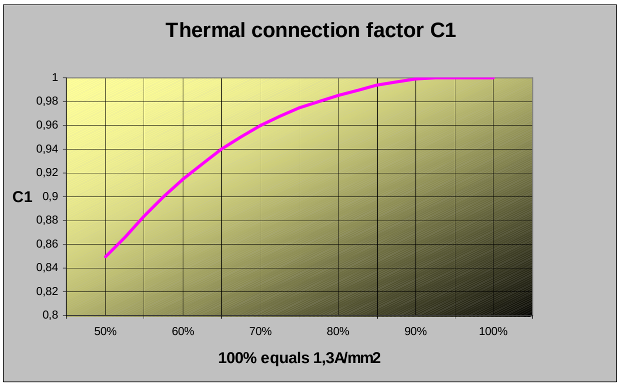
Factor A1 can be read from the graph in figure above, representing its dependence on the fuse element ambient temperature ϑ_O given in ºC. The flow A1 (ϑ_O) for fuse elements type DO, D, BS, C is different from the flow A1(ϑ_O) for NV type fuse elements. The ambient temperature ϑ_O is measured with still ambient air, very close to the fuse element casing.

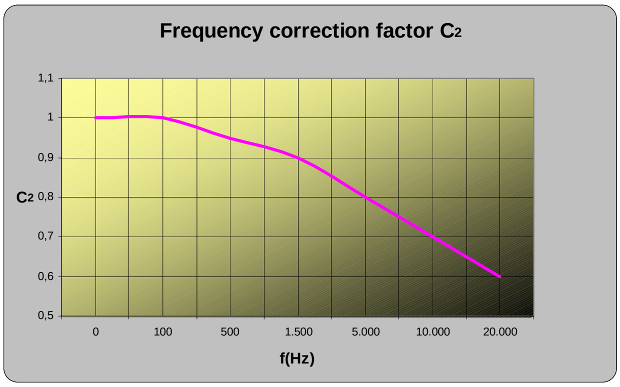


Factor B1 includes forced cooling of the fuse element with a fan, e.g. when fuses are installed in the cooling rib of a semiconductor rectifier power section:

Calculation : $B1 = 1 + 0{,}05 * V_Z$

Air speed V_Z is measured in m/s at a distance of 1-2 cm from the fuse element casing.





Working conditions	A_2
a few stops per year	0,95
1 stop per day	0,9
up to 12 stops per day	0,8

Calculation example:

1000A fuse has the following data:

a =150°C	C_1=0,95	ϑ_0=25°C	$C_2 = 0,9$
ϑ = 60°C	f = 500Hz	forced air cooling with v=3m/s… B_1=1,15	$A_2 = 0,8$

$$A_1 = \sqrt{\frac{a-\vartheta}{a-\vartheta_0}} = \sqrt{\frac{150-60}{150-25}} = 0,84$$

$$I_n^* = I_n \times A_1 \times B_1 \times C_1 \times C_2 \times A_2 = 1000 \times 0,84 \times 1,15 \times 0,95 \times 0,9 \times 0,8 = 660A$$

Fuse elements dimensioning for uneven operation and load surges

Quite frequent operation mode of electrical energy transformation semiconductor devices is periodically uneven load, typically e.g. for machine tools, conveyor bands, manipulators... And also aperiodic uneven operation typically e.g. for rail vehicles and some transportation devices.

Calculation of the fuse element rated current in such cases is performed by means of a coefficient A2, B2 or C3. With the load according to Figure 24 this coefficient is applied over the effective value of current in one load period T, and with the load corresponding to Figure 25 coefficient A2 is applied over the effective value of current over complete load duration. The use of the coefficient A2 will be clarified in the next paragraph.

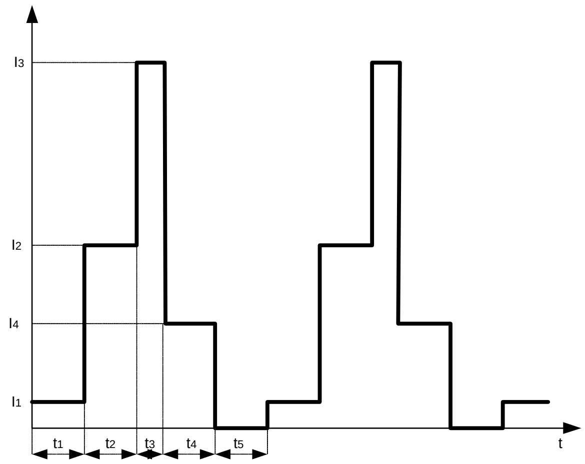


Figure 20

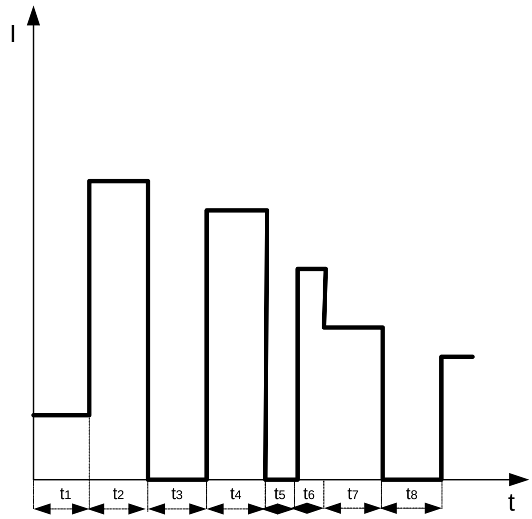


Figure 21

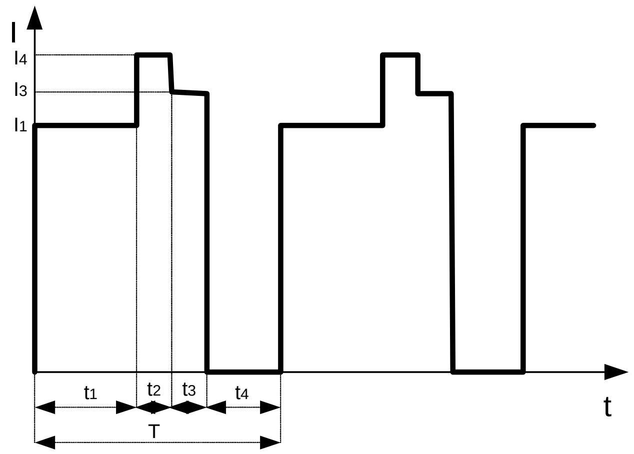


Figure 22

Example: A fuse element is periodically asimetrical loaded with a current shown in Figure 26. In the table and graph you can find: A2 = 0.8, A1=0,84, B1=1,15, C1=0,95

I_1= 250A t_1=20min
I_2=360A t_2=4min
I_3=300A t_3=5min
I_4=0A t_4=10min

The effective (rms) value of current in the whole period T amounts to:

$$I = \sqrt{\frac{I^2 t_1 + I_2{}^2 t_2 + I_3{}^2 t_3 + I_4{}^2 t_4}{T}} = \sqrt{\frac{250^2 \times 20 + 360^2 \times 4 + 300^2 \times 5 + 0 \times 10}{20 + 4 + 5 + 10}} = 238{,}5A$$

By means of the coefficient A2, A1, B1, C1, minimum current I_{min} is calculated, the fuse element must be able to conduct permanently.

$$I_{\min} = \frac{I}{A2 \times A1 \times B1 \times C1} = \frac{238{,}5A}{0{,}8 \times 0{,}84 \times 1{,}15 \times 0{,}95} = 326A$$

Owing to the condition $I_{min} <= I_N$, a fuse element with I_N=355A will be selected.

Sometimes, during normal operation, load current impulses (surge currents) exceeding fuse element rated current. Lest such current impulses leave durable consequences on the fuse element, specific conditions must be fulfilled:

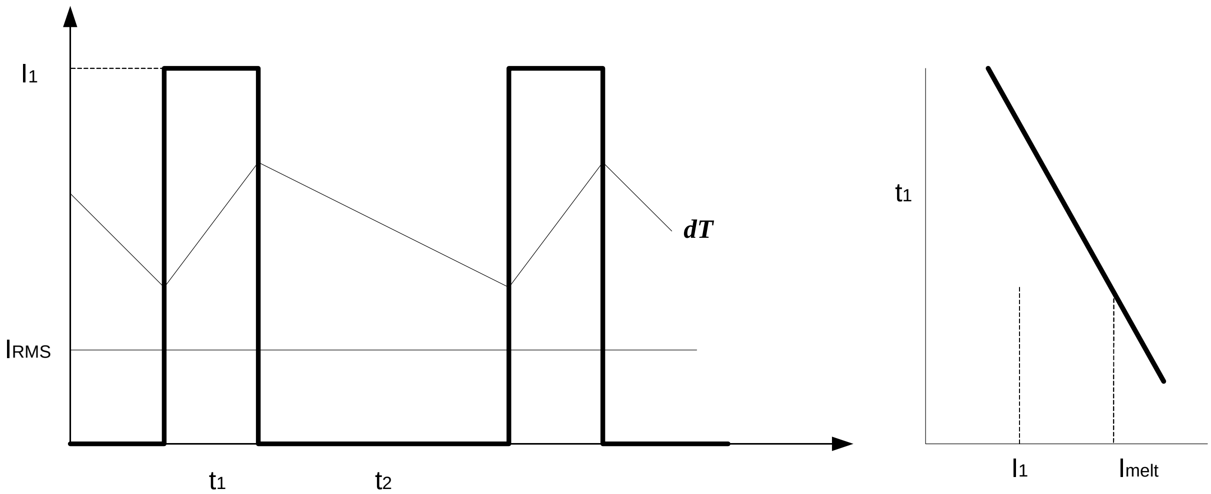
- At precedingly unloaded, i.e. cold fuse, the duration of such an impulse can amount to 30-50% of fusing time with that current. When impulse duration exceeds 50% of the fusing time, we must take into account fuse element ageing, where its fusing characteristics suffers irreversible changes. The higher preceding load, or fuse element temperature, the shorter can be current impulse duration.
- After each load impulse the fuse must sufficiently cool down. The minimum cooling time between two impulses must be:

$$t_{cooling} \geq 2 \times t_{pulse} \times (\frac{I_{pulse}}{I_N})^2$$

The inequation can be used for current impulses above 2 x I_N, while under that value it yields too long cooling times.

Cyclic overloads

If the duty cycle contains 'overload' (periods when the current is in excess of the fuse current rating), it is necessary to consider their magnitude and duration, in relation to the time – current characteristics of the fuse.



Coeficient B2

A simple method to ensuring that the fuse is large enought to withstand the cyclic overload is to require that the ON current I1 does not exceed a certain fraction B2 of the current which would cause the fuse to melt in the time t_1

$$I_1 \langle= B_2 \times I_{melt}$$

In modern application the fuse may need to withstand several milions cycles and the value of B_2 depends on the number of cycles N. typical values of B_2 as a function of the number of cycles are given in table:

B_2	N
0,31	10^6
0,35	10^5
0,45	10^4
0,5	4000
0,55	2000

Non-repetitive overload coefficient C_3

Another overload condition to be considered is the single (non-repetitive) pulsed overload. Such as situation occurs only a few times during the service life of a fuse and would apply for example when the fuse has to ride through a fault which is cleared by a downstream overcurent protection device. The objective is to ensure that the peak element temperature is below a level which would cause damage to the element notches.

$$I_1 \langle = C_3 \times I_{melt}$$

The coefficient C_3 is typically **0,75**.

Considering thermal influences which cannot be included into calculations

In addition to the ambient temperature and ventilation, the temperature, and thereby fusing characteristics are influenced by a series of factors which can be included into calculations with difficulty, or not at all. Loadability of a fuse element can be reduced or increased through closed fuse bases, through contact rails cooling, through supply of heat from the neighbouring elements... In such cases it is indispensable to carry out measurements on the fuse element during operation.
The fuse base temperature should be measured at the location of the conductor ϑ_p screw connection.
The temperature should be measured in real operating conditions, and only then, when the fuse element reaches its stationary temperature. Take into consideration that heating time constant of the fuse element amounts to 10-30min, depending on its size.
The value measured must not exceed the corresponding value at rated load of the fuse element in regular conditions.

Optimizing semiconductor elements protection

When designing semiconductor devices the following fuse elements selection criteria for optimum protection of semiconductor elements must be considered:
$I_p \leq I_N$ Load current I_p through fuse element must be lower or equal to its rated current. Also must be taken into account special load modes and other influences, e.g. periodical load, thermal influences...
$U_p \leq U_N$ Operating voltage U_p of the fuse element must be lower or equal to its rated voltage U_N. If in doubt, act according the rated voltage of the element being protected. Consider the fact that with an inverter fault the voltage on the fuse element equals 1.8 times input DC voltage. There can occur the addition of DC and AC voltages.

The operating Joule integral I_2t_c must be smaller than the Joule integral of the semiconductor. If this data is not given directly, it can be calculated from I_{TSM}.

$I''_K \leq I_1$ Maximum possible short-circuit impulse (surge) current, as to the circuit impedance, must be lower than the maximum breaking capacity tested of the fuse element.

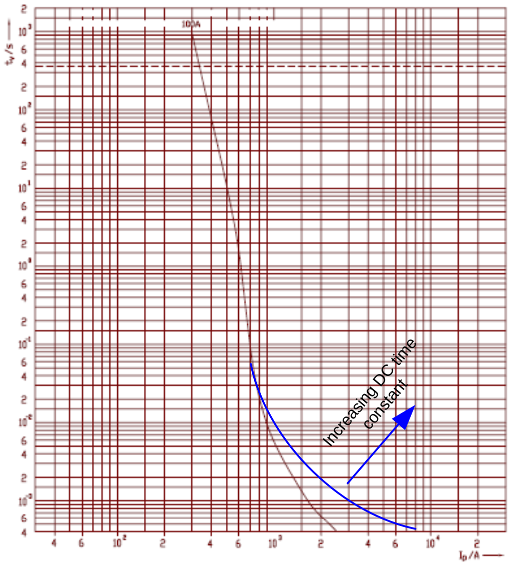
The switching voltage, or U_L voltage of the fuse element must not exceed the peak voltage repetition of the semiconductor in negative or positive direction.

The scope of semiconductor protection using ULTRA QUICK fuse links.

A correctly dimensioned ULTRA QUICK fuse link protects a semiconductor element against the effects of short-circuit currents, if it is intended for protection within the limited area aR, or it provides protection against the effects of short-circuit currents and overloads, if it is intended for protection within the whole area gR. But they cannot protect semiconductor elements against exceeding the permissible current or voltage slope, or against excessive blocking voltage. Such a protection has to be carried out by protective measures in circuitry, and by other protection elements (e.g. overvoltage arresters).

DC operating conditions

In DC operating conditions the rated voltage is lower than in AC conditions for which the fuses have been dimensioned. At the types UQ01, UQ1 and UQ2, on whose bases there is no DC voltage defined, the graph below must be applied. Thus, DC voltage depends on the L/R circuit constant.



A typical LR constant is up to 15-20ms, and with railway systems it is greater. Consequently, for each individual case DC operating conditions must be defined. If these conditions are unknown, the table below can be helpful. What the time constant L/R actually is? This is the time during which a current rises to 63% of the rated current value in DC conditions. The influence of the L/R constant on I/t characteristic can be seen on the graph below.

Figure 23

Typical values of the L/R constant for individual cases are given in the table:

Type of equipment	**Typical L/R, ms**
Battery supply/ capacitor bank	<10
Bridge circuit	<25
DC motor armature	20-60
DC traction systems	40-100
DC motor field*	1000

- It is never recommended as fuse in DC motor field circuit.

Fuse element operation indicator

Figure 24

All ULTRA QUICK fuse links are fitted with an optical operation indicator which makes it possible to reliably identify a blown fuse element. Minimum voltage required for indicator operation is 12V. In addition to the blown state indication at fuse links NV U-Quick and NV U-N-QUICK (except at the type U size 1), a remote blown fuse signalization by means of the microswitch NVS5 is also possible.

In the same way can be carried out switching-off of circuits in case of a blown fuse link.

Figure 25

At the UQ1, UQ01 type fuse links it is possible to attach a microswitch MK by means of an AMK1 (690V) or AMK2 (1000V) adapter. For this purpose the fuses are provided with special prongs onto which is attached an adapter with a microswitch stuck on it – see the catalog pages 44, 45 (Commercial Catalog) or pages 76, 77 (Catalog with characteristics). The name of these fuses includes the mark 'M' – microswitch.

Fuse base

For NV fuses of type M (knife-shaped) the fuse base PK1,2,3 are used. And for the type S fuses the fuse base US00-1/80 and US1…3-1/80-110 are used.

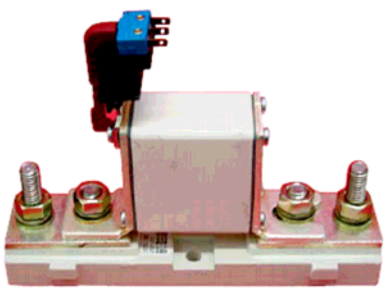


Figure 26

The first one at fuses with the size 00C and 00, the second one for the size 1,2,3. The fuse base US1…3-1/80-110 has the possibility of 80 or 110mm distance between screws.

Current limitation:

- US00-1/80, 160A/690V, 125A/1000V
- US1…3-1/80-110, 710A/690V, 500A/1000V

For higher amperages screwing directly on the »rails« is suggested.

Figure 27

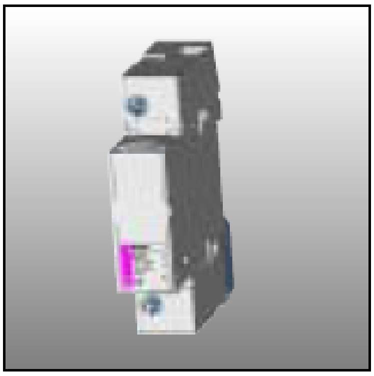
The type G fuses are usually screwed directly on copper »rails«. The knife-shaped fuses of type M are less suitable for use than the ultra quick ones, because fuse cooling over knives is poorer. For this reason in 1973 was developed the DIN 43653 standard with S-type of knives, allowing screwing-on, and there by better electrical and thermal contact. G-type of knives is included into the international standard IEC 60269-4-1. This type of connection is optimal with regard to thermal and electrical contacts. It also allows maximum building-in flexibility.

The table below includes data about torques to be used when screwing screws into G-type fuses with the use of the paste or without it.

Size	Thread	Torque (Nm)	Torque (Nm) with thermoconductive (Rhodorsil Paste 4)
1	M8	20	10
2	M10	40	20
3	M12	50	40

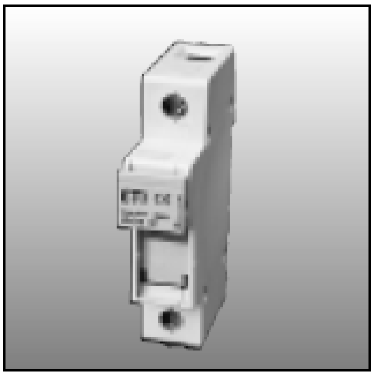
Fuse disconnectors PCF 10

Type	Imax	Rated voltage	Indicator
1P	Consult ETI technical dep.	690V	-/LED
1P+N		690V	-/LED
2P		690V	-/LED
3P		690V	-/LED
3P+N		690V	-/LED



Fuse disconnectors VLC 10

Type	Imax	Rated voltage	Indicator
1P	Consult ETI technical dep.	690V	-/LED/NEON
1P+N		690V	-/LED/NEON
2P		690V	-/LED/NEON
3P		690V	-/LED/NEON
3P+N		690V	-/LED/NEON

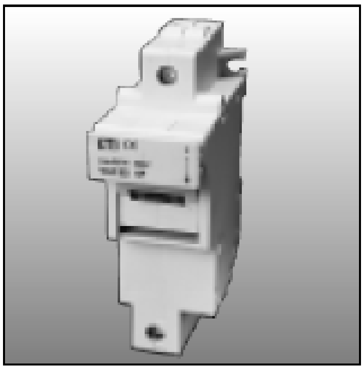


Fuse disconnectors VLC 14

Type	Imax	Rated voltage	Indicator
1P	Consult ETI technical dep.	690V	-/LED
1P+N		690V	-/LED
2P		690V	-/LED
3P		690V	-/LED
3P+N		690V	-/LED

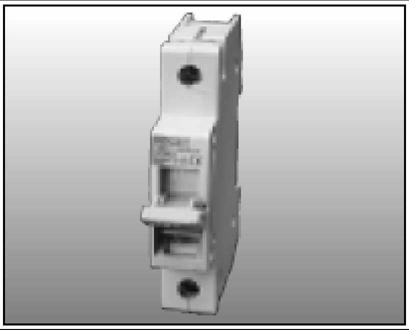
Fuse disconnectors VLC 22

Type	Imax	Rated voltage	Indicator
1P	Consult ETI technical dep.	690V	-/LED
1P+N		690V	-/LED
2P		690V	-/LED
3P		690V	-/LED
3P+N		690V	-/LED



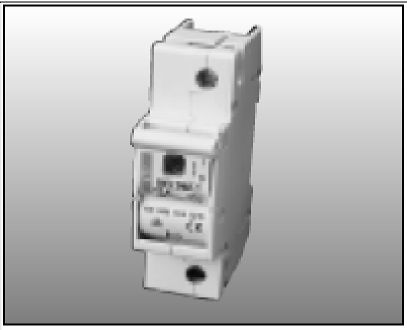
Fuse disconnectors VLD 01

Type	Imax	Rated voltage
1P	Consult ETI technical dep.	400V
1P+N		400V
2P		400V
3P		400V
3P+N		400V



Fuse disconnectors STV D02

Type	Imax	Rated voltage
1P	Consult ETI technical dep.	400V
1P+N		400V
2P		400V
3P		400V
3P+N		400V



Storage

Fuse elements must be stored in dry rooms. The use of wet fuse elements is dangerous because of reduced breaking capacity; moisture will diminish their electric arc extinguishing capability.

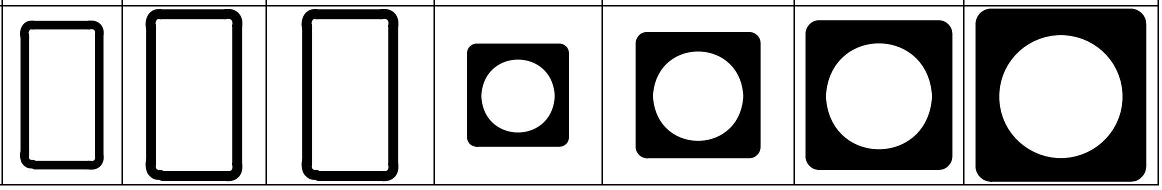
Relative humidity: must not exceed 70%.

Storage temperature: must be within the range –40ºC to +85ºC.

Vibrations: maximum long-lasting vibrations can be up to an acceleration of 5g, and the short-term ones up to an acceleration of 8g.

BODY CROSS SECTION for NV/NH fuse -links:

Size	00C	00	0	1	2	3	4
UQ1, UQ01, UQ02 maximum cross-section mm	21 x 40	30 x 51	30 x 50	51 x 51	60 x 60	75 x 75	
UQ2 maximum cross-section mm	21 x 42			46 x 52	54 x 61	64 x 74	95 x 112
U/U-N maximum cross-section mm	21 x 48	27 x 48	27 x 48	46 x 51	57 x 61	69 x 71	



TYPE of end contact:

Type **M**:
with knife contact

Type **S**:
with slotted tags

Type **S-M**:
with sloted tags + microswitch MK

Type **G**:
with thread for plain end-face fixing

Type **G-M**:
with thread for plain end-face fixing + microswitch MK

FUSE PRODUCT LINE

<table>
<tr><td>UPS

Motor control

Switching Mode Power Supply</td><td>Up to
1kW
Using
Mainly
TRIAC
IGBT
DIODES</td><td>
</td></tr>
<tr><td>UPS

Motor control

Drives

Rectifier</td><td>Between
1kW
to 100kW
Using
mainly
THYRISTORS
IGBT
DIODES</td><td></td></tr>
<tr><td>UPS

Drives

Traction

High Voltage</td><td>Up to
1MW
Using
mainly
Diodes
GTO
THYRISTORS</td><td rowspan="2"></td></tr>
<tr><td>Distribution
Cycloconverter
Inverter
UPS
with
Laminated
BusBar</td><td>Up to
1MW
Using
Mainly
IGBT
And IGCT</td></tr>
</table>

Glossary of Terms:

Arcing I^2t

Value of the I^2t during the arcing time under specified conditions.

Arcing Time

The time when fuse link has melted until the over current is safely interrupted.

Pre-arcing time

The time required to melt the fuse element during a specified over current.

Total operating I^2t

The total operating I^2t value is the total of the pre-arcing and the arcing I^2t values under specified conditions.

I^2t, Ampere Squared Seconds

The measure of heat energy developed within a circuit during the fuse operation. »I« stands for effective let-through current (RMS), which is squared, and »t« stands for time of opening, in seconds. It can be expressed as »pre-arcing I^2t«, »Arcing I^2t« or the sum of them as »Operating I^2t«.

Ampere Rating

The current capacity of a fuse.

Arc Voltage

This is the voltage, which occurs between the terminals of a fuse during operation.

Breaking capacity

This is the maximum value of prospective current, RMS symmetrical, which a fuse is capable of breaking at stated conditions.

High Speed Fuses

Fuses with no intentional time-delay in the overload range and designed to open as quickly as possible in the short-circuit range. These fuses are often used to protect solid-state devices like semiconductors.

Total operating time

The total time between the beginning of the over current and the final opening of the circuit at system voltage. Total operating time is the total of the pre-arcing time and the arcing time.

Current-Limitation

A fuse operation relating to short-circuits only. When a fuse operates in its current-limiting range, it will clear a short-circuit before the first peak of the current.

Cut-off current

The maximum value reached by the fault current during the breaking operation of a fuse. In many cases the fuse will be current limiting device.

Fuse

An over current protective device with a fusible link that operates and opens the circuit on an over current cond

Overcurrent

A condition which exists on an electrical circuit when the normal load current is exceeded. Over currents take on two separate characteristics – overloads gR and short-circuits aR.

Overload

This is a condition in which an over current exceeds the normal full load current of a circuit that is in an otherwise healthy condition.

Peak Let-Through Current

The instantaneous value of peak current let-through by a current-limiting fuse, when it operates in its current-limiting range.

Power Factor

The ratio of active power (kW) to apparent power (kVA) drawn by a load. It corresponds to the cosine of the phase angle between the voltage and current (cos fi)

Power dissipation

The power released in a fuse when loaded according to stated conditions.

Prospective short-circuit current

This is the current that would flow in the fault circuit if the fuse was replaced by a link with an infinitely small impedance. Normally it is given as symmetrical RMS value.

Recovery voltage

This is the voltage which can be measured across the fuse connections after operation.

Resistive Load

An electrical load which is characteristic of not having any significant inductive or capacitive component. When a resistive load is energized, the current rises instantly to its steady-state value, without first rising to a higher value.

RMS Current

Also known as the effective value, it corresponds to the peak instantaneous value of a sinusoidal waveform divided by the square root of two. The RMS value of an alternating current is equivalent to the value of direct current which would produce the same amount of heat or power.

Semiconductor Fuses

Fuses used to protect solid-state devices (thyristors, diodes…).

Short-Circuit Current

Can be classified as an over current which exceeds the normal full load current of a circuit by a factor many times.

Short-Circuit Current Rating

The maximum short-circuit current an electrical component can sustain without the occurrence of excessive damage when protected with an over current protective device.

Voltage Rating

The maximum open circuit RMS voltage in which a fuse can be used, yet safely interrupt an over current. Exceeding the voltage rating of a fuse impairs its ability to clear an overload or short-circuit safely.