CRITICAL PARAMETERS INFLUENCING THE CO-ORDINATION OF FUSES AND SWITCHING DEVICES

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ABSTRACT

A switching device in series with a protective fuse when properly co-ordinated is required to disconnect all currents up to its breaking capacity, provided the duration is not above the withstand of the protected circuit. All higher levels must be disconnected by the fuse. The let-through of the fuse passes between the contacts, and there are three critical regions:

(1) The maximum short-circuit level, at which contacts may be flung apart, resulting in severe arc erosion to the contacts.

(2) Intermediate levels at which the contact system is close to the minimum throw-off force at the cut-off of the fuse, which may result in welding of the contacts.

(3) Lower overcurrents exceeding the breaking capacity of the switching device, but in a region of long pre-arcing time.

These problems influence the choice of time/current characteristic for fuses protecting motor starters, analysed in this paper with reference to the fuses available in IEC Publication 269 (Second Edition 1986).

1 INTRODUCTION

Switching devices of limited breaking capacity such as contactors require fuse back-up to protect the switching device and the circuit when fault currents occur above the breaking capacity of the switching device.

The fuse is the most effective limiter of high fault currents, but a period of time, though very small at large overcurrents, is always necessary to fuse the element and clear the circuit, and high cut-off currents may be attained in this period.

At small overcurrents the pre-arcing time becomes much longer and this is the region where the time/current characteristic of the fuse will cross the time/current characteristic of an overload relay in a protected motor-starter.

We identify here a third critical region where the cut-off current of the fuselink is close to the throw-off current of the contacts of the switching device.

This problem was recognised in IEC Publication 292-1A where tests are specified for the co-ordination of low voltage motor-starters with short-circuit protection devices. The tests specified were at test currents 'p' equal to 0.75 I_C and 1.25 I_C where I_C is the crossover current. A further test was specified at test current 'q' not less than the maximum short-circuit current associated with the type of co-ordination needed. The tests conditions specified were as in Publication 157-1 for three phase tests, which is less severe than the single-phase conditions of test specified for the fuses in Publication 269, but sufficiently close to enable a choice to be made of a suitable fuselink on the basis of catalogue data derived during tests to IEC 269.

Up to now, however, it has been necessary to specify in many cases the type, rating, and manufacturer of the protective fuselink to ensure performance as good as in the type test, because of the wide spread of characteristics permitted in the first edition of Publication 269. With the advent of the latest edition of Publication 269 recently published this position is greatly improved Internationally, and the substitution of another general purpose fuse of the same rating has become much more practical.

2 THREE CRITICAL REGIONS OF CURRENT FOR CO-ORDINATION

Three critical regions are identified:

(1) The maximum short-circuit level, at which contacts may be flung apart, resulting in severe arc erosion to the contacts.

(2) Intermediate levels at which the contact system is close to the minimum throw-off force at the cut-off of the fuse, which may result in welding of the contacts.

(3) Lower overcurrents exceeding the breaking capacity of the switching device, but in a region of long pre-arcing time.

We now consider each region individually.

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2.1 **Maximum Short-Circuit Level**

The current through the fuse protected circuit at the maximum short-circuit level rises to a peak cut-off value near the end of the pre-arcing time which will vary with the point-on-wave of closing as indicated in Fig. 1.

To obtain an approximate estimate of the maximum cut-off current and actual pre-arcing time, knowing the value of the pre-arcing I^2t of the fuse, a maximum rate of rise can be taken to be that corresponding to peak applied voltage. This would be 1.4 E/L where E is the r.m.s. voltage appropriate to the phase in which the fuse is situated and L the inductance in the circuit. From the integration of this linear rate of rise and the known value of the pre-arcing I^2t the approximate cut-off current and time may be easily calculated.

The accelerating force f produced by a current i causing the contacts to be thrown off is then given (Ref. 1) by the equation:

$$f = 10^{-7} i^2 (l_n B/a - k) - p \tag{1}$$

Where B is the radius of the end face of the contacts, a the radius of the area in physical contact, k the constant corresponding to any hold-on force provided by the design of the contact system and p the force exerted by the contact spring.

For simple switching devices with butt contacts k is negligible and the throw-off of the contacts may be calculated from the Newtonian laws of motion. Detail of these calculations is not appropriate in this context but it can be reported that calculation and experience (Ref. 2) show that for most contactors under these conditions the contacts are flung apart resulting in arcing at high current which is extinguished by the fuse before the contacts re-close. In that time they generally have cooled to a sufficient extent to avoid welding together on reclosure.

However, the contacts can be seriously eroded by the high current arc burning between the contacts, the rate of erosion being approximately proportional to the time multiplied by the current raised to the power 1.6. When the contacts are thrown-off well before cut-off, the degree of erosion produced when protected by a given fuselink may then be approximately assessed by its let-through I^2t.

When the contactor is closed on to the short-circuit current, there is a further complication if there is any bounce of the contacts prior to reaching the throw-off level, because any such bounce action will cause the contacts to open momentarily and then reclose onto the arc so initiated. This may cause dynamic welding of the contacts. This phenomenon is also troublesome when closing onto lower fault currents where high peak currents may be attained during a contact bounce separation. To permit calculations to be made in this region a new Appendix C has been added to IEC 269-1 in which a method is given for the calculation of cut-off current/time characteristics. An example of the typical results of such calculations is shown in Fig. 2 for the fuselinks of a well known British manufacturer based on data derived from the catalogue. With the much closer limits of time/current characteristics, and the limits on the joule integral now specified in IEC 269 it is possible to draw bands covering a substantial international range of fuselinks which should ease the burden of the controlgear designer in the International market.

2.2 **Intermediate Region**

This is the most sensitive region for the likely welding of the contacts.

Throw-off force may be evaluated by equation (1) as before, but as the cut-off current is reduced from the value at maximum prospective short-circuit current, a value of current is approached at which $f = 0$.

Near this condition, the contacts will be either briefly separated at the peak high current, or lightly touching with a tiny area of silver in contact which will be melted by the through current peak. Any such melting can cause an increase in the value of 'a' in equation (1) causing the contacts to 'sink-in' to the molten area as the current passes the peak value.

Either of these conditions is likely to produce severe welding of the contacts.

Using the same methods of calculation and further contact theory related to the temperature of contact areas at high current density, it is possible to make calculations of critical parameters related to contactor design which can improve performance in this area. The effects are seen in Section 2.1 above to be directly related to the I^2t values of the fuselinks studied.

In order to make these calculations however, the designer needs precise fuse data, and with the first edition of Publication 269-1 the variations of time/current characteristic were too wide and there were no limits set to the joule integral values which made an Internationally applicable calculation practically impossible. Now that these aspects have been greatly improved in the new Edition, and closer limits set to permissible variations, designers are enabled to take cognisance of the likely behaviour of fuselinks worldwide.

2.3 Lower Overcurrent Region

At low overcurrents of the order of 10 times the rated current of the fuse, the contacts of the motor starter are subjected to the thermal effects of the overcurrent for a much longer time, especially since the pre-arcing joule integral is much larger in this region than in the short-circuit region. Due to the usual practice of using a fuse of higher current rating than the AC3 or AC4 rating of the contactor, a current of 10 times the fuse rating may be of the order of 15 times the contactor rating, which is in excess of the breaking capacity of the contactor.

During this period the contactor may trip and arcing will then commence at its contacts at a current above the breaking capacity reducing the current and causing the first fuse to take longer to blow. When the first fuse blows, the current drops to 87% as was reported by S Lindgren (Ref. 3). The pre-arcing time of the next fuse is extended to a time corresponding to this reduced current, causing the arcing to persist. It was pointed out that this problem would arise in practice with a fault at the terminals of a motor fed by long cables.

The form of the fuse time/current characteristic best suited to deal with this problem is still very much a matter for debate.

Two forms of characteristic are shown in Fig. 3, 3a being the type of general purpose characteristic found in the gG types standardised in the new IEC 269, and 3b being representative of the dual-element types available as an alternative choice in the USA.

At first sight the type 3b appears to have advantages operating with the breaking current above the point 'A' on the time/current characteristic, due to the very fast operating time at this level compared with the type 3a.

However, when the current is reduced as indicated above, the very steep inflection at current 'A' can result in a very much longer pre-arcing time for currents between 'A' and 'B' when the first fuse blows and the current drops into that region. In fact, the problem reported by Lindgren was precisely at a similar inflection (but less steep) in the characteristic of the gI fuses with which he was experiencing problems. A more shallow characteristic as in 3a is clearly better in this region giving a more nearly constant joule integral and therefore a more consistent performance, although needing a design of contactor capable of a limited withstand of currents above its normal breaking capacity.

This matter is at present under discussion in 32B WG8. There ae strong arguments for both forms of characteristic depending partly on National established practices, and these will need much further debating in the IEC before a rationalised International policy can be established.

3 THE NEW IEC REQUIREMENTS AND THE IMPROVEMENTS IN ACHIEVING CO-ORDINATION

The new requirements for IEC 269 have reduced the spread of available characteristics and also set limits to the range of pre-arcing I^2t of all general purpose fuses Internationally. No limits were set for I^2t in the earlier specifications.

These pre-arcing I^2t values are standardised at a pre-arcing time of 0.01 seconds and the values for the calculation of conditions considered in 2.1 above will in general be lower than these values, giving a margin of safety if calculations are made on the basis of the IEC values.

If a contactor is designed to meet these maximum levels, it should be possible to use any other replacement fuselink of the same rating made to IEC 269 requirements when the new standard is fully implemented without running into new problems in regions (1) and (2).

The situation in region (3) should also be improved, as is shown in Table 1 where the range of current corresponding to a pre-arcing time of 0.1 seconds is seen to be considerably reduced in the new standard. This was the region where trouble was experienced in the past.

4 CONCLUSIONS

(1) Problems with co-ordination of fuses with switching devices are of a different character at different levels of overcurrent.

(2) Three critical levels of current have been identified:

- (i) Maximum breaking capacity;
- (ii) Critical throw-off current;
- (iii) Small overcurrents exceeding the breaking capacity of the contactor.

(3) Potential problems of fuselink replacement will be greatly reduced when the new edition of IEC Publication 269 is fully implemented.

REFERENCES

(1) Holm, R: 'Electric contacts' published by Springer, 1967 page 57.

(2) Turner, H W, and Turner, C: 'Phenomena relating to temperature rise and welding in high current electric contacts', 4th International Research Symposium on Electric Contact Phenomenon, pp 168-171.

(3) Lindgren, S: 'Operating times at low short-circuit currents', International Conference on Electric Fuses and their Applications, Trondheim, 1984, pp 134-138.

TABLE 1

Comparison of the Specification of the Zone of Current for a Prearcing Time of 0.1 Seconds by IEC Publication 269 in 1973 and 1986

Rated Current (A)	gI and gII (1975)		gG (1986)	
	I_{min} (0.1 S) (A)	I_{max} (0.1 S) (A)	I_{min} (0.1 S) (A)	I_{max} (0.1 S) (A)
16	77	240	85	150
20	100	300	110	200
25	135	380	150	260
32	175	480	200	350
40	220	600	260	450
50	285	780	350	610
63	370	980	450	820
80	550	1,240	610	1,100
100	760	1,600	820	1,450
125	970	2,100	1,100	1,910
160	1,240	2,600	1,450	2,590
200	1,600	3,500	1,910	3,420
250	2,100	4,550	2,590	4,500
315	2,600	6,000	3,420	6,000
400	3,500	7,750	4,500	8,060
500	4,550	9,800	6,000	10,600
630	6,000	15,000	8,060	14,140
800	7,750	20,000	10,600	19,000
1,000	9,800	25,000	14,140	24,000
1,250	-	-	19,000	35,000

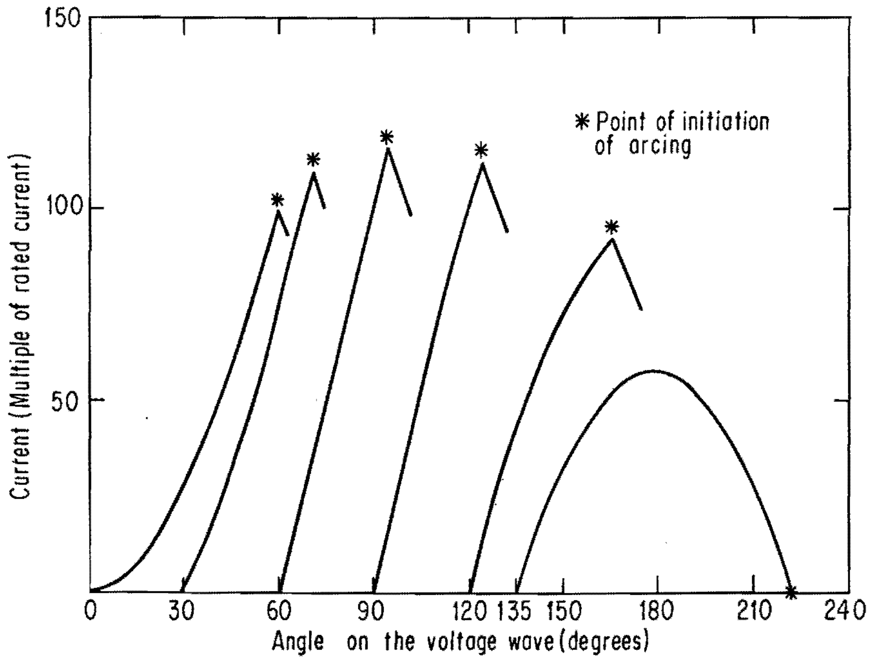

FIG1 CURRENT AS A FUNCTION OF TIME FOR A TYPICAL FUSELINK AT A PROSPECTIVE CURRENT APPROACHING MAXIMUM BREAKING CAPACITY AT 0·1 POWER FACTOR, ILLUSTRATING THE VARIATION WITH CLOSING ANGLE OF CUTOFF CURRENT AND ARCING ANGLE

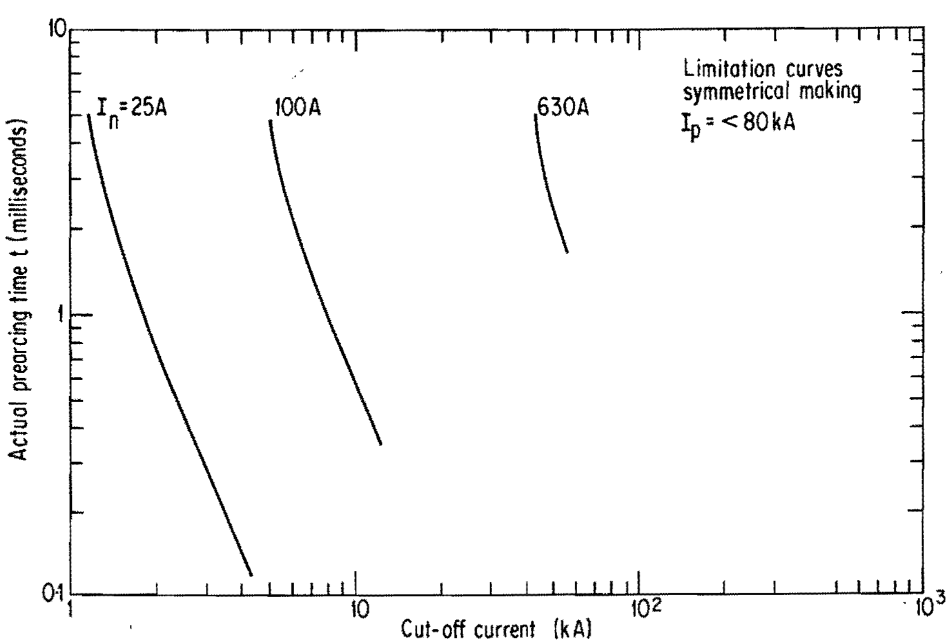

FIG. 2. CALCULATED CURVES OF CUT-OFF CURRENT AS A FUNCTION OF ACTUAL PREARCING TIME FOR A WELL KNOWN BRITISH MANUFACTURER

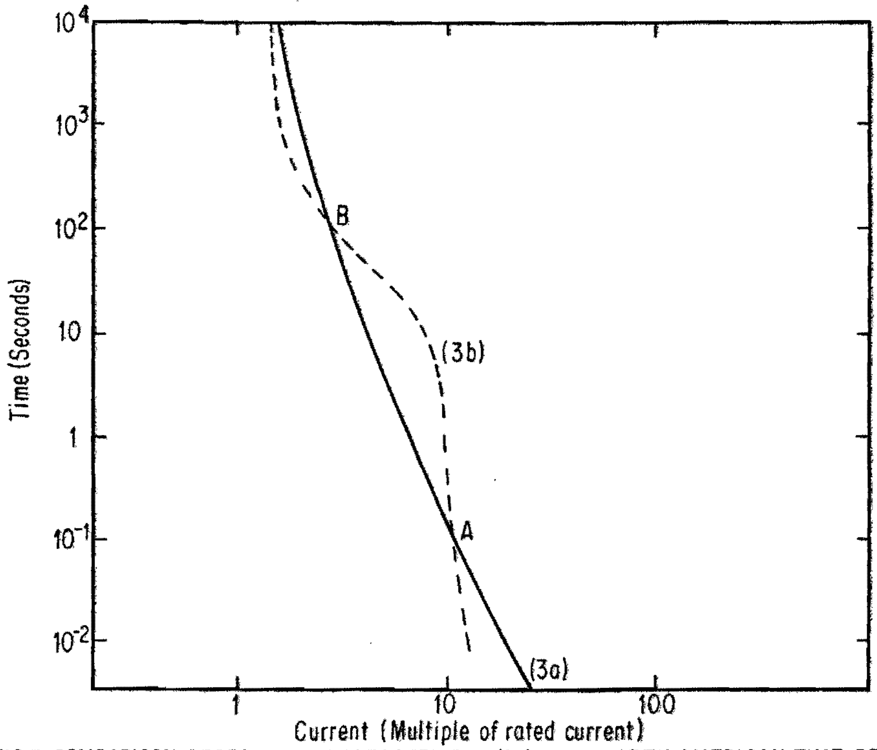

FIG 3. COMPARISON OF IEC gG/gM CHARACTERISTIC(3a) WITH NORTH AMERICAN TIME DELAY TYPE(3b)