# CURRENT LIMITATION BY CIRCUIT-BREAKER AND POLYMER COMBINATION

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*Abstract:* A new technology using current limitation offered by semiconducting polymers in combination with breaking capacity, provided by traditional miniature circuit-breakers, allows to merge the best characteristics of both solutions.

PROLIM™ (PROtection LIMitation), the ABB commercial name of his "permanent fuse", consisting in a semiconducting polymer device, with a temperature-dependent transiction from very low (3mΩ) to very high (300mΩ) internal resistivity, is current limiting device of short-circuit current level (Ik) and associated specific thermal energy ($I^2t$), in similar, better way as traditional devices: fuses and current limiting circuit breakers.
An associated-coordinated circuit-breaker is necessary to clear the residual current and to permit the requested necessary selectivity.

This solution improves the short-circuit protection for motor starters and distribution applications.

PROLIM™, together with miniature circuit-breaker, is the ideal solution when there are:

- High short-circuit levels
- Medium current levels (In < 63 A)
- Voltages between 400 – 500 V (depending of the circuit-breaker).

The most likely applications are:

- Off shore
- Mining
- Power Generation
- Wind mills

This work shows how PROLIM™ operates, why and when gives real advantages.

Many short-circuit tests up to 50kA are included; these tests also compare PROLIM™ performances vs traditional components; the main results out of this comparison are:

- Cost saving
- Space saving
- Smaller cable area
- Personell safety
- Reliability of service
- Selective back-up

## I PRODUCT PRESENTATION

Short-circuits are the cause of high or even very high fault currents flowing in distribution systems.
If effective protection is not provided, these currents can cause serious damage to plants and equipment connected to the systems.
Short-circuit protection therefore has to interrupt fault currents as quickly as possible.
In practice, this means it has to prevent the first high "spike" of the fault current from forming.
The time it takes to form depends on the actual circuit and the moment switching takes place, but is in the range of just a few milliseconds.
The development of PROLIM™ should be regarded as a logical step in meeting the steadily increasing requirements made of apparatus in the low-voltage range-apparatus for high performance.
Designing fast, reliable electromechanical circuit-breaker to fulfil present and future requirements is becoming more and more difficult.
The break-time of conventional circuit-breakers is several milliseconds.
In most breakers, arc extinction takes place when the current passes through zero – ie, if the moment of switching is not ideal, after about 10 to 15 ms (50Hz).
Even high speed circuit-breakers take 3 to 5 ms to open.
Circuit-breakers designed for short-circuit duty therefore have to be dimensioned for very high current values.
Because of mechanical constraints, traditional circuit-breaker technology offers hardly any potential for a further reduction in breaker operating time.
Many R&D efforts were spent on finding a new solution, in which short-circuit currents are limited safely and effectively before the current is interrupted using a conventional miniature circuit-breaker.
The current limiting device represents innovative technical thinking in the electrical business, where mechanical breaking contacts have always been found in some form or other to interrupt or limit short-circuit currents.
The new material technology involved will probably make a breakthrough in many other areas too.
The polymer material of the PROLIM™ contains electrically conducting particles.

In normal operation no change takes place and the entire polymer body remains is a state of low resistance.
PROLIM™ is a short-circuit limiting device available both as a product alone and as a combination unit together with a miniature circuit-breaker.
In any case it operates only together with a circuit-breaker: PROLIM™ limits the short-circuit current level (Ik, $I^2t$), then the circuit-breaker interrupts the current
As a result, a significant improvement in the break time has been achieved and, even more dramatic, the let-through energy and the current peak are very limited.

PROLIM™ improves the short-circuit protection especially where a strong limitation of energy is required and it's important to safe space.

## II HOW IT WORKS

PROLIM™ is made like a sandwich: the polymer material is inserted between two copper electrode plates, a strong pressure is mechanically applied by springs on both sides; all this assembly is encapsulated.
Polymers are usually non-conductive.
Some, however, can be transformed by doping into a state in which they conduct electricity.
The polyethylene current limiter is connected in parallel with an ohmic protective resistor.
Its purpose is to carry the current during the transitional phase during which the resistance increases.
This also reduces the voltage drop across the limiter.

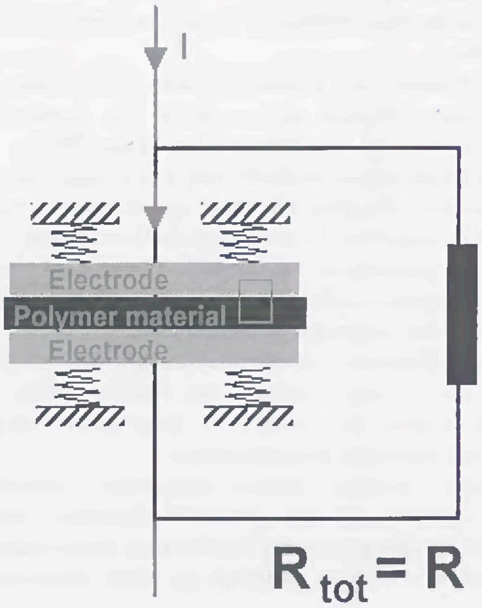



Figure 1 – Situation up to the nominal current

During normal circuit operation (see figure 1) the current will flow through the current limiter.
Only when a short-circuit occurs, and the conductivity of the doped polymer decreases drastically, does some of the fault current flow through the resistor.
The distinctive feature of the current limiter is that when a short-circuit occurs the temperature, and therefore the resistance, rises only in the thin surface layer adjacent to the copper electrodes.
A rise in temperature of this layer to about 120°C, which is the crystalline melting point of polyethylene, causes the resistance to increase within only 0.1 to 0,5 ms to some hundred times its original value.
It is also this ohmic resistor that decides the value of the current passing to the circuit-breaker in series with the current limiter.
The reason behind such a phenomena is that when after a short-circuit, the dramatic temperature rise inside PROLIM™ makes the polymer to melt and to loose its conductivity and also to create a high pressure gas that push the two electrodes away from the polymer producing a high resistive gap.
After the fast response time the resistance increases by some 100 times and the current peak is limited.
The let-through energy ($I^2t$) becomes independent of the short-circuit current, and obviously advantage of this is that the calculation work on short-circuit currents is then unnecessary.

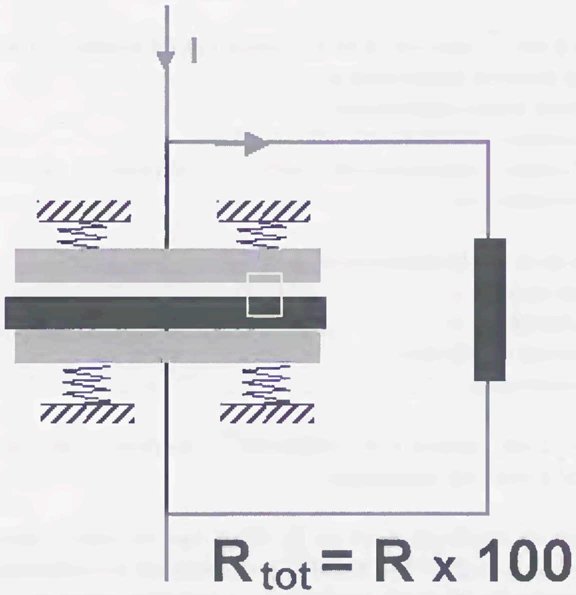



Figure 2 – Situation during the short-circuit

Laboratory tests shows that PROLIM™ is very quick and able to dramatically limit the current and therefore the energy.

The following diagrams show current and voltage during the first 30ms after the short-circuit; the prospective short-circuit current is 50kA r.m.s.

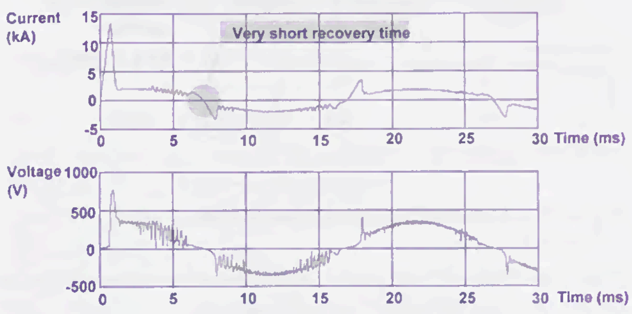



Figure 3 – PROLIM™ alone

Looking into these diagrams it's quite clear that the actual current is always very far from the prospective value, and therefore this current can be easily interrupted by a circuit-breaker.
These diagrams also show that when the current pass through the zero value the PROLIM™ is so quick to recover that it's possible to appreciate a current attempt to increase again suddenly limited by the PROLIM™ increasing again its resistivity.

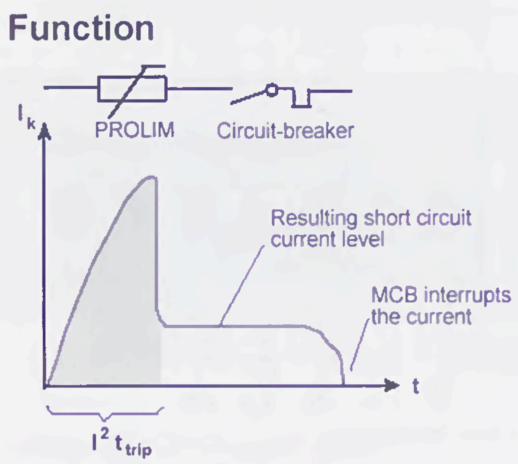



Figure 4 – Coordination with a circuit-breaker

PROLIM™ always have to be coordinated with a specified circuit-breaker.
The diagram in figure 4 shows the cooperation between PROLIM™ and a miniature circuit-breaker.
The short-circuit current is drastically reduced as a result, for some circuits to as much as one fifth of the original value.

The lower fault current has to interrupted by the circuit-breaker and its breaking time must still be fast so as not to endanger the thermal strength of the current limiter.
As mentioned, only thin surface layer is heated by the current: otherwise, the polymer material remains completely intact.
The surface layer automatically "resets"; the copper electrodes cool the surface, close the gas gap while the polyethylene plate absorbs some of the heat.
Overload currents are a normal situation in distribution networks in which there are motors, and short-circuit protection are not supposed to respond for them.
For example the current can rise to 7 to 10 times the continuous rating for a period of several seconds as a result of direct starting of a cage-induction motor.
During this time interruption is not desired.
The current limiter therefore has to be dimensioned so that the critical surface temperature will not be reached in such cases.
This is the reason for the two solid copper electrodes, which absorb the heat energy produced during the first 10s.
During the short-circuit, however, the current rises so fast that the heat cannot be transferred to the electrodes in this time.

## III Advantages

The main advantages given by the PROLIM™ solution are:

- Cost saving
- Space saving
- Smaller cable area
- Personell safety
- Reliability of service
- Selective back-up

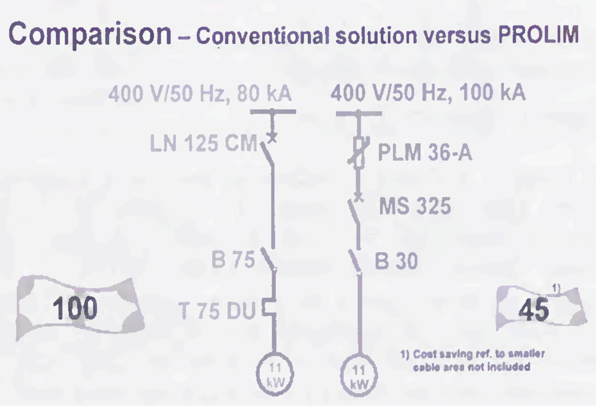



Figure 5 – Cost comparison

In figure 5, there are two different solutions to feed tha same 11kW motor: on the left we use a current limiting MCCB type ABB SACE Limitor LN125 with 80kA as breaking capacity a strong contactor ABB B75 and a thermal relay ABB T75DU; on the right a PROLIM™ PLM36-A in combination with a small manual motor starter ABB MS325 and a small contactor ABB B30 gives the same service with an higher breaking capacity.
Even not considering the saving in the smaller cross sectional area the PROLIM™ solution cost only 45% than the traditional one. (Price list comparison)

Also the space saving can be easily shown by an example:

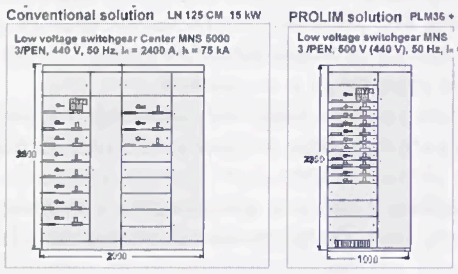



Figure 6 – Space comparison

These two ABB low voltage switchgear center have the same performances but the volume of the one on the right (MNS) is only 50% of the one on the left (MNS 5000).

Another important advantage is the very interesting possibility to have selectivity and back-up at the same time.

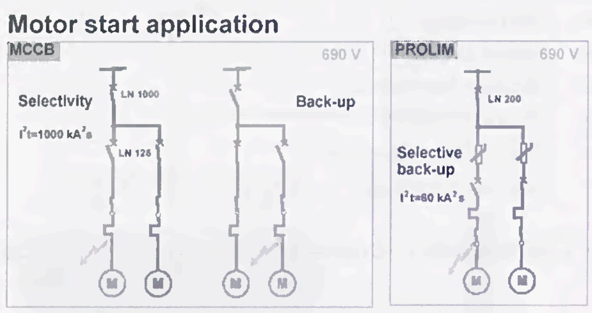



Figure 7 – Selective Back-up

In Figure 7 is shown a comparison between a traditional motor start application where it's possible to choose between selectivity by using as many expensive and strong current limiting breaker (ABB LN125) as the number of motors and a big breaker upperstream (ABB LN1000) that can withstand the short-circuit current during the breaking time or back-up by using only a limiting breaker but facing a total black-out when there is single fault in one motor.
On the right of the figure, vice-versa, thanks to PROLIM™ it's possible to have total discrimination without expensive current limiting devices and because of the let-through energy limitation of the PROLIM™, without a big breaker upperstream.

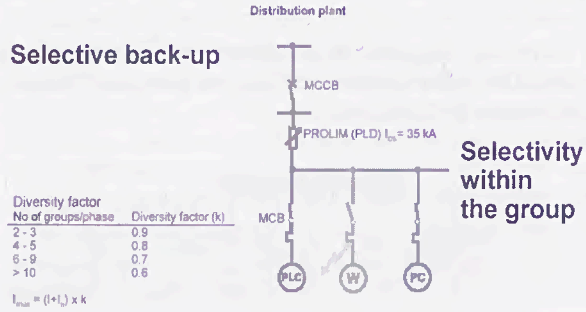



Figure 8 – Distribution plant selective back-up

Also in distribution plant application it's possible to obtain this special selective back-up.

In figure 8 there is a typical example of a distribution plant where considering also the diversity factor it's possible to save a lot when dimensioning the line and the size of the main breaker without loosing total discrimination.
Please note that, in this case, only one PROLIM™ is sufficient, and also if the prospective short-circuit current is pretty high (35kA r.m.s.) it's possible to use standard 6kA miniature circuit-breaker.
Since also PROLIM™ it's available in modular compact shape suitable to be fit onto a standard din rail, the pratical solution above described it's very small (see figure 9).

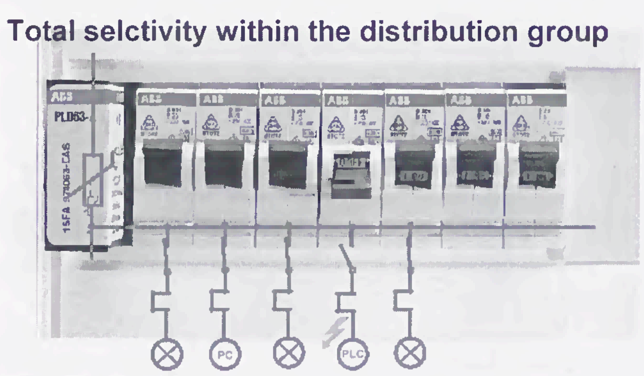



Figure 9 – Real dimension

## IV Constructive solution

Actually PROLIM™ is available in two different sizes:

- 32A
- 63A

The lower size is availble in single pole version and in three poles one, while the 63A is only available in the single pole configuration.

"The PROLIM family"

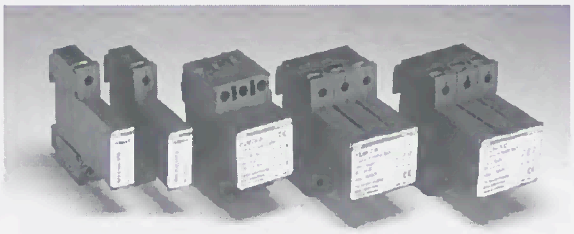


Figure 10 – PROLIM™ family

## V Technical Data

Here below the most significant technical data of PROLIM™ available on the market:

Specifications: IEC 60947-2, IEC 60947-4-1

| | |
|---|---|
| Rated operational voltage: | $U_e$=400V and 500V |
| Rated operational current: | $I_e$= 25 and 36A |
| Max short circuit current: | Ik=50kA |
| Max ambient temperature: | 55°C |
| Power losses per phase: | Approx. 3-4W |
| Current limiting | 6kA peak (at 50kA) |
| Response time | 0.5ms (at 50kA) |
| Total break time | 2.5ms with MCB |

**Diagram 1a Current limiting**

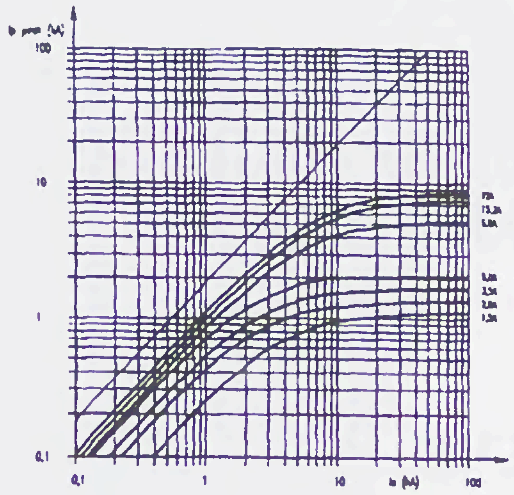


Figure 11 – Current limiting diagram

| | |
|---|---|
| Response energy (PROLIM™) | $I^2t = 15*10^3\ A^2s$ |
| Total let-through energy | $I^2t = 40*10^3\ A^2s$ |
| Resistance, cold: | 3mΩ/phase |
| Resistance, tripped | 300mΩ/phase |

**Diagram 1b Let-through energy**

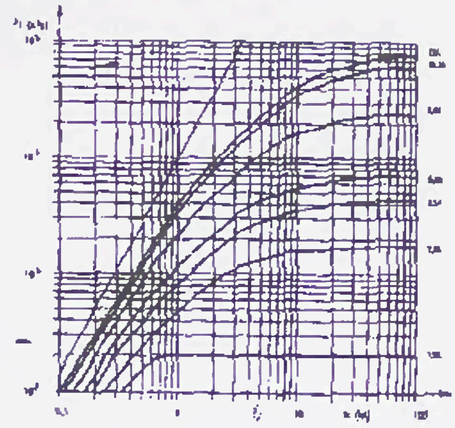


Figure 12 – Let-through energy diagram

## VI Likely future

ABB R&D efforts are actually concentrated on the integration of the PROLIM™ inside the miniature circuit-breaker.

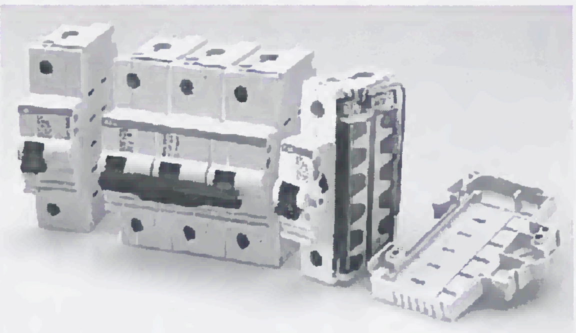


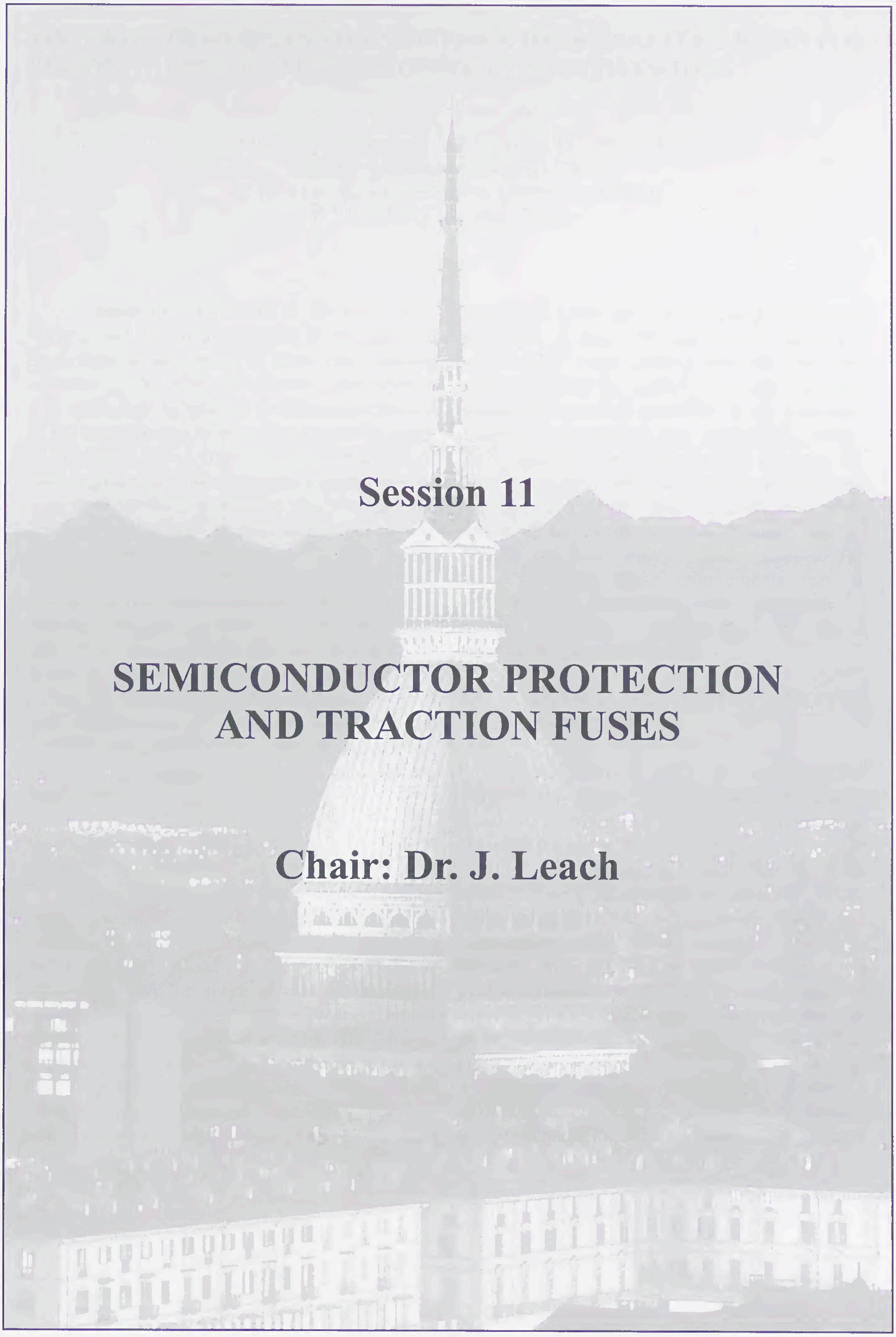
Figure 13 – New integrated version S620

It consists of the combination in one device of a standard miniature circuit-breaker designed for motor protection and a PROLIM™.

It can be assembled to have multipole version, typically 3p.

The tripping curve is the "K" typically tailored for motor protection: it carries 1.05 times the nominal current for one hour and it trips within one hour when the current is 1.2 times.

The breaking capacity of this new device is 50kA while the performance of the mcb from which it derives it's only 6kA.



# Session 11

# SEMICONDUCTOR PROTECTION AND TRACTION FUSES

## Chair: Dr. J. Leach