Technical explanations

Overview

The fuse links are selected according to rated voltage, rated current, breaking I^2t value I^2t_A and varying load factor, taking into consideration other specified conditions. Unless stated otherwise, all of the following data refer to AC operation from 45 Hz to 62 Hz.

Rated voltage U_n

The rated voltage of a SITOR fuse link is the voltage specified as the r.m.s. value of the AC voltage on the fuse link and in the order and configuration data and the characteristics.

Always ensure that the rated voltage of the fuse link you select is such that the fuse link will reliably quench the voltage driving the short-circuit current. The driving voltage must not exceed the value U_n + 10 %. Please note that the supply voltage U_{v0} of a power converter can also be increased by 10 %. If, in the shorted circuit, two arms of a converter connection are connected in series, and if the short-circuit current is sufficiently high, it can be assumed that voltage sharing is uniform. It is essential to observe the instructions in *"Series connection of fuse links"* on page 2/84.

Rectifier operation

With converter equipment that can only be used for rectifier operation, the supply voltage U_{v0} is the driving voltage.

Inverter operation

With converter equipment that can also be used for inverter operation, shoot-throughs may occur as faults. In this case, the driving voltage U_{WK} in the shorted circuit is the sum of the infeed direct voltage (e.g. the e.m.f. of the DC generator) and the AC-line supply voltage. When rating a fuse link, this sum can be replaced by an AC voltage whose r.m.s. value is 1.8 times that of the AC-line supply voltage (U_{WK} = 1.8 U_{v0}). The fuse links must be rated so that they reliably quench the voltage U_{WK}.

Rated current I_n, load rating

The rated current of a SITOR fuse link is the current specified as r.m.s. value of the alternating current for the frequency range 45 Hz to 62 Hz in the *Selection and ordering data* and *characteristic curves*, as well as on the fuse link itself.

When operating fuse links with rated current, the following are considered normal operating conditions:

- Natural air cooling with an ambient temperature of +45 °C
- Conductor cross-sections equal test cross-sections (see Test cross-sections table), for operation in LV HRC fuse bases and switch-disconnectors, please refer to the Selection and ordering data
- Conduction angle of a half-period 120 °el
- Continuous load maximum with rated current.

For operating conditions that deviate from the above, the permissible load current I_n' of the SITOR fuse link can be determined using the following formula:

$$I_n' = k_u \times k_q \times k_\lambda \times k_l \times WL \times I_n$$

whereby

- I_n Rated current of the fuse link[1)]
- k_u Correction factor; ambient temperature (page 2/79)
- k_q Correction factor; conductor cross-section (page 2/79)
- k_λ Correction factor; conduction angle (page 2/79)
- k_l Correction factor; forced-air cooling (page 2/79)
- *WL* Varying load factor (page 2/80)

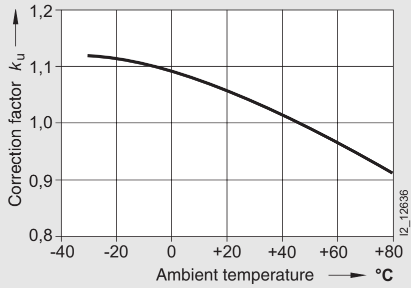
Test cross-sections

Rated current I_n A	Test cross-sections (series 3NC1 0, 3NC1 1, 3NC1 4, 3NC1 5, 3NC2 2, 3NE1 ..., 3NE8 0.., 3NE4 1) Cu mm²	(all other series) Cu mm²
10	1.0	–
16	1.5	–
20	2.5	45
25	4	45
35	6	45
40	10	45
50	10	45
63	16	45
80	25	45
100	35	60
125	50	80
160	70	100
200	95	125
224	–	150
250	120	185
315	2 x 70	240
350	2 x 95	260
400	2 x 95	320
450	2 x 120	320
500	2 x 120	400
560	2 x 150	400
630	2 x 185	480
710	2 x (40 x 5)	560
800	2 x (50 x 5)	560
900	2 x (80 x 4)	720
1000	–	720
1250	–	960

1) When using SITOR fuse links in LV HRC fuse bases according to IEC/EN 60269-2-1 and fuse switch disconnectors and switch disconnectors with fuses, please also refer to the data in the selection and ordering data.

Correction factor; ambient temperature k_u

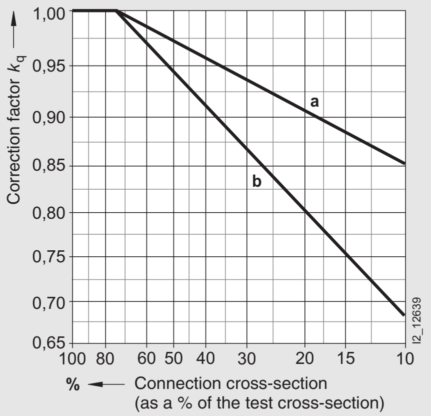
The influence of the ambient temperature on the permissible load of the SITOR fuse links is taken into account using the correction factor k_u as shown in the following graph.



Correction factor; conductor cross-section k_q

The rated current of the SITOR fuse links applies to operation with conductor cross-sections that correspond to the respective test cross-section (see the table on page 2/78).

In the case of reduced conductor cross-sections, the correction factor k_q, must be used as shown in the following graph.

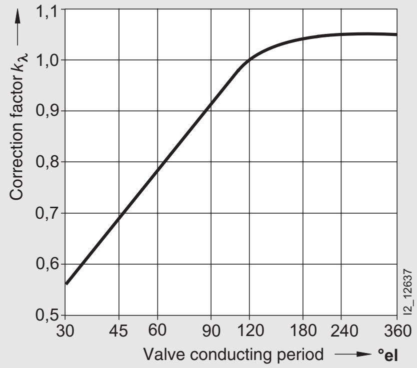


a = Reduction of cross-section of one connection

b = Reduction of cross-section of both connections

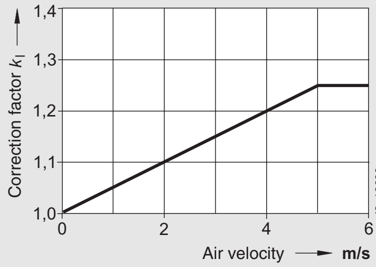
Correction factor; conduction angle k_I

The rated current of the SITOR fuse links is based on a sinusoidal alternating current (45 Hz to 62 Hz). However, in converter operation, the arm fuses are loaded with an intermittent current, whereby the conduction angle is generally 180 °el or 120 °el. With this load current wave form, the fuse link can still carry the full rated current. In the case of smaller conduction angles, the current must be reduced in accordance with the following graph.



Correction factor; forced-air cooling k_l

In the case of increased air cooling, the current carrying capacity of the fuse link increases with the air speed, air speeds > 5 m/s do not effect any significant further increase of current carrying capacity.



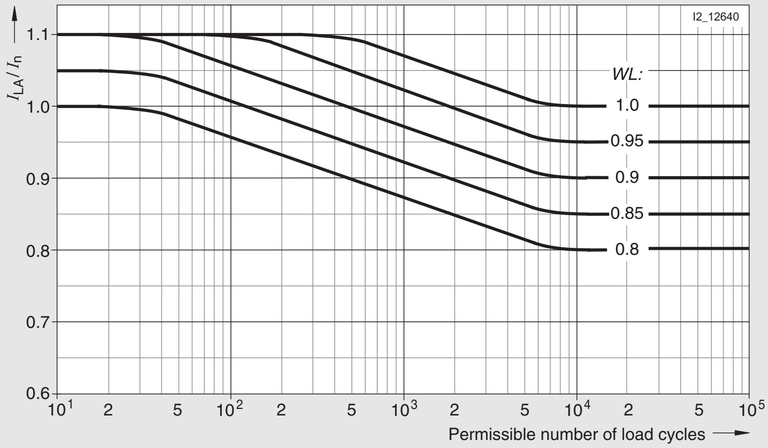
Notes on Dimensioning

Technical explanations

Varying load factor *WL*

The varying load factor *WL* is a reduction factor by which the non-aging current carrying capacity of the fuse links can be determined for any load cycles. Due to their design, the SITOR fuse links have a range of different varying load factors. In the characteristic curves of the fuse links, the respective varying load factor *WL* for >10000 load changes (1 hour "ON", 1 hour "OFF") is specified for the expected operating time of the fuse links. In the event of a lower number of load changes during the expected operating time, it may be possible to use a fuse link with a smaller varying load factor *WL* as shown in the following graph.

In the case of uniform loads (no load cycles and no shutdowns), the varying load factor can be taken as *WL* = 1. For load cycles and shutdowns that last longer than 5 min. and are more frequent than once a week, you need to select the varying load factor *WL* specified in the characteristic curves of the individual fuse links.



Waveform of the varying load factor *WL* for load cycles

Fuse currents for operation in power converter

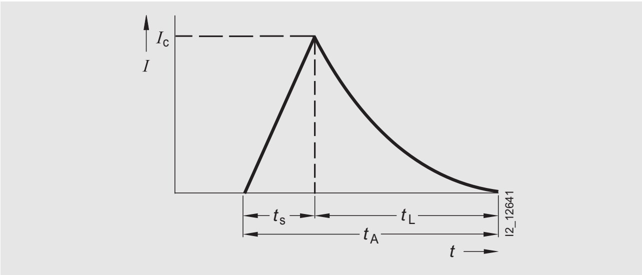
The r.m.s. value of the fuse current can be calculated for the most common converter connections from the (smoothed) direct current I_d or the conductor current I_L according to the following table.

Converter connection		R.m.s. value of the conductor current (phase fuse)	R.m.s. value of the branch-circuit current (arm fuse)
One-pulse center tap connection	(M1)	1.57 I_d	--
Double-pulse center tap connection	(M2)	0.71 I_d	--
Three-pulse center tap connection	(M3)	0.58 I_d	--
Six-pulse center tap connection	(M6)	0.41 I_d	--
Double three-pulse center tap connection (parallel)	(M3.2)	0.29 I_d	--
Two-pulse bridge circuit	(B2)	1.0 I_d	0.71 I_d
Six-pulse bridge circuit	(B6)	0.82 I_d	0.58 I_d
Single-phase bidirectional connection	(W1)	1.0 I_L	0.71 I_L

I^2t values

In the event of a short-circuit, the current of the fuse link increases during melting time t_s up to let-through current I_c (melting current peak).

During the arc quenching time t_L, the electric arc develops and the short-circuit current is quenched (see the following graph).



Current path when switching fuse links

The integral of the current squared $(\int I^2 dt)$ over the entire switching period (t_s+t_L), known as the breaking I^2t value, determines the heat to be fed to the semiconductor device that is to be protected during the breaking procedure.

In order to ensure sufficient protection, the breaking I^2t value of the fuse link must be smaller than the I^2t value of the semiconductor device. As the temperature increases, i.e. preloading increases, the breaking I^2t value of the fuse link decreases almost in the same way as the I^2t value of a semiconductor device, so that it is enough to compare the I^2t values in a non-loaded (cold) state.

The breaking I^2t value (I^2t_A) is the sum of the melting I^2t value (I^2t_s) and the quenching I^2t value (I^2t_L).

$(\int I^2 dt)$ (semiconductor, t_{vj} = 25 °C,
t_p = 10 ms) $> (\int I^2 t_A)$ (fuse link)

Melting I^2t value I^2t_s

The melting value I^2t can be calculated for the value pairs of the time/current characteristic curve of the fuse link for any periods.

As the melting time decreases, the melting value I^2t tends towards a lower limit value at which almost no heat is dissipated from the bottleneck of the fuse element to the environment during the melting process. The melting I^2t values specified in the Selection and ordering data and in the characteristic curves correspond to the melting time t_{vs} = 1 ms.

Melting I^2t value I^2t_L

While the melting I^2t value is a characteristic of the fuse link, the quenching I^2t value depends on circuit data, such as

- the recovery voltage U_w
- the power factor p.f. of the shorted circuit
- the prospective current I_p (current at the installation site of the fuse link if this is bridged)

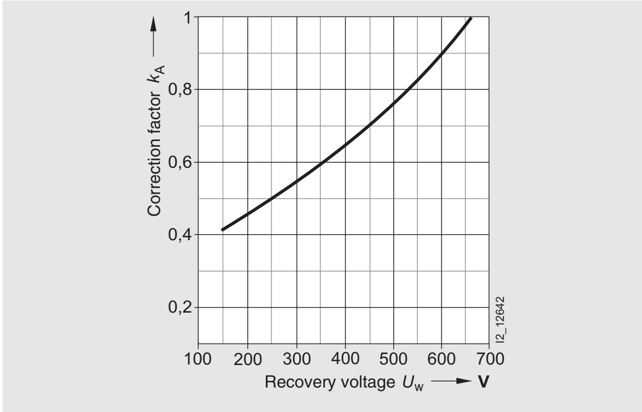
The maximum quenching I^2t value is reached at a current of 10 x I_n to 30 x I_n.

Breaking I^2t value I^2t_A, correction factor k_A

The breaking I^2t values of the fuse link are specified in the characteristic curves for the rated voltage U_n. In order to determine the breaking I^2t value for recovery voltage U_w the correction factor k_A must be taken into account.

I^2t_A (at U_w) = I^2t_A (at U_n) x k_A

The characteristics "correction factor k_A" (see the following graph) is specified in the characteristic curves for the individual fuse series. The breaking I^2t values determined in this way apply to prospective currents $I_p \geq 10$ x I_n and p.f. = 0.35.



Correction factor k_A for breaking I^2t value

Example: Series 3NE8 0..

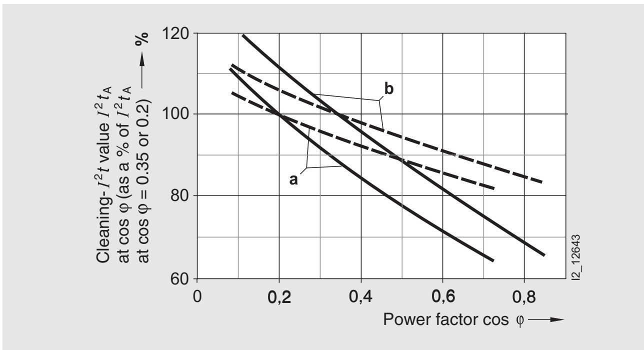
Taking into account the recovery voltage U_w

The recovery voltage U_w is derived from the voltage driving the short-circuit current. For most faults, the driving voltage is equal to the supply voltage U_{v0}, however, for shoot-throughs it is 1.8 times the value for the supply voltage U_{v0} (see rated voltage, page 2/78). If the shorted circuit contains two arms of a converter connection and thus two fuse links in series, and if the short-circuit current is sufficiently high (see series connection, page 2/84) it can be assumed that there is a uniform voltage sharing, i.e. U_w = 0.5 x U_{v0} or, in the case of shoot-throughs U_w = 0.9 x U_{v0}.

Influence of the power factor p.f.

The specifications in the characteristic curves for the breaking I^2t values (I^2t_A) refer to power factor = 0.35 (exception: for 3NC5 8.., 3NE6 4.., 3NE9 4.. SITOR fuse links the following applies: p.f. = 0.2).

The dependence of the breaking I^2t values on the power factor at 1.0 x U_n and at 0.5 x U_n is shown in the following graph.



Dependence of breaking I^2t value I^2t_A p.f.

—— at 1.0 U_n

– – at 0.5 U_n

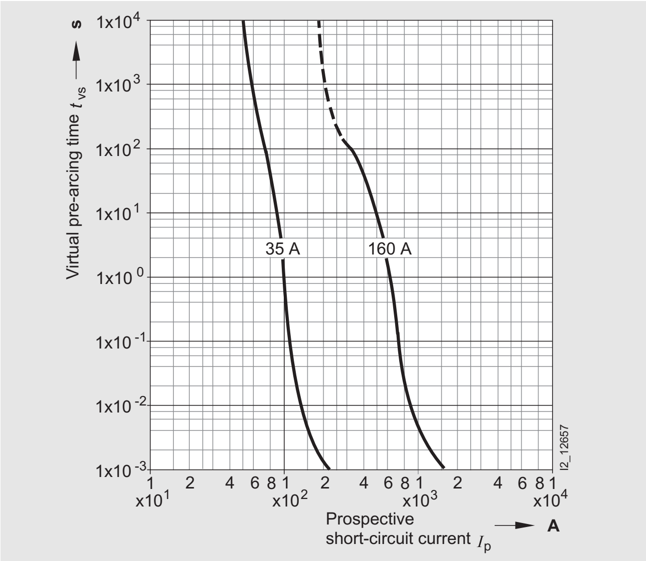
a = 3NC5 8.., 3NE6 4.., 3NE9 4.. for SITOR fuse links (reference to p.f. = 0.2)

b = for all other SITOR fuse links (reference to power factor φ = 0.35)

Technical explanations

Time/current characteristics

The solid time/current characteristic curves in the following graph specify the time to melting for the non-loaded fuse link in a cold state (max. +45 °C).



35 A: Operational class: gR

160 A: Operational class: aR

If the time/current characteristic curve in the long-time range (t_{vs} > 30 s) is dashed (fuse links of aR operational class), this specifies the limit of the permissible overload in a cold state. If the dashed part of the characteristic curve is exceeded, there is a risk of damage to the ceramic body of the fuse link. The fuse links can only be used for short-circuit protection. In this case, an additional protective device (overload relay, circuit-breaker) is required to protect against overload. In the case of controlled converter equipment, the current limiter is sufficient.

If the time/current characteristic curve is solid over the entire setting range (fuse links of operational class gR or gS), then the fuse link can operate in this range. This means it can be used both for overload and short-circuit protection.

Actual melting time

The virtual melting time t_{vs} is specified in the time/current characteristic curve, depending on the prospective current. It is a value that applies to the current squared (d*i*/d*t*) = ∞).

In the case of melting times t_{vs} < 20 ms the virtual melting time t_{vs} deviates from the actual melting time t_s. The actual melting time may be several milliseconds longer (depending on the rate of current rise).

Within a range of several milliseconds, during which the rise of the short-circuit current can be assumed to be linear, the actual melting time for a sinusoidal current rise and 50 Hz is as follows:

$$t_s = \frac{3xI^2t_s}{I_c^{\ 2}}$$

Taking into account preloading, residual value factor RW

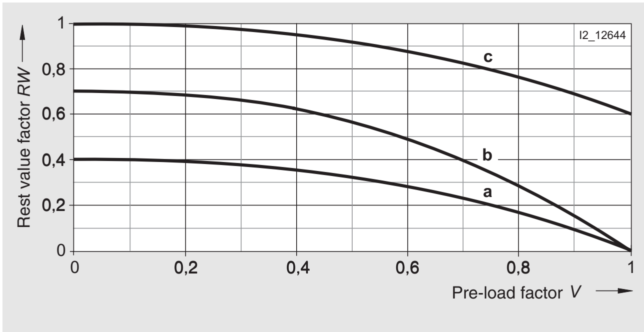
Preloading the fuse link shortens the permissible overload duration and the melting time.

The residual value factor *RW* can be used to determine the time that a fuse link can be operated during a periodic or non-periodic load cycle, above and beyond the previously determined permissible load current I_n, with any overload current I_{La} without aging.

The residual value factor *RW* is dependent on the preloading *V* (I_{eff} r.m.s. value of the fuse current during the load cycle at permissible load current I_n')

$$V = \frac{I_{eff}}{I_n'}$$

and the frequency of the overloads (see the following graph, curves a and b).



Permissible overload and melting time for previous load

a = Frequent surge/load cycle currents (> 1/week)

b = Infrequent surge/load cycle currents (< 1/week)

c = Melting time for preloading

Permissible overload duration =
residual value factor *RW* x melting time t_{vs} (time/current characteristic curve)

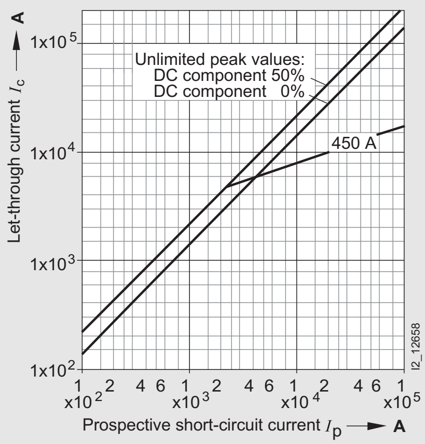
A reduction of the melting time of a fuse link in the case of preloading can be derived from curve c.

Melting time =
residual value factor *RW* x melting time t_{vs} (time/current characteristic curve)

Let-through current I_c

The let-through current I_c can be determined from the current limiting characteristics (current limitation at 50 Hz) specified for the respective fuse link. This depends on the prospective current and the DC component when the short-circuit occurs (instant of closing).

The following graph shows the let-through current I_c of a fuse link, depending on the prospective short-circuit current I_p using the 3NE4 333-0B SITOR fuse link as an example.



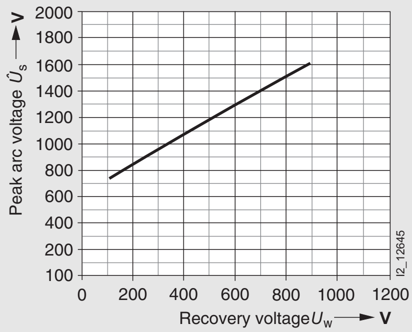
Example:
3NE4 333-0B SITOR fuse link

Rated breaking capacity

The rated breaking capacity of all SITOR fuse links is at least 50 kA, unless higher values are specified in the characteristic curves. This data applies to a test voltage of 1.1 x U_n, 45 Hz to 62 Hz and 0.1 ≤ p.f. ≤ 0.2. In the case of inception voltages that are below the rated voltage, or rated currents of the fuse links that are below the maximum rated current of a fuse series, the breaking capacity is considerably higher than the rated breaking capacity.

Peak arc voltage $\hat{U}_s$

During the quenching process, a peak arc voltage $\hat{U}_s$ occurs at the connections of the fuse link, which can significantly exceed the supply voltage. The level of the peak arc voltage depends on the design of the fuse link and the level of the recovery voltage.
The characteristic curve shown below depends on the recovery voltage U_w (see the following graph).



Example:
3NE4 333-0B SITOR fuse link

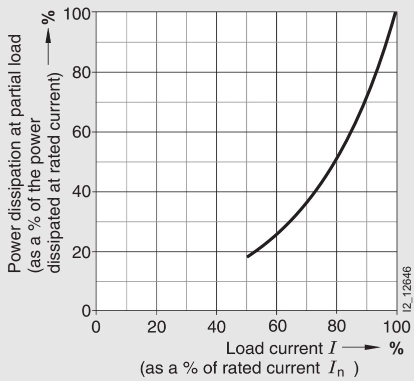
The peak arc voltage occurs as a cutoff voltage at the semiconductor devices not in the shorted circuit. In order to prevent voltage-related hazards, the peak arc voltage must not exceed the peak cutoff voltage of the semiconductor devices.

Power dissipation, temperature rise

On reaching the rated current, the fuse elements of the SITOR fuse links have a considerably higher temperature than the fuse elements of line protection fuse links.

The power dissipation specified in the characteristic curve is the upper variance coefficient if the fuse link is loaded with the rated current.

In the case of partial loads, this power dissipation decreases as shown in the following graph



The temperature rise specified in the characteristic curve applies to the respective reference point and is determined when testing the fuse link (test setup according to DIN VDE 0636, Part 23 and IEC 269-4).

Technical explanations

Parallel and series connection of fuse links

Parallel connection

If an arm of a converter connection has several semiconductor devices so that the fuse links are connected in parallel, only the fuse link connected in series to the faulty semiconductor device is tripped in the event of an internal short-circuit. It must quench the full supply voltage.

To boost the voltage, two or more parallel fuse links can be assigned to a single semiconductor device without reducing the current. The resulting breaking I^2t value increases with the square of the number of parallel connections. In this case, in order to prevent incorrect distribution of the current, you should only use fuse links of the same type.

Series connection

There are two kinds of series connection available:

- Series connection in the converter arm
- 2 fused converter arms through which a short-circuit current flows in series

In both cases, uniform voltage sharing can only be assumed if the melting time of the SITOR fuse link does not exceed the value specified in the following table.

SITOR fuse links Type	Maximum melting time for uniform voltage sharing ms
3NC1 0.. 3NC1 4.. 3NC1 5.. 3NC2 2..	10
3NC2 4.. 3NC5 8.. 3NC7 3.. 3NC8 4..	40 10
3NE1 0.. 3NE1 2.. 3NE1 3.. 3NE1 4.. 3NE1 8..	10 20 10
3NE3 2.. 3NE3 3.. 3NE3 4.. 3NE3 5.. 3NE3 6..	10 20
3NE4 1.. 3NE4 3..	10
3NE5 4.. 3NE5 6..	20
3NE6 4..	10
3NE7 4.. 3NE7 6..	20
3NE8 0.. 3NE8 7..	10
3NE9 4.. 3NE9 6..	10 20

Cooling conditions for series-connected fuse links should be approximately the same. If faults are expected, during which the specified melting times are exceeded (as a result of a slower current rise), it can no longer be assumed that voltage sharing is uniform. The voltage of the fuse links must then be rated so that a single fuse link can quench the full supply voltage.

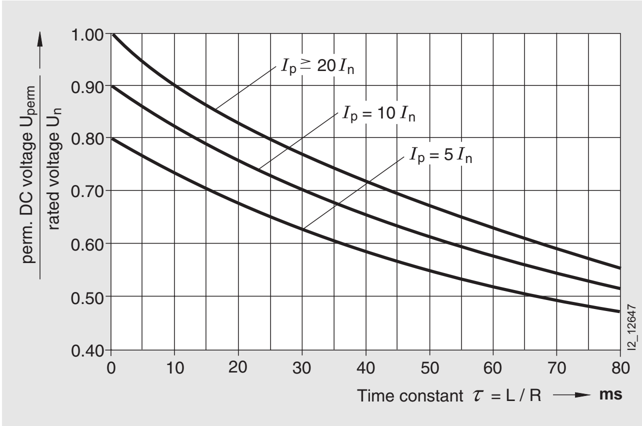
It is best to avoid the series connection of fuse links in a converter connection arm and instead use a single fuse link with a suitably high rated voltage.

Use with direct current

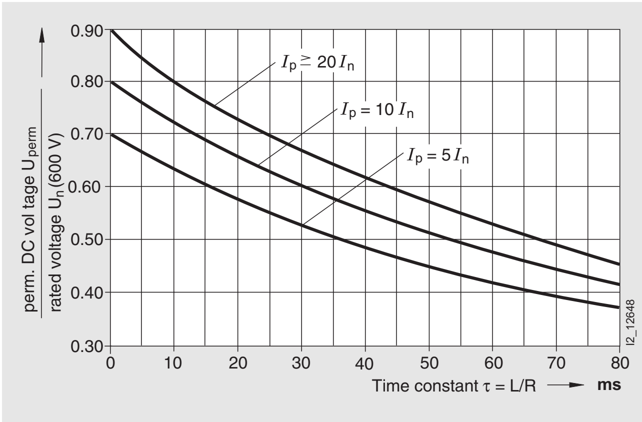
For fuse links that are to be used in DC circuits, some data may vary from the data specified in the characteristic curves for alternating current.

Permissible direct voltage

The permissible direct voltage U_{perm} of the fuse links depends on the rated voltage U_n, of the time constants $\tau = L/R$ in the DC circuit and on the prospective current I_p. The permissible direct voltage refers to the rated voltage U_n and is specified depending on the time constants τ, the prospective current is a parameter (see the following graphs).



Applies to all series except 3NE1 0.., 3NE1 8..



Applies to all series except 3NE1 0.., 3NE1 8..

Melting I^2t value I^2t_A

The breaking I^2t value I^2t_A depends on the voltage, on the time constants $\tau = L/R$ and on the prospective current I_p. It is calculated from the I^2t_A value specified in the characteristic curve for the respective fuse link at rated voltage U_n and correction factor k_A whereby, instead of the recovery voltage U_w, the direct voltage is used against which the fuse link is to switch.

The breaking I^2t value determined in this way applies under the following conditions:

- Time constants $L/R \leq 25$ ms for $I_p \geq 20 \times I_n$
- Time constants $L/R \leq 10$ ms for $I_p = 10 \times I_n$
- The breaking I^2t values increases by 20 %
- For $I_p \geq 20 \times I_n$ and time constants $L/R = 60$ ms
- For $I_p = 10 \times I_n$ and time constants $L/R = 35$ ms

Peak arc voltage $\hat{U}_s$

The peak arc voltage $\hat{U}_s$ is determined from the curve specified in the characteristics for the respective fuse link, whereby instead of the recovery voltage U_w, the direct voltage is used against which the fuse link is to switch.
The peak arc voltage determined in this way applies under the following conditions:

- Time constants $L/R \leq 20$ ms for $I_p \geq 20\ I_n$
- Time constants $L/R \leq 35$ ms for $I_p = 10\ I_n$

The switching voltages increase by 20 %

- For $I_p \geq 20\ I_n$ and time constants $L/R = 45$ ms
- For $I_p = 10\ I_n$ and time constants $L/R = 60$ ms

Indicator

An indicator shows the switching of the fuse link. The indicator of the SITOR fuse links has a transformer operational voltage between 20 V ($U_n \leq 1000$ V) and 40 V ($U_n > 1000$ V).

Accessories

Fuse bases, fuse pullers

Some of the SITOR fuse links can be inserted in matching fuse bases. The matching fuse bases (single-pole and three-pole) and the respective fuse pullers are listed in the technical specifications, from page page 2/4.

Note
Even if the values of the rated voltage and/or current of the fuse bases are lower than that of the allocated fuse link, the values of the fuse link apply.

Fuse switch disconnectors, switch disconnectors with fuses

Some series of SITOR fuse links are suitable for operation in 3NP4 and 3NP5 fuse switch disconnectors or in 3KL and 3KM switch disconnectors with fuses (see catalogs LV 10 and LV 30).

When using switch disconnectors, the following points must be observed:

- Because, compared to LV HRC fuses, the power dissipation of the SITOR fuse links is higher, the permissible load current of the fuse links sometimes needs to be reduced, see below (Configuration manual).
- Fuse links with rated currents $I_n > 63$ A may also not be used for overload protection when they have gR operational class.

Note
All fuse links of the 3NE1 ... series with rated currents I_n from 16 A to 850 A and gR or gS operational classes can be used for overload protection.

- The rated voltage and rated isolation voltage of the switch disconnectors must at least correspond to the available voltage.
- When using fuse links of the 3NE3 2.., 3NE3 3.., 3NE4 3.., 3NC2 4.. and 3NC8 4.. series the switching capacity of the fuse switch disconnectors must not be fully utilized due to the slotted blade. Occasional switching of currents up to the rated current of the fuse link is permissible
- When used in fuse switch disconnectors, fuse links of the 3NE4 1.. series may only be occasionally switched, and only without load, as this places the fuse blade under great mechanical stress.

In the technical specifications, from page 2/4, the switch disconnectors are allocated to their respective individual fuse links.

The permissible load of the fuse link and the required conductor cross-section can be found in the configuration manual "Configuring SITOR", Order No.: E20001-A700-P302.