INTRODUCTION TO PROTECTION BY FUSES

SUMMARY

1. PROTECTIONS AGAINST OVERCURRENTS ARE ABSOLUTELY NECESSARY

There are 2 types of overcurrents:

- Overload
- Short circuit

1.1. Overload

1.1.1. Definition

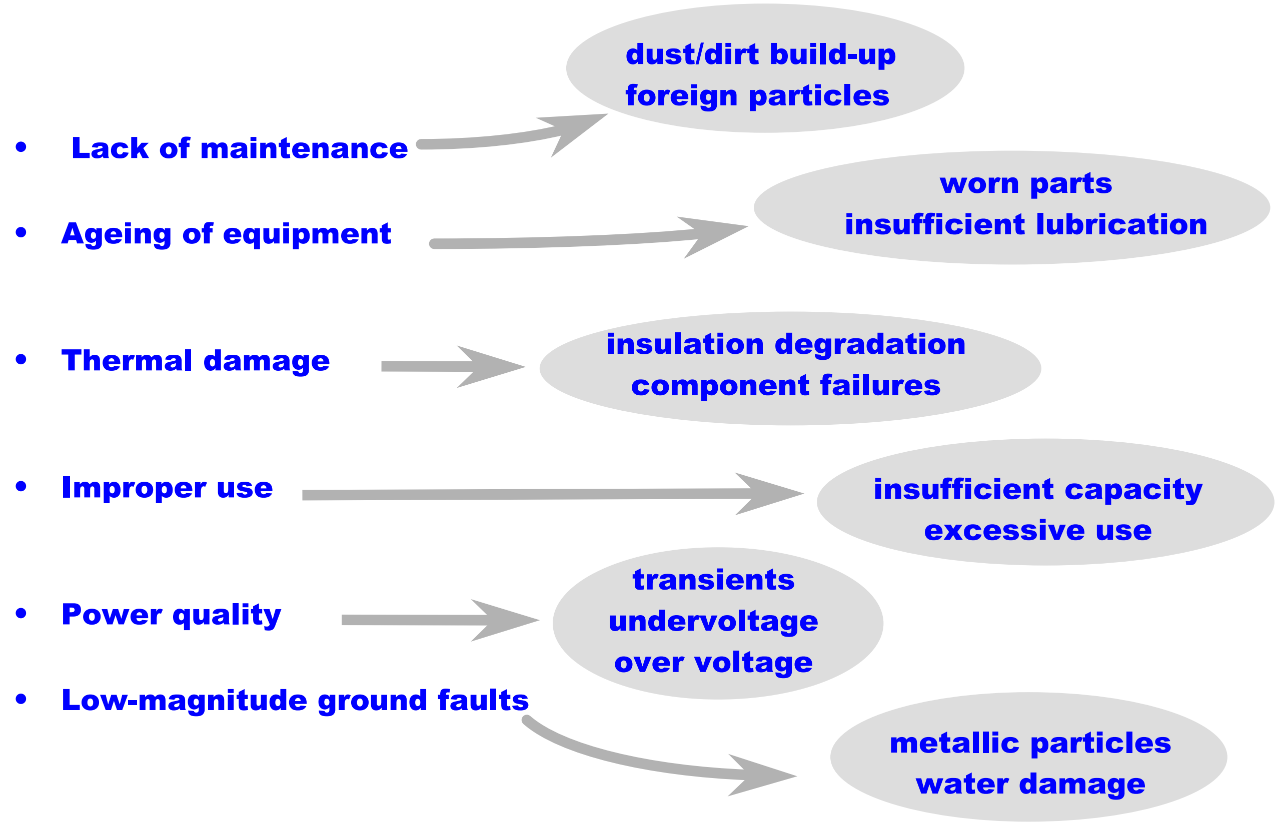
the term "overload" is used for excess current flowing in a circuit which is electrically sound. Overload currents are usually not much greater than the normal full-load current of the system, but if allowed to persist will eventually cause damage.
As a rough rule the overload current is less than 8 times or 10 times the rated current

Damage to the system, especially to insulating materials in contact with the circuit conductors, can result, due to the heating effect of the current.

The heating time is relatively long (from seconds up to several hours), and the overload can therefore be characterized by the **R.M.S. value** * of the overload current.
* **The RMS value of an AC current is the value of the DC current that will produce the same temperature rise in a pure resistance.**

For overload protection, the requirement for a protective device is that it should limit the duration of the overload current.
Some fuse ranges are designed for this type of protection.

1.1.2. Common causes of overloads



1.2. Short circuit

1.2.1. Definition

Short-circuits are usually due to a catastrophic electrical failure, such as insulation breakdown or accidental conditions, and the resulting r.m.s. value of the prospective (available) short-circuit current is high, typically more than 10 times the normal full-load current of the system.

The heating effect is so rapid that damage to the system can occur within milliseconds.
The heating effect cannot be characterized by the r.m.s. value of the prospective (available) current, as in the case of overloads, because it depends upon the **waveform** of the current.

In this case the protective device must limit the energy associated with the fault, which depends upon the value of the following parameter:

$$i^2t$$

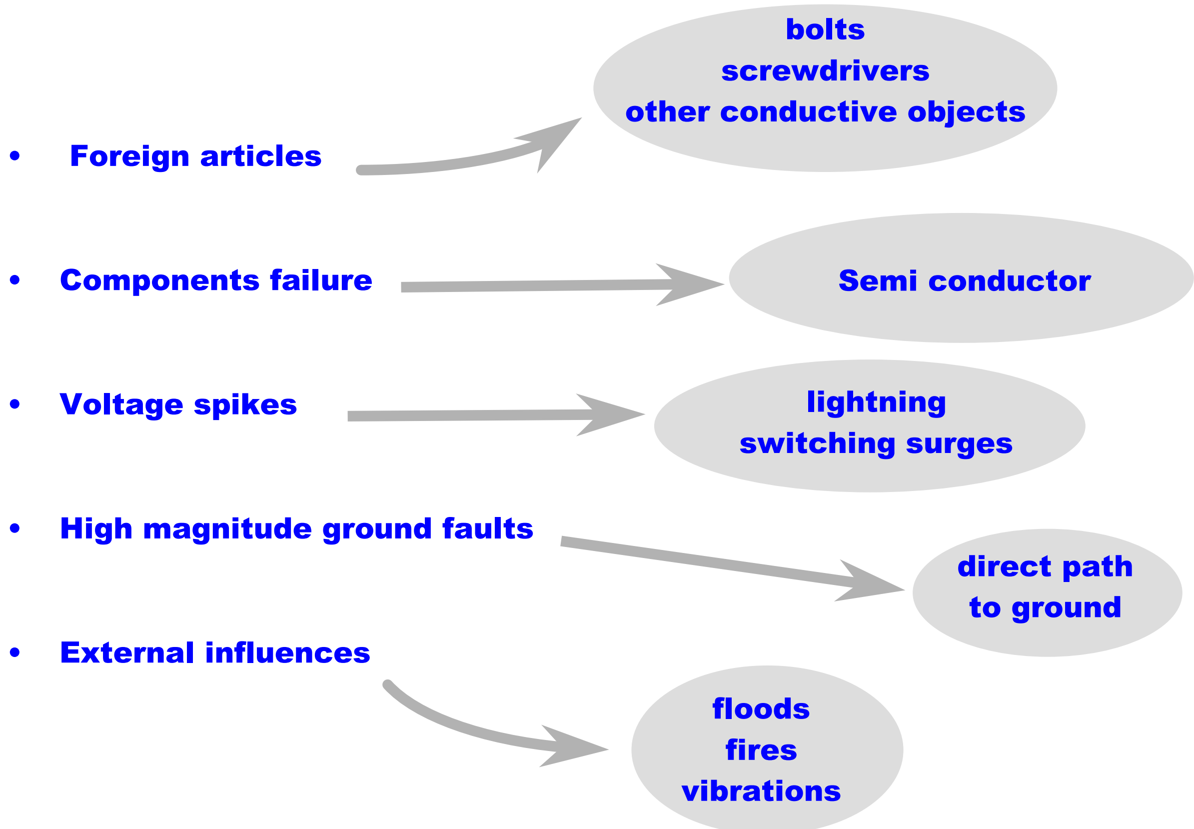
where **i** is the instantaneous current.

An additional requirement for a short-circuit protective device is that it should also limit the **peak value** of current permitted to flow in the circuit.
Electromagnetic forces are dependent on the square of the instantaneous current and may produce mechanical damage to equipment when short circuit currents are not « limited » very quickly.

The welding of circuit breakers contacts as well as contactors and disconnectors contacts can occur when the peak value of the current is not limited down to a low enough value.
Melting of circuit conductors can occur and be followed by arcing between the molten fragments, possibly causing fires and hazards to personnel as well as the further destruction of the electrical system.

Fuses provide the best protection in case of short circuit.

1.2.2. Common causes of short- circuits



1.3. Consequences of overcurrents

It is usually a combination of the following results !

- **Injury** → - loss of life / - burns / - flash blindness
- **Downtime** → thousands of dollars or euros per minute
- **Loss of process control** → - continuous process / - steel in arc furnace / - non-conforming parts
- **Mechanical effect** → - equipment damage / - destruction from magnetic movement
- **Thermal effect** → - equipment damage / - destruction from energy arcs

1.4. Global convergence of legal considerations

- Codes & Standards: harmonization... IEC, UL, NEC…
- Product liability (legal precedents having worldwide impact)
- New French law (98-388) holds manufacturers responsible for personnel & product liability for «less-than-expected» product performance... disclaimers are null and void for users!

1.5. Impact of legal considerations

- Manufacturers are fully responsible for their components
- OEM's are fully responsible for their assemblies / equipment
- «Limited liability» is a thing of the past!
- Cost of settlements are growing astronomically! (personnel injury, equipment, downtime, mental anguish, punitive damages)

Figure 1 : danger of the arc flash energy

2. FUSE ADVANTAGES

2.1. Safety

This is a key factor when designing or upgrading an installation. The fuse is still the best because:

- The metallic element inside the fuse melts directly upon the fault current effect without any intermediate mechanism , sensors etc ….
- The arc extinction is totally enclosed so that there are no emission of gas, flames, arcs or other materials when clearing the highest levels of short circuit currents.
- FERRAZ SHAWMUT made a lot of tests demonstrating the arc flash energy is drastically reduced when the peak current is limited by a fuse.

Maximized energy limitation = Minimized damage & injury

2.2. Speed / peak let through current

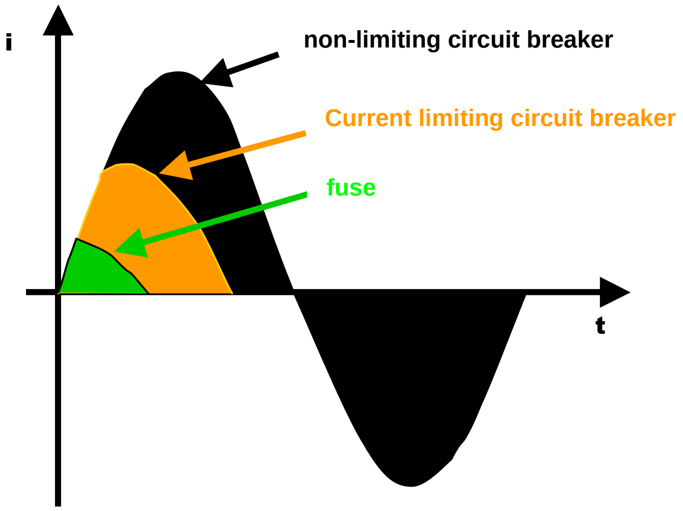


Figure 2: comparison of protective devices

In case of large short circuit currents no other protection system is faster than the fuse . The consequence is that the peak current is limited down to low values by the fuse.

Fuses are then particularly suitable for circuit protection without damage to components involved in the fault circuit..

Figure 2 illustrates clearly the advantage of the speed of the fuse:

fuse = energy limitation and safe breaking operation

2.3. Breaking capacity

This is the largest current the fuse can interrupt. The fuse can provide values up to 100 000 A, 200 000 A and even 300 000 A.

2.4. Maintenance before a short-circuit

No maintenance is needed because the fuse characteristics do not change.

2.5. Maintenance after a short-circuit

After the interruption of the fault current it is necessary to replace the blown fuse by a new one. However this is done quickly and gives the insurance the equipments are still protected with exactly the same efficiency as before.

2.6. Selectivity (or discrimination)

With fuses the selectivity is very easily achieved. Figure 3 shows that only fuse F1 melts while all other fuses do not melt and are still as good as they were before the fault.

With IEC gG fuses selectivity is achieved when F2 fuse rating is 1.6 times fuse F1 rating. Same rule applies for F3 and F2 fuse ratings.

Fuse = minimized circuit disruption, no black out.

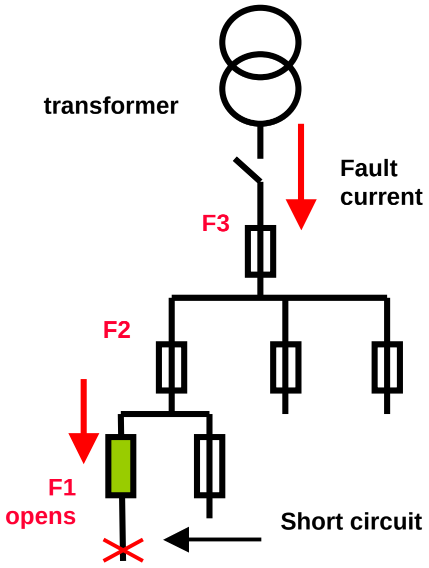


Figure 3 : selectivity

2.7. Future system growth

In many plants the total power increases with the time. Consequently the total short circuit current increases as well. Breaking capacities of all protection devices must be checked. Fuses generally still comply with the new requirement owing to their initial large breaking capacities. Furthermore adding fuses to an existing system helps to upgrade the breaking capacity of the protection system.

2.8. Low power consumption

Low voltage fuses have a low power loss sometimes lower than circuit breakers power losses. For example FERRAZ SHAWMUT fuse losses are:

3 W for a 32 A gG or aM size 10x38 in our “MODULOSTAR” fuse holder (3.2 W for a circuit breaker)
5 W for a 50 A gG or aM size 14x51 in our “MODULOSTAR” fuse holder (same for a circuit breaker)
9.5 W for a 125 A aM size 22x58 in our “MODULOSTAR” fuse holder (14 W for a circuit breaker)

2.9. Reliability

The simplicity of the fuse concept provides a highly reliable protection. Obviously better than many other concepts.

2.10. Universal

Fuses can protect cables, transformers, motor circuits, capacitors, contactors, old circuit breakers and power electronic equipments.. They are designed for low voltage and medium voltage applications.

FERRAZ SHAWMUT offers:

- all type of IEC 60269 fuses
- all type of American fuses complying with UL 248 (class J,L, H,CC,T,RK1, RK5 etc…),
- medium voltage fuses as per IEC 282 , DIN43625 and American standard ANSI C37.46
- DC rated fuses
- the widest catalogue of fuses for semi conductors.

2.11. Price

Fuses are still the most economical protection. This is more obvious if the cost of all maintenances, power consumption and repairs are included over the years of service.

3. CONSTRUCTION OF A FUSE

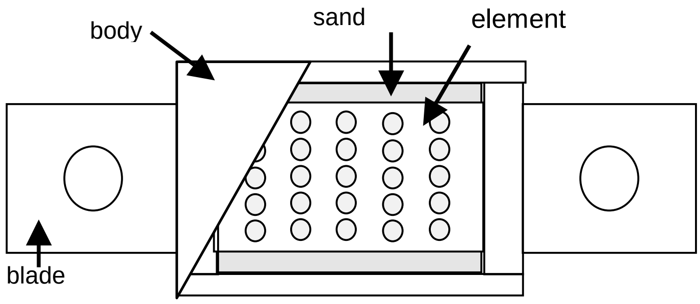


Figure 4: construction of a fuse

Figure 1 shows the construction of a typical fuse. The fuse elements are usually made of pure silver strips or copper, with regions of reduced cross-sectional area (often called *notches*). There may be several strips in parallel, depending on the ampere rating of the fuse. They are enclosed within an insulating tube or ceramic body, which is filled with pure quartz sand. At each end there are terminals with a variety of designs to permit installation in fuse-holders or connection to busbars.

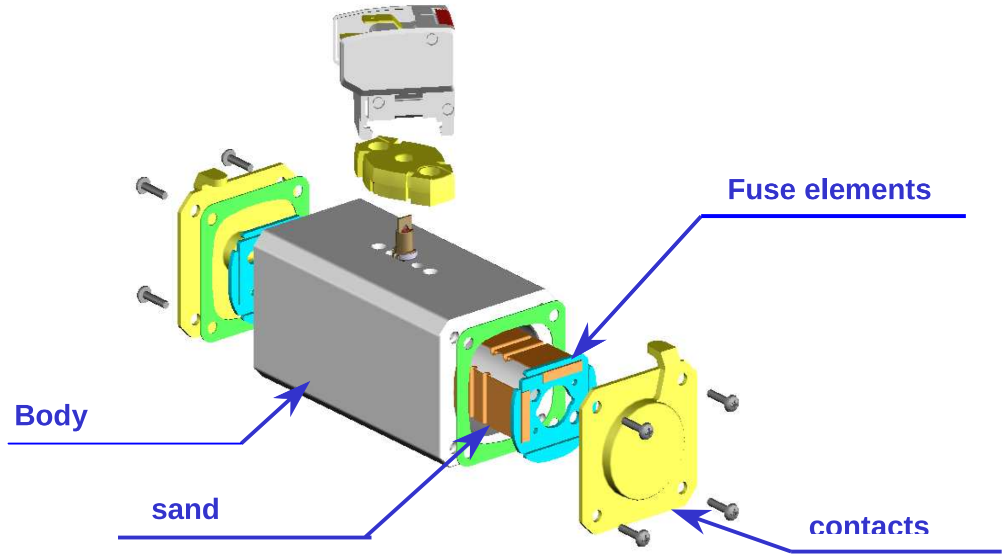


Figure 5: fuse for semi conductor protection (PSC range)

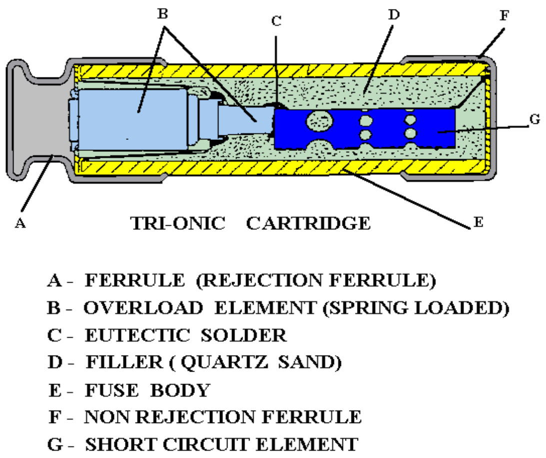
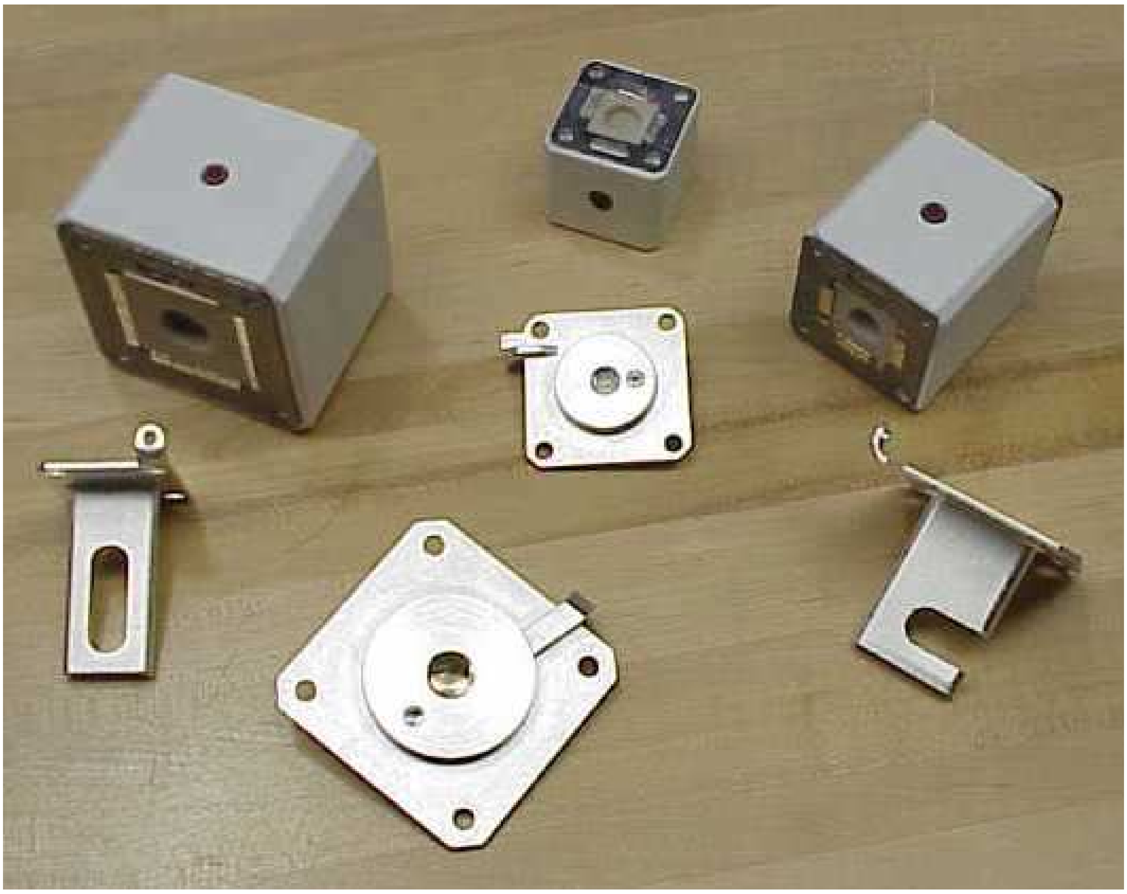
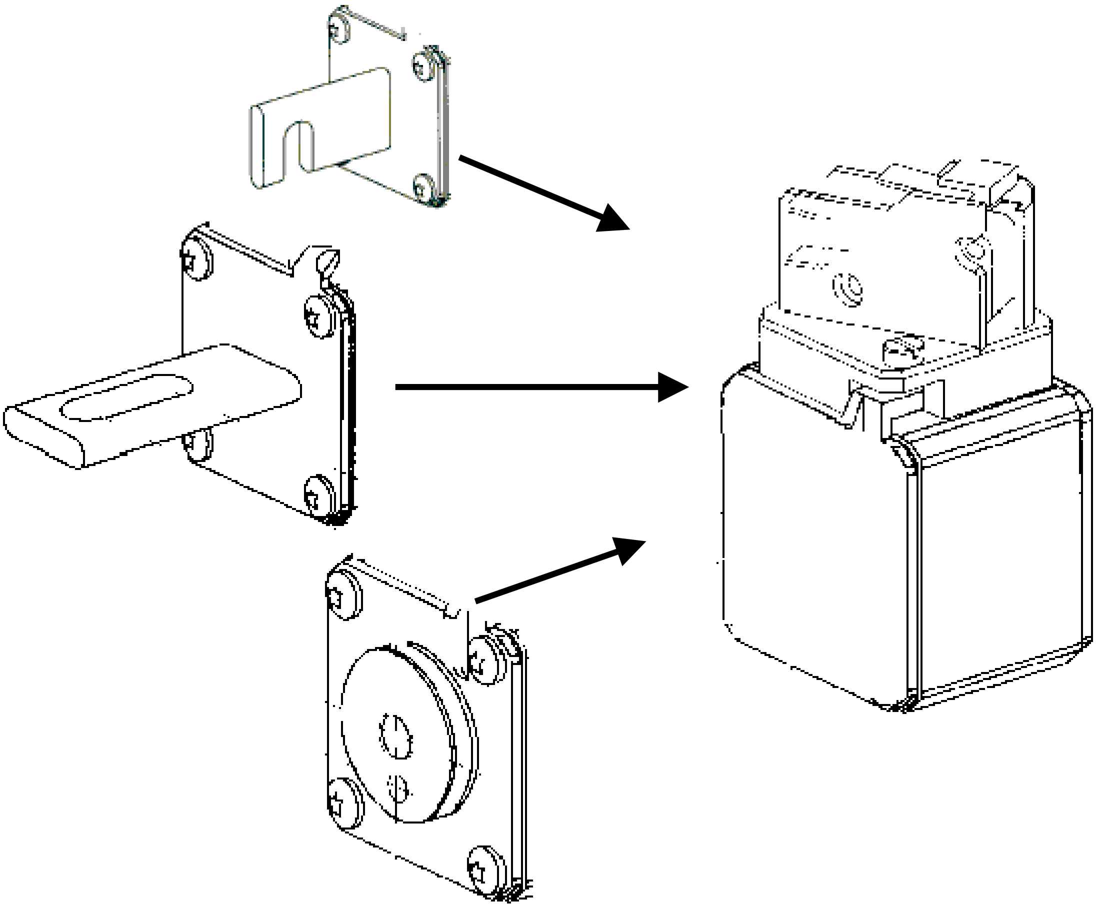


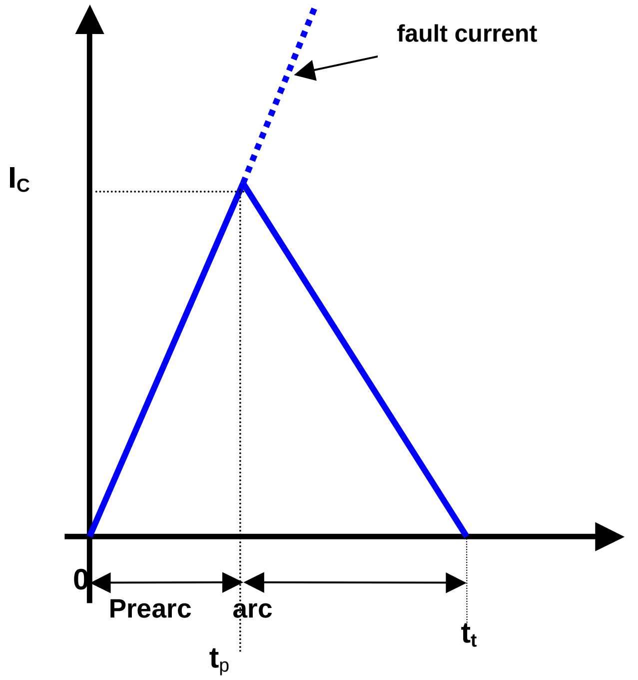
Figure 6 : American Time Delay fuse with dual element construction for motor circuit protection





4. INTERRUPTION OF OVER CURRENTS

4.1. Interruption of short circuit currents



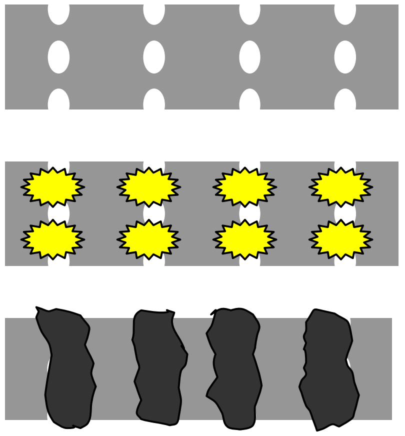
t_p = prearc time
t_t = total clearing time
$t_t - t_p$ = arcing time
I_C = peak let through current or cut off current

Figure 7: interruption of a short circuit current

Figure 7 shows how the fuse interrupts a short circuit current. There are always two stages:

- **Prearc**: during this stage the current heats up the temperature of the notches. All notches melt when the melting temperature of the metal is reached (960 °C for silver). At the end of the prearc time the current rise is stopped at a peak value I_C (figure 7).

- **Arc**: as soon as the notches melt multiple arcs are ignited (figure 8).



All notches melt simultaneously for high-magnitude currents

Multiple arcs in series (4 in this example) are created. Internal pressures (created by the sand) assist with arc choking

Arc energy melts silica sand producing a glass-like substance (see figure 9)

Figure 8

The sand is absolutely necessary in order to obtain:
the shortest arc time, the best current limitation, less I^2t and less energy

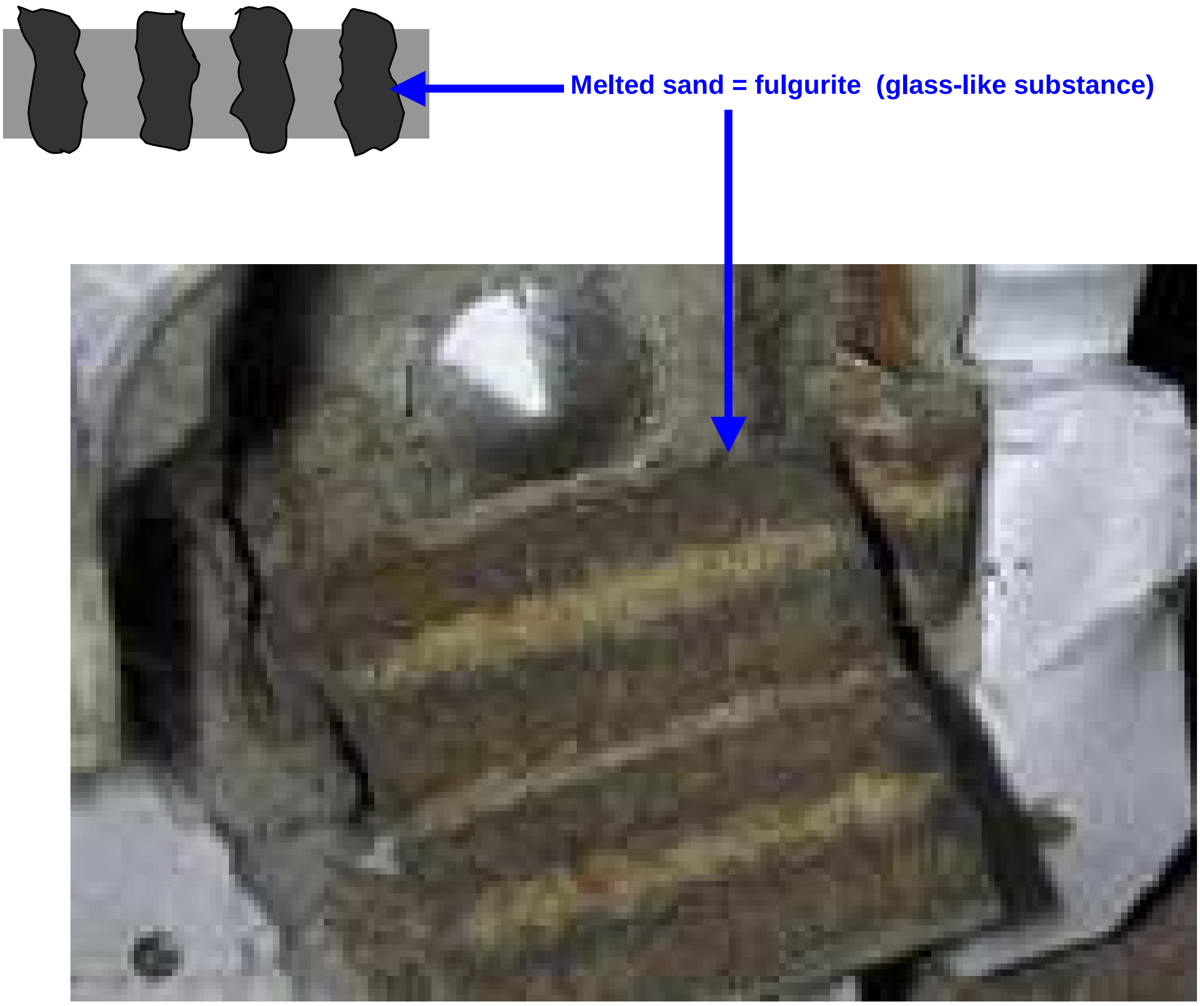


Figure 9: fuse element after the interruption of a short circuit current

4.2. Interruption of overloads

As for a short circuit current the fuse operation starts with the prearc stage followed by the arc stage, but the prearc time is much longer (figure 10).
Some fuses are not designed to interrupt low overloads, they must be associated to other protective devices.
Other fuses are designed to interrupt low overloads down to 160 % fuse rating in IEC standards or 135 % in UL standards.

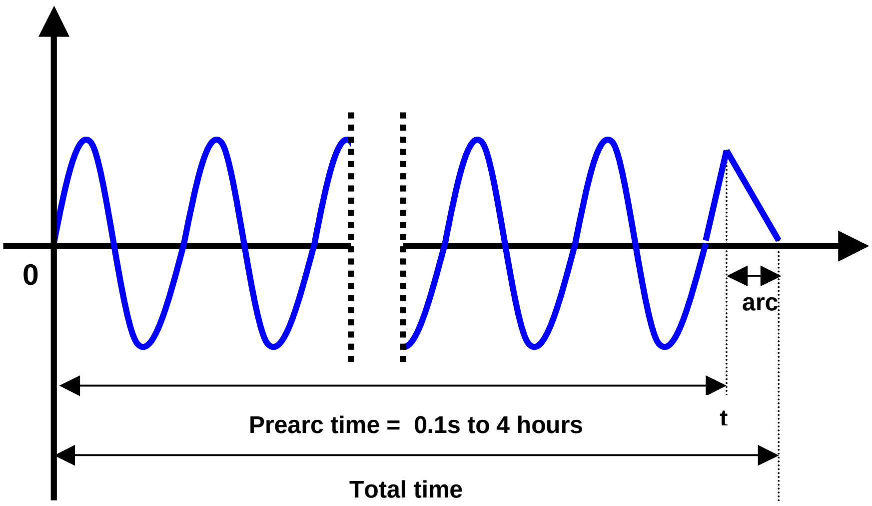
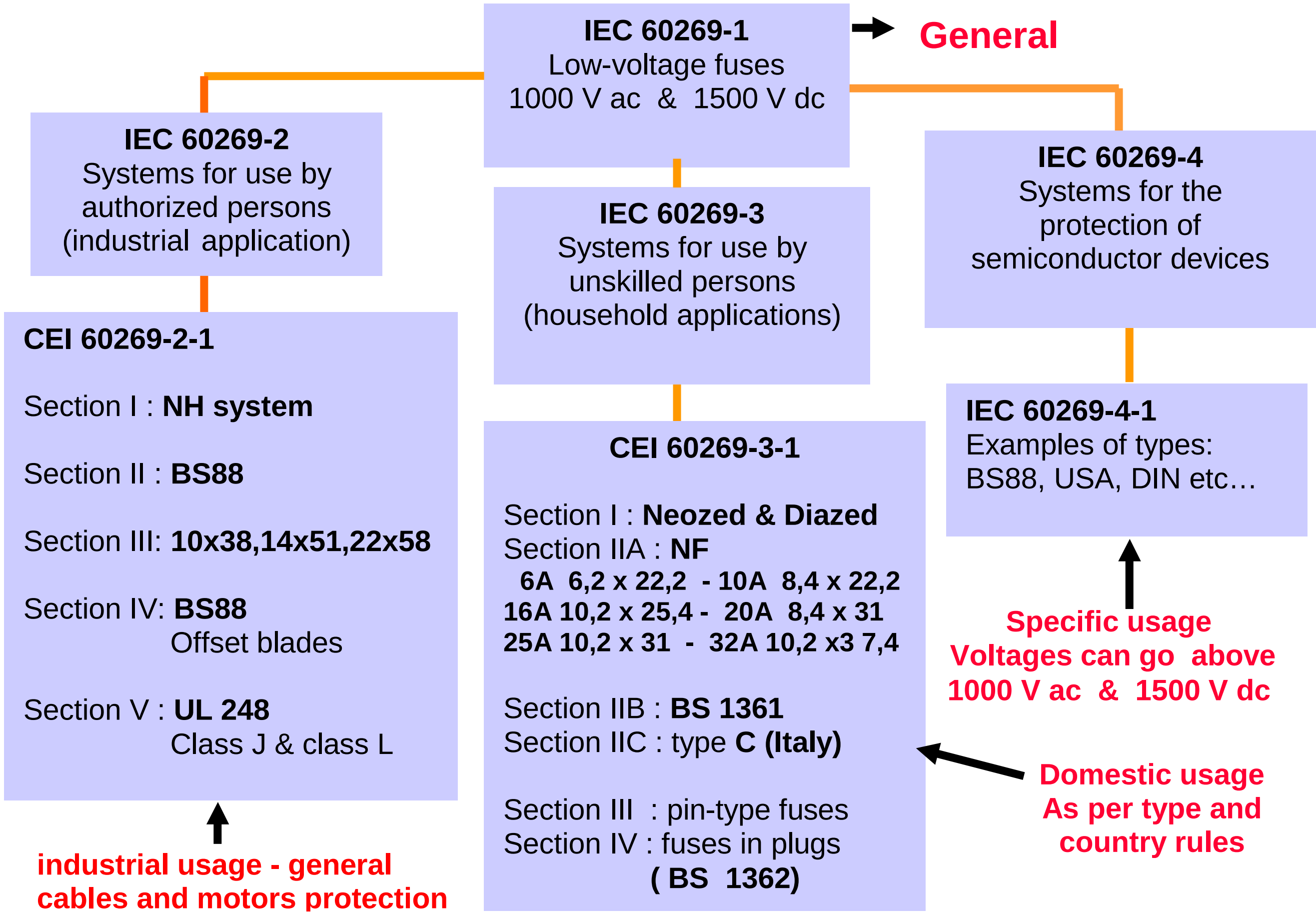


Figure 10

When the fuse is not designed to interrupt overloads damaged to the body may occur due to excessive temperatures reached inside the fuse before melting the fuse elements.

5. INTRODUCTION TO THE IEC 60269 STANDARD

5.1. IEC 60269 has four main chapters



5.2. There are two large family of fuses:

" a " type fuses: designed for short circuits only, they are not able to interrupt low overloads. They have a " partial " operating range.
" g " type fuses: designed to interrupt overloads and short circuits. They have a full operating range

FUSE TYPE	TYPICAL INDUSTRIAL APPLICATIONS	OPERATING RANGE
aM	Motor circuits protection against short circuit only	**PARTIAL RANGE**
aR	IEC 269-4 fuse for semi conductor protection	
gG	General purpose fuse essentially for conductor protection	**FULL RANGE**
gM	Motor protection	
gN	**North American** fast acting fuse for general purpose applications, mainly for conductor protection. As per UL 248 class J and class L fuses.	
gD	**North American** general purpose time-delay fuse for motor circuit protection and conductor protection (for example: fuse class AJT, RK5 and A4BQ)	
gTR	Transformer protection	
gR, gS	IEC 269-4 semi conductor protection and conductor protection	
gL, gF, gI	Former type of fuses for conductor protection replaced today by the gG fuses	

5.3. Typical IEC curves

Full range and partial range operation are illustrated in figure 11

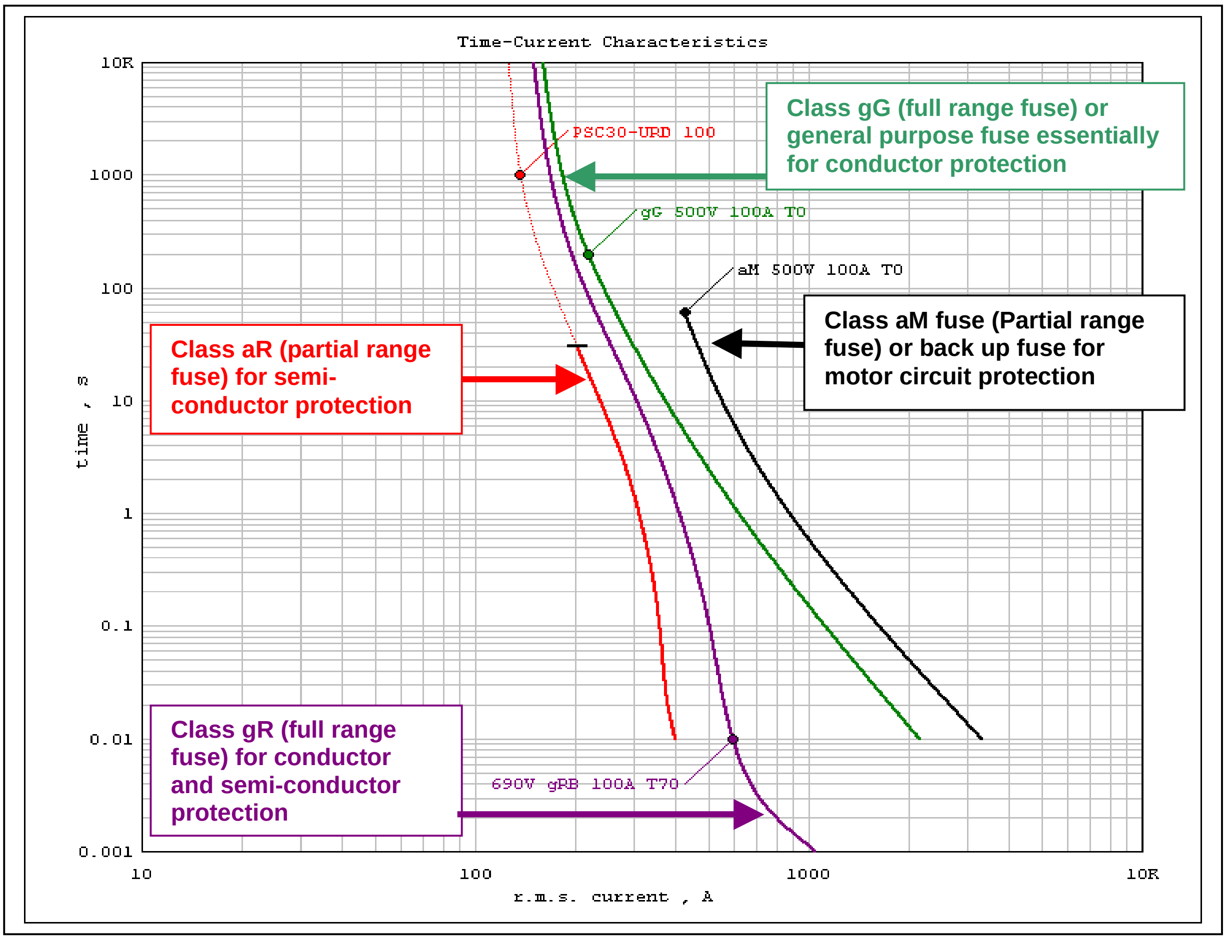


Figure 11: comparison of the time current curve of 4 different IEC fuses rated 100 A

Temperature rise test station rated 4000 A

6. TYPICAL GENERAL LAY OUT OF A LARGE PRODUCTION PLANT (cement, pulp & paper, steel mill etc.)

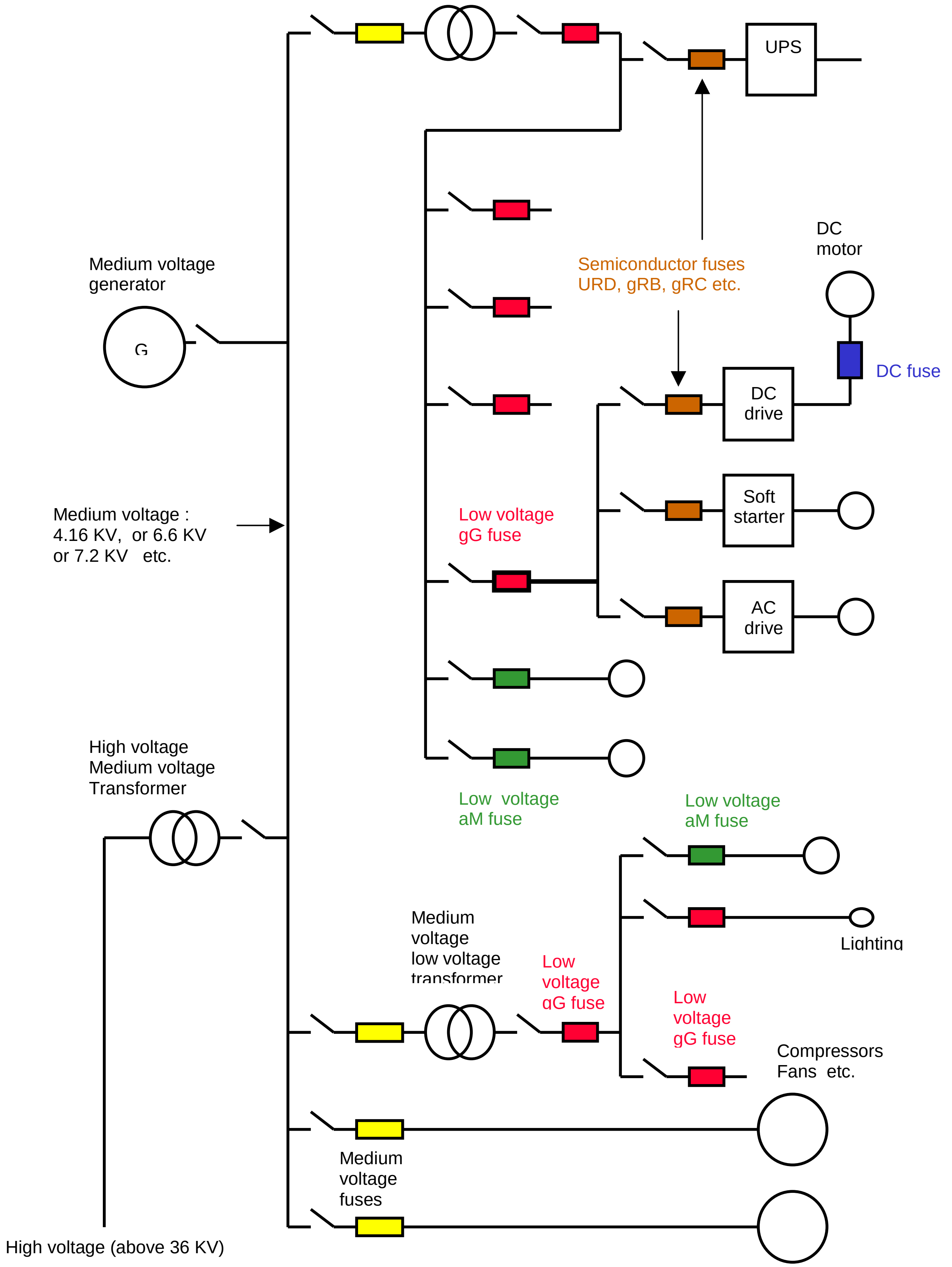


Figure 12

7. SELECTION OF THE FUSE VOLTAGE RATING U_N

The fuse selection needs to consider information on the equipment to be protected and parameters of the power supply that has to be interrupted.

The key parameters of the power supply are:

- **Maximum system voltage: $V_{CIRCUIT\ MAX}$**
- **Frequency (for dc applications see §): normally 50 or 60 hertz**
- **Prospective short circuit currents: to be compared to the fuse breaking capacity and minimum interrupting rating**

Voltage is the most critical parameter. Any fuse selection must start by the choice of the voltage rating U_N of the fuse.
The maximum voltage of the circuit $V_{CIRCUIT\ MAX}$ (this is the rated voltage + variation) must be lower than the maximal operational voltage of the fuse $U_{FUSE\ MAX}$ given in the table .

$$U_{FUSE\ MAX} > V_{CIRCUIT\ MAX}$$

FUSE TYPE	U_N Rated voltage of the fuse (V)	$U_{FUSE\ MAX}$ Maximum operational voltage of the fuse (V)
gG, gM, aM, aR(1), gR(1), gS(1)	230	253
	400	440
	500	550
	690	725
gN, gD (American ranges)	600	600

(1) However when semi conductor fuses are protecting power electronic equipments it is necessary to calculate the voltage of the fault as it can be higher than the line to line voltage and the shape of the voltage wave is not always a 50 Hz or 60 Hz sinusoidal wave. 0n other cases it can be capacitor discharge under a DC voltage.

Example 1: a circuit is rated 400 V ± 15%, then Vcircuit max = 460 V
Consequently the fuse rated 500 V must be used.

Example 2: a circuit is rated 400 V ± 10% then Vcircuit max = 440 V
Consequently the fuse rated 400 V can be used.

8. CABLE PROTECTION

After the voltage rating selection as explained in § 7, the protection of the cable is checked with the following parameters:

I_B : operating current of the cable
I_Z : maximum current carrying capacity of the cable
I_N : rated current of the gG style fuse
I_F : conventional fusing current of the fuse

The cable is protected when the 2 following conditions are fulfilled:

$$I_B \leq I_N \leq I_Z$$

$$I_F \leq 1.45\, I_Z$$

The choice of the fuse is made after :

- **calculation of the acceptable current in the conductors**
- **determination of the number of conductors according to the installation method**
- **correction when the temperature inside the cubicle is above 40℃ (fuse is derated)**
- **correction when there is a forced air cooling (it helps the fuse to carry more current)**

The fuses have to be fitted at the starting point of the circuit to be protected

9. MOTOR CIRCUIT PROTECTION

The aM fuse must be associated to other protective devices because it must not operate for times above 60 seconds

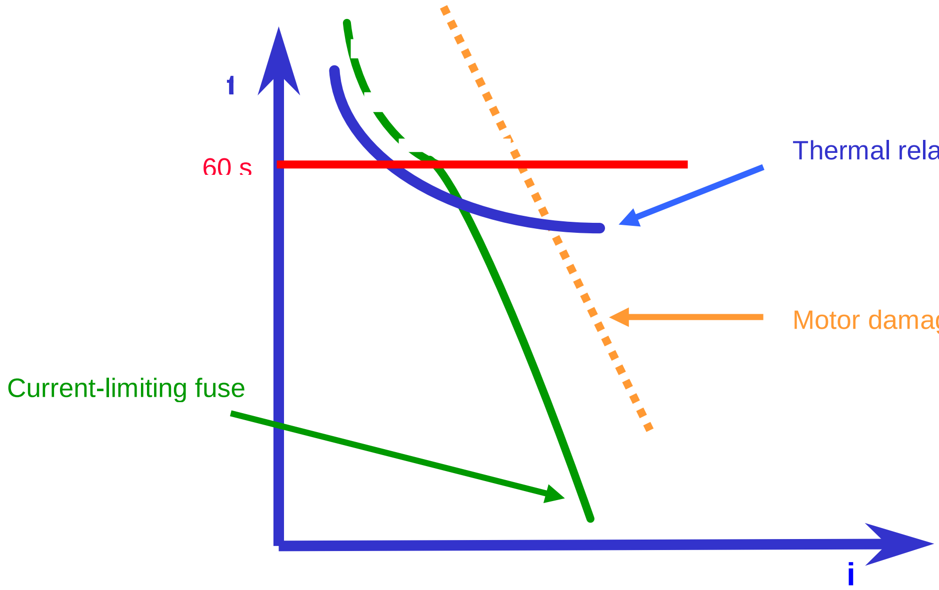


Figure 13

Tables with selected fuses are supplied. Tables on the next page are valid only for 1500 RPM asynchronous motors. Other tables giving a correction factor versus RPM value and power are available. But it is necessary to check:

- **correction when the temperature inside the cubicle is above 40℃ (fuse is derated)**
- **correction when there is a forced air cooling (it helps the fuse to carry more current)**

1500 RPM three phase asynchronous motor									Selected fuses: class, voltage rating and current rating																			
220 V			380 V			660 V			380 V		250 V à 500 V		400 V à 690 V		400 V à 690 V		400 V à 500 V		500 V à 690 V								440 V à 660 V	
									8 x 32		10 x 38		14 x 51		22 x 58		T 00		T 0		T 1		T 2		T 3			
kW	Ch	I_N (A)	kW	Ch	I_N (A)	kW	Ch	I_N (A)	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM
						0,10	0,14	0,18					0,25		0,25													
0,05	0,068	0,39	0,10	0,135	0,30	0,20	0,27	0,35			1		1	0,5	1	0,5												
0,10	0,135	0,53	0,18	0,25	0,55	0,37	0,50	0,60	2	1	2	1	2	1	2	1												
0,18	0,25	0,94	0,37	0,5	1,1	0,55	0,75	1	4	2	4	2	4	2	42													
			0,55	0,75	1,6	1,1	1,5	1,5	4	2	4	2	4	2	4	2												
0,37	0,5	1,9	0,75	1	2	1,5	2	2	6	4	6	4	6	4	6	4												
0,55	0,75	2,8	1,1	1,5	2,6	2,2	3	2,9	8	4	8	4	8	4	8	4												
0,75	1	3,5	1,5	2	3,5	2,8	3,8	3,5	10	4	10	4	10	4	10	4												
1,1	1,5	4,4	2,2	3	5	4	4,5	4,8	12	6	12	6	12	6	12	6												
1,5	2	6	3	4	6,6	5	7,5	6,6	16	8	16	8	16	8	16	8	16											
2,2	3	8,7	4	5,5	8,5	7,5	10	8,8	20	10	20	10	20	10	20	10	20											
3	4	11,5	5,5	7,5	11,5	10	13,5	11,5			25	12	25	12	25	12	25	25										
4	5,5	14,5	7,5	10	15,5						32	16	32	16	32	16	32	16	32									
						15	20	17				20	40	20	40	20	40	20	40									
5,5	7,5	20	10	13,5	20	18,5	25	21				25	50	25	50	25	50	25	50	25	50							
7,5	10	27	15	20	30	26	35	29							50	32	50	32	50	32	50							
10	18,5	35	18,5	25	37	30	40	34							63	40	63	40	63	40	63							

1500 RPM three phase asynchronous motor									Selected fuses: class, voltage rating and current rating																			
220 V			380 V			660 V			380 V		250 V à 500 V		400 V à 690 V		400 V à 690 V		400 V à 500 V		500 V à 690 V								440 V à 660 V	
									8 x 32		10 x 38		14 x 51		22 x 58		T 00		T 0		T 1		T 2		T 3			
kW	Ch	I_N (A)	kW	Ch	I_N (A)	kW	Ch	I_N (A)	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM	gI	aM
10	18,5	35	18,5	25	37	30	40	34							63	40	63	40	63	40	63							
11	15	39	22	30	44	37	50	41							80	50	80	50	80	50	80	50						
15	20	52	25	34	51	50	68	55							100	63	100	63	100	63	100	63						
18,5	25	64	30	40	60	55	75	60							125	80	125	80	125	80	125	80	125					
22	30	75	37	50	73										125	80	125	80	125	80	125	80	125					
25	34	85	45	60	85	75	100	78								100	160	100	160	100	160	100	160					
30	40	103	55	75	105	90	125	96								125		125		125	200	125	200	125				
45	60	147	75	100	138	132	175	140												160	250	160	250	160				
55	75	182	90	125	170	160	220	175														200	315	200	315			
75	100	239	110	150	205	220	300	236														250	400	250	400			
			132	175	245	250	350	271														315		315	500	315	500	
90	125	295	160	220	300	275	375	300														315		315	500	315	500	
110	150	356	200	270	370	330	450	350																400	630	400	630	
132	175	425	250	350	475	400	550	430																500		500	800	500
160	220	520	300	400	560	550	750	577																		630	1000	630
220	300	705	400	550	750	736	1000	778					T 4														1250	800
300	400	970	500	700	950																							1000
365	500	1150	600	800	1090																							1250

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10. SEMICONDUCTOR FUSE SELECTION MAIN CRITERIONS

10.1. Main crirerions

FUSE PARAMETERS	REQUIREMENTS
Voltage rating	$V_{FUSE} > V_{LINE\ TO\ LINE}$ and $V_{FUSE} > V_{FAULT}$ In regenerative DC drives V_{FAULT} is higher than $V_{LINE\ TO\ LINE}$ Faults are not always with an AC voltage (inverters & regenerative DC drives)
Current rating	$I_{FUSE} > I_{RMS}$ **The calculation of the current rating of the fuse must use corrective coefficients taking into account the effect of :** • **ambient temperature inside the cubicle** • **cooling** • **size of cables or copper bars connected to the fuse** • **variations of the current (reduce the fuse life time)** Coordination with a circuit breaker requires a suitable melting curve at 15 ms Such coordination may require a fuse rating higher than the rating calculated from the RMS value of the current.
total I²t	**Fuse total I^2t < I^2t of the semiconductor junction** **or / and** **Fuse total I^2t < I^2t of the semiconductor case rupture**
Breaking capacity	**Fuse Breaking Capacity > largest RMS value of the short circuit current I_{FAULT}**
Minimum interrupting capacity	**Fuse minimum interrupting capacity > minimum fault current**
Arc voltage	**Fuse Peak Arc voltage < Reverse Voltage of the semiconductor**

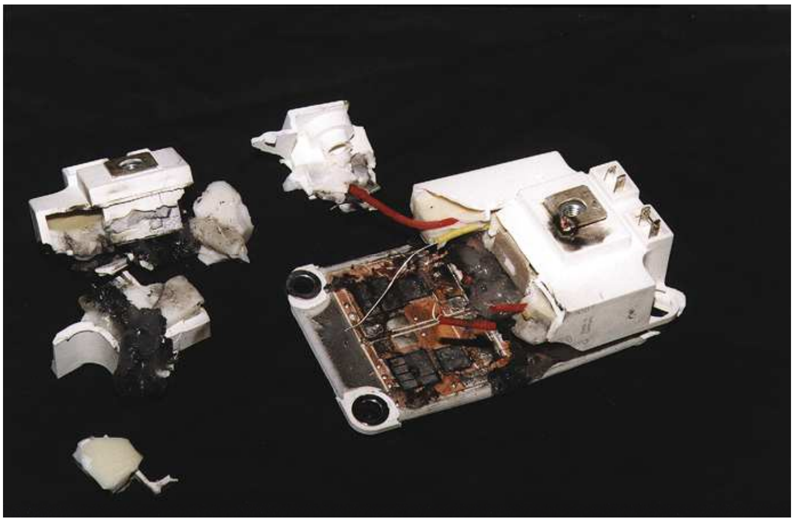

Figure 14: IGBT after case rupture due to a high fault current peak value

10.2. Three phase bridge

In all following examples $V_{AC\ MAX}$ **is the maximum R.M.S. value of the line-to-line voltage** therefore it includes the variation of the voltage : $V_{AC\ MAX}$ = rated voltage + possible variation (usually + 5% to 10%)

10.2.1. Three phase bridge, non regenerative, with 1 semi-conductor per arm

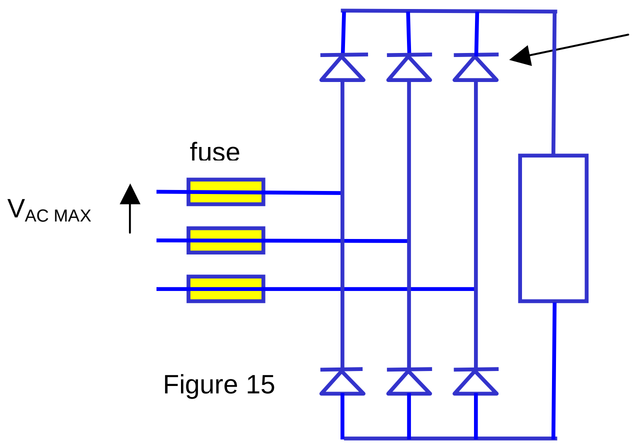

Figure 15

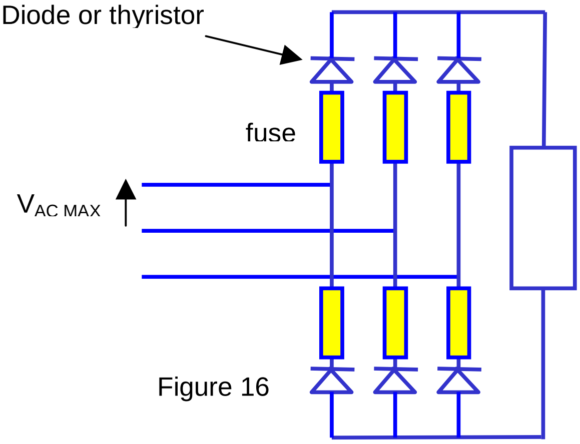

Figure 16

- **Fuse location:** fuses can be fitted in the AC lines (figure 15) or in each arm in series with each semi-conductor (figure 16). The current rating of the fuses in the arms is $\sqrt{2}$ times smaller than the fuses in the AC lines.
- **Fuse voltage rating U_N :**
-

Fuses complying with IEC 60269	**For most ratings**	$V_{AC\ MAX} \leq 1.06\ U_N$
	For some ratings	$V_{AC\ MAX} \leq 1.10\ U_N$
	For some 690 V fuses	$V_{AC\ MAX} \leq 1.05\ U_N$
Fuses complying with UL 248 only		$V_{AC\ MAX} \leq U_N$

10.2.2. Three phase bridge rectifier, non regenerative, with several semi-conductor in parallel per arm

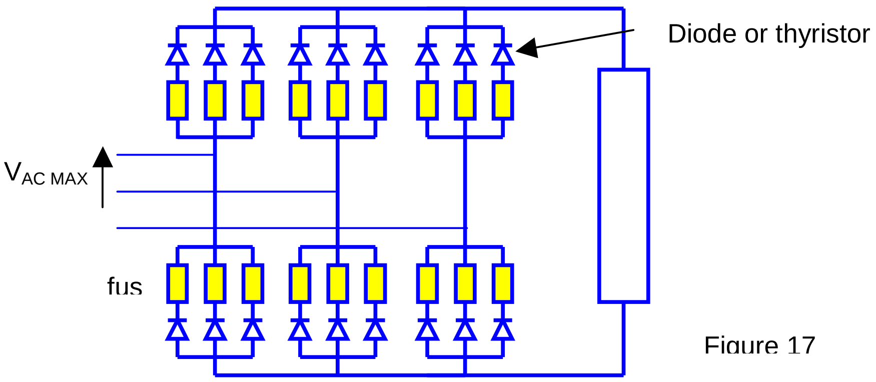

Figure 17

- **Fuse location:** fuses must be fitted in the arms (figure 17) in series with each semi-conductor.
- **Coordination with the AC circuit breaker:** is often required in case of a short circuit in the DC side.
- **Fuse voltage rating U_N :**

Fuses complying with IEC 60269	**For most ratings**	$V_{AC\ MAX} \leq 1.06\ U_N$
	For some ratings	$V_{AC\ MAX} \leq 1.10\ U_N$
	For some 690 V fuses	$V_{AC\ MAX} \leq 1.05\ U_N$
Fuses complying with UL 248 only		$V_{AC\ MAX} \leq U_N$

10.3. Regenerative DC drive

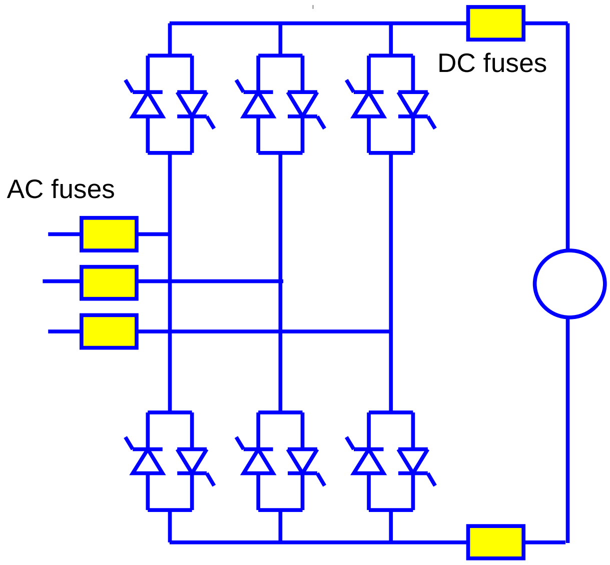

Figure 18

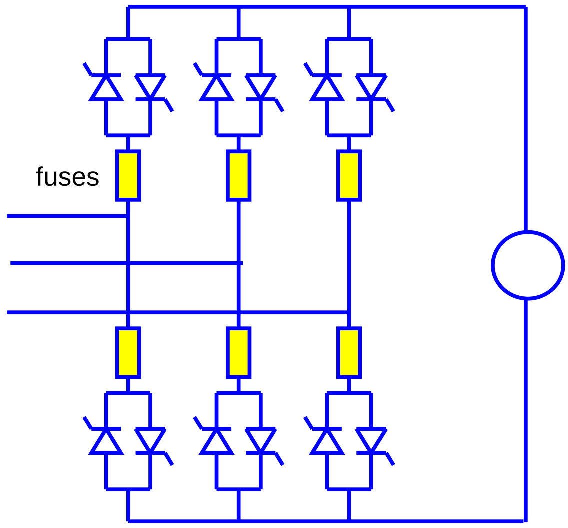

Figure 19

- **Fuse location**

    - Solution 1: fuses must be fitted in the AC lines **and** in the DC side (figure 18). Fuses in the DC side are absolutely necessary because of the DC shoot through fault described in figure 20. This fault occurs when the machine is working as a generator regenerating energy. The fault is caused, for example, by the triggering of thyristors at the wrong time, short circuiting the DC machine. Obviously fuses in the AC lines can not interrupt this fault.

    - Solution 2: in the arms of the bridge, in series with semi-conductors (figure 19). In this case fuses are involved in all kind of faults (figure 21). The current rating of the fuses in the arms is $\sqrt{2}$ times smaller than the fuses in the AC lines.

- **Fuse voltage rating U_N**

Due to a commutation fault where the AC and DC voltages are in series the AC fuses and DC fuses (figure 18) and arm fuses (figure 19) must have a rated voltage U_N as follows:

$$U_N = K_{AC}\ V_{AC\ MAX} \quad \text{with} \quad 1.25 \leq K_{AC} \leq 1.70$$

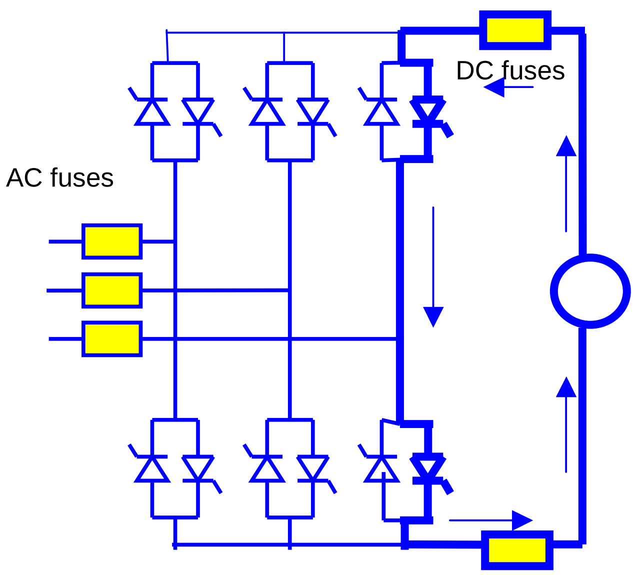

Figure 20 : DC shoot through fault

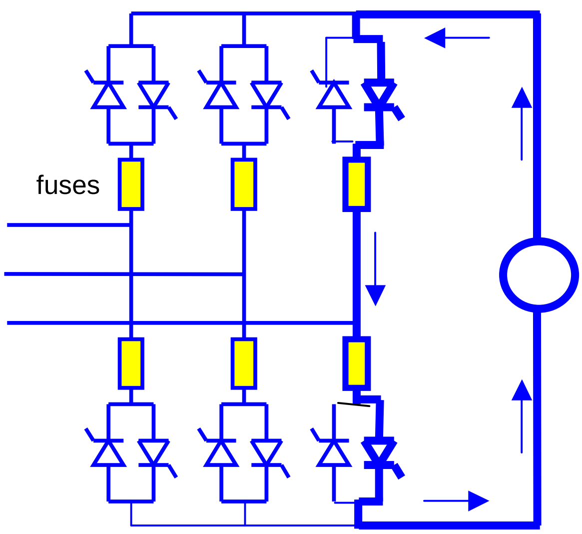

Figure 21 : DC shoot through fault

10.4. Soft starters and static switches

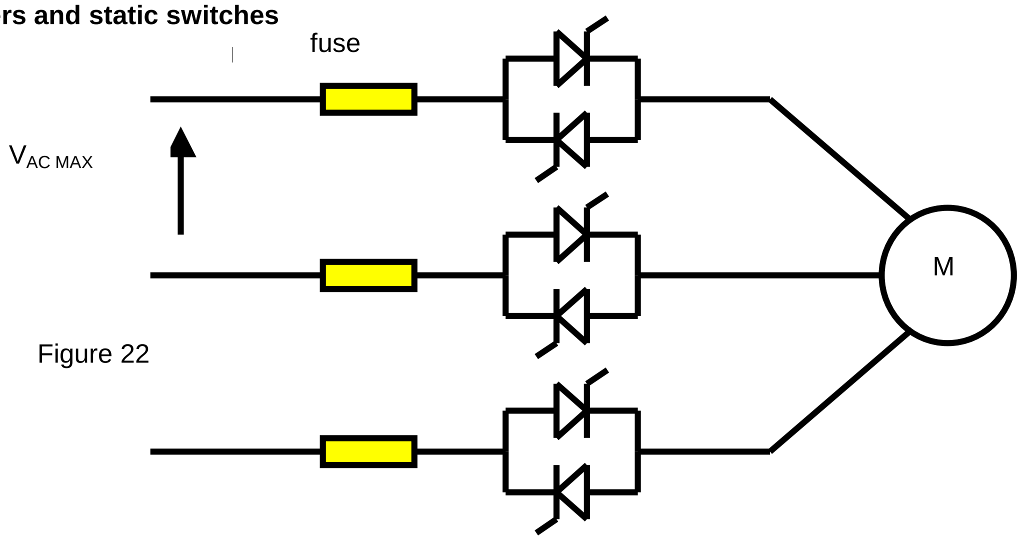

Figure 22

- **Fuse location:** fuses must be fitted in each line in series with each pair of semi-conductors (figure 22). However for some special cases (very high ratings) it might be necessary to fit fuses in series with each semi-conductor.
- **Fuse voltage rating U_N :**

Fuses complying with IEC 60269	**For most ratings**	$V_{AC\ MAX} \leq 1.06\ U_N$
	For some ratings	$V_{AC\ MAX} \leq 1.10\ U_N$
	For some 690 V fuses	$V_{AC\ MAX} \leq 1.05\ U_N$
Fuses complying with UL 248 only		$V_{AC\ MAX} \leq U_N$

10.5. Inverters

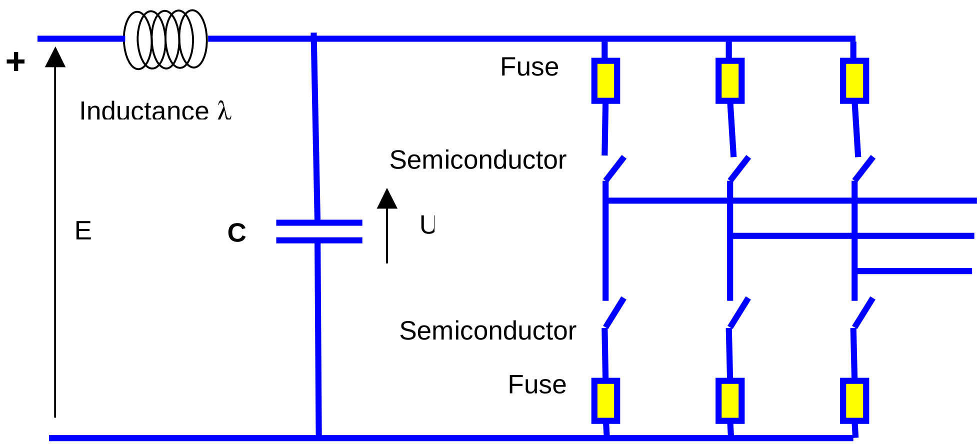

Figure 23

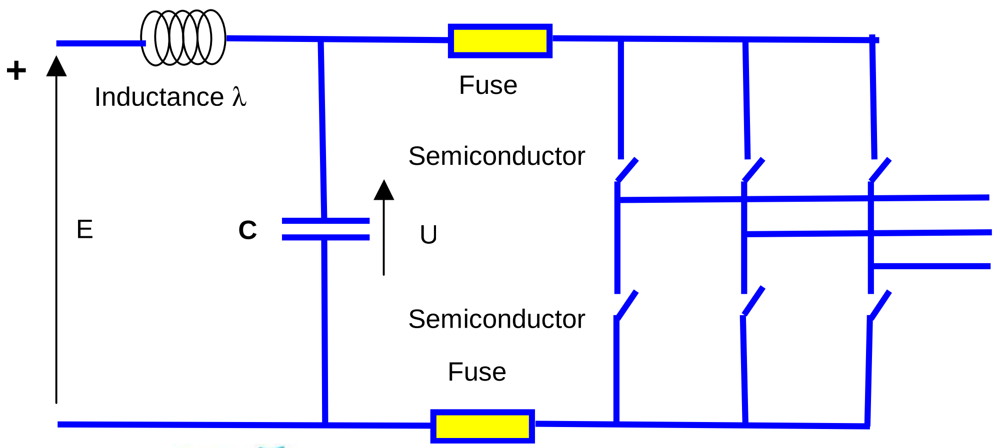

Figure 24

- **Fuse location:**

  2 possibilities :

  - fuses in the arms of the inverter (figure 23)
  - fuses in the DC loop of the inverter (figure 24): note, in this case, the fuse current rating is 1.7 times the current rating of the fuse in the arms

- **Fuse voltage rating U_N :**

the fuse will interrupt the capacitor discharge current generated by the short circuit created by the failure or bad triggering of semiconductors (figures 25 & 26). The fuse selection is based on the knowledge of the fuse maximum DC voltage rating at time constants lower than 1 ms (L/R < 1 millisecond).

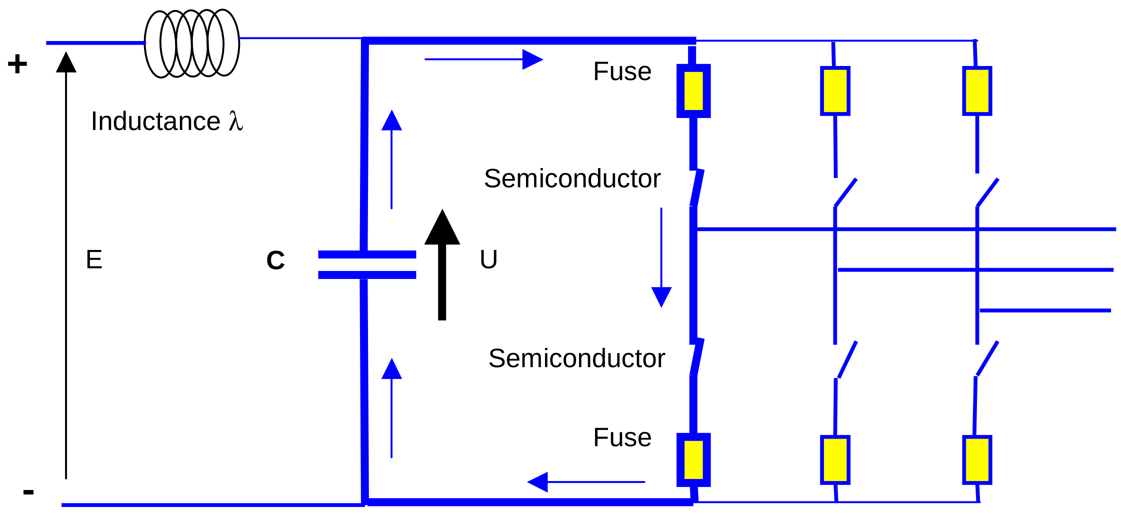

Figure 25

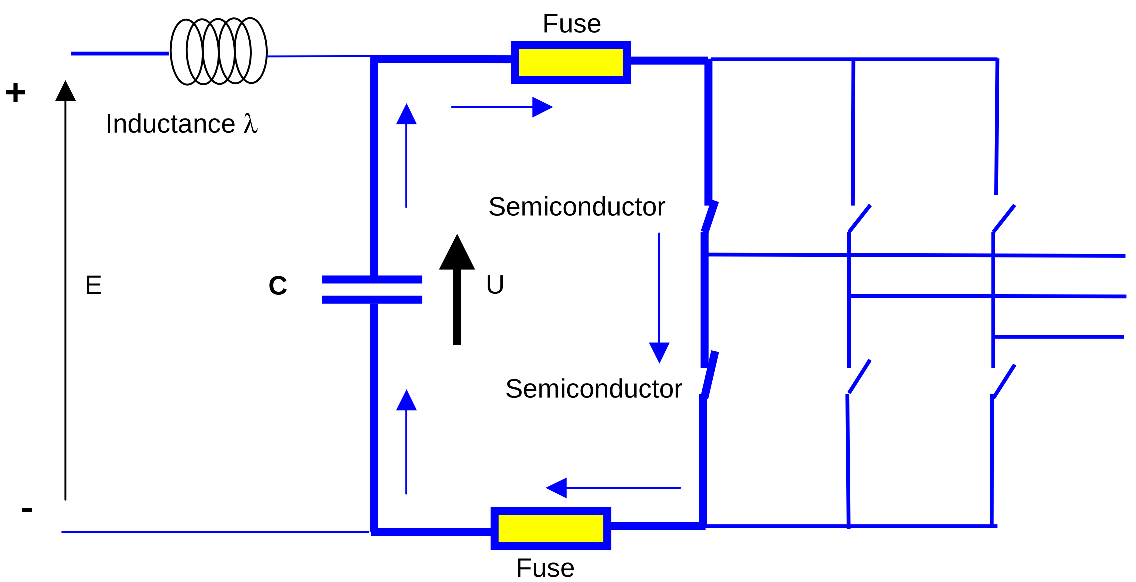

Figure 26

10.6. Multi-Inverters system

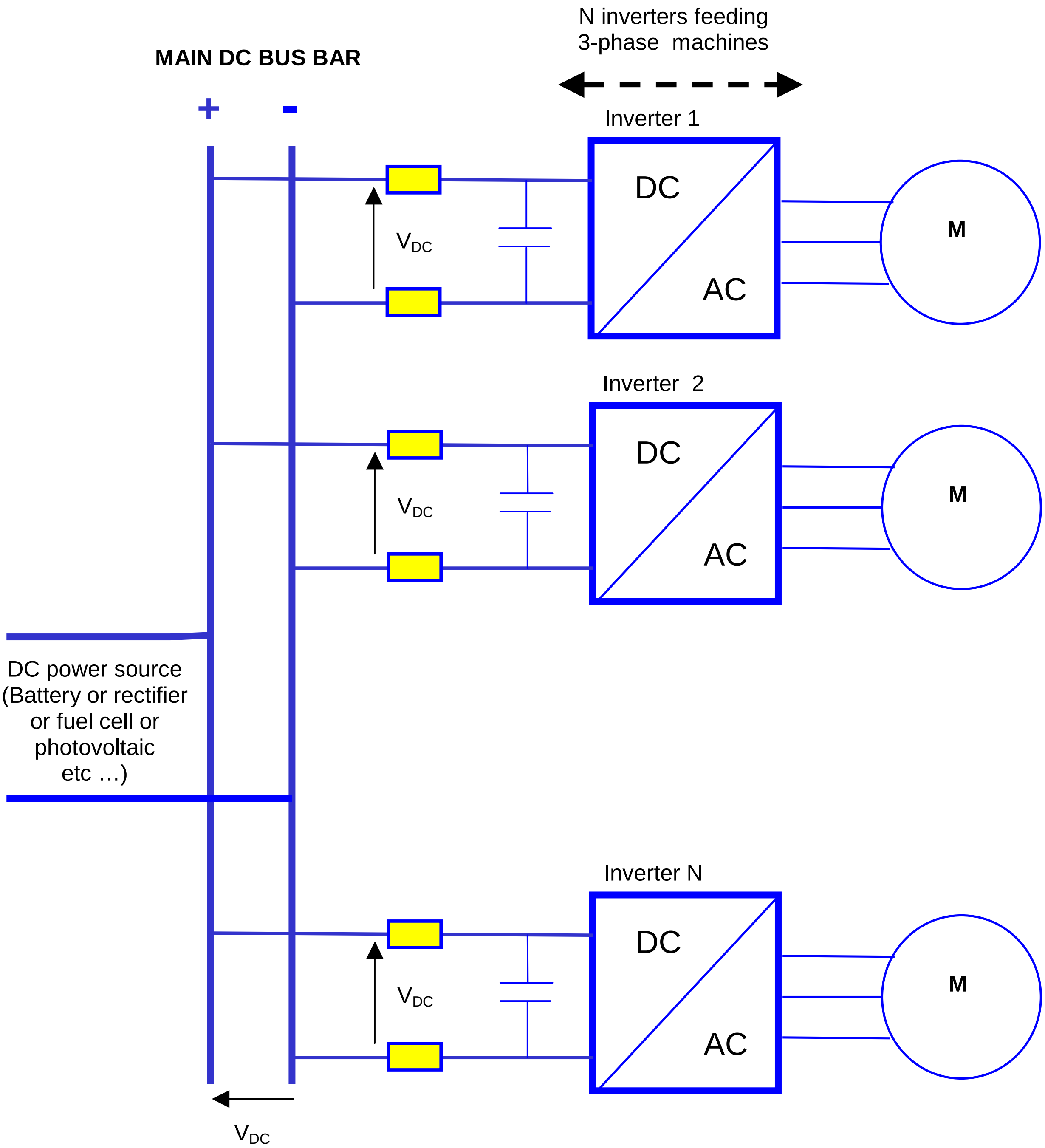

Figure 27

- **Fuse location:**
  - fuses in the feeder of each inverter (figure 27)

- **Fuse voltage rating U_N :**

the fuse will interrupt the capacitor discharge currents from all capacitors in all other feeders (they are in parallel) and the DC current supplied by the DC power source. The fuse selection is based on the knowledge of the fuse maximum DC voltage rating at time constants lower than 1 ms (L/R < 1 millisecond).

11. FUSE OPERATION UNDER DC VOLTAGE

FERRAZ SHAWMUT has a wide catalogue of DC rated fuses but any kind of fuse can operate under a DC voltage.

The absence of natural voltage zero makes the interruption of DC faults more difficult than the interruption of AC faults as only the fuse arc will force the current to decrease to zero. Moreover when the time constant L/R of a DC circuit is large the interruption of a fault is much more difficult. Another arduous operating condition is the interruption of a low over current.
In trains fed by a DC voltage (metros and railways) there is wide range of L/R values and over current levels. Consequently special DC rated fuses with fully enclosed operation are used in order to ensure people safety and protection of the equipments.
FERRAZ SHAWMUT has developed and designed such fuses for voltages up to 4000 V DC (as required by Italian and Belgian railways), as other fuses would be unsuitable. DC rated fuses must have passed specific tests in order to publish all necessary information on the DC capabilities of the fuse. Specific data are essential in order to safely apply fuses in DC circuits.
However some applications are easier and do not require fuses with a special design for DC interruption. In such cases AC rated fuses can be used providing the fuse manufacturer publishes the DC capabilities of the fuse.

11.1. Comment on the fuse rated voltage – practical values of L / R

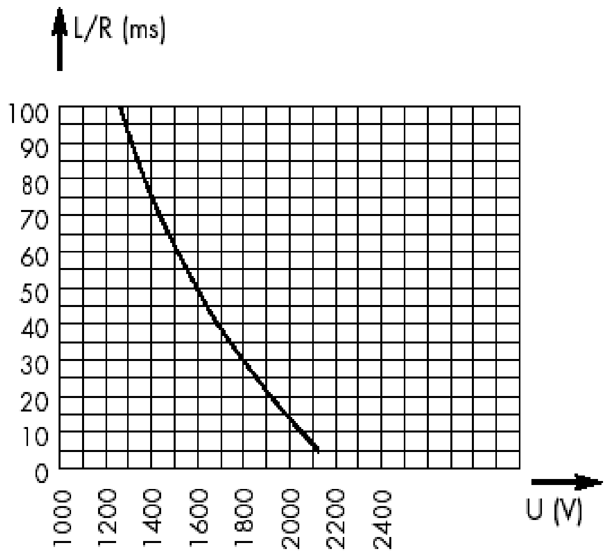

Figure 28: L / R = f(U) of the 2000 V DC SRD fuses

The curve in figure 28 show that it is not possible to select the DC voltage rating of a fuse purely on the basis of the working voltage value of the DC circuit to be protected.
It is absolutely necessary to plot the curve L/R = f(U)

This curve is plotted from the maximum energy tests results. Larger values of L / R are acceptable when the prearcing time is much smaller than L / R.

A L / R value must always be associated to the voltage and the range of possible fault current levels must be known.

It is often difficult to obtain a precise value for **L/R** in practice. In the absence of better information the following table gives some typical guideline values.

Equipment	**L / R in ms**
Capacitor bank	< 1
Battery	< 10
Output of a three phase bride feeding a main DC bus bar	< 25
DC motor armature	20 - 60
DC traction systems	40 - 100
DC motor field circuit	1000

11.2. Example of DC capabilities for an ac rated fuse range

Maximum L /R of the fault path versus the DC working voltage U

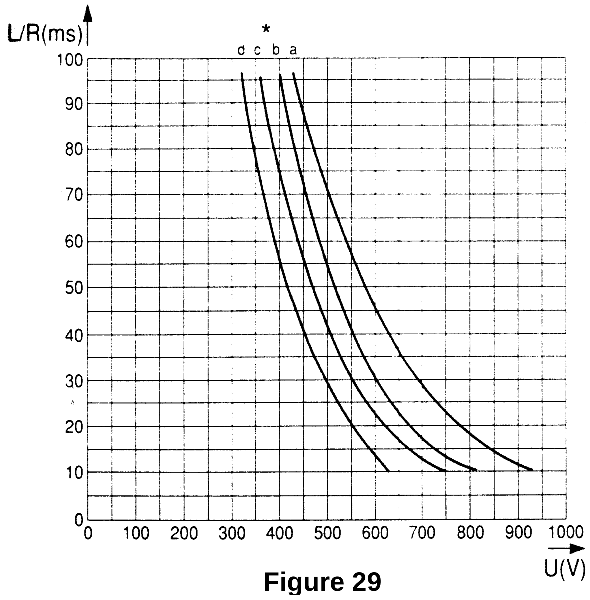

Figure 29

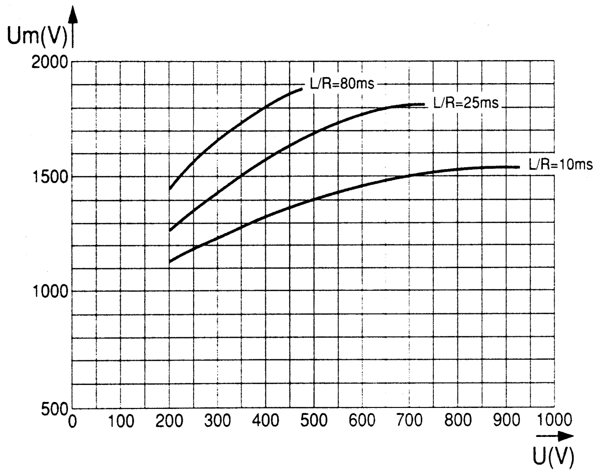

Figure 31: Peak arc voltage **U_m** of the fuse versus the DC working voltage U for three values of the time constant L / R

Body size

Letters a , b, c and d indicates the L / R curve to use in figure 7
I_{pm} is the minimum breaking current of each fuse

	70 * Ipm (A)	71 * Ipm (A)	72 * Ipm (A)	73 * Ipm (A)	2x72 * Ipm (A)	2x73 * Ipm (A)
63	a 270					
80	a 400					
100	a 520					
125	a 700					
160	a 950	a 950				
200	a 1300	a 1300				
250	a 1800	a 1800				
280	b 2200	a 2000	a 1800			
315	b 2600	a 2300	a 2200	a 2000		
350	c 3000	a 2700	a 2600	a 2400		
400		b 3500	a 3200	a 3000		
450		b 4000	a 3800	a 3500		
500		c 4800	a 4600	a 3900		
550		c 5200	b 5000	a 4400		
630		c 6400	b 6200	a 5300	a 4400	
700			c 6800	a 6000	a 5200	
800			c 8000	b 8000	a 6400	a 6000
900				b 9000	a 7600	a 7000
1000				c 11000	a 9200	a 7800
1100				c 12000	b 10000	a 8800
1250				c 13500	b 12400	a 10600
1400				c 15000	c 13600	a 12000
1600					c 16000	b 16000
1800						b 18000
2000						c 22000
2200						c 24000
2500						d 27000
2800						d 30000

Figure 30

11.3. Fuse definition for a DC circuit protection

For all DC applications it is absolutely necessary to define the fuse with:

- The voltage
- The time constant of the circuit
- The fault currents

It is required as well to get all necessary information about the rated current passing in the fuse as well as the load cycles and overloads to withstand in order to calculate the current rating of the fuse so that its life time fits with the life time of the equipment it must protect.

12. CONCLUSION

Alone or associated to other protection devices the fuse is an ideal solution for the protectionof:

- Low voltage distribution circuits
- Medium voltage distribution circuits
- Power electronic equipments
- Low voltage and medium voltage DC circuits

F	**F**ull overcurrent protection, **F**idelity of operation
U	**U**niversal use (gM or gD ideal all-purpose fuse)
S	**S**electivity, **S**implicity, **S**afety
E	**E**conomical, **E**nergy-limiting, **E**asy-to-use

Simply perfect !