INFLUENCE OF SHORT-CIRCUIT POWER FACTOR ON THE CUT-OFF CURRENT OF LOW VOLTAGE FUSES

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Summary

The severest conditions in the breaking process of a short-circuit current operated by a fuse usually occur with low values of the short-circuit power factor. In accordance with this fact, the Electrotechnical Standards concerning low voltage fuses, establish, for short-circuit tests, the value of the power factor as a function of the prospective test current; this value corresponds to the lowest occurring in actual installations. However, as regards the cut-off characteristics, the maximum peak values of the current likely to be experienced in the case of power factors close to unity are higher than those indicated by the manufacturers, usually given for lower values of power factor. After an analytical approach to the problem, the paper presents the results of numerous tests, carried out in our laboratories, on several types of fuses of different rated currents.

1. <u>Introduction</u>

The knowledge of the fuse operating characteristics, which is useful to estimate the fuse behaviour under overload and short-circuit conditions, becomes essential in solving problems of coordination of the apparatus (such as circuit-breakers, contactors, motor-starters, disconnectors, etc...) and protection of controlgear and controllers (such as semiconductor devices, capacitors, etc...). In particular, the quantities involved in the interruption process of a short-circuit current, in a circuit protected by a fuse, are the let-through energy I^2t and the cut-off current I_p. These quantities are functions of the mode of operation of the fuse as well as of the circuit parameters, which determine the prospective current and power factor.

As known, damages to the devices to be protected strictly depend on the values of the cut-off current and I^2t as well as on the rate of rise of the current (di/dt). As a consequence, in order to represent the most severe conditions that can be experienced in the installations, the International Electrotechnical Standards, concerning low voltage fuses, establish the conditions for short-circuit breaking tests; in particular, the value of the power factor is expressed as a function of the prospective test current (*). Since, usually, the most severe conditions correspond to low values of the short-circuit power factor, as a consequence of the greater electromagnetic energy stored in the circuit and of the higher instantaneous value of the applied voltage during the arc period, the values indicated by the Standards are the lowest which occur in the actual installations.

However, as regards the cut-off characteristics, the maximum peak values of the current, likely to be experienced in the case of power factors close to unity, are higher than those indicated by the manufacturers because of the higher rate of rise of the current during the pre-arcing period.

(*) IEC Standards (Publication 269-1) indicate the following power factor ranges:
0.2-0.3 for prospective test currents up to 20 kA;
0.1-0.2 for prospective test currents above 20 kA.

2. Simulation of the fuse behaviour

The current in a single-phase circuit protected by a fuse, under short-circuit conditions, can be obtained by the following equation:

$$e = Ri + L\,di/dt + v_a \qquad (1)$$

where $e=e(t)$ is the supply voltage, R and L are the resistance and the inductance of the circuit and v_a the arc voltage.

In order to represent the arc voltage behaviour the V-I arc characteristic is represented by [5]:

$$v_a = v_o + ri \qquad (2)$$

where, for low voltage fuses, v_o is 0.6 times the r.m.s. value of the supply voltage E and r is equal to 0.7 $E/I_{T/2}$; $I_{T/2}$ is the so called "one-half-cycle fusing current".

By introducing expression (2) in equation (1), the expression of the current can be evaluated:

$$i(t) = c\,e^{-(R+r)/Lt} - \frac{v_o}{R+r} + \frac{E}{(R+r)^2+(\omega L)^2}\sin(\omega t+\psi-\varphi) \qquad (3)$$

where c is the integration constant, φ is the phase angle of the current, ψ the making angle and v_o and r are equal to zero during the pre-arcing period.

The knowledge of the current behaviour permits the evaluation of the cut-off current. The peak of the current is computed as a function of the making angle for a defined prospective power factor; then it is possible to evaluate the maximum cut-off current, with respect to the making angle, versus the power factor. Different circuit conditions of installations protected by fuses of different rated currents have been analyzed. In particular, the behaviour of fuses with rated currents of 16, 25 and 50 A in short-circuit tests with prospective currents from 3 kA to 10 kA has been considered. For each condition, the cut-off current, obtained in the case of the power factor indicated for the breaking tests by the Standards, has been compared with the one which results when the power factor is close to unity. As an example Fig.1 shows the behaviour of the cut-off current versus the making angle for a prospective short-circuit current of 3 kA, with a 16 A fuse, for a power factor of 0.28 and for a power factor of 0.98. It can be noted that the maximum value of current is reached with the highest value of power factor.

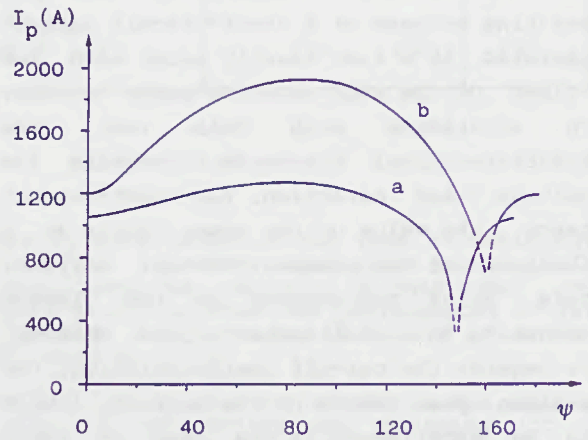

Fig.1 - Computed behaviour of the cut-off current versus the making angle, for a prospective short-circuit current of 3 kA, with a 16 A fuse:
a) power factor = 0.28
b) power factor = 0.98

In order to put in evidence the dependence of the maximum cut-off current on the prospective power factor, the computation results have been summarized in Fig.2, 3 and 4, which correspond respectively to prospective short-circuit currents of 3, 5 and 10 kA. It can be seen that the cut-off current values increase when the power factor tends to unity.

As regards the actual installations, the maximum and minimum power factor values that can be experienced must be taken into account. Fig.5 shows these values as a function of the supply transformer rated power for short-circuit currents of 3, 5, 10 and 20 kA. As can be seen, the higher the rated power of the transformer, the higher the possibility of high values of power factor.

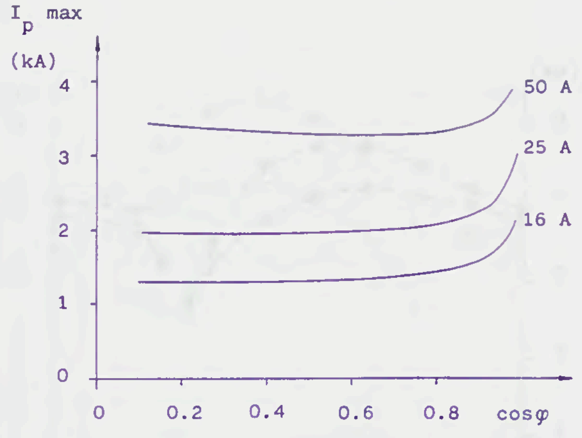

Fig.2 - Maximum cut-off current versus the prospective power factor for a short-circuit current of 3 kA. The rated current of the fuse is indicated as parameter.

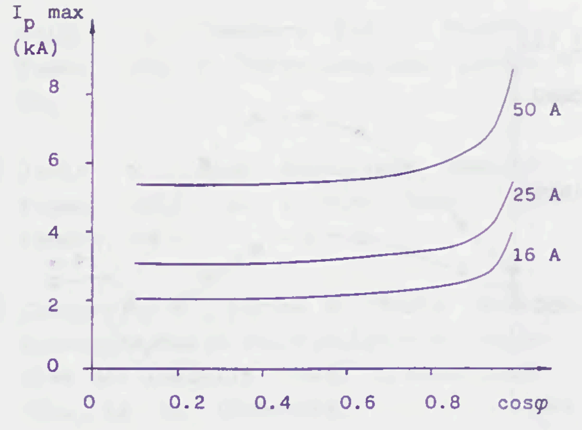

Fig.4 - Maximum cut-off current versus the prospective power factor for a short-circuit current of 10 kA. The rated current of the fuse is indicated as parameter.

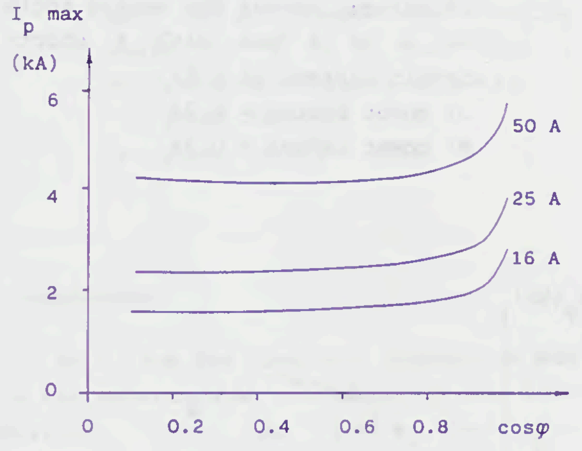

Fig.3 - Maximum cut-off current versus the prospective power factor for a short-circuit current of 5 kA. The rated current of the fuse is indicated as parameter.

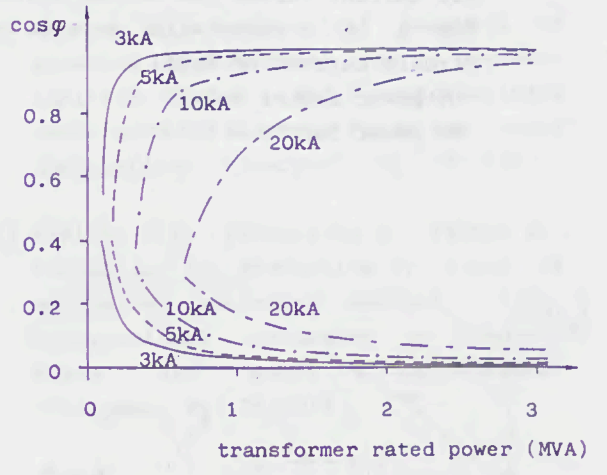

Fig.5 - Maximum and minimun power factor obtainable in actual installations versus the transformer rated power for different short-circuit currents.

3. Experimental results

The indications obtained by the simulation have been compared with the results of an experimental investigation carried out on several types of fuses. The single-phase test circuit was supplied at 420 V, 50 Hz and the tests were carried out with prospective currents of 3, 5 and 10 kA. The making instant was determined by two controlled thyristors connected in antiparallel. Each type of fuse has been tested with the lowest and the highest power factor available in the laboratory test circuit.

The experimental data are summed up in Fig.6-10. The diagrams confirm the previous considerations and are in accordance with the computation results.

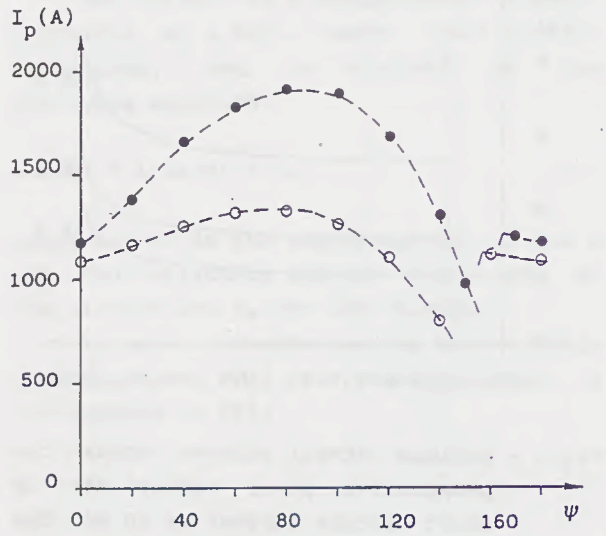

Fig.6 - Experimental behaviour of the cut-off current versus the making angle for a 16 A fuse with a short-circuit current of 3 kA:
○) power factor = 0.28
●) power factor = 0.98

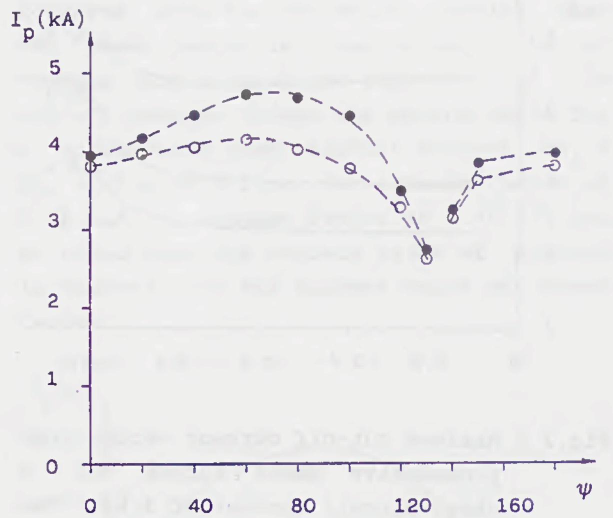

Fig.8 - Experimental behaviour of the cut-off current versus the making angle for a 50 A fuse with a short-circuit current of 5 kA:
○) power factor = 0.29
●) power factor = 0.94

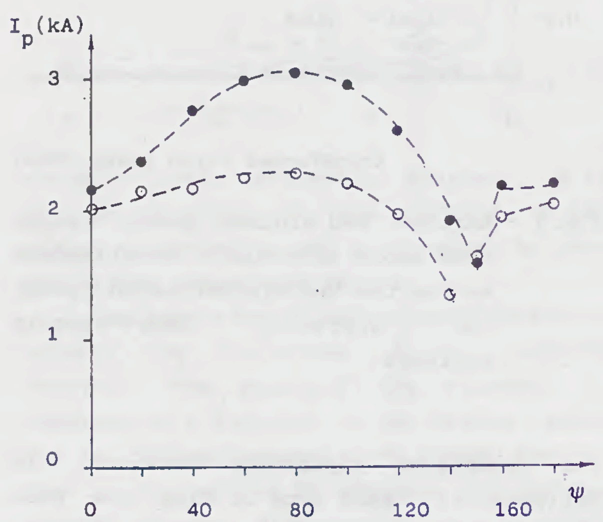

Fig.7 - Experimental behaviour of the cut-off current versus the making angle for a 25 A fuse with a short-circuit current of 5 kA:
○) power factor = 0.29
●) power factor = 0.94

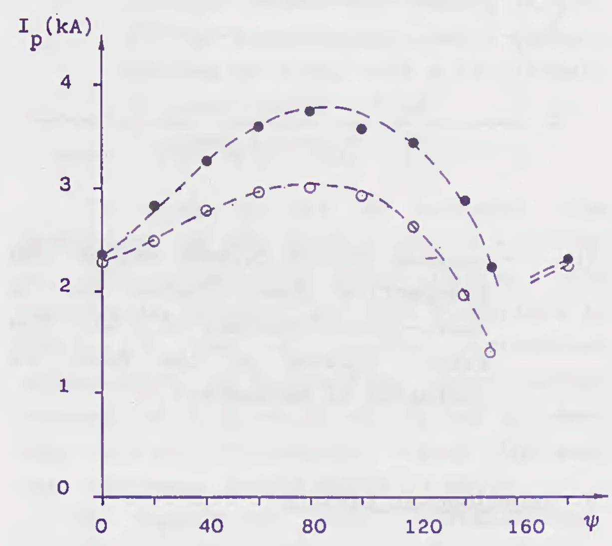

Fig.9 - Experimental behaviour of the cut-off current versus the making angle for a 25 A fuse with a short-circuit current of 10 kA:
○) power factor = 0.35
●) power factor = 0.96

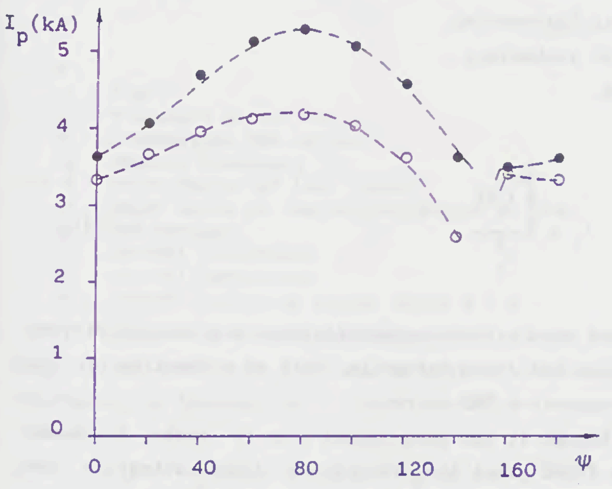

Fig.10 - Experimental behaviour of the cut-off current versus the making angle for a 50 A fuse with a short-circuit current of 10 kA:
○) power factor = 0.35
●) power factor = 0.96

4. Conclusions

Both from the numerical simulation and the the experimental procedure, it has been verified that the test conditions representative of the severest conditions, as regards the cut-off current, are those corresponding to power factor values approaching to unity. Therefore, for particular applications, in order to verify completely the fuse behaviour as regards the maximum cut-off current, tests, carried out with the highest values of the power factor that can be experienced in the actual installations, may be necessary.

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