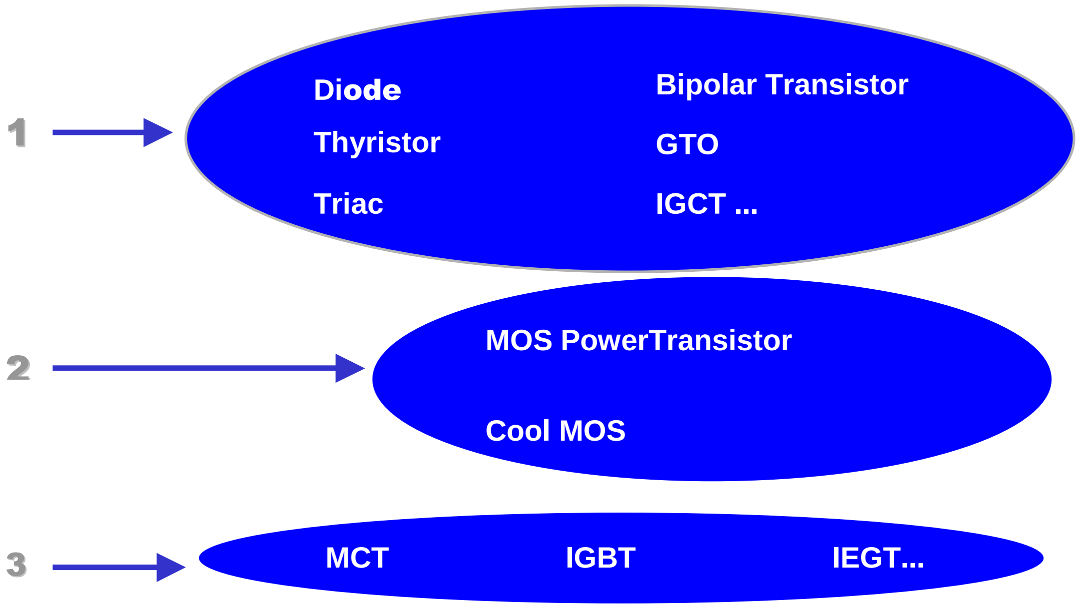
EduPack

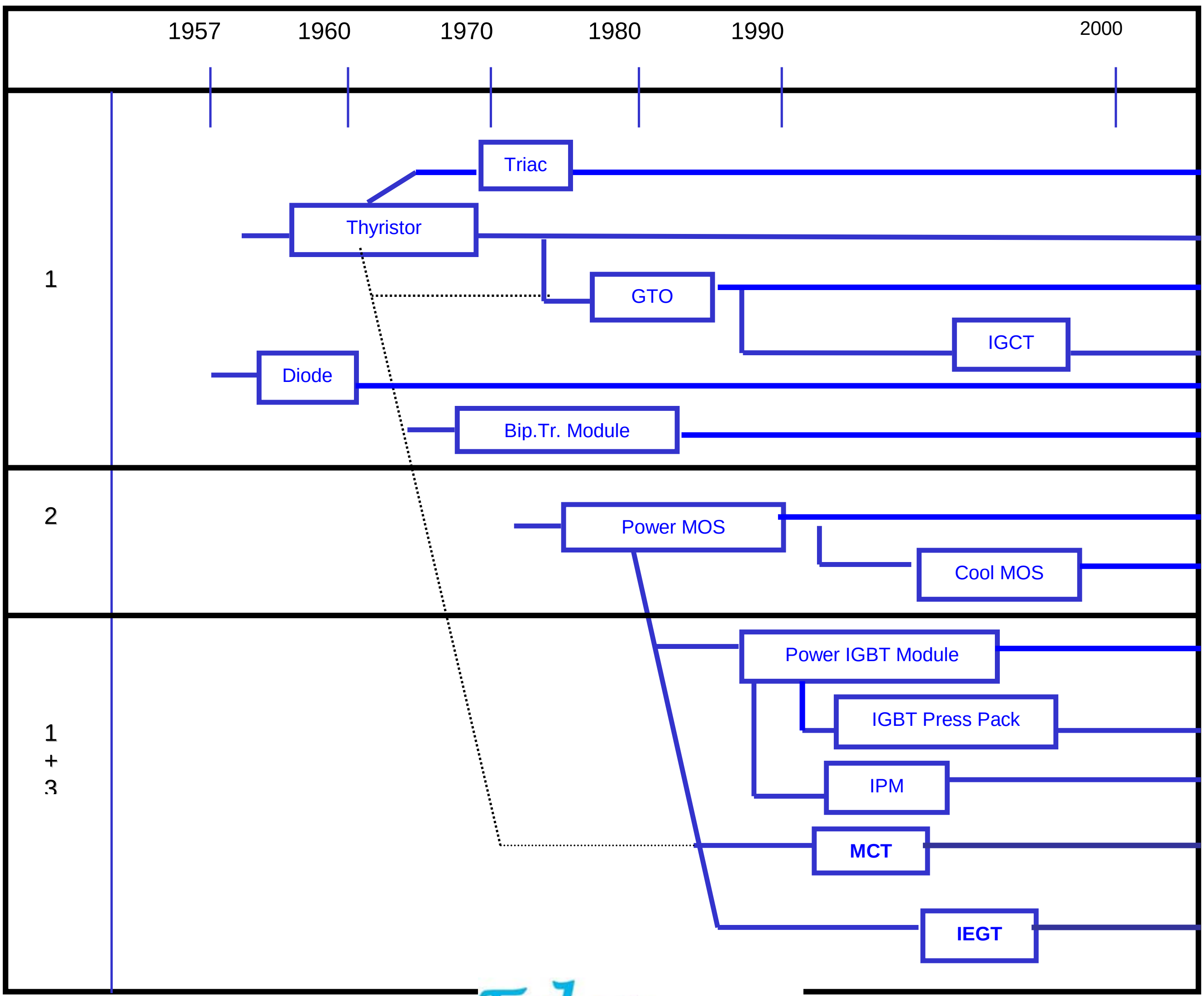
FUSES FOR SEMICONDUCTORS

1. POWER SEMICONDUCTORS

1.1. Three families of power semiconductors



1.2. Power semiconductors history



1.3. Current conversion: one application of the power semiconductors

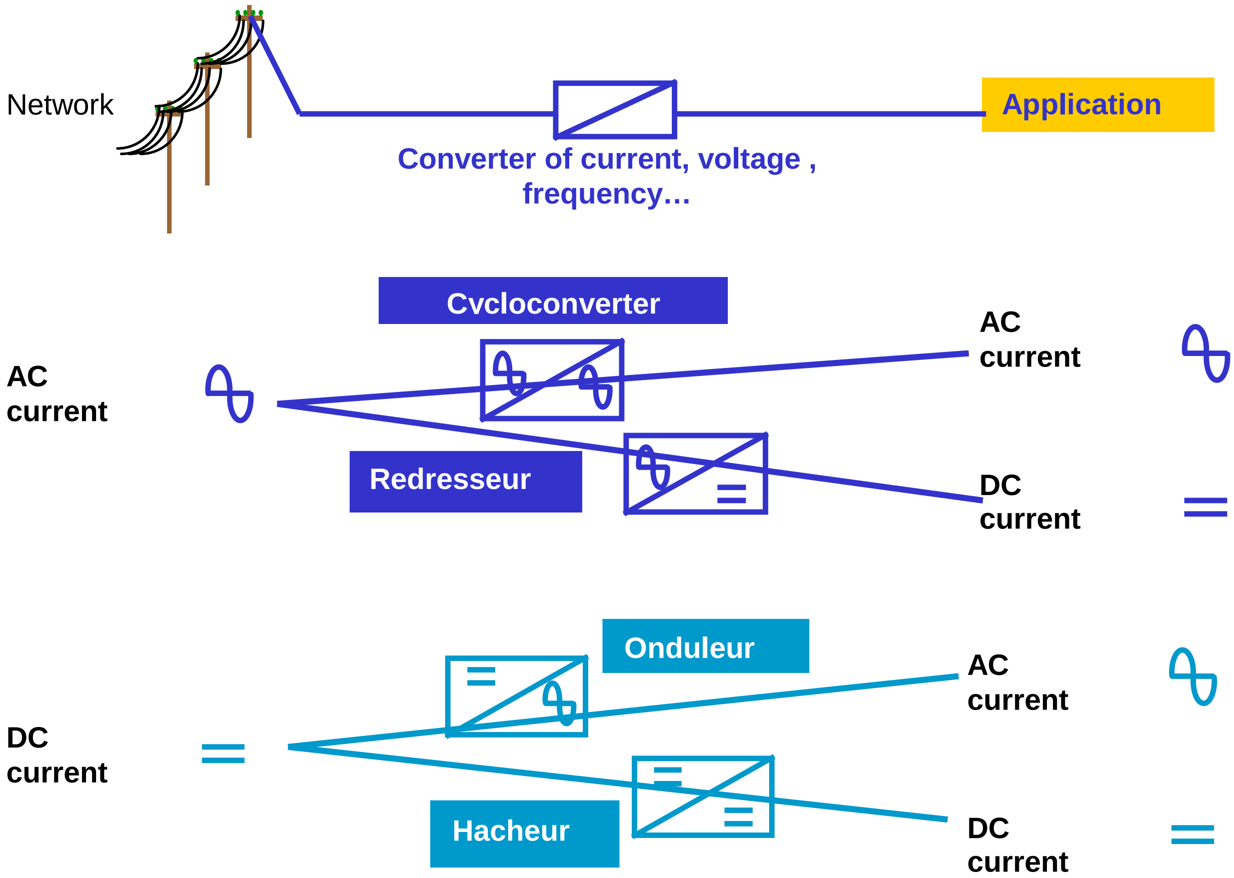
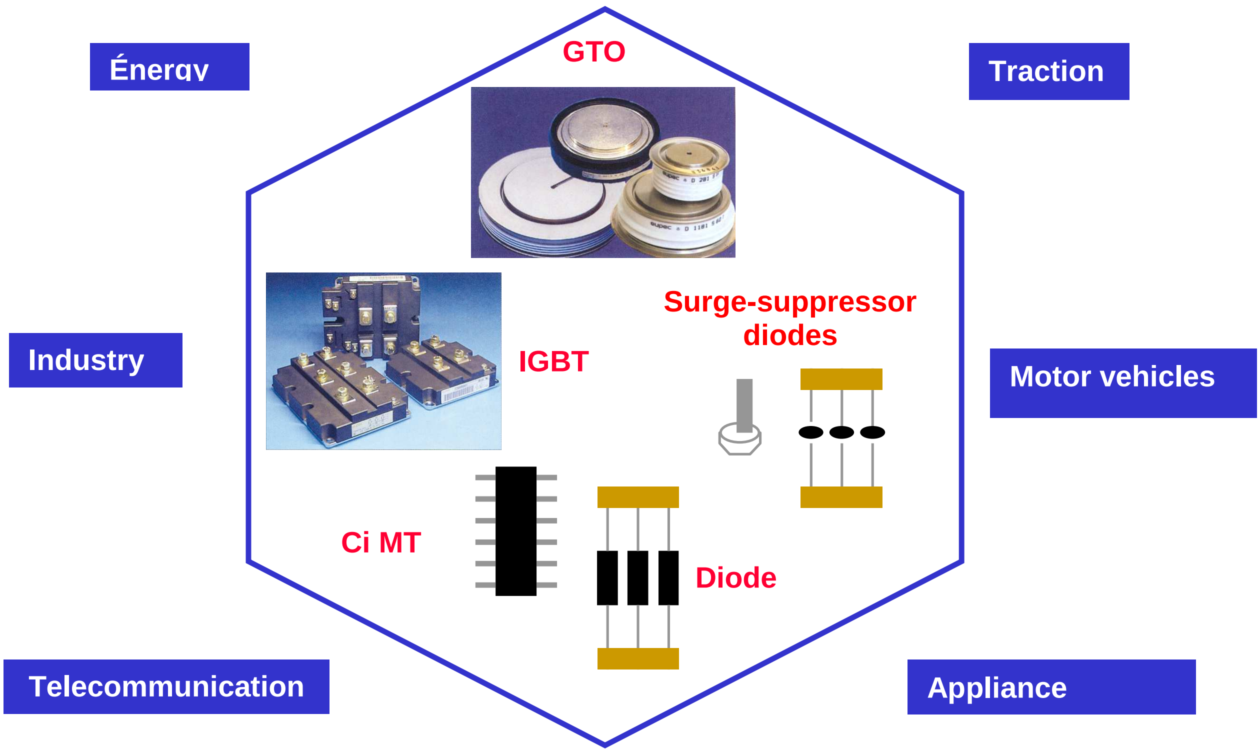


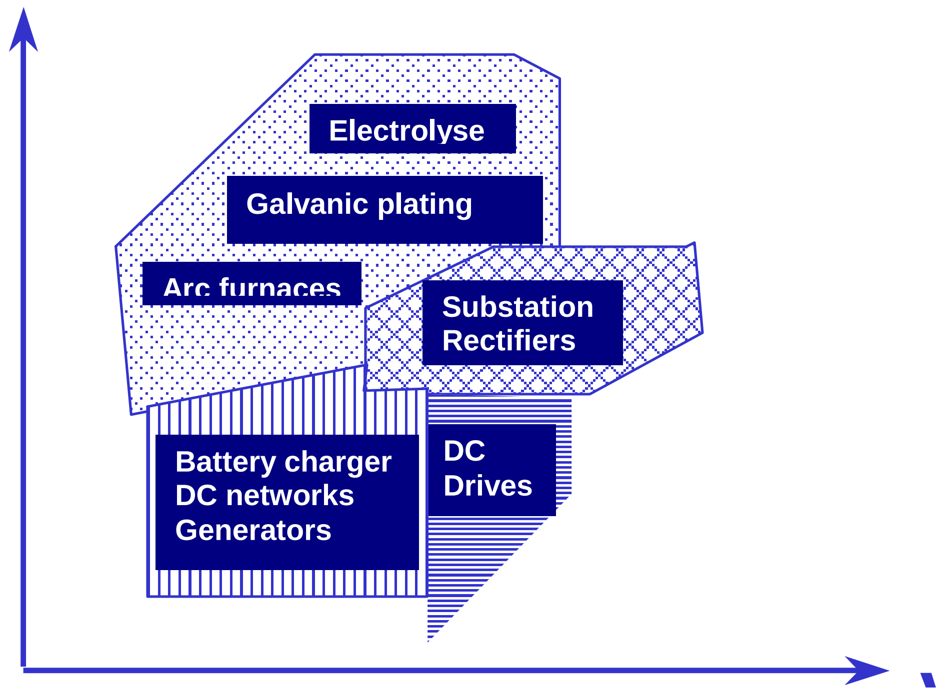
Figure 1 : current conversion

1.4. Power semiconductors application fields

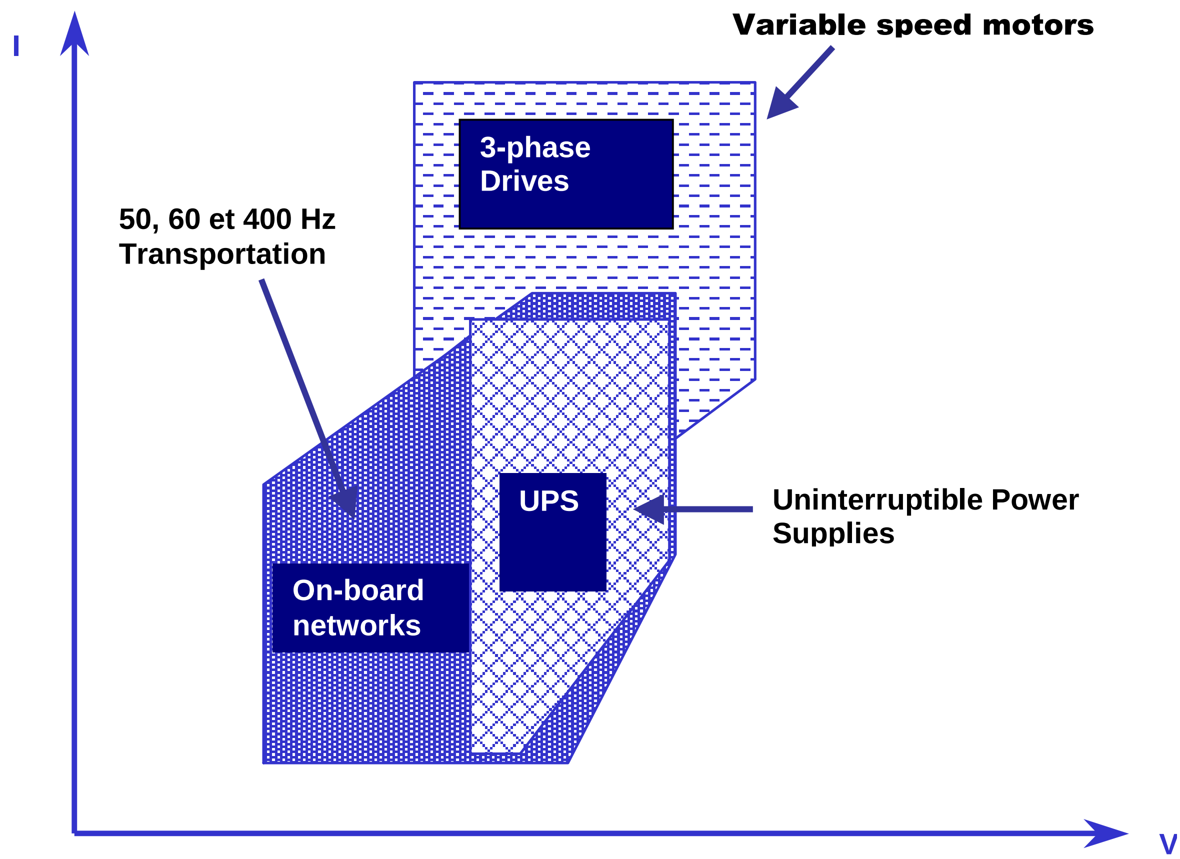


2. CURRENT CONVERTERS APPLICATIONS

2.1. Rectifier applications



2.2. Inverter applications



3. POWER STATIC CONVERTERS PROTECTION WITH FUSES

3.1. Two main families of faults

There are two kind of faults: internal faults and external faults

- **Internal faults : they are generated by a failure inside the converter**

Example : a semiconductor fails creating a short circuit.

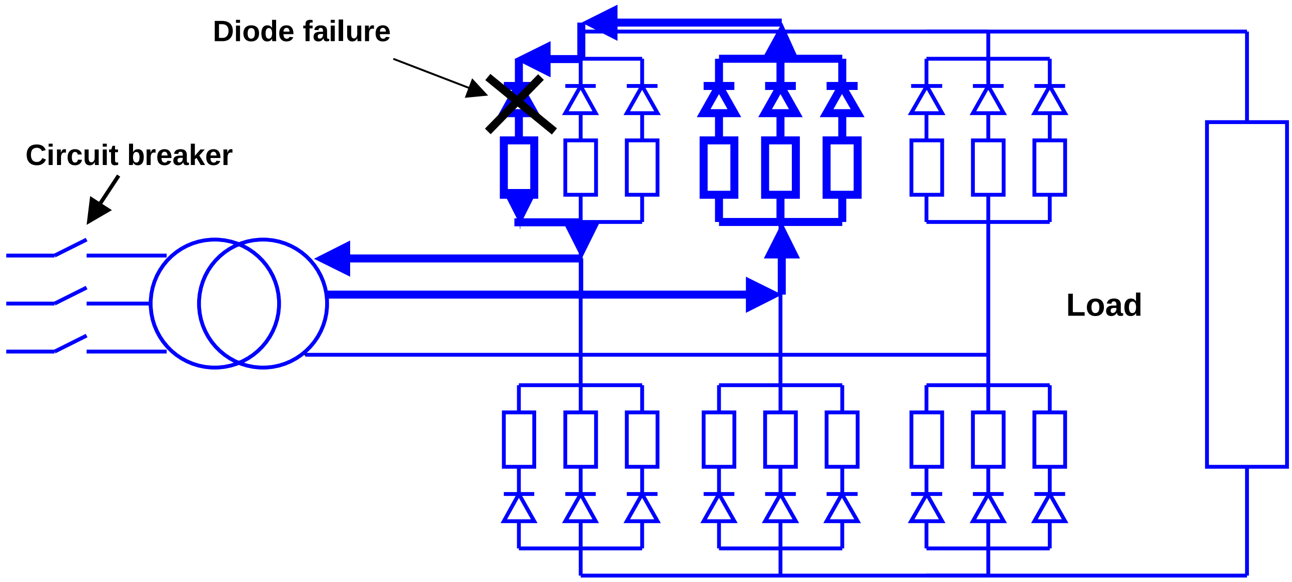


Figure 2: internal fault

- **External faults** : they are generated outside the converter

Example : short circuit in the equipment fed by the converter

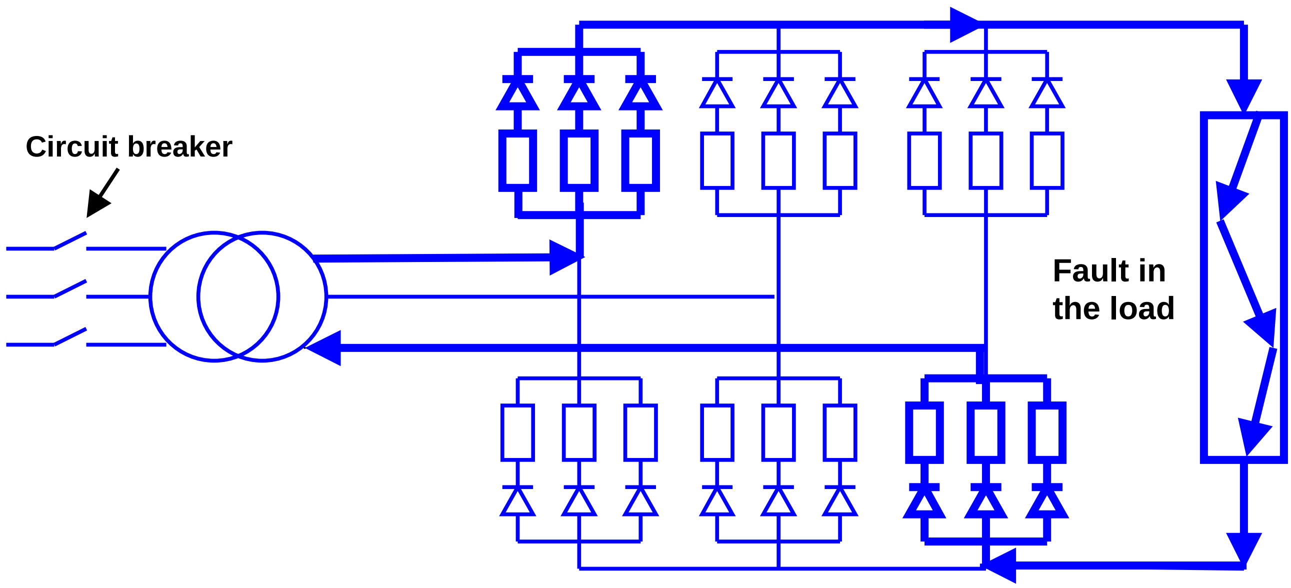


Figure 3: external fault

3.2. Two main types of protection

- **Total protection: protection example of a rectifier with 1 diode per arm**

Choice of the fuses location:
in the case of the three phase bridge with one diode per arm (known as well as « Graêtz » bridge) there are two possibilities:

- Fuses can be fitted in the input lines as per figure 4 (3 fuses F1)
- or fitted in series with each diode as per figure 5 (6 fuses F2).

The fuse must interrupt all fault currents: internal faults and external faults. In such cases the selected fuse has an I^2t smaller than the semiconductor junction I^2t.
After a fault interruption by fuses it is enough to replace the melted fuses (2 fuses mnimum) and sometimes to replace one diode (or thyristor) when the fault was created by a diode failure.

However it is not always possible to ensure the protection with 3 fuses F1 since the rated current of these fuses is $\sqrt{2}$ times larger than the current rating of F2 fuses. Indeed the R.M.S. current in the three imput lines is $\sqrt{2}$ times larger than the R.M.S. current in each diode (or thyristor).
The consequence is that the I^2t of F1 fuses will be about 2 times the F2 fuses I^2t making the protection of the diode junctions (or thyristor) sometimes impossible.

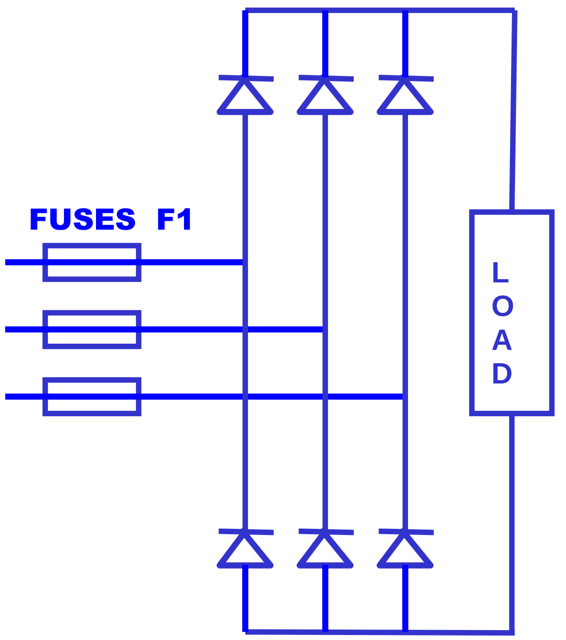


Figure 4 : protection with 3 fuses

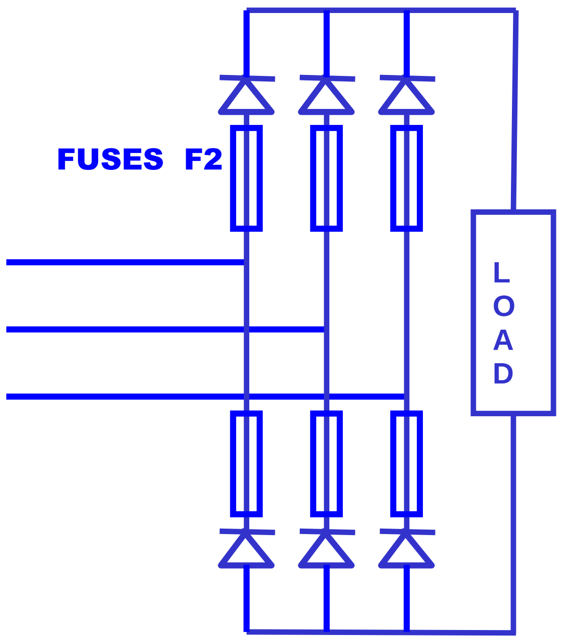


Figure 5 : protection with 6 fuses

- **Internal protection : example of the rectifier with several diodes in parallel per arm**

This case is illustrated in figures 2
There is only one possible location for the fuses: in series with each semiconductor.
The fuse interrupts only the short circuit current generated by internal faults. The fuse must prevent the failed semi-conducteur from explosion. Damages inside the converter are mminimised.
Another protection system interrupts the external faults. In general the fuse is coordinnated with the other protection system in such a manner to be not at all dammaged when this other protection system interrupts the external faults.
The protection of the equipment is ensured when:

- The fuse i^2t is smaller than the explosion i^2t of the semiconductor (i.e. the case rupture I^2t of the semiconductor). Sometimes the manufacturer of the semiconductors give a maximum peak current value instead of an I^2t.
- The fuse i^2t is smaller than the global junction I^2t of « N » semiconductors in parallel (i.e. N^2 times the junction I^2t of one semiconductor)
- Fuse arc voltage is smaller than the semiconductor peak reverse voltage

3.3. Semiconductor fuse selection criterions

TABLEAU 1

PARAMETERS	CONDITIONS
Voltage	$V_{FUSE} > V_{FAULT}$
Current	$I_{FUSE} > I_{RMS}$
total I²t	$I^2t_{TOTAL} < I^2t_{SEMICONDUCTOR}$ (JUNCTION OR CASE)
Breaking capacity	$BC_{FUSE} > I_{FAULT}$
Arc voltage	$V_{ARC\ FUSE} < V_{SEMICONDUCTOR}$

4. SELECTION OF THE FUSE RATED VOLTAGE U_N

The selection of the fuse rated voltage **U_N** is not based only on the line to line voltage of the network feeding the current converter but must take into account the voltage of the faults the fuse must interrupt as stated in TABLE 1 of § 3.3 .

TABLEAU 2

Rectifier	Figure 6	$U_N \geq V_{RESEAU}$
PWM inverter	Figure 7	No formula because the fuse must interrupt a capacitor discharge. A specific application leaflet with special appropriated curves must be used.
Soft starters	Figure 8	$U_N \geq V_{RESEAU}$
Regenerative DC drive	Figure 9	$U_N \geq V_{RESEAU} + \frac{V_{CONTINU}}{\sqrt{2}}$

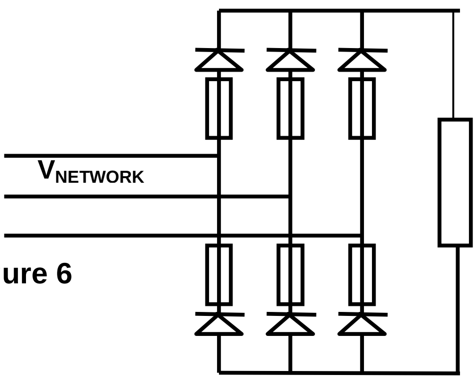


Figure 6

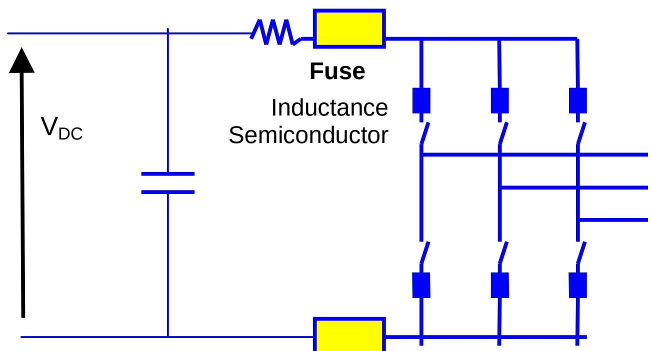


Figure 7

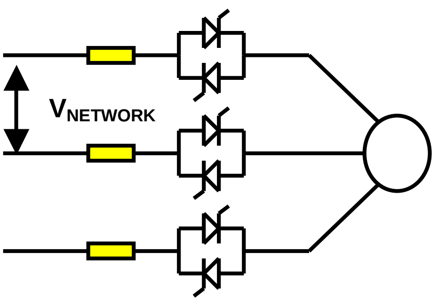


Figure 8

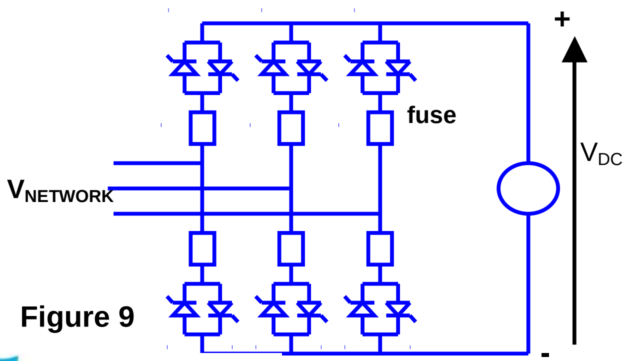


Figure 9

5. SELECTION OF THE FUSE RATED CURRENT I_N

The rated current $\mathbf{I_N}$ or rating of PROTISTOR or AMP-TRAP fuses is the R.M.S. value of the current flowing continuously through the fuse without any alteration of the fuse characteristics. The value of $\mathbf{I_N}$ is obtained from a temperature rise test done according to the conditions given by the IEC 60269-4 standard or UL 248 part 13 standard. For this type of fuse the standards do not specify any maximum values of the operating temperatures.

For general purpose fuses and circuit with motor protection IEC 60269 and UL 248 standards specify the temperature rise test conditions as well as results like: power loss, connections temperature rise etc.
The standards specify as well melting current and non melting currents for given melting times, taking into account the applications of the fuses. The time current curve must go between these points.
The selection of these types of fuse is then greatly simplified. Nevertheless all principles described in this document concern all type of fuses.

The fuse working conditions inside an equipment are never the same as the test conditions. TABLE 1 summarises the basic differences.

TABLE 3 summarises the basic differences:

TABLE 3

PARAMETERS	IEC-269 TEST CONDITIONS	WORKING CONDITIONS INSIDE EQUIPMENTS
Ambient temperature	30 ℃ max.	40 ℃ to 60 ℃ in mo st cases
Cable & bus bar dimensions	1 m long on each side of the fuse cables up to 400 A 240 mm² copper cable for 400 A 600 mm² copper bars for 1000 A (see table in annexe 1)	length is shorter than 1 m , one end can be connected to a hot component or to a water cooled heat sink in most applications the current density in the cables or busbars is higher the material is copper or aluminium
Cooling	natural	natural or forced air cooling or water cooling
Load current	continuous or stable	variable with overloads in most cases
Frequency	50 or 60 hertz	0 to 20 kilohertz

Such differences require the use of corrective coefficients in order to calculate the fuse rating I_N that will not age prematurely because of excessive temperatures or repetitive current variations.
With another coefficient it is possible as well to avoid the undesired melting of the fuse caused by some large overloads or to ensure the coordination between fuses and circuit breakers.

The lifetime of the fuse is function of the temperature variation $\Delta\theta$ in the fuse elements . The number of cycles or overloads the fuse can withstand will decrease when $\Delta\theta$ increases and conversely. Specific tests with a variable load must be conducted in order to evaluate the corrective coefficients .

All parameters listed in TABLE 1 will affect the fuse life duration because they have a direct influence on the operating temperature of the fuse .

Note: the use and the values of the corrective coefficients are not necessarily the same for all fuse manufacturers because the choice of the materials and maximum operating temperatures are different.

6. CORRECTIVE COEFFICIENTS PRESENTATION

The coefficient used are: a - B_1 - C_1 - C_{PE} - A'_2 - A_3 - B'_2 - Cf'_3
Note : coefficients A_2 - B_2 - Cf_3 sometimes published with the time current curves of fuses for the semi-conductors protection are particular values of coefficients A'_2 - B'_2 - Cf'_3 , and are usable in specific conditions.

6.1. Coefficients applied on the RMS value of the load current: a - B_1 - C_1 - C_{PE} - A'_2

The fuse rating I_N is obtained by dividing the RMS value of the load by the corrective coefficients. The use of several coefficients is combined in the same calculation as shown in the examples described in this paragraph.

- **Ambient temperature inside the cubicle: coefficient a**

When the ambient temperature θ_a is above a reference temperature θ_0 (given by standards and test conditions), it allows the calculation of coefficient A_1 :

$$A_1 = \sqrt{\frac{a - \theta_a}{a - \theta_0}}$$

then coefficient A_1 is applied on the continuous load or on the RMS value of a variable current

the fuse current rating I_N is: $I_N \geq \frac{I_{RMS}}{A_1}$

- **Forced air cooling : B_1 coefficient**
-

when a forced air-cooling is applied on the fuse so that the air velocity is v , it allows calculating

$$B_v = 1 + (B_1 - 1) * \frac{v}{5} \quad \text{with } v \text{ in m/s and with } v \leq 5\ m/s$$

When $v \geq 5\ m/s$ there is no improvement of the heat exchange between the fuse and the air.

then the fuse current rating I_N is: $I_N \geq \frac{I_{RMS}}{A_1 * B_V}$

- **Connections: coefficient C_1**

This coefficient allows to take into account the size of the conductors connected to the fuse, the presence of other components generating heat, and the cooling of the fuse connecting parts as well. Some examples of recommended values in TABLE 4 are experience results:

then the fuse current rating I_N is: $I_N \geq \frac{I_{RMS}}{A_1 * B_V * C_1}$

TABLE 4 : C_1 coefficient for some semiconductor fuses

TECHNOLOGY	SIZE	TYPE	without cooling on terminals	fuse contacts kept at 60 °C or less on both sides
Square ceramic bodies	30-31-32-33 & doubles	UR-	0.85	1.30
		gR-	0.85	1.25
	70-71-72-73 & doubles	UR-	0.90	1.25
		gR-	0.90	1.20
	83-84 & doubles	UR-	0.90	1.20
		gR-	0.90	1.15

- **Effects of frequencies above 60 hertz: coefficient C_{PE}**

This coefficient is used when the load current carried by the fuse is at frequencies abpve 100 hertz. There are 2 problems when the frequency is too high:

the proximity effect
the skin effect .

When inside the fuse there are several fuse elements in parallel the current is not well shared between the fuse elements if another conductor (see figure 10) carrying the current back to the power source is close to the fuse.
The problem remain the same for any direction of the current in the other conductor.
This is the proximity effect**.**
Since some fuse elements are overloaded a corrective coefficient must be used.

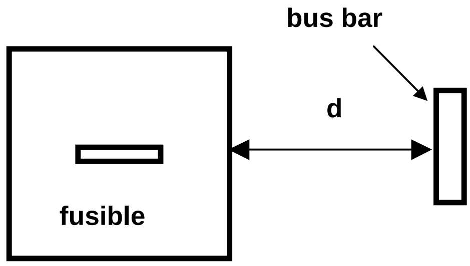


figure 10

TABLEAU 5

FREQUENCE (hertz)			**C_{PE}**
100	à	500	0.95
500	à	1500	0.90
1500	à	5000	0.80
5000	à	10000	0.70
10000	à	20000	0.60

The unbalance is function of the frequency and the distance **d** between the fuse and the other conductor (when the distance d is shorter the unbalance is greater).
The values given in TABLE 5 are not accurate because they do not take into account the number of fuse elements and they do not show the influence of the distance d . But it is enough for a good approach .

then the fuse current rating I_N is: $I_N \geq \dfrac{I_{RMS}}{A_1 * B_V * C_1 * C_{PE}}$

- **Effects of « cyclic » variable currents: coefficient A'_2**

This coefficient is used when the load current is a **« cyclic »** one The published coefficient **A_2** is only a particular value of **A'_2** corresponding to the long cycle cases; (i.e. the most difficult ones)

I_{RMS} : RMS value of the current cycle

then the fuse current rating I_N is: $I_N \geq \dfrac{I_{RMS}}{A_1 * B_V * C_1 * C_{PE} * A'_2}$

6.2. Repetitive overloads : coefficient B'_2 defining the fuse prearc curve

In figure 11 the RMS value of the current cycle is small in comparison to the value of the overload **I_C . In such a case it is necessary to calculate the position of the fuse prearc curve with respect to I_C .**
For time t_{on} the fuse melting current I_F is calculated dividing **I_C** with coefficient **B'_2.**

$$I_F \geq \frac{I_C}{B'_2}$$

B'_2 value depends upon the expected number of overloads

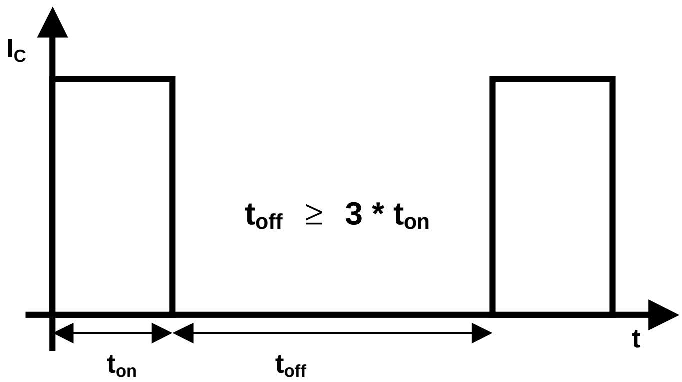


Figure 11

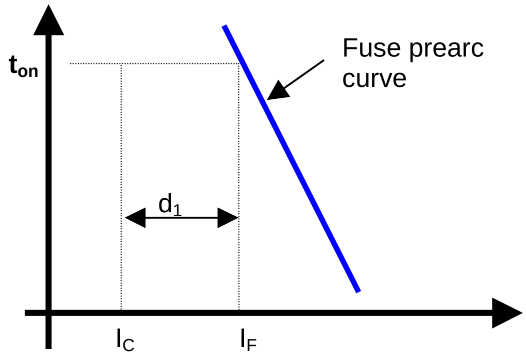


Figure 12

For 1 00 000 overloads:

- I_F = 3 I_C with square body PSC fuses
- I_F = 3,5 I_C with aM or ferrule fuses type UR- & gR-

6.3. Occasional overload (coordination with circuit breaker): coefficient Cf'_3

The method is the same as for a repetitive overload. The difference is the sole coefficient value equal to:

$$Cf'_3 = 0{,}75$$

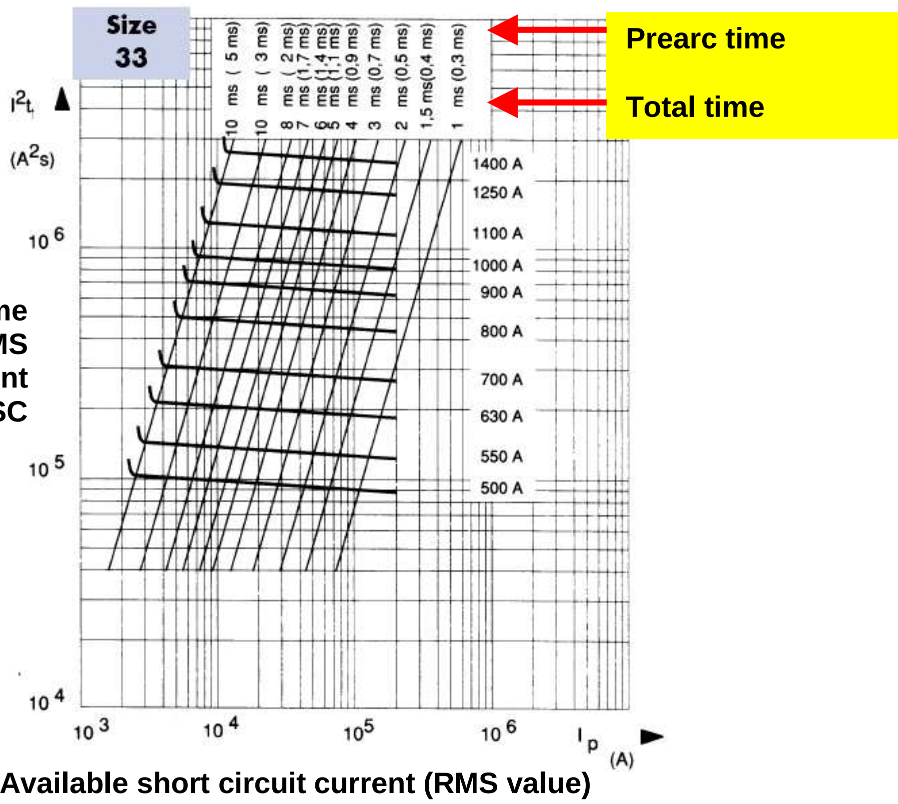
The position of the fuse prearc curve is given by the calculation of the melting current for a given time as follows:

$$I_F \geq \frac{I_C}{Cf'_3} \quad \text{then} \quad I_F = 1{,}33\ I_C$$

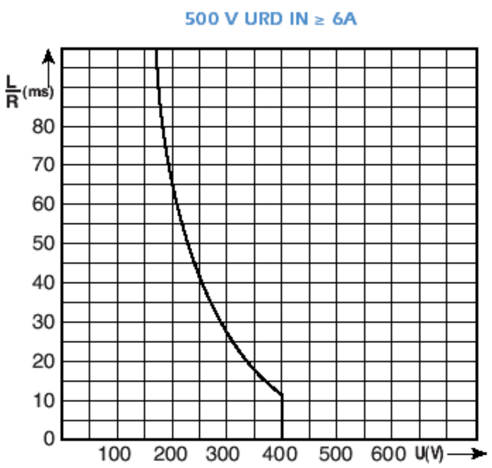
this coefficient is used to check the coordination between fuses.
The coefficient value allows to withstand about 100 to 150 overloads.

7. COURBE DU I²t

figure 13: total I²t, total time and prearc time versus RMS value of the available current (short circuit) of fuses PSC 690 V URD size 33



8. DC CAPABILITIES CURVE



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 prearc 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.

Figure 14 : capabilities of 500 V URD ferrule fuses size 10.38

9. MAIN TECHNOLOGIES

Figure 6

10. EXEMPLE OF AN ELECTRICAL SCHEMATIC IN A LARGE PRODUCTION PLANT (cement, pulp and paper, sugar etc….)