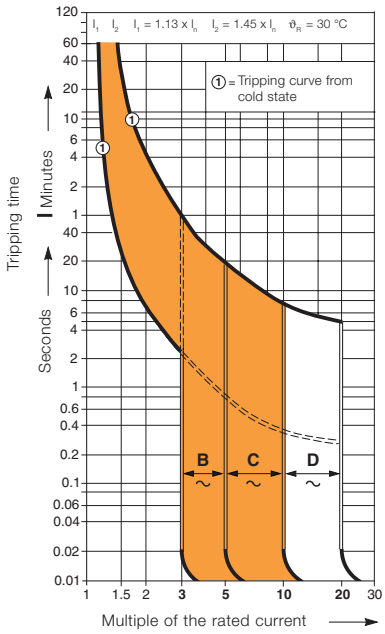
Comparison of tripping characteristics for miniature circuit-breakers

The requirements for “Protection for safety – Protection against overcurrent” are specified in IEC 60364-4-43. Miniature circuit-breakers are used to protect cables in installations. They should disconnect automatically as soon as the combination of the current rise and duration causes the cable or a component to heat up excessively.



Miniature circuit-breaker are used for:
- overload protection and
- short circuit protection

in electrical circuits as well as
- protection against electric shock by automatic disconnection.

The disconnection is performed by two different releases. The instantaneous tripping by electro-magnetic release provides protection against short circuits. This is only dependent on current. The thermal bi-metal release is used for protection against overload. It trips by temperature rise, in other words both current and time.

When selecting miniature circuit-breakers for short-circuit protection in accordance with IEC 60364-4-43, the permissible let-through value $I^2 \times t$ for extremely short disconnection times (<0.1s) is contrasted with the Joulean heat impulse of the current $k^2 \times S^2$ of the cable in order to verify whether sufficient **protection is guaranteed in the event of a short circuit.**

The combination of tripping curves of the electro-magnetic release and the thermal bi-metal release result in an overall tripping curve for overload protection. This curve – referred to the individual tripping characteristic – represents the time/current behavior of a miniature circuit-breaker.

The desire for the best protection, which requires miniature circuit-breakers to be highly sensitive, has to be reconciled with the different operating characteristics of the loads to be protected. Load current peaks must be permitted to pass unhindered, yet at the same time a disconnection must be ensured in the event of relatively low, but continuous, overloads. Various tripping characteristics are therefore available for circuit-breakers depending on the type of component or equipment to be protected:
- B, C and D for overcurrent protection of cables in accordance with IEC/EN 60898-1
- K for the protecting motors and transformers and simultaneous overcurrent protection of cables with overload tripping based on IEC/EN 60947-2
- Z for control circuits with high impedances, voltage converter circuits and semicable protection and simultaneous overcurrent protection of cables with overload tripping based on IEC/EN 60947-2

Protection against short-circuits

Figure 1 shows typical let-through or I^2t values of overcurrent circuit-breakers. In the case of S201-B16 miniature circuit-breaker, this causes the let-through energy to be limited to approx. 20,000 A^2s if a prospective short-circuit current i_K = 6 kA occurs. This value is far less than 29,700 A^2, meaning PVC-insulated Cu cables with a cross-section of 1.5 mm^2 can be protected in the event of a short-circuit.

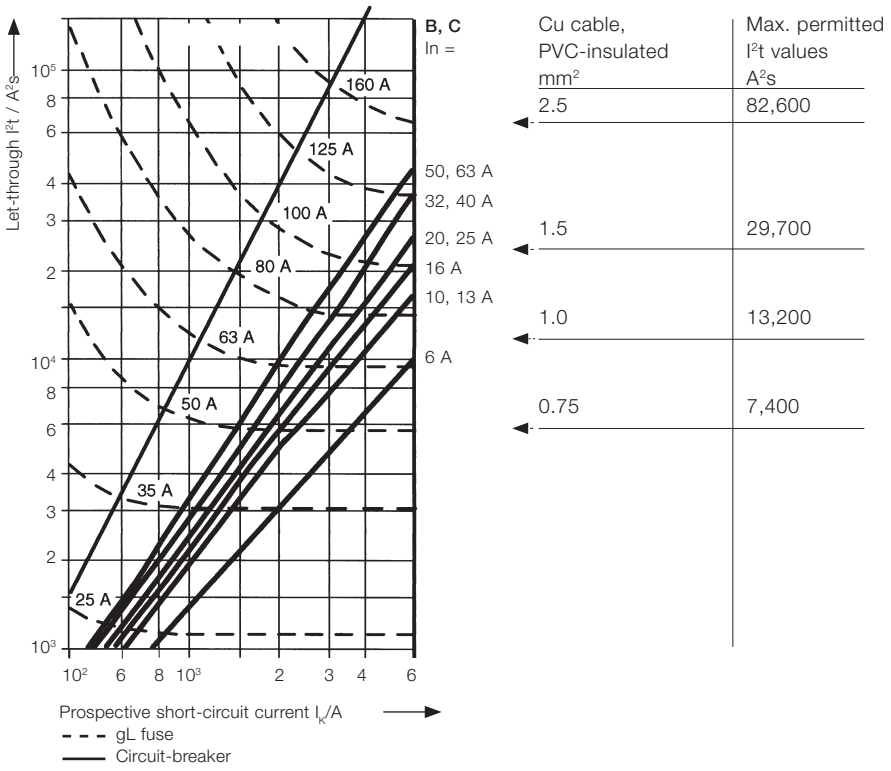


Fig. 1 Let.-through energy I^2t

Overload protection in accordance with IEC 60364-4-43

For protection against overload, the protective device must be selected based on the current carrying capacity I_z of the cable:

$I_b \leq I_n \leq I_z$ (1)

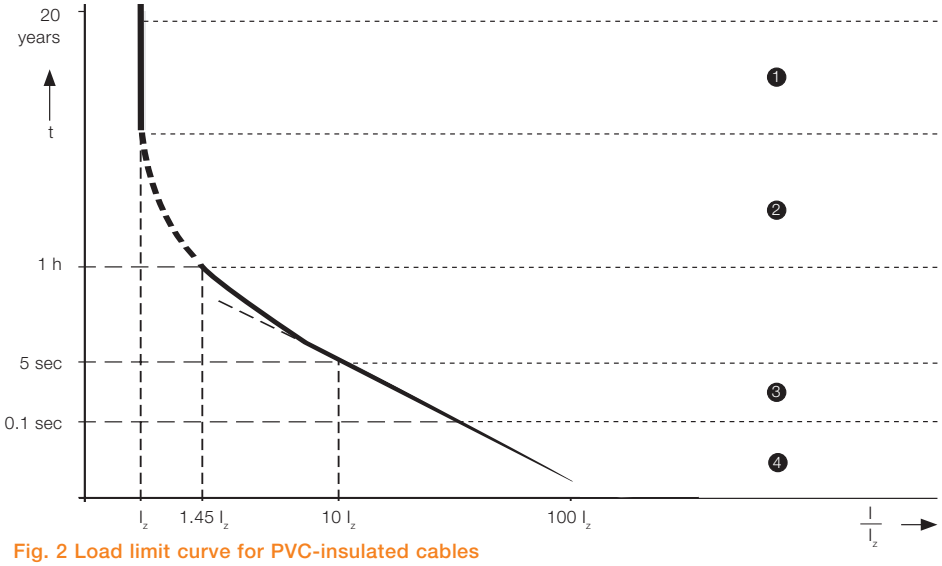
$I_2 \leq 1.45 \times I_z$ (2)

I_b = Design current of a circuit

I_n = Rated current of the protective device

I_z = Current carrying capacity of the cable in accordance with IEC/HD 60364-5-52

I_2 = Current ensuring effective operation in the conventional time of the protective device



① Area of complete heat dissipation with continuous current I_z
Permissible operating temperature 70 °C (PVC)

② Area of limited heat dissipation in the event of overload $I_2 \leq 1.45 \times I_z$

③ Area without heat dissipation for a maximum short circuit duration of 5s
I^2t = constant, permissible short circuit temperature 160 °C

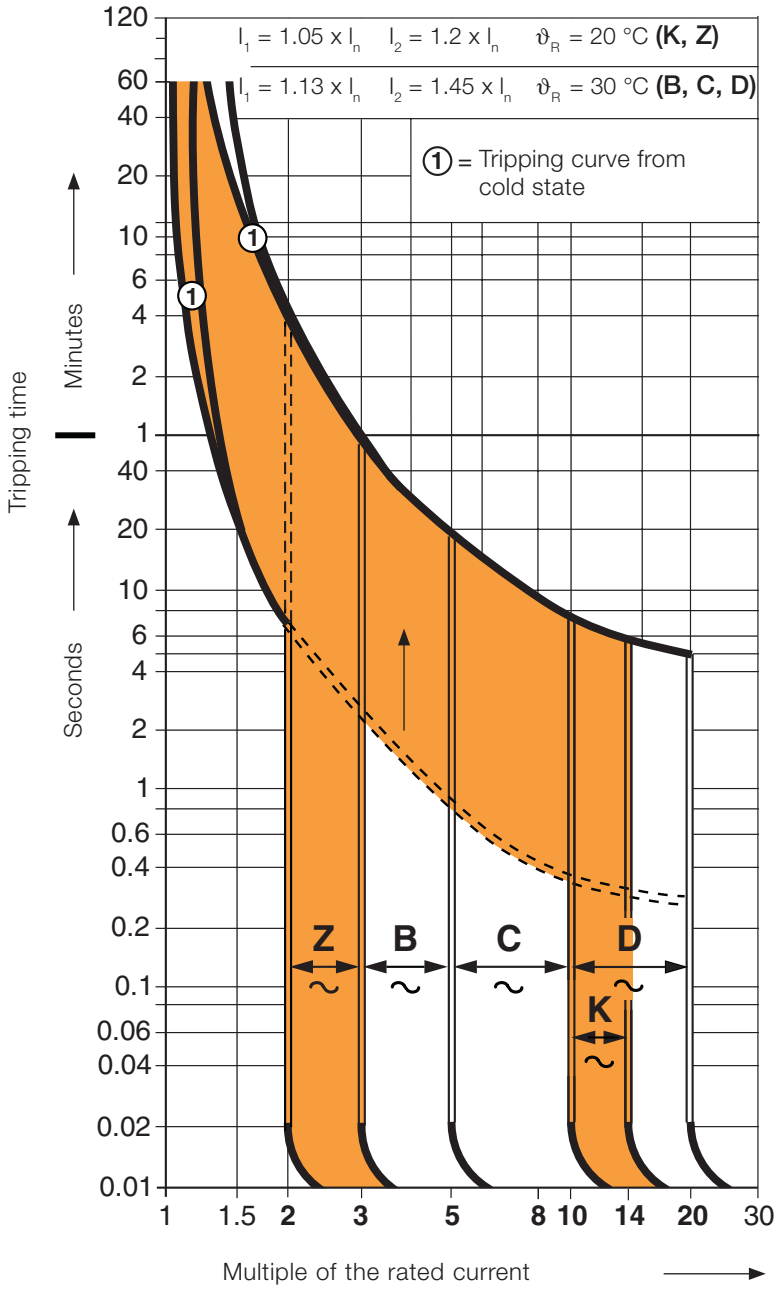
④ With a disconnection time of < 0.1s, the I^2t of the miniature circuit-breaker must be less than $k^2 \cdot S^2$ of the cable
(k = material value in accordance with IEC /HD 60364-4-43;
S = cable cross section in mm^2)

Fig. 2 Load limit curve for PVC-insulated cables

IEC 60364-4-43

In individual cases, conditions (1) and (2) may not guarantee complete protection in accordance with the rules as aforesaid may not assure protection in certain cases, for example where sustained overcurrents less than I_2 occur. In such cases, consideration should be given to selecting a cable with a larger cross-section area.

The general aim is to use the selected characteristic to protect a cable in accordance with its load capacity limit as shown in figure 2.



Protection against overload

Furthermore, protection devices with I_2 values close to the rated current I_n can increase the effectiveness of overload protection significantly. Please refer in these cases to K- or Z-characteristic with I_2 = 1,2 x I_n.

Temperature of PVC-insulated cables at overload

Load	Cable temperature*
1.0 x I_n	70 °C
1.2 x I_n	86 °C
1.45 x I_n	116 °C

Service life of PVC-insulated cables according to the Arrhenius equation

Cable temperature	Service life
70 °C	20.0 years
90 °C	2.5 years
100 °C	1.0 year

* 90 % of the temperature value is reached from operating temperature after 5 minutes.

Comparison of tripping characteristics “Z” and “B”

24 V DC control circuits

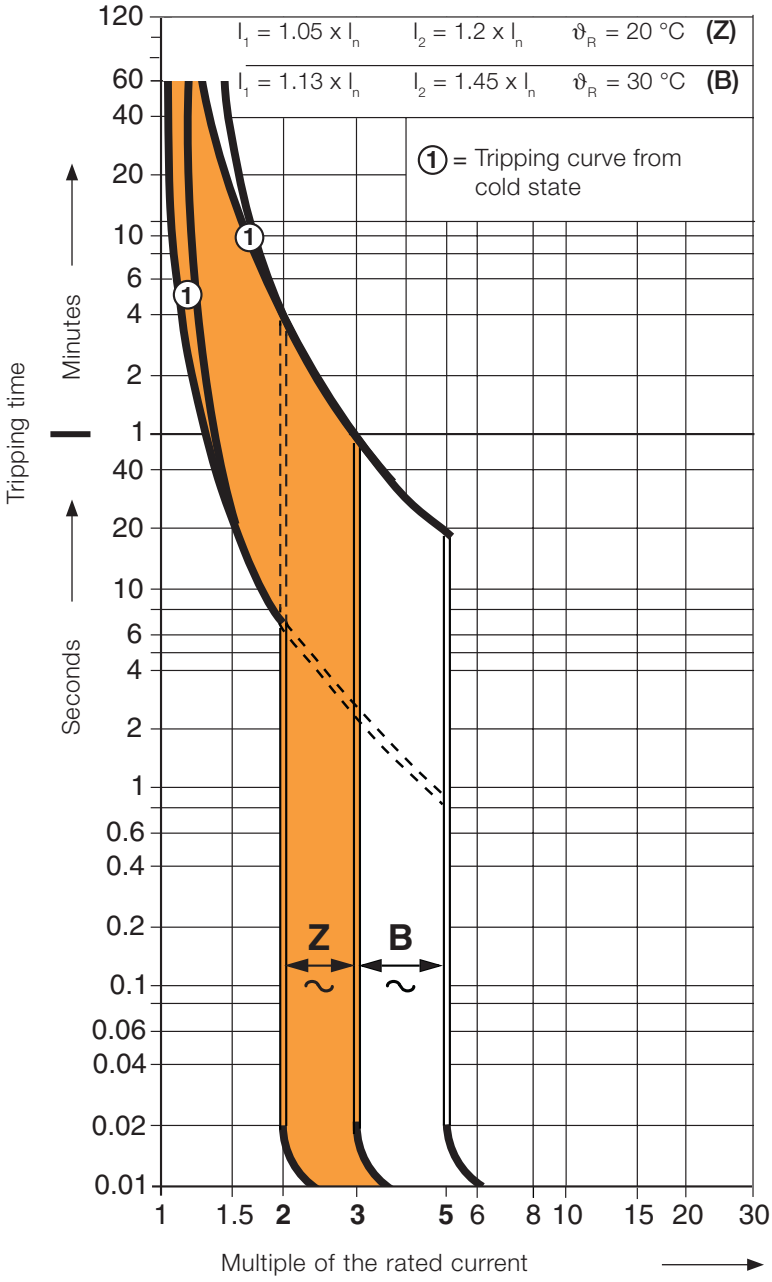
In order to achieve the best possible protection of sensitive devices, such as contacts or prefabricated cables of sensors/limit switches, the instantaneous tripping must clear even low short-circuit currents within milliseconds.

The maximum cable lengths in relation to loop resistance must not be exceeded. Taking account of various parameters, the maximum cable lengths could be as follows:
1.5 mm^2, two-wire, Cu:
– MCB B6 max. 10 m
– MCB Z2 max. 47 m
– MCB Z6 max. 18 m

Due to the low instantaneous tripping current, the maximum cable lengths can be realized by using the Z characteristic.

Note
With direct current, the tripping values of the electromagnetic releases are increased by a factor of 1.5.

Protection against overload
As stated before it is obvious that tripping characteristic “Z” provides better protection during operation and is easier to choose when planning.



Temperature of PVC-insulated cables at overload

Load	Cable temperature*
1.0 x I_n	70 °C
1.2 x I_n	86 °C
1.45 x I_n	116 °C

Service life of PVC-insulated cables using the Arrhenius equation

Cable temperature	Service life
70 °C	20.0 years
90 °C	2.5 years
100 °C	1.0 year

* 90 % of the temperature value is reached from operating temperature after 5 minutes.

Comparison of tripping characteristics “C” and “K”

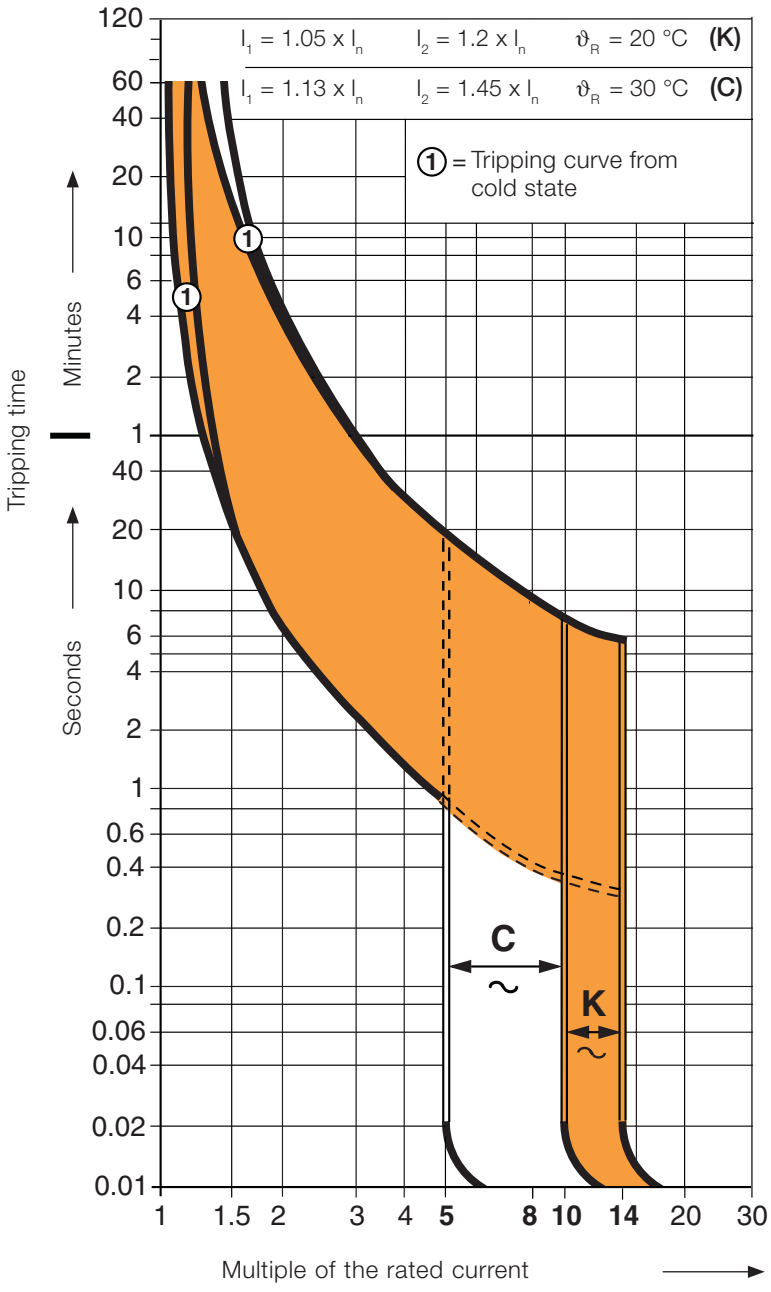
“K” solves the conflict of service continuity in the event of peak currents and rapid disconnection in the event of a short-circuit.

In circuits where inrush currents or starting current peaks can occur due to motors, chargers, welding transformers, etc., tripping characteristic “K” has proven to be successful for more than 70 years.

Current peaks of up to 10 · I_n do not lead to unintentional disconnection. Tripping characteristic “C” only withstands current peaks of up to 5 · I_n.

Note
With direct current, the tripping values of the electromagnetic releases are increased by a factor of 1.5.

Protection against overload
As stated before it is obvious that tripping characteristic “K” provides better protection during operation and is easier to choose.



Temperature of PVC-insulated cables at overload

Load	Cable temperature*
1.0 x I_n	70 °C
1.2 x I_n	86 °C
1.45 x I_n	116 °C

Service life of PVC-insulated cables using the Arrhenius equation

Cable temperature	Service life
70 °C	20.0 years
90 °C	2.5 years
100 °C	1.0 year

* 90 % of the temperature value is reached from operating temperature after 5 minutes.

Comparison of tripping characteristics “K” and “D”

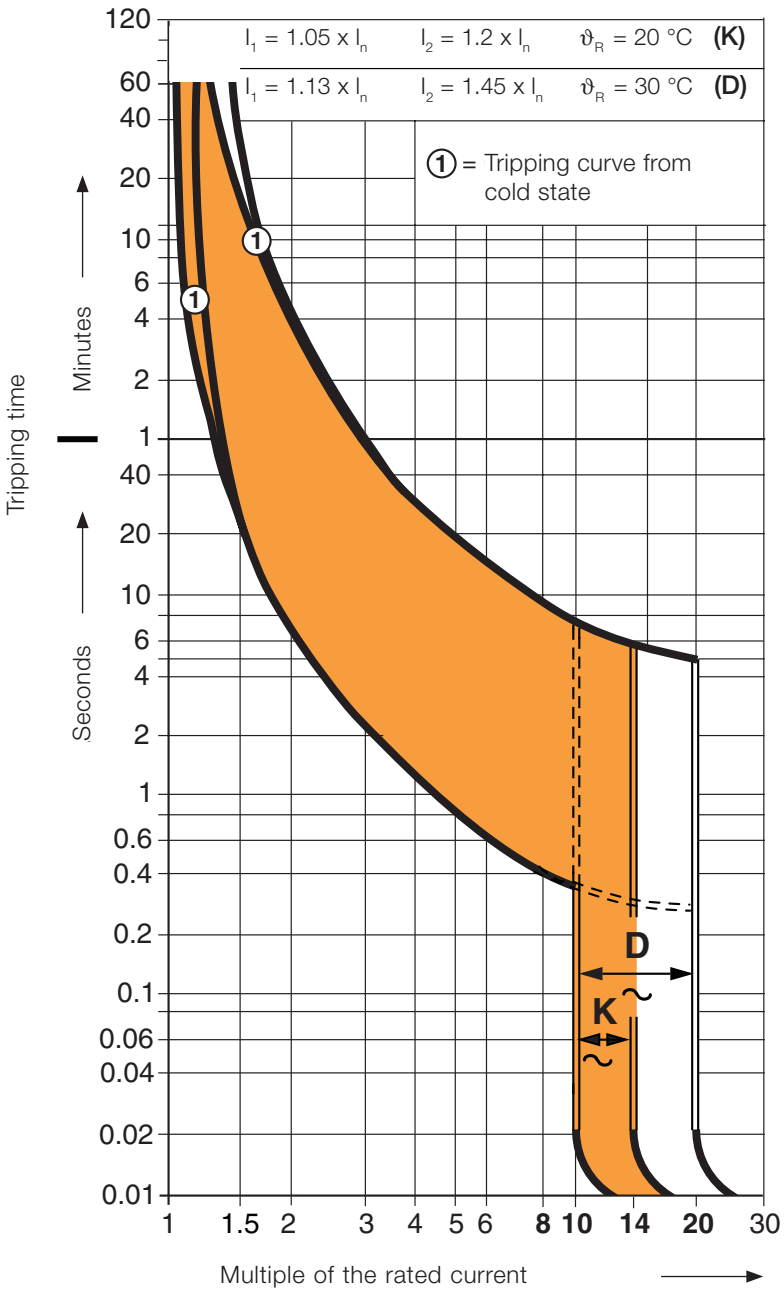
“K” solves the conflict of service continuity in the event of peak currents and rapid switch off in the event of a short circuit.

Tripping characteristic “K” trips at the latest at 14 · I_n in <0.1 seconds. By contrast, tripping characteristic “D” disconnect the device at 20 · I_n in <0.1 seconds, which could be a disadvantage both with regard to the loop resistance and for cable protection in the range from 10-20 x I_n.

Example:
A socket is protected with a D16 miniature circuit-breaker. A minimum short-circuit current ≥320 A must be ensured in order to comply with the disconnection condition of ≤0.4 s for protection against electric shock.

Note
With direct current, the tripping values of the electromagnetic releases are increased by a factor of 1.5.

Protection against overload
As stated before it is obvious that tripping characteristic “K” provides better protection during operation and is easier to choose.



Temperature of PVC-insulated cables at overload

Load	Cable temperature*
1.0 x I_n	70 °C
1.2 x I_n	86 °C
1.45 x I_n	116 °C

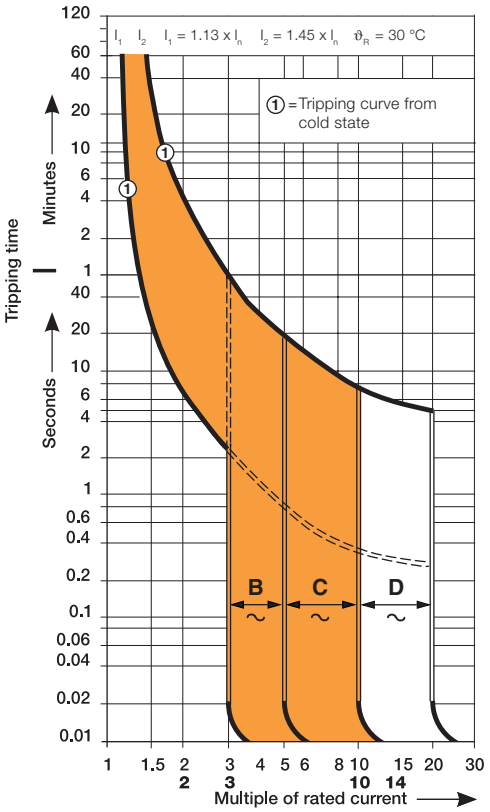
Service life of PVC-insulated cables according to the Arrhenius equation

Cable temperature	Service life
70 °C	20.0 years
90 °C	2.5 years
100 °C	1.0 year

* 90 % of the temperature value is reached from operating temperature after 5 minutes.

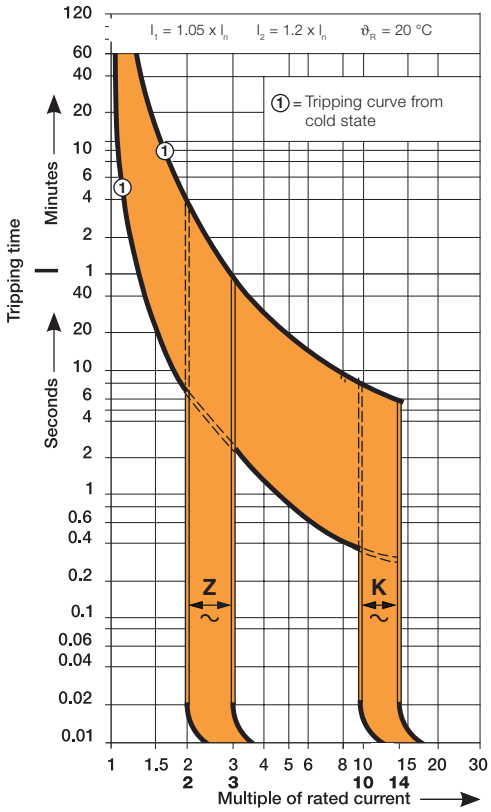
Tripping characteristics B, C, D, Z, K

Tripping characteristics B, C, D
in accordance with IEC/EN 60898-1
Constructional requirements for MCBs for household installations and similar purposes.



Compared with tripping characteristics “B”, “C” and “D”, “K” and “Z” provide better protection during operation and is easier to choose.

Tripping characteristics K, Z
in accordance with IEC/EN 60947-2
Constructional requirements for MCBs.



Assignment

- B, C and D for overcurrent protection of cables in accordance with IEC/EN 60898-1
- K for protecting windings in motors and transformers and simultaneous overcurrent protection of cables
- Z for control circuits with high impedances, voltage converter circuits and semiconductor protection and simultaneous overcurrent protection of cables

Other criteria when selecting miniature circuit breakers

In order to protect a circuit optimally, additional considerations and constraints must be considered when selecting the miniature circuit-breakers.

Deviating ambient temperature

For installations of miniature circuit-breakers at other temperatures than the reference value, derating factors have to be considered. The rated value of the current of a miniature circuit-breaker refers to a reference ambient temperature of 30 °C for miniature circuit-breakers with the characteristics B, C and D and 20 °C for miniature circuit-breakers with the characteristics K and Z. If the ambient temperature is higher, the maximum operating currents are reduced by approx. 6 % per +10 °C temperature difference. For precise calculations and extremely high or low ambient temperatures, reference tables must be consulted.

Influence of adjacent devices

If several miniature circuit-breakers are installed directly side by side with high load on all poles, a correction factor has to be applied to the rated current (see table). If distance pieces are used, the factor is not to be considered.

No. of adjacent devices	Factor F
1	1
2, 3	0.9
4, 5	0.8
≥ 6	0.75

Tripping characteristics

Acc. to	Tripping characteristics	Rated current	Thermal release [1]			Electromagnetic release [2]		
			Currents: conventional non-tripping current	conventional tripping current	Tripping time	Range of instantaneous tripping		Tripping time
		I_n	I_1	I_2				
IEC/EN 60898-1	B	6 to 63 A	1.13 · I_n		> 1 h	3 · I_n		0.1 ... 45 s (I_n ≤ 32 A)/0.1 ... 90 s (I_n > 32 A)
				1.45 · I_n	< 1 h [3]		5 · I_n	< 0.1 s
	C	0.5 to 63 A	1.13 · I_n		> 1 h	5 · I_n		0.1 ... 15 s (I_n ≤ 32 A)/0.1 ... 30 s (I_n > 32 A)
				1.45 · I_n	< 1 h [3]		10 · I_n	< 0.1 s
	D	0.5 to 63 A	1.13 · I_n		> 1 h	10 · I_n		0.1 ... 4 s (I_n ≤ 32 A)/0.1 ... 8 s (I_n > 32 A)
				1.45 · I_n	< 1 h [3]		20 · I_n	< 0.1 s
IEC/EN 60947-2	K	0.5 to 63 A	1.05 · I_n		> 1 h	10 · I_n		> 0.2 s
				1.2 · I_n	< 1 h [3]		14 · I_n	< 0.2 s
	Z	0.5 to 63 A	1.05 · I_n		> 1 h	2 · I_n		> 0.2 s
				1.2 · I_n	< 1 h [3]		3 · I_n	< 0.2 s

[1] The thermal releases are calibrated to a nominal reference ambient temperature; for B, C, D the reference value is 30 °C, for K and Z the reference value is 20 °C. In the case of higher ambient temperatures, the current values fall by approx. 6 % for each 10 K temperature rise.

[2] The indicated tripping values of electromagnetic tripping devices apply to a frequency of 50/60 Hz. The thermal release operates independent of frequency.

[3] As from operating temperature (after I_1 > 1h)

Miniature circuit breakers for cable and equipment protection and their fields of application

Fields of application		S 200 S 200 M	S 200 P S 200 U/UP S 200 UDC S 280 UC	S 220	S 800 S 500 HV S 800 PV	S 700 S 750 (DR) WT 63 ①	S 400 SMISSLINE
Industrial networks 690 V AC 1000 V AC				S 220	S 800 S 500 HV		
Motor protection, transformer		S 200-K S 200 M-K	S 200 P-K S 280 UC-K	S 220-K	S 800-K S 800-D	S 700-K WT 63 S 750 DR-K	S 400 M-K S 400 M-D
UPS Photovoltaics	250 V DC to 1200 V DC		S 280 UC		S 800 UC S 800 PV		S 400 M-UC C
Semicable protection	Control circuits 24 V DC	S 200-Z S 200 M-Z	S 200 P-Z				S 400 M-UC Z
Selectivity						S 700 S 750 (DR)	
Isolating function in accordance with IEC 60364-5-537		S 200 S 200 M	S 200 P	S 220	S 800	S 700 S 750 (DR)	S 400 S 400 M
USA, Canada 489	480 V AC 240 V AC 60 V DC		S 200 UP S 200 U S 200 UDC				
USA, Canada 1077	600 V AC 480 V AC 60 V DC 500 V DC	S 200 M S 200 M	S 200 P S 200 P S 280 UC	S 220			
Marine classifications GL LRS BV DNV		S 200 S 200 M	S 200 P		S 800	S 700 (GL)	S 400 M
Rated switching capacity (230/400 V AC)	I_{cn}/A	6 000 10 000	max. 25,000	max. 10,000	max. 50,000	25,000	6,000 10 000
	I_n/A	≤ 63	0.5 ... 63	≤ 63	≤ 125	≤ 100	≤ 63

① As a selective group or upstream MCB

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