OVERVOLTAGES PRODUCED BY LOW RATED CURRENT FUSE OPERATION IN L.V. INSTALLATIONS

G. Crotti (*), G. Farina (*), R. Tommasini (**)

(*) Istituto Elettrotecnico Nazionale Galileo Ferraris, Torino - ITALY
(**) Dipartimento di Ingegneria Elettrica Industriale, Politecnico di Torino - ITALY

Abstract: The breaking operation of a fault current in an inductive circuit protected by fuses can lead, under particular circuit conditions, to the generation of high overvoltages, which can result dangerous for the plant and its components.
While for fuses with rated current over 16 A the maximum value of arc voltage as a function of the rated voltage of the fuse is stated by the related standard, for fuses with rated current below 16 A the admitted maximum arc voltage is still under consideration.
In the paper the values of arc voltage measured in the breaking operation of low rated current fuses are reported with reference to the test conditions stated by the IEC standard; in addition, a proposal about the values of the test circuit power factor is discussed.

I. GENERAL

The breaking process of a short-circuit current operated by a fuse is described by the well-known equation:

$$e = v_a + R \cdot i + L\,di/dt \qquad (1)$$

where e is the supply voltage, v_a is the arc voltage, R and L are the circuit resistance and inductance and i is the current which flows in the circuit.
The arc voltage that appears across the fuse plays a fundamental role in the breaking process. The higher the arc voltage, the shorter will be the arcing time and the let-trough energy in the circuit interested by the fault. On the other hand, high values of arc voltage could result harmful for the electrical components to be protected with particular reference to semiconductor devices which are affected by the peak voltage value. For this reason, the manufacturers indicate an upper limit on the arc voltage that the semiconductor can tolerate and semiconductor fuses are designed according to the relevant standards to maintain the arc voltage below such values in all the operating conditions.
The same considerations can be applied to general purpose fuses which, according to IEC 60269-1 standard [1], must have maximum arc voltage values which are function of the rated voltage of the fuse; compliance with this requirement is verified by the breaking capacity test, which has to be performed according to clause 8.5 of the above indicated standard.

II. TEST CONDITIONS PRESCRIBED BY IEC STANDARD

The IEC 60269-1 "Low voltage fuses: Part 1 - General requirements" defines the test conditions for fuses. In particular for a.c. breaking capacity test, these prescriptions concern supply and recovery voltage, test current, power factor and making instant where applicable. As regards the power factor the values stated by the standard are reported in Table I as a function of the prospective test current.

Table 1 – Breaking capacity test: circuit power factor as a function of the prospective test current

Test current	I_1-I_2 (*)	I_3-I_4-I_5 (**)
Power factor	0.2 ÷ 0.3 for currents up to 20 kA 0.1 ÷ 0.2 for currents over 20 kA	0.3 ÷ 0.5

(*) I_1: rated breaking capacity;
I_2: current corresponding to test conditions giving the maximum arc energy.
(**) I_3=3.2I_f, I_4=2.0I_f, I_5=1,25I_f where I_f is the conventional fusing current.

As regards the maximum values of arc voltage, they are indicated as a function of the rated voltage of the fuse: for fuses with rated voltage of 500 V, as those to which this paper refers, the admitted maximum arc voltage is 2500 V; however, in the case of fuses with rated current up to 16 A the maximum arc voltage is under consideration and is not specified in the standard.

The above limit is quite easily accomplished by the majority of fuses. Generally, the fuse element is realised with one or more restrictions of the cross sectional area in which the arc begins; the arc length then increases up to the total melting of the element. In such a way the arc voltage is gradually increased, the fault current reduces and dangerous overvoltages do not occur in the circuit.

Some problems can arise for fuses with low rated current, usually not exceeding 10 A. For these fuses, the fuse element is constituted by a single wire with constant cross section [2]. In the case of a fault with heavy short-circuit currents, the heating process can be considered adiabatic with a temperature distribution assuming a rectangular form along the element. The melting temperature is reached along the whole length of the fuse element all at once; this fact leads to a uniform disintegration of the fuse element causing the creation of a great number of series arc with a resulting high value of arc voltage.

The overvoltage generation process then occurs in the case of instantaneous evaporation of the whole length of the fuse element, leading to current-free interval [3, 4]. This current-free interval appears in a certain range of temperatures for which the vapours produced by the evaporation of the fuse element are non-conductive. In this case, the current rapidly decreases and consequently the overvoltage, which depends on the derivative of the current and on the circuit inductance, can reach dangerous values for the electrical components of the plant.

III. EXPERIMENTAL INVESTIGATION

A test campaign aimed at investigating the overvoltages occurring with low voltage fuses has been carried out at IEN on general purpose fuses of different manufacturers with rated current 6 A, 10 A and 16 A and rated voltage 500 V.

The adopted test circuit, shown in Fig. 1, has been accurately designed in order to avoid damages to the components of the circuit and to the measuring instruments. To this end, an air spark-gap calibrated at the discharge voltage of 4500 V has been connected on the supply side of the circuit.

The arc voltage has been measured by means of a suitable voltage divider connected to a transient recorder, while the current has been measured by means of a resistive shunt.

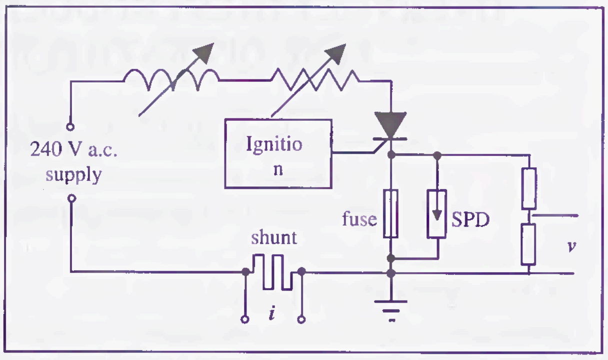


Fig. 1 - Test circuit arrangement.

The test conditions have been stated according to IEC 60269-1. The tests have been carried out with supply voltage of 240 V, 50 Hz, which is a usual voltage for single-phase circuit both for domestic and industrial applications. The test currents ranged from 300 A to 4200 A. For each test current, the making instant ψ has been varied in order to determine, for each type of fuse, the critical condition as regards the overvoltages.

Fig 2 shows a typical diagram of breaking test of a 10 A fuse (flink type) tested at 1500 A, 240 V, power factor ($\cos\varphi$) 0.3. In this case a maximum value of 3500 V was recorded.

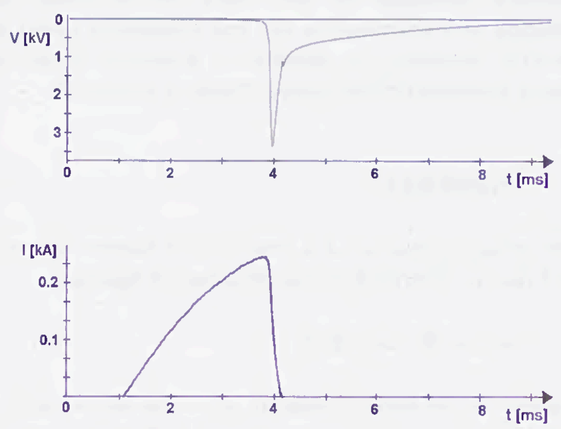


Fig. 2 - Voltage and current behaviour in a breaking test on a 10A fuse at 240 V, 1500 A, $\cos\varphi$=0.3.

The maximum values of arc voltage measured in the breaking operation of fuses, carried out according to the IEC standard indications, are reported in Figs. 3÷5 as a function of the prospective short-circuit current for gL/gI and flink type fuses respectively. Fig. 3 reports the maximum arc voltage values recorded with fuses rated 6 A, while Fig. 4 and Fig. 5 refer to 10 A and 16 A fuses.

From these diagrams, it can be observed that 6 A fuses give, both for gL/gI and flink type fuses, values of arc voltage which are in most cases higher than 2500 V. For 10 A fuses this overvoltage is exceeded only for flink type fuses, while for the 16 A fuses, the measured values, both for gL/gI and flink types, are always within the voltage limit indicated by the standards.

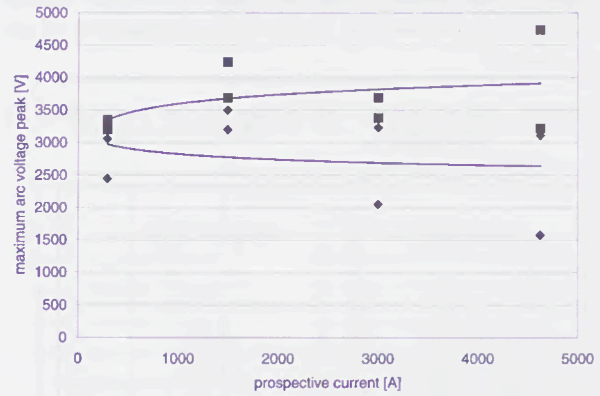


Fig. 3 - Maximum arc voltage values as a function of the prospective current for fuses of two different manufacturers with rated current of 6 A: (◆) flink, (■) gL/gI.

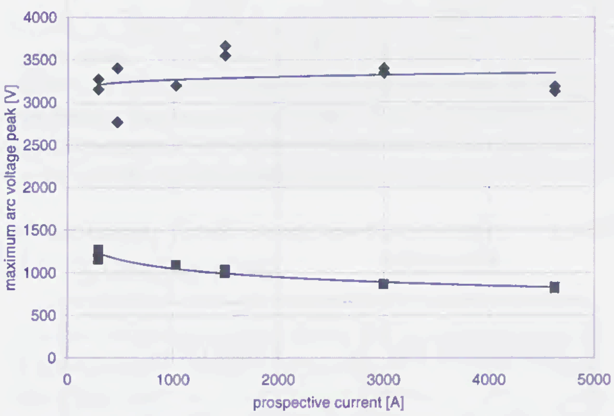


Fig. 4 - Maximum arc voltage values as a function of the prospective current for fuses of two different manufacturers with rated current of 10 A: (◆) flink, (■) gL/gI.

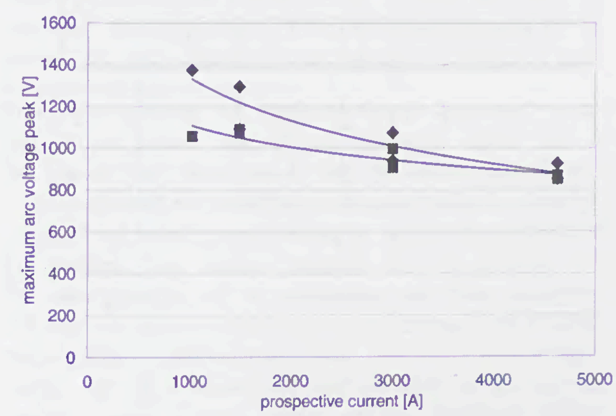


Fig. 5 - Maximum arc voltage values as a function of the prospective current for fuses of two different manufacturers with rated current of 16 A: (◆) flink, (■) gL/gI.

The different behaviour of the tested fuses can be explained taking into account the structure of the fuse element: for the 6 A and 10 A fuses, it is constituted by a single wire of constant cross section area, while for the 16 A fuses the element is a thin blade with a central restriction with a reduced cross section area. This arrangement avoids the contemporary fusion and evaporation of the element and limits the generation of overvoltages in the breaking operations.

The recorded peak voltage values versus the making angle of two fuses rated 6 A, respectively of gL/gI and flink type, are reported in Fig. 6 and Fig. 7 for different values of the test circuit power factor.

In Fig. 8 the peak values of arc voltage versus making angle of three 10 A fuses, two gL/gI and one flink type, are reported in the case of a test performed at 240 V, cos φ=0.3, with currents of 290 A and 470 A.

As can be observed, for low power factors the maximum arc voltage can reach very high values, which can result undoubtedly dangerous for the circuit and its components.

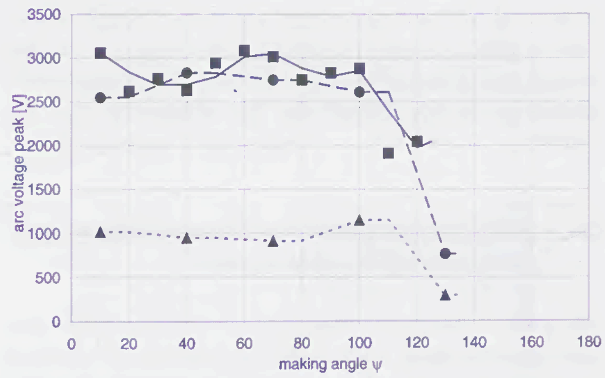


Fig. 6 - Breaking operation of a flink fuse, rated 6 A, tested at 290 A, 240 V: maximum peak values of arc voltage versus making instant for cosφ=0.3 (■), cosφ=0.5 (•) and cosφ=0.9 (▲).

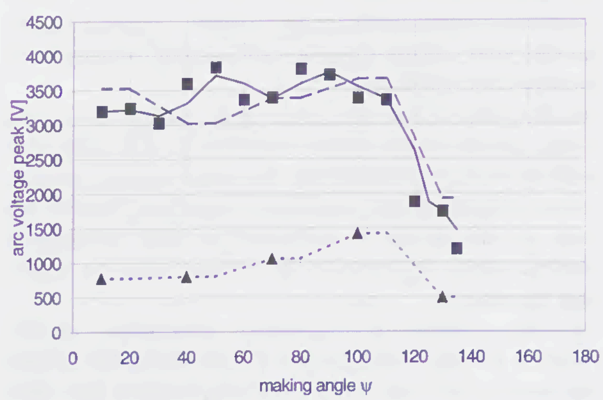


Fig. 7 - Breaking operation of a gL/gI fuse, rated 6 A, tested at 290 A, 240 V: maximum peak values of arc voltage versus making instant for cosφ=0.3 (■), cosφ=0.5 (•) and cosφ=0.9 (▲).

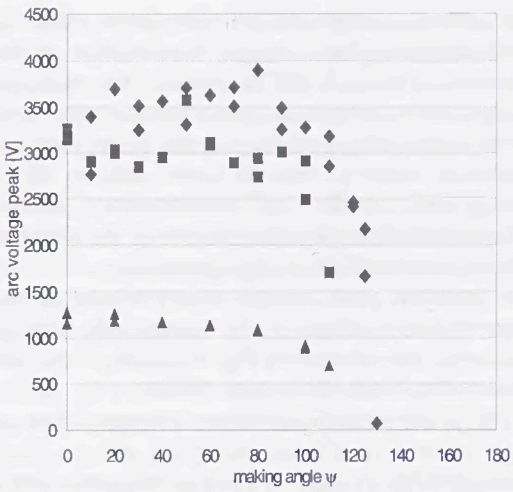


Fig. 8 - Breaking operation of 10 A fuses (gL/gI (▲), flink (■), flink (◆)) tested at 290 A (■, ▲) and 470 A (◆), 240 V, cos φ = 0.3: peak value of arc voltage versus making instant.

In the case of the tests carried out with a circuit power factor equal to 0.9 the maximum peak of the arc voltage has resulted considerably lower than 2500 V and then, according to IEC standards, not dangerous for the circuit.

IV. STANDARD PRESCRIPTIONS FOR FUSES AND CIRCUIT-BREAKERS

The tests carried out have put in evidence that low rated current fuses, with a melting element of constant cross section area, can generate dangerous overvoltages in the breaking operation of fault currents with low circuit power factors.

The power factor stated by IEC 60269-1 for the tests at I_1 and I_2 (0.1 ÷ 0.3) is independent of the rated current of the fuses.

For high rated current fuses, the test power factor indicated by the standard undoubtedly corresponds to the one that can be experienced in all installations in short-circuit conditions.

On the other hand, for low rated current fuses, the power factors in the range from 0.2 to 0.3 seem very unlikely to be experienced in the actual circuits; in fact, the resistance of the conductors used to connect the fuses to the circuit is sufficient, at high prospective current values, to increase the power factor to values near the unity.

For this reason, the standards concerning circuit-breakers for industrial [5] and for domestic and similar applications [6] state, for the breaking tests at low value of prospective current (up to 10 kA), values of power factor much higher than those fixed by the standards for fuses [1], as can be observed by comparing the data of Table 2 and Table 3, which report the power factors indicated respectively by [5] and [6] as a function of the test current.

Table 2 - Short-circuit test power factor prescribed by IEC 60947-1

Test Current (A)	Power factor
. < 1500	0.95
1500 ÷ 3000	0.90
3000 ÷ 4500	0.80
4500 ÷ 6000	0.70
6000 ÷ 10000	0.50
10000 ÷ 20000	0.30
20000 ÷ 50000	0.25
> 50000	0.20

As can be seen, the power factor stated for the circuit-breakers becomes very high for low currents, while for fuses a power factor which is practically irrespective of the test current is indicated in IEC 60269-1 (Table 1).

Table 3 – Short-circuit test power factor prescribed by IEC 60898

Test Current (A)	Power factor
< 1500	0.93 ÷ 0.98
1500 ÷ 3000	0.85 ÷ 0.90
3000 ÷ 4500	0.75 ÷ 0.80
4500 ÷ 6000	0.65 ÷ 0.70
6000 ÷ 10000	0.45 ÷ 0.50
10000 ÷ 25000	0.20 ÷ 0.25

Since fuses and circuit-breakers are usually employed in the same type of circuit and being equal the installation conditions, the short-circuit test should be carried out under the same conditions for both devices.

In addition, the value of power factor stated for fuses at low values of test current seems not realistic if compared with the conditions of the actual plants. In Table 4 the current and power factor values in a circuit supplied at 240 V, with prospective short-circuit current up to 100 kA are compared with the actual values resulting in the same circuit when a fuse connection, realised with a cable of 1 m l ength and cross section area of 1 mm^2, is considered.

Table 4 – Influence of fuse connections, realised with a cable of 1 m length and 1 mm^2 cross section area, on prospective short-circuit conditions.

Prospective values			Actual values		
I [kA]	Z [mΩ]	$\cos\varphi$	I' [kA]	Z' [mΩ]	$\cos\varphi'$
1.5	160	0.3	1.4	170	0.50
3	80		2.4	100	0.64
6	40		3.7	64.8	0.80
10	24		4.6	47.2	0.90
20	12		5.3	43.6	0.96
30	8	0.2	5.7	41.6	0.98
50	4.8		5.8	41	0.99
80	3		5.9	40.6	0.99
100	2.4		5.9	40.5	0.99

It can be easily verified from Table 4 that such a connection, which is suitable for fuses with rated current of 10 A, is sufficient to reduce in the heaviest conditions the current below 6 kA and to increase the power factor value; with longer conductors the power factor will be further on increased.

V. CONCLUSIONS

The risk of overvoltages during the breaking operation of short-circuit currents operated by low rated current fuses has been investigated by means of short-circuit tests carried out according to the prescriptions of the IEC 60269-1 standard.

For tests carried out with low values of power factor ($\cos\varphi$=0.3 for currents up to 20 kA) high overvoltage values, up to 4.5 kV, have been experienced on low rated current fuses characterised by fuse elements of constant cross section. With higher values of power factor the overvoltages in the breaking operation have less probability to occur.

Since in the actual plants low values of power factor are very unlikely to occur for low values of short-circuit current, the test conditions imposed by the IEC 60269-1 do not seem to correspond to the effective situations of the plants. Taking into account that the power factors indicated for fuses are very different from those stated by IEC 60947-1 and IEC 60898, concerning circuit-breakers, it should be advisable to adequate the power factor values of short-circuit tests on fuses to the actual plant conditions by adopting the same values stated for circuit-breakers by the relevant standards.

REFERENCES

[1] IEC 60269 Standard: Low-voltage fuses - Part 1: General requirements, 1998.

[2] R. Wilkins, P.M. Mc Ewan: "A.C. short-circuit performance of uniform section fuse elements", Proceedings IEE, Vol. 122, no. 3, pp. 285-288, March 1975.

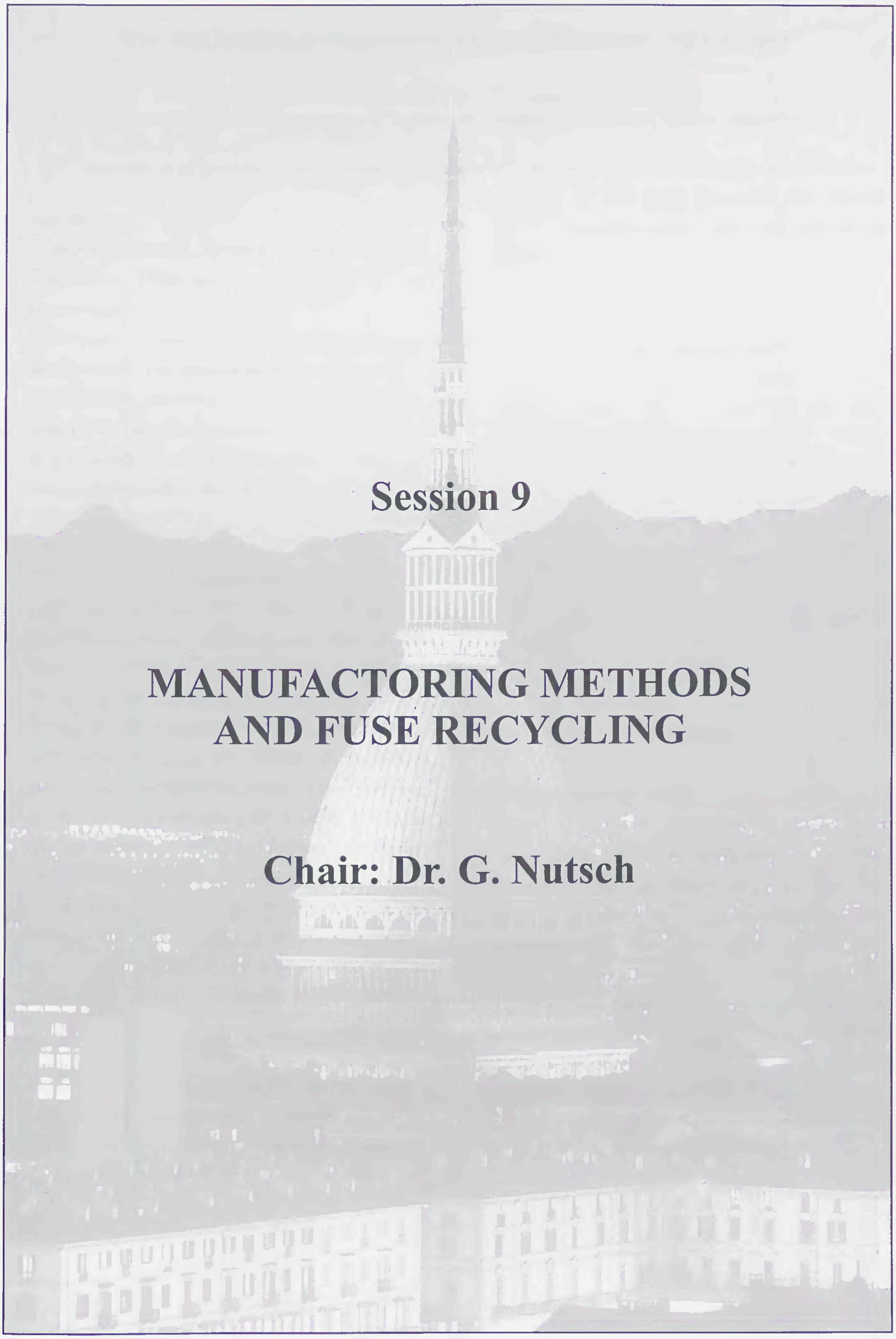
[3] J. Paukert: "Overvoltages produced by fuses", Proceedings of the International Conference on Electric Fuses and their Applications, pp 59-69, Liverpool, U.K., 1976.

[4] J. Hibner: "The calculation of overvoltage characteristics of H.R.C. fuses", Proceedings of the International Conference on Electric Fuses and their Applications, pp 70-77, Liverpool, U.K., 1976.

[5] IEC 60947-1 Standard: Low voltage switchgear and controlgear - Part 1: General rules, 1999.

[6] IEC 60898 Standard: Electrical accessories – Circuit-breakers for overcurrent protection for household and similar installations, 1995.

[7] A.Wright, P.G. Newbery: "Electric fuses", Peter Peregrinus Ltd, London, U.K. 1984.



Session 9

MANUFACTORING METHODS AND FUSE RECYCLING

Chair: Dr. G. Nutsch