COORDINATION OF FUSES-STARTERS : NEW STANDARDS, NEW NEEDS

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Summary

In the new contactors and motor-starters standard there are new coordination needs and requirements. The behaviour of the devices submitted to these requirements is analyzed in detail. Then, the consequences on the fuses and on their characteristics are considered in order the possible improvements regarding coordination.

1 Introduction to Coordination

1.1 General

Issued since May 1990, 947-4-1, IEC standard requires that the manufacturer of a starter shall give the type of coordination of the product and the associated Short Circuit Protective Device (SCPD).

Tests have to be done on starters and fuses following the conditions of 947-4-1 IEC standard in order to permit coordinated association. For this purpose, fuses standards are preparing guide of coordination to explain how to proceed. The aim of this study is to develop how the standards deal with coordination and what are the needs.

1.2 Definition

An assembly of two or more devices in series (e.g. SCPD associated with a contactor and an overload-relay) is coordinated if it is able to permit normal duty and to eliminate unexpected over-current under the following conditions :

- Discrimination (selectivity) between over-current protective devices ensured
- Effects on devices and on environment limited within acceptable limits (e.g.: no danger to persons)
- Back up protection (cascading) between over-current protective devices in case of association with more than one short-circuit protective device (one protective device may assist one other in case of too high short-circuit current). This condition will no be analized in this study.

1.3 Applicable standards

Speaking about coordination between fuses and motor starters, the following international standards are to be taken into account :

IEC 947-4-1 dealing with contactors and motor starters

32B(Sec)112 : Application guide for coordination between fuses and motor-starters. It will be part of IEC 269 (dealing with fuses).

IEC 947-4-1 replaces IEC 158 and IEC 292-1 and, although these two standards are well known it is preferred not to speak of them in this study

2. Rules of the coordination

Following the definition given in Sub-clause 1, coordination of protection between fuses and motor-starter implies verification of :

a) that the rating of the fuses is adequate for the starter : that is for its rated operational current Ie under the corresponding voltage and utilization category (e.g. AC3 for starting and switching of motors during running).

b) that the discrimination between the fuses and the overload protection of the starter (overload relay + contactor) is fulfilled

c) that the protection is ensured: that is short-circuit cleared without unacceptable damage.

These 3 points are developed here below :

Regarding <u>adequate rating</u> a) of the fuses to the load it shall be checked that they can withstand expected currents for normal duty such as starting of motors, plugging, inching corresponding to the utilization category without any melting.

Regarding <u>discrimination</u> b), it shall be checked that :

- for small over-currents, only the overload relay shall operate (the fuses shall not)
- for high over-currents, the fuses shall operate before the starter

Bad discrimination will happen in case of poor accuracy and/or too wide a tolerance of the tripping curve of the overload relay or of the melting curve of the fuses. So, if attention has not been given to discrimination, unexpected melting of the fuses may occur (sometimes inducing the customer to increase the fuse rating) and/or the withstand capabilities of the starter may be exceeded. In both cases the consequences can be damage to the assembly, or worse, to the whole installation.

Regarding protection c), the standards allow two types of coordination, "1" or "2". For both of them, it is required that, under short-circuit conditions, there shall be no danger to persons or installation. In addition, it is said that.

- For type "1", the starter may not be suitable for further use.
- For type "2", the starter shall be suitable for further use, the risk of contact welding (of the contactor) is recognized, in which case the manufacturer shall indicate the measures to be taken as regards to the maintenance of the equipment.

The purpose of this study is to consider mainly coordination type "2" and the corresponding requirements

3. Requirements and procedures of Standard

3.1 IEC 947-4-1

The best way to consider the standard requirements is to analyse the specific needs of the tests. It can be noticed first that these are three phase tests contrary to single phase tests fuses : sometimes, this may induce some difficulties in finding the optimum fuse rating for the association.

3.1.1 Discrimination test current

The diagram fig. 1 illustrates the tests :

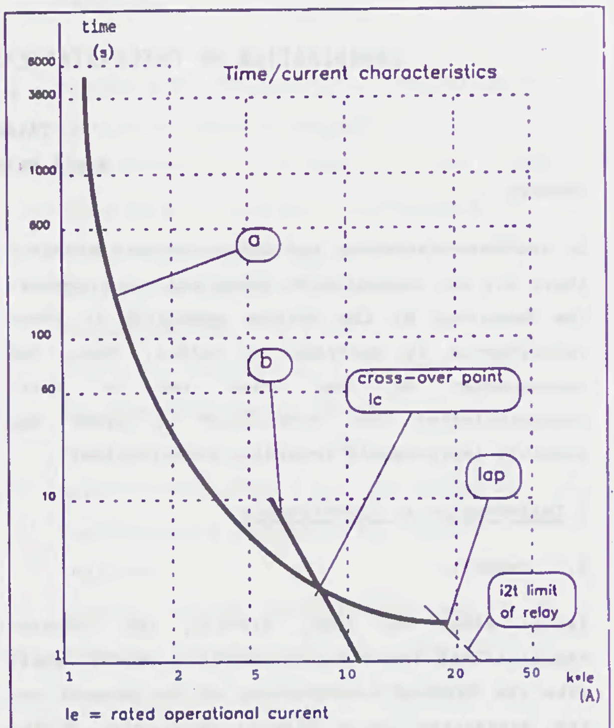

Fig.1 Discrimination between overload relays (a) and fuse (b)

Two tests shall be done, one with a current Ic1 = 0,75 Ic and one with Ic2 = 1,25 Ic, Ic being the current corresponding to the cross-over point of the overload relay and the fuse charateristics respectively. The power factors shall be those corresponding to the utilization category of the starter (e.g. 0,45 for AC3) under the nominal voltage

It shall be verified that :

- After the test Ic1 the fuse has not operated and the overload relay has operated to open the starter.
- After the test Ic2, the fuse has operated before the starter.

3.1.2 Short-circuit test current

There are two test currents :

- current "r" which is a conventional prospective test current related to the rated operational current Ie (AC-3), e.g. 3kA for $16 < I_e \leq 63$A.The power factor has generally a higher value than those used to test the fuses (e.g cos phi = 0,9 for "r" current = 3kA)
- current Iq, which is the rated conditional short-circuit current, stated by the manufacturer of the starter, withstandable satisfactorily by the association (e.g. 50kA).

Note : Iq ≥ current "r"

For each of these short-circuit tests, the current is applied twice, the fuses being changed and, if necessary, the overload relay reset and any welded contacts separated between the two operations (Coordination type "2")

The starter may be replaced between tests at current "r" and tests at Iq.

It shall be verified, after these tests, that the fault current has been successfully interrupted without any breakdown to earth (or the safety perimeter), without any damage to the conductors and without cracking or breaking of insulating parts.

It shall also be verified that no damage has occurred to the overload relay (by checking its characteristics) and to the contactor (e.g. by checking the making - breaking capabilities after having separated welded contacts if necessary); the adequacy of the insulation shall also be verified by a dielectric test.

3.2 32B(Sec)112

This draft is mainly based on IEC 947-4-1. It innovates in the way that it gives tools to likely predict the behaviour of association type "2" between fuse and starter, that by comparison of characteristics of these devices.

The characteristics taken into account are :

- Peak-current of the fuse and of the contactor
- I^2t of fuse, overload-relay and contactor
- Clearing-time of the fuses

Fig. 2 and 3 (respectively starter and fuses charateristics) illustrate how to choose a suitable fuse rating to protect the starter assembly.

The horizontal axes give the rated operational current Ie AC3 of the starters and the rated current In of the fuses. The vertical axes give peak-current and I^2t corresponding values.

Knowing the value of the current setting of the overload-relay I1 (I1 = nominal current of the load), it is possible to determine its I^2t limits (A). Due to having a fixed AC3 rating for the contactors, the rating I2 of the contactor to be used is often higher than that of the overload relay ($I2 \geq I1$). The corresponding peak current limit (B) and the I^2t limit (C) are shown on fig.2.Then, by comparison of these (D), (E) and (F) of the fuses, find the appropriate fuse rating (only the smallest rating, (II), is valid). These I^2t and peak charateristics are commonty used for fuses but not usually used for contactors and overload relays: the next clause will give an explanation of this new approach.

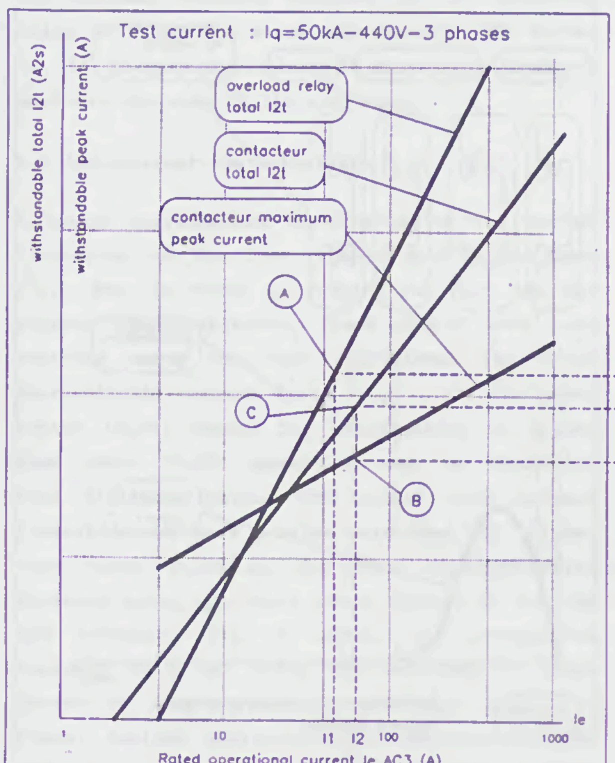

Fig.2 Starter characteristics

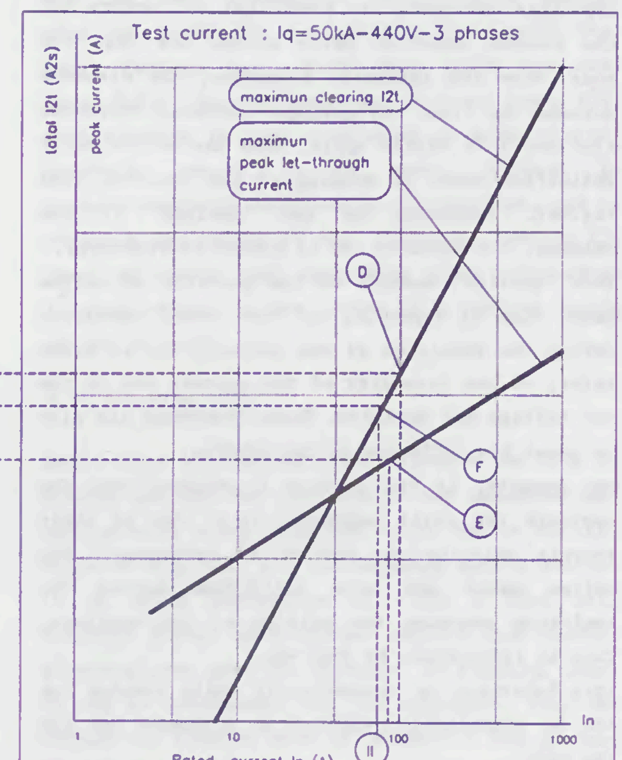

Fig.3 Fuses characteristics

4. Behaviour and needs of contactors and overload relays

4.1 Overload relays

The withstand limit of overload-relays is given by withstandable I^2t. Although this limit may depend on the short-circuit current, a value of 100 Ie^2 can be withstood by main overload-relays for the highest short-circuit currents (values of more than 400 Ie^2 are often withstandable). This limit is to be taken in account for currents higher than Iap (e.g. see Iap = 17 Ie on fig.1).

4.2 Contactors

Regarding discrimination problems, it shall be verified that the breaking capacity of the contactor is higher than the crossover current Ic (see fig.1)

Regarding short-circuit currents area, the behaviour of the contactor is more complex, and can be illustrated by fig. 4.

The electrodynamic forces increase approximately in proportion to the square of the intensity of the current. When the force applied on the moving part of the contact is large enough, this separates from the fixed part : this is the repulsion phenomena. An electrical arc occurs and the contact material melts around the feet arc area. When the intensity decreases, the distance between the fixed and movable contacts decreases also until it closes again. When the molten metal solidifies there is welding of the contacts (see Fig.4a). Depending on the "quality" of the welding, the contacts can or cannot be separated.

This "quality" depends on the quantity of molten metal that is depending on the energy developed during the repulsion of the contact, or, in other terms, on the intensity of the current and on the arc voltage and duration. Other phenomena can also be great big influence on the welding.

For example, if the current is cleared when the contacts are still separated (e.g. due to their inertia delaying the instant of reclosing), the molten metal may have solidified before the reclosing avoiding the welding of the contacts. That is illustrated by fig. 4b.

This behaviour is theoretically quite complex but can be practically resolved in a simple way for the user.

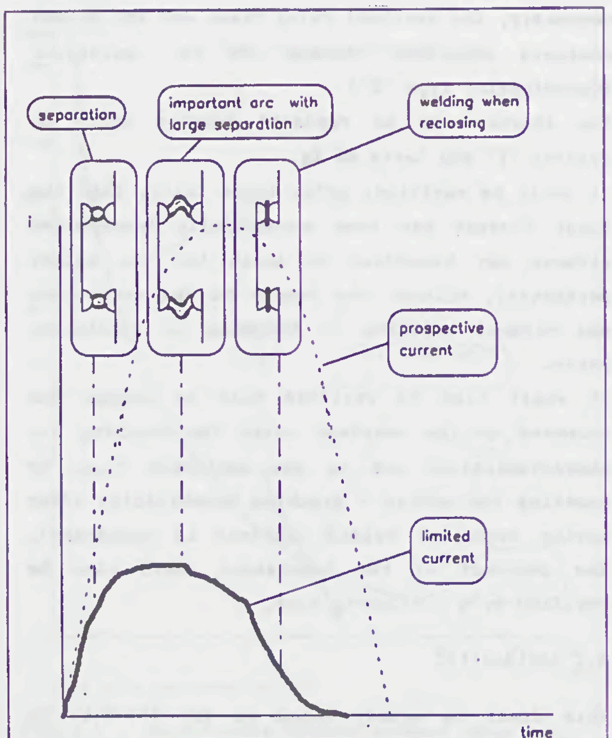

Fig.4a Behaviour of contacts under badly limited current

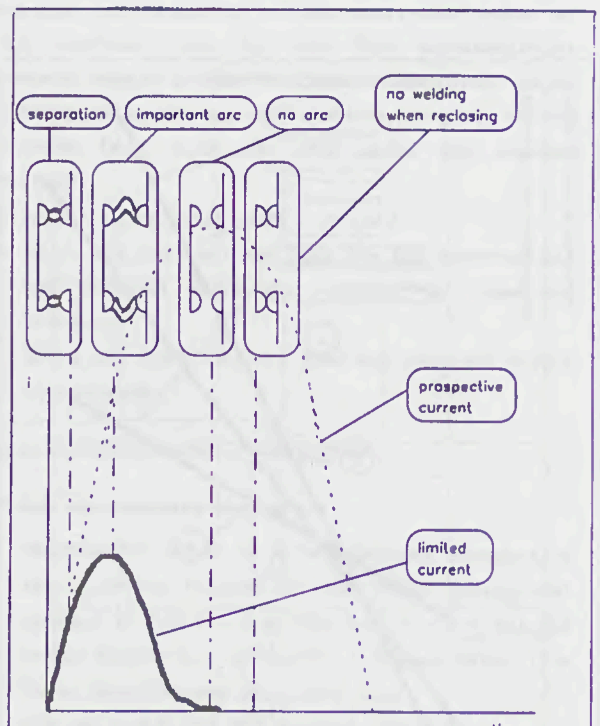

Fig.4b Behaviour of contacts under limited current

Having done several short-circuit tests, the manufacturer knows the withstandable current's characteristic curve of the starter. These waves such as those of Fig. 4b can be described by their peak, their I^2t and their approximate duration. Then, by analyses on several ratings of starter, it becomes possible to draw characteristic limits as shown on fig. 2.

It must be noticed here that limits given for one short-circuit prospective current under one voltage (e.g. 50 kA, 400 V) cannot be extrapolated to other short-circuit conditions (e.g. 3 kA, 500 V) because the shape of the current characteristic is generally different.

5. Consequences and requirements for the associated fuses

5.1 Time - current characteristic

The fuse characteristic must be selected such that the cross over point Ic (see fig. 1) is greater than the actual starting current ; IEC 947-4-1 requiring the overload relay to trip between 2 or 4 seconds and 10 seconds at 7,2 times Ie (Trip class 10A or 10 relays), it is hoped that the fuses can withstand these values without melting to be easily coordinated regarding this need.

The minimum breaking capacity of the contactor being 10 times its rated AC4 current (IEC 947-4-1), it is very convenient to have Ic < 10 Ie to minimize the size of the contactor.

5.2 Peak-current characteristic

A better coordination is expected with a better limitation of the fuse (lower peak-current and I^2t). But, in order to compare the fuse and the starter characteristics, these should have been obtained using the same conditions. For lower short-circuit current tests (e.g. 1 kA) the power factor (0.95) needed for coordination is higher than those (0.25) generally used for obtaining fuse limiting curves. The actual peak current limitation may have a value more than 20% higher than those shown on the fuse characteristics declared using the lower power factors in the IEC 269 standard. Fig. 5 shows, for prospective currents of 1 and 3 kA, the influence of power factor on peak current for different rating of fuses. Revised characteristics according to IEC 947-4-1 needs should be a useful improvement for determining coordinated associations.

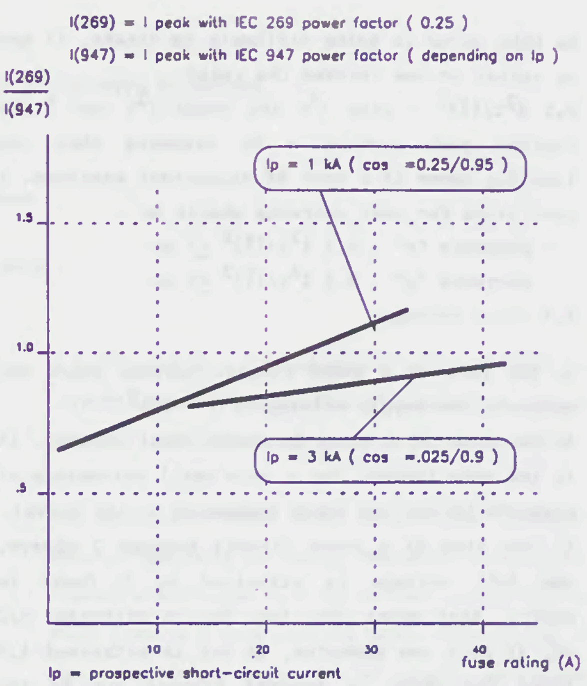

Fig.5 Influence of power factor on limitation

5.3 I^2t characteristics

For the same prospective short-circuit current with the total I^2t are generaly lower with high power factors (e.g. 0.95) than which low ones (e.g. 0.25). So, the knowledge of total fuses I^2t) corresponding to test conditions of motor-starter standards should be of great interest to predetermine more accureetely coordination, and to optimize the choice of the different devices (It shall be remind that decreasing total let-through I^2t may conduct to the choice of a smaller rating of the starter).

5.4 Clearing time

Long values of clearing time increases the risk of welding because the contacts of the contactor may reclose when there is melted metal due to the arc (case of fig. 4a). For coordination with a starter it is often preferable to use a fuse with slightly higher peak current and I^2t but shorter clearing time than the opposite. By clearing time, it can be considered, for the contactor, that the current is cleared when it becomes a few percent less than its limiting peak value (e.g. 5%).

As this value is quite difficult to obtain, it can be easier to use instead the ratio $0.5\ I^2t/(\hat{I})^2$ - with I^2t the total I^2t and $\hat{I}$ the limited peak current - by assuming that the limiting curve is a part of sinusoidal waveform. A good ratio for test currents should be :

- currents "r" : $0.5\ I^2t/(\hat{I})^2 \leq 6$ ms
- currents "q" : $0.5\ I^2t/(\hat{I})^2 \leq 5$ ms

5.5 Test voltage

In the case of a short circuit between phase and neutral, the supply voltage is $V = U/3^{0,5}$
In the case of a phase to earth short circuit, it is the same (except for a very small percentage of networks having one phase connected to the earth).
In the case of a short circuit between 2 phases, the full voltage is withstood by 2 fuses in series, that means each fuse has to withstand U/2 or, if only one operates, it has to withstand 1,5 times the phase to neutral voltage due to the neutral point displacement voltage,
that is $1{,}5\ V = U \times 1{,}5/3^{0,5} = 0{,}87\ U$.
The same condition appears in case of a 3 phase short-circuit.
That means that it could be of interest to take the limiting characteristic corresponding to,0,87 of the nominal voltage of the fuses to optimize the coordination.

VI. Conclusion

The new contactors and motors-starters standard (IEC 947-4-1) gives coordination requirements and that insolves some consequences for uses. In particular, attention should be taken regarding :

- time current characteristics (discrimination problem)
- limiting characteristics (short-circuit consequences on the starter)
- conditions of test (power-factor, voltage ...)

In order to facilitate ethe interpretation of this Standard, an application guide of coordination is under preparation. It will be of good help, mainly if users know the mechanisms of coordination. It will be a very useful tool to :

- estimatee the rating of fuses and starters to establish tables of coordinated devices
- compare different kind of fuses (e.g. fuses used for direct tests with others)
- choose device in order to do verification coordination tests

Due to the needs and requirements regarding coordination, a new philisophy of coordination will appear and more adapted fuses characteristics will appear in the futur.