INCORRECT USE OF FUSE CHARACTERISTICS IN IEC 62271-105 RESTRICTS H.V. FUSE APPLICATION IN RING MAIN UNITS

8th ICEFA
Clermont-Ferrand, September 12th, 2007

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Abstract: *IEC 62271-105 "Alternating current switch-fuse combinations" goes back to IEC 420:1973, when relatively slow acting switches in air and under oil were used in ring main units. SF_6 insulated switchgear did not exist in m.v. secondary distribution systems by than. This may explain why no one cared about the limitations in the use of fuse time-current characteristics in a time range below 100 ms.*
The paper highlights the conflicting claims of IEC 62271-105 to IEC 60282-1 "High voltage fuses" and IEC TR 60787 "Application guide for the selection of high voltage current-limiting fuse-links for transformer circuits" and explains the consequences with respect to h.v. fuse application in combinations with SF_6 switches. Indeed, important and well established fuse applications will virtually be ruled out by IEC 62271-105.
Alternative proposals are presented to resolve the conflicting situation in the International Standards.

Keywords: (h.v. fuse, fuse-switch combination, IEC 62271-105, transfer current)

1 Introduction

Distribution type transformers are commonly protected by means of current limiting back-up fuses on the h.v. side. Switch-fuse combinations, according to IEC 62271-105, with trip-free switches operated by the fuse striker, have gained importance with the introduction of metal encapsulated SF_6 insulated switchgear. Major objectives of this combinations are three-pole disconnection in case of fuse operation and thermal protection of the fuse compartment in case of partially damaged fuse-elements.

IEC 62271-105 is by definition a switchgear standard that describes a full-range protective device.. It interferes however heavily with transformer protection rules and is at least partly conflicting with fuse standards and transformer back-up protection practice. Conflicts result mainly from one single postulation laid down in sub clause 8.101.2 of IEC 62271-105:

The transfer current of the combination shall be less than the primary fault current caused by a solid short-circuit on the transformer secondary terminals.

$$I_{transfer} \leq I_{SC} \qquad (1)$$

The solid l.v. terminal short-circuit current on the primary side can be calculated from the Transformer rated current I_T and the relative short-circuit voltage u_K as follows:

$$I_{SC} = I_T \,/\, u_K\,\% \qquad (2)$$

A primary fault current, caused by a solid short-circuit on the transformer secondary terminals, corresponds to very high TRV values which a switch may not be able to cope with. The fuses shall therefore be selected to interrupt such fault currents without transferring any breaking duty to the switch, i.e. before the switch opens

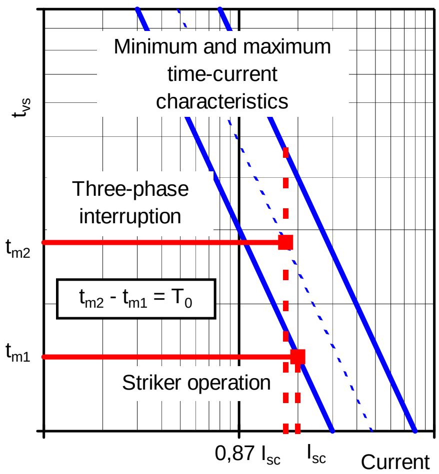

Fig. 1: Determination of transfer current

This postulation sounds reasonable and may be applied to switch-fuse combinations having a fuse initiated opening time of 100 ms and above. The application to fast acting switches, that open within 20 to 30 ms is just unrealistic, as real time-current characteristics of fuses do not exist in this time range.

2 Determination of transfer currents

The transfer current $I_{transfer}$ represents the value of the three-phase symmetrical current at which the fuse and the switch exchange breaking duties. It applies to striker initiated switch operation and depends on the tolerances of fuse time-current characteristics and the fuse-initiated opening time of the switch. Above this value a three-phase current short-circuit is interrupted by the fuses only. Overcurrents below this value are interrupted by a fuse in one phase and by the switch in the other phases.

Fig. 1 illustrates the practical determination of the transfer current:

- The symmetrical three-phase fault current I_{SC} melts the first fuse-link at the melting time t_{m1} and initiates striker operation.
- The three-phase fault current turns into a two-phase current of $0{,}87\,I_{SC}$ intensity.
- The second fuse-link operates at the time t_{m2} and interrupts the fault current.
- The switch opens after the fuse-initiated opening time T_0.

The transfer current $I_{transfer}$ represents the current value at which T_0 equals the time difference $t_{m2} - t_{m1}$.

$$T_0 = t_{m2} - t_{m1} \qquad (3)$$

Fault currents above this value are cleared by the fuses only. Below this value the breaking duty is transferred from the fuses to the switch.

In a simplified method explained in IEC 62271-105 Annex B, assuming a statistic tolerance for the fuse time-current characteristics of ± 6,5 % and gradient of 4, the transfer current can be determined from the minimum time-current characteristic of the fuse using equation (4):

$$I_{transfer} = I_{(0{,}9\,T_0)} \qquad (4)$$

As fuse manufacturers usually publish mean time-current characteristics rather than minimum values, the author suggests a further, more user oriented, approximation given in equation (5):

$$I_{transfer} = I_{(T_0)} \qquad (5)$$

The transfer current is approximately the current that corresponds to the time T_0 on the mean time-current characteristic.

3 Fuse selection acc. to IEC TR 60787

Distribution type transformers are preferably protected against the effects of internal faults by means of h.v. current-limiting fuses on the primary side. Overloads and faults on the l.v. side are disconnected by a main fuse or a c.b. in the feeder line (fig. 2). (Transformers with overload protection by means of non-current-limiting fuses on the h.v. side are not considered here.)

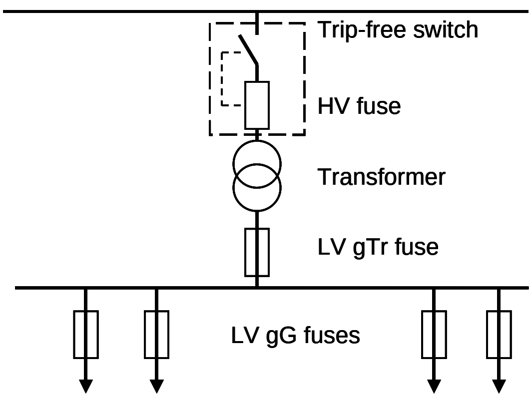

Fig.2: Circuit diagram of ring main unit

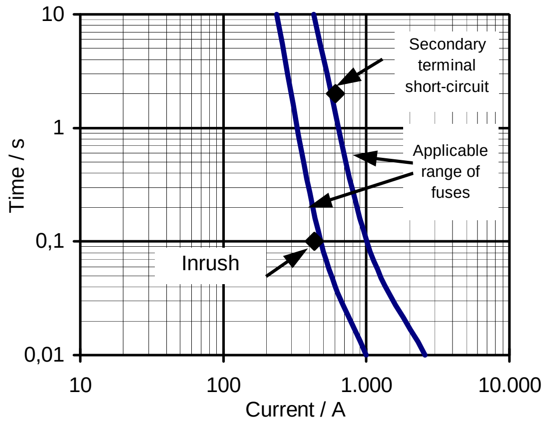

Fig. 3: Fuse selection for transformer circuits

Fuse-links for transformer circuits have to meet two basic requirements that limit the range of applicable fuses:

- The fuses shall interrupt a solid short-circuit current (I_{sc}) on the l.v. terminals within the specified short-circuit withstand duration of the transformer in order to prevent disruptive transformer failure. According to IEC 60076-5, the short-circuit withstand duration of transformer shall be at least 2 s unless otherwise stated by the manufacturer.
- The fuses shall withstand transformer inrush without deterioration in order to avoid nuisance operation and potential malfunction. Transformer inrush may be assumed equivalent 10 times to 12 times transformer rated current for a duration of 100 ms.

It is obvious that the time-current characteristics of appropriate fuse-links have to pass through the gate formed by these two corner points to meet the requirements (fig 3). In practice, the user may select from 4 to 5 consecutive fuse rated currents that fit the applicable range. Additional criteria, e.g. co-ordination with upstream and downstream protective devices may apply to make up the final choice.

4 Fuse selection acc. to IEC 62271-105

As mentioned above, fuse selection for switch-fuse combinations in transformer circuits is governed by the solid short-circuit current (I_{sc}) on the l.v. terminals and the transfer current $I_{transfer}$ of the combination, i.e. by the fuse initiated opening time T_0 of the switch. Whereby T_0 represents the time interval from arc initiation in the fuse to the instant when the arcing contacts of the switch have separated in all three poles.

T_0 depends on the duration of travel of the striker as well as on the mechanical opening time of the switch. As strikers commonly act very fast, i.e.

within some milliseconds, T_0 is dominated by the mechanical behaviour of the switch. (The 50 ms

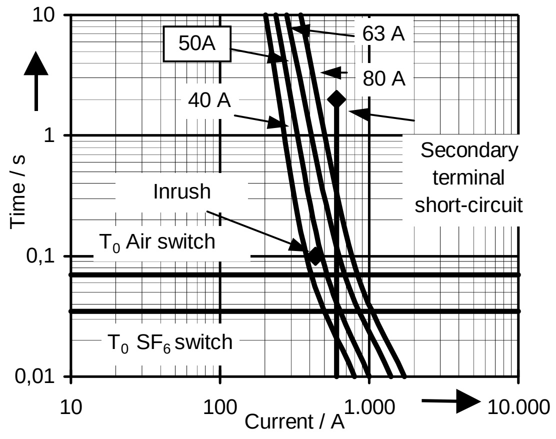

Fig. 4: Fuse selection acc. to IEC 62271-105

maximum duration of strikers travel as defined in IEC 60282-1cannot be considered representative. It is required for the arcing withstand and shall allow for the switch to open before the fuse body breaks at currents below the minimum breaking current.)

While IEC TR 60787 requires that the fuses interrupt the secondary terminal fault current I_{SC} within 2 s in order to prevent disruptive transformer failures, IEC 62271-105 claims that fuses shall interrupt this current within the fuse initiated opening time T_0 of the switch. Since the opening time of the switch is generally much below 2 s, selection according to IEC 62271-105 will result in smaller fuse rated currents and in different fuse rated currents depending on the type of switch, e.g. air switch and SF_6 switch.

Because of superior dielectric strength and arc quenching performance of the gas, SF_6 switches exhibit more compact dimensions. The mass as well as the travel distances of moving parts are significantly less than the ones of air switches. Consequently, SF_6 switches open much faster than air switches.

A simple procedure to select appropriate fuses for switch-fuse combinations by means of a time-current chart, is to draw a horizontal line corresponding to the fuse initiated opening time of the switch T_0 and a vertical line at the secondary terminal short-circuit current I_{SC} (fig. 4). The point of intersection of these two lines discriminates acceptable and unacceptable fuses: Only fuse characteristics that pass below the point of intersection meet the requirements of IEC 62271-105.

Fig. 4 shows the example of a 10 kV, 630 kVA transformer, that would usually be protected by means of a 80 A fuse. In combination with an air switch having an opening time of 70 ms, a 50 A fuse will have to be chosen. The same transformer in combination wit an SF_6 switch would require a 40 A fuse. The latter that does however not exhibit enough tolerance to the transformer inrush. Strictly speaking, would fuses be eliminated from this application and a circuit-breaker would have to be used instead.

As can be seen from fig. 4, fuse selection according to IEC 62271-105 leads to significantly (2 to 3 steps) smaller current ratings than selection according to IEC 60787 with the following consequences:

- Greater power dissipation,
- higher risk of inrush damage,
- loss of selectivity to l.v. fuses,
- limitation in fuse applications.

The severity of these consequences increases with the operating speed of the switch and the size and short-circuit impedance of distribution transformers (see table 1). SF_6 switches have opening times down to 20 ms. Combinations with fast acting SF_6 switches can therefore not meet the inrush requirements of larger size transformers having a common short-circuit impedance, e.g. $S_N \geq 630$ kVA, $u_K = 6$ %.

Table 1: Fuse selection for transformer circuits

Transformer		Fuse rated currents acc. to		
S_N/kVA	u_K/% *)	IEC 60787	IEC 62271-105	
			Air switch T_0=70 ms	SF_6 switch T_0 = 35 ms
400	4	50A	50A	40A
500	4	63A	63A	50A
630	4	80A	80A	63A
630	6	80A	50A	40A
800	6	100A	63A	50A
1000	6	125A	80A	63A
*) acc. to CENELEC HD 428.1 S1				

As a matter-of-fact, IEC 26271-105 is discriminating fuses by claiming unreasonably low current ratings and thus actually limiting fuse application to relatively small size transformers.

Table 1 gives a comparison of actual fuse selection acc. to IEC 60787, representative for German public utility 10 kV distribution transformers, and fuse selection for air and SF_6 switches in combinations acc. to IEC 62271-105.

IEC 62271-105 does not only make fuse selection very complicated, may be too complicated for users, but is in some respect conflicting with IEC 60787, IEC 60282-1 and well established transformer protection practice:

- IEC 62271-105 requires smaller fuse rated currents for SF_6 insulated switchgear while IEC 60787 claims greater current ratings for fuses in enclosures.
- IEC 60787 recommends a relatively high operating current in the 0,1 s (inrush) region, while IEC

62271-105 requires fuse characteristics much closer to the inrush point.

- IEC 62271-105 defines the performance of the combination in a range below I_{SC}, while many applications with back-up fuses are selected for a protection range starting with I_{SC} to greater fault currents.

The latter may imply that there is no rational in the application of IEC 62271-105 rules for transformer protection by means of h.v. back-up fuses as there is no overlap in the application range. For applications without overcurrent release and where the fuses provide short-circuit protection only, IEC 62271-105 does not contain any applicable performance tests. What's left is solely the requirement of equation (1) concerning transfer currents. It seems that this requirement is causing more problems than it solves.

Indeed, the German National Committee made clear that in case of conflicting results of fuse selection for transformer protection, existing rules for transformer protection shall have priority over IEC 62271-105. This decision was justified by the excellent long-term experience with national practice and some uncertainty about solid short-circuit current (I_{sc}) on the l.v. terminals the determination of transfer currents for SF_6 switches.

5 Incorrect use of fuse characteristics

The limitations in fuse application has caused irritation among customers, switchgear and fuse manufacturers alike. This is even more annoying as there is no real physical background for transfer current determination in the respective time range of SF_6 switch operation. IEC 62271-105 suggests that the switch of a combination would not be involved in fault current interruption below the transfer current. This suggestion is misleading when transfer currents are determined according to Annex B of said standard in a time range significantly below 100 ms, for

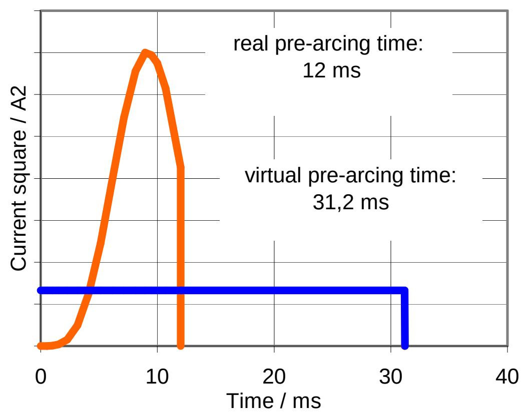

Fig 5: Real and virtual pre-arcing time

the following reasons:

- IEC 60282-1 says clearly that for the purpose of coordination between fuses and other protective devices, time-current characteristics may not be employed in a time range below 100 ms.
- IEC 62271-105 assumes a symmetric short-circuit current without aperiodic d.c. component.
- IEC 62271-105 assumes same instantaneous current values in all three phases.
- IEC 62271-105 assumes time-current characteristics without discontinuities, having a tolerance of ± 6,5 % on the current.
- IEC 62271-105 assumes fuse characteristics representing real operating time to compare with opening time of the switch.

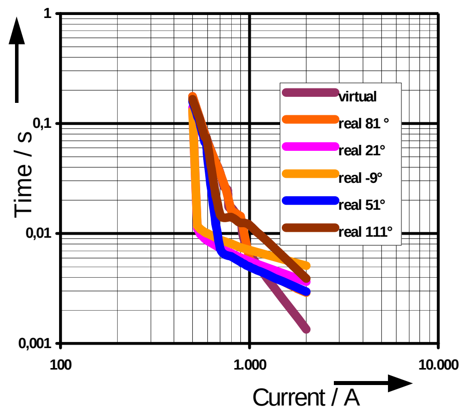

Fig. 6: "Chaotic" pre-arcing time range

Unfortunately, it is not mentioned in IEC 62271-105 that none of these assumptions apply in the time range well below 100 ms and transfer currents can therefore not be determined by means of time-current characteristics as demonstrated in Annex B.

Fuse time-current characteristics represent virtual time values calculated from I^2t values and cannot be compared with real time values, e.g. opening times of a switch. Real pre-arcing time values may be significantly different to the calculated values (Fig. 5). Depending on the power factor and making angle of a solid short-circuit, the currents passing through the fuses of a three-phase system are significantly different and their pre-arcing times may vary much more than the manufacturing tolerances assumed in Annex B of IEC 62271-105.

Figure 6 shows calculated pre-arcing time-current curves for different making angles of a short-circuit current. The graph illustrates why the respective time range is called "chaotic". Due to the fact that fuses do not melt near current zero, the curves show periodic steps in the direction of time according to the frequency of the current. The pre-arcing time variation and consequent tolerances on the current caused by the nature of the three-phase a.c. power supply system are not considered for the determination of transfer currents in Annex B and would have to be added to the manufacturing tolerances of the fuses.

Two conclusions may be drawn from these facts:

- The determination of transfer currents according to Annex B of IEC 62271-105 cannot be applied to switches having opening times in the range of 20 ms to 40 ms as is typical for SF_6 switches. Because of greater tolerances between real time-current characteristics, breaking duty may still be transferred to the switch.
- Annex B and probably the entire Standard IEC 62271-105 was likely not meant for this application originally. Annex B mentions an opening time range of 50ms to 300 ms for the simplified method for determination of transfer current which sounds more realistic.

That's why revision or amending of IEC 62271-105 in co-operation with fuse committees seems to be advisable.

6 Proposals to eliminate contradictory requirements

SF_6 switch-fuse combinations non-complying with IEC 62271-105 have been installed in many countries over decades with excellent results. As shown above, there are good reasons for to believe that formal compliance with the standard does not mean more safety in reality. The good results in the field may just be based on the fact that fast acting switches exhibit better breaking capacity than tested and certified or on the fact that bolted l.v. terminal short-circuits don't happen very often.

There is some doubt on whether the advantages of meeting the requirements of IEC 62271-105 outweigh the greater risk of inrush damage and greater power dissipation. Nevertheless users and manufacturers share the desire to comply with applicable standards.

6.1 De-activation of strikers

To eliminate interaction between fuses and switch has been a solution chosen by some utilities. This way to comply with the standard means to give up several important features of the combination, e.g. automatic three-phase disconnection and thermal protection of fuse canisters.

6.2 Delayed switch operation

This solution is costly and may require special fuses with extended arcing withstand time to meet the requirements of IEC 62271-105.

6.3 Fused circuit switcher

A new standard, IEC 62271-107, has been developed describing functional assemblies of a circuit switcher and a current-limiting fuse with the switching device being able to interrupt small short-circuit currents as may occur on distribution type transformers. Commercial availability is still somewhat open.

6.4 Closer definition of the standard's scope

The scope of IEC 62271-105 could be closer defined. The application of annex B should be limited to a time range of 100 ms and above.

6.5 Elimination of subjects concerning transformer protection

IEC 62271-105 is a switchgear standard by definition. Requirements for transformer protection are covered in IEC 60787 and should consequently be taken off. At least IEC 62271-105 should not be applicable to transformer back-up protection covering solely the fault current range from I_{SC} and above.

6.6 Reducing u_K

As shown above, low short-circuit impedance makes it easier to select fuses that meet the requirements of both standards and application guide respectively. This may be a viable solution for some applications

7 Summary

Fuses appear to be simple products to those not familiar with fuse technology. In reality, fuse operation is not easy to understand and not many engineers are familiar with fuse application. More information on fuse application and involvement in education and fuse related standardisation work seems to be necessary to control the results and prevent negative effects on the use of fuses. Lack of information and applications mistakes are detrimental to fuses an their application.