HARMONISATION OF IEC & UL REQUIREMENTS FOR LOW VOLTAGE FUSES - IS IT POSSIBLE?

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The recent revision of IEC.269 Part 1 contains internationally standardised time-current gates and pre-arcing I^2t limits for general purpose fuses type gG, and also requirements for fuses for motor circuits. This marks a significant advance in International standardisation and there will inevitably have to be a period of time to enable the various National fuse systems, examples of which are given in IEC.269 Parts 2a and 3a, to align with these new requirements. There is however no indication that such requirements are acceptable to U.S.A. and it is well known that the typical requirements for low voltage fuses contained in the Underwriters Laboratory Specification UL.198 differ considerably from those contained in the revised IEC.269 Part 1. There are a number of reasons for these differences, many of which stem from the requirements of the American National Electrical Code, which at present is not harmonised with the IEC Installation Rules. Nevertheless with the increasing involvement of U.S.A. in many of the low voltage product Committees, e.g. circuit breakers, contactors, switches, etc, it seems inevitable that the problem posed by the differing requirements has to be met, and some agreement reached.

This Paper compares the important differences between IEC and UL requirements for low voltage fuses, comments on the reasons why these differences exist, and suggests some lines of investigation which may lead towards an acceptable compromise.

Historical Background The fundamental difference between the IEC and UL fuse characteristics seems to stem from the requirements of the American National Electric Code which specifies that over-current devices must operate within a stated time at 135% of their rated current in order to ensure overload protection of associated cables. Fuses with such low fusing currents, if produced in a conventional manner, have a much faster time-current characteristic than those to IEC requirements and therefore have inferior motor starting capabilities. This inevitably has led to the introduction of the time-delay fuse which combines the low fusing current

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required with an improved withstand capability in the region of 10 seconds. The very popular range of fuses manufactured to what is known as the 'Code' dimensions at present dominate the North American market. These dimensions, rating for rating, are considerably larger than those to the British or DIN dimensions given in IEC.269 Part 2 (FIG.1). The breaking capacity of such fuses vary according to UL classifications but the highest value is 200kA r.m.s. symmetrical at 600 volts a.c. The cut-off and I^2t limits for such fuses have varied in the past but the existing limits which are recognised as an acceptable maximum are referred to as K5 values, in other words a time-delay fuse complying with the requirements of UL.198D and classified as K5 must have total I^2t values and cut-off values not exceeding those given in Table 1.

In the early 1960's another set of dimensions was introduced into UL Specification 198C covering a range of non-time-delay fuses known as Class J whose outline dimensions are similar to the British and DIN low voltage fuse systems. (FIG.2). The main purpose of these fuses, in addition to the introduction of compact dimensions, was to introduce much lower values of cut-off and I^2t than the K5 values. The 'J' fuses have not proved to be very popular, presumably because their very fast characteristic makes them unsuitable for the protection of motor circuits. A recent modification to UL.198C provides for a time-delay type 'J' fuse whilst still requiring the same I^2t limits as the non-time-delay type but to date such fuses have not appeared in any quantity.

There is another set of cut-off and I^2t values for a class known as K1, which is intermediate between the 'J' and K5 values and these cover standard characteristics in the Code dimensions i.e. non-time-delay.

Table 1 compares the K5 and 'J' I^2t values with those of IEC.269 Part 1. One of the problems of comparison is the fact that IEC.269 Part 1 specifies limits of <u>pre-arcing I^2t</u> at 10 milliseconds whereas the UL Specification specifies limits of <u>total I^2t</u> at either 100kA or 200kA. A study of the time-current characteristics of popular American fuses, together with an assessment of designs of elements used in such fuses, indicates that the pre-arcing I^2t of the type K5 and 'J' fuses at 10 milliseconds are as shown in FIG.2. This figure also shows the limits of pre-arcing I^2t at 10 milliseconds specified in IEC.269-1.

It is evident from FIG.2 that whereas the K5 limits are of a similar order to those in IEC.269-1, the values for the 'J' type fuses are considerably lower.

<u>Overload Protection</u> IEC Committee TC20 has spent a considerable amount of time and effort in determining the overload withstand capability of P.V.C. insulated cables in collaboration with IEC Committee TC64. The Rule, which is now contained in IEC.364 'Electrical Installation of Buildings' states that a P.V.C. insulated cable is protected if the associated overcurrent device operates at $1.45I_Z$, within a

specified time. (I_Z = current rating of cable). This is based upon the assumption that on overload the total temperature which the conductor must not exceed is 120°C for a specified time. The rated current of the IEC cable is based on a maximum conductor temperature of 70°C. Therefore to provide the necessary protection to the IEC requirements, the fusing current (I_f) of the fuse must not exceed $1.45I_Z$. This value takes into account the possibility of repetitive overloads in the life of the installation.

The N.E.C. requirements for cable protection are fairly comprehensive and stipulate different current ratings for conductors with different insulating coverings. Table 310-12 of the National Electrical Code gives data for P.V.C. insulated cables having a total temperature limit of 60°C. This limit is reflected in the overload requirements of UL198. Table 2 compares the time-current characteristic requirements of UL.198D with IEC.269-1.

Overload protection of cables rated for a 60°C limit in the N.E.C. Rules is the nearest installation condition to that which exists in the IEC Rules and has been used for the following comparison:-

There are two restrictions imposed by N.E.C.

(1) The Code only recognises a 60°C temperature limit for P.V.C. insulated cables.

(2) The protective device must operate at not more than $1.35I_Z$.

There is, however, one alleviation. In the Code, Exemption 1 of Article 240-5 states that if the fuse rating does not coincide with the cable rating in a particular situation, then a fuse of the next higher current rating can be used. This infers that that factor of $1.35I_Z$ can be exceeded in certain circumstances.

Figure 3 compares the IEC and N.E.C. current ratings for various sizes of P.V.C. insulated cable, together with the IEC ratingsadjusted to the N.E.C. requirements of 60°C total temperature, and it shows the significant difference in the basis of rating and the overload protection requirements required between N.E.C. and I.E.C. for P.V.C. insulated cables.

<u>Short Circuit Protection.</u> If short circuit protection of cables is considered, then regardless of what limits are imposed for overload protection, it is reasonable to assume that the formula given in IEC.364 is equally applicable to both IEC and N.E.C. rated cables and Figure 2 compares the I^2t withstand limits of P.V.C. insulated cables with the pre-arcing I^2t values for both IEC and UL fuses. Also superimposed on this Figure are typical I^2t withstand levels of popular contactors and switches of European design.

Determination of breaking capacity. Another comparison which must be made is the method of determining the breaking capacity of fuses. In IEC.269 Part 1 for General Purpose Fuses, there are five test duties ranging from the prospective current equating to the breaking capacity of the fuse, down to $1.25I_f$. (See Table 1). The breaking capacity tests in UL.198D consist of six test duties from the breaking capacity rating of the fuse down to twice rated current (which equates to $1.5I_f$) so it is reasonable to state that the range of test currents are similar, but one noticeable difference is the fact that the power factor required for the test at twice rated current ($1.5I_f$) in UL.198D is 0.8 or less which can permit a considerably easier test duty than that specified in IEC.269 Part 1 for a similar test current (I_5) where the power factor is 0.35.

Another noticeable difference is that UL.198D does not specify any breaking capacity tests for minor ratings in a body size and does not recognise the Rules for a homogeneous series which is a significant deviation from IEC.269-1.

Fuse-switch combinations. IEC.269 Part 1 recognises fuses specifically designed for motor circuit protection (type gM and aM) and many European fuse switch arrangements permit the use of such fuses to fully utilise the capability of the switch and the fact that in such instances the fuse only provides back-up protection. For example, a fuse-switch combination of 100 amps rating can utilise a motor circuit fuse capable of withstanding the starting current of a motor whose full load current is 100 amps without the need for such a fuse to have an I_f as low as 145A ($1.45I_N$). The N.E.C. does not permit such an arrangement except in certain restricted circumstances and this is a further difficulty in trying to align UL and IEC fuse requirements.

Discussion. It is obvious from the foregoing that the difference between UL and IEC practice with regard to fuse design and application is considerable but as stated earlier in this Paper, the discussions which are now taking place in many of the Committees dealing with associated low voltage equipment, indicate that some effort must be made to find a compromise.

The areas of compromise fall into three categories, breaking capacity, overload protection and short circuit protection.

Breaking Capacity. As the two requirements are similar, apart from the issues of the test power factor for the 200% test and the absence of tests on minor ratings in UL.198D, it seems reasonable for UL to accept the IEC Rules particularly the reduction of the power factor to 0.35 in the test at $1.5I_f$ because this reflects the power factor of a stalled motor and as the time delay fuses are specifically designed for motor circuits, it is logical that this alignment is made. It is also significant that in the recent amendment to 198C it is required, for type 'J' fuses, that all of the ratings in each body size must be tested at 100kA to establish the value of total I^2t let-through.

Overload Protection. The obvious solution to this problem would be if N.E.C. recognised the IEC requirements for the overload protection of P.V.C. insulated cables but this is a major change which may not be possible to achieve. Nevertheless, the fact that the National Electrical Code permits a fuse of the next size up to the cable rating in certain instances, shows that there is some flexibility permitted. A simple step would be to agree that fuses to IEC.269 Part 1 could be applied to the existing N.E.C. Rules provided the current rating of the fuse did not exceed 90% of the current rating of the cable in the N.E.C. Tables. This ratio takes account of the fact that the IEC fuse rating must comply not only with an I_f value not exceeding $1.6I_n$ but must also comply with the conventional cable overload test given in IEC.269 Part 1.

Short Circuit Protection A study of Figure 2 shows that the K5 values, which are in popular use in U.S.A. compare very favourably with those of the IEC values for pre-arcing I^2t at 10 milliseconds but the 'J' values are substantially lower. Figure 2 also shows that the IEC and K5 values give adequate short-circuit protection to P.V.C. insulated cables and also appear to give adequate protection to associated equipment such as contactors and switches.

This is probably the area which requires the greatest investigation. The low values specified for the type 'J' fuses would suggest that the associated devices which this type of fuse must protect in U.S.A. are much more sensitive to short circuit let-through than their European counterparts. This is not borne out by experience and there must be some other explanation which is not obvious from an examination of the basic equipment.

If the K5 limits have given satisfactory protection over many years, then one must query the basis for the type 'J' fuse limits particularly when such fuses (except those which claim compliance with the recently introduced time-delay requirements in UL.198C) have a much inferior performance when used for motor circuit protection. It is in all probability this fact which has stifled the use of the 'J' range fuse in U.S.A. up to the present time when it has the obvious advantage of compact dimensions. It is significant that in the draft Canadian Standard for Low Voltage Fuses, there is a proposition to include requirements for time-delay type 'J' fuses, but at the present time, the cut-off and I^2t limits for such fuses are not finalised. It is also of significance that type 'J' dimensioned fuses with cut-off and I^2t values greater than the UL limits for type 'J' have been used in Canada for at least 25 years for the protection of equipment manufactured in U.S.A., without any service problems whatsoever. It is obvious from the foregoing that the basis for these low I^2t values for the type 'K' fuse must be critically reviewed.

<u>Standard time-current gates</u> A comparison of the time-current characteristics of popular American fuses show that although all characteristics would readily fall within the IEC limits of $1.25I_{nf}$ and $1.6I_f$, problems occur at the other gates. If the K5 values are considered, it would appear that there is a distinct possibility that they could fall within the IEC limits for pre-arcing I^2t at 10 milliseconds and this also suggests the possibility for a non-time-delay fuse to comply with the IEC gates at 0.1 seconds and also the 10 second minimum and 5 second maximum gates. A problem would undoubtedly arise when considering the time delay characteristic which, whilst meeting the 10 millisecond pre-arcing I^2t limits and possibly the 0.1 second minimum and maximum gates, would not comply with the 5 second maximum-10 second minimum gates for general purpose fuses. There is however a distinct possibility that the time-delay fuse could be classified in a similar manner to a gM fuse by relating its short-time time current characteristic, (less than 30 seconds) to a fuse of a higher standard current rating. (See FIG.4.). More accurate information on the time-current characteristics of the popular types of American fuses would be necessary in order to verify this proposal as a possibility.

<u>Conclusion</u> The main objective of this Paper is to outline the difference which exist at present between UL and IEC with regard to Low Voltage Fuse Specifications, and to give some of the reasons for this situation. The proposals for a possible compromise are given primarily to initiate discussion on this subject because sooner or later this problem must be faced if we are to have truly International Rules for low voltage fuses and this particular forum seems an ideal starting point.

TABLE 1.

COMPARISON OF BREAKING CAPACITY REQUIREMENTS.

IEC.269-1	UL198D
TEST AT 110% RATED VOLTAGE	TEST AT RATED VOLTAGE
I_1 : 3 tests at 0.1-0.2 PF	I_1 : 1 test at max 0.2 PF
I_2 : 3 tests at 0.1-0.2 PF	I_2 : 1 test at max 0.2 PF
	50kA : 1 test at max 0.2 PF
	25kA : 1 test at max 0.2 PF
	10kA : 1 test at max 0.5 PF
I_3 ($3.2I_f$): 1 test at 0.3-0.5 PF	
I_4 ($2.0I_f$): 1 test at 0.3-0.5 PF	
I_5 ($1.25I_f$): 1 test at 0.3-0.5 PF	$2I_n$: 1 test at max 0.8 PF
Pre-Arcing I^2t at 0.01 seconds	Total operating I^2t specified for I_1 (100kA or 200kA RMS Symm).

Fuse Rating	P.A. I^2t $kA^2secs.$	Fuse Rating	Total I^2t Class K5 kA^2secs	Total I^2t Class J Ka^2secs
32A	5	30A	50	7
63A	27	60A	200	30
100A	86	100A	500	80
200A	400	200A	1600	300
400A	2250	400A	5000	1100
630A	7500	600A	10000	2500

IEC.269-1	UL198D
Minor Ratings in Body Size : which for a homogeneous series I_1 : 3 tests	Minor Ratings in Body Size No tests required in UL198D

TABLE 2.

COMPARISON OF OVERLOAD CHARACTERISTIC REQUIREMENTS

IEC.269-1	UL198D AND C. CLASS K AND J FUSES
$I_{N.F} \geqslant 1.25I_N$	$I_{N.F} \geqslant 1.1I_N$
$I_F \leqslant 1.6I_N$	$I_F \leqslant 1.35I_N$
I (10 SECS) : Withstand for 10 seconds specified currents from 2.3 to $3.6I_N$ (Refer NOTE 1)	I (10 SECS): TIME DELAY ONLY - withstand $5I_N$ for 10 secs
I (5 SECS): Operate in 5 seconds with specified currents from 4.7 to $8.1I_N$ (Refer NOTE 2)	Operate at $2I_N$ in specified time Fuse Rating / Time: 30A — 2 Minutes 60A — 4 " 100A — 6 " 200A — 8 " 400A — 10 " 600A — 12 "

NOTE 1 : IEC 10 second Current limits (minimum)

Fuse Rating	Min I (10 Secs)
32A	75 amps
63A	160 "
100A	290 "
200A	610 "
400A	1420 "
630A	2200 "

NOTE 2 : IEC 5 second Current Limits (maximum)

Fuse Rating	Max I (5 secs)
32A	150 amps
63A	320 "
100A	580 "
400A	2840 "
630A	5100 "

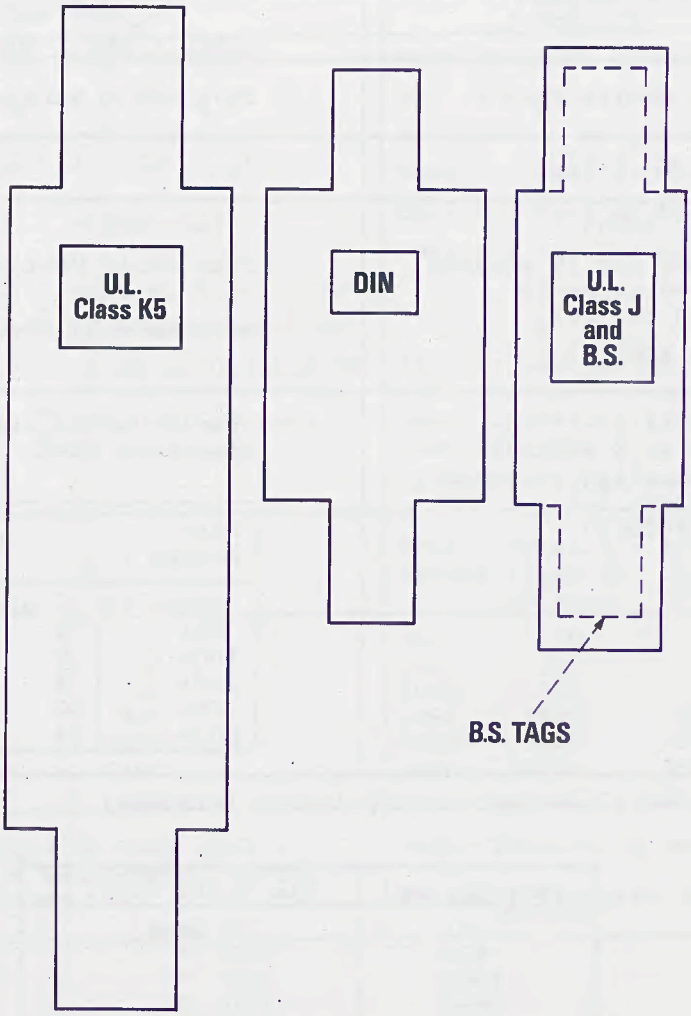
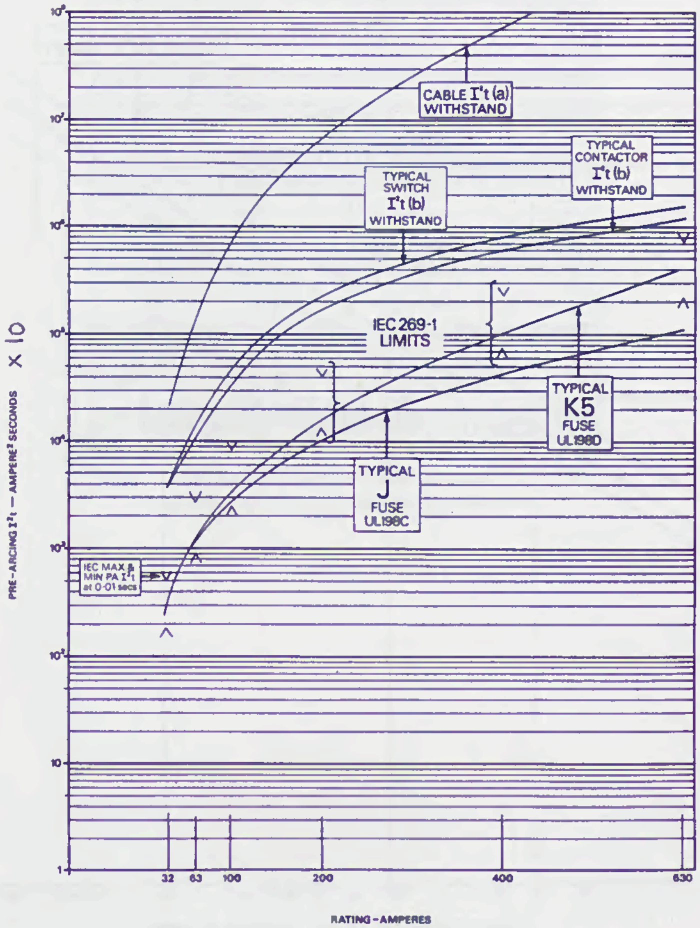


FIG.1 COMPARISON OF DIMENSIONS OF 200A FUSES

FIG.2: Comparison of I^2t withstand values of (a) PVC Insulated Cables
(b) Typical Switches and Contactors with prearcing
I^2t of Fuses to IEC 269-1 and UL198D



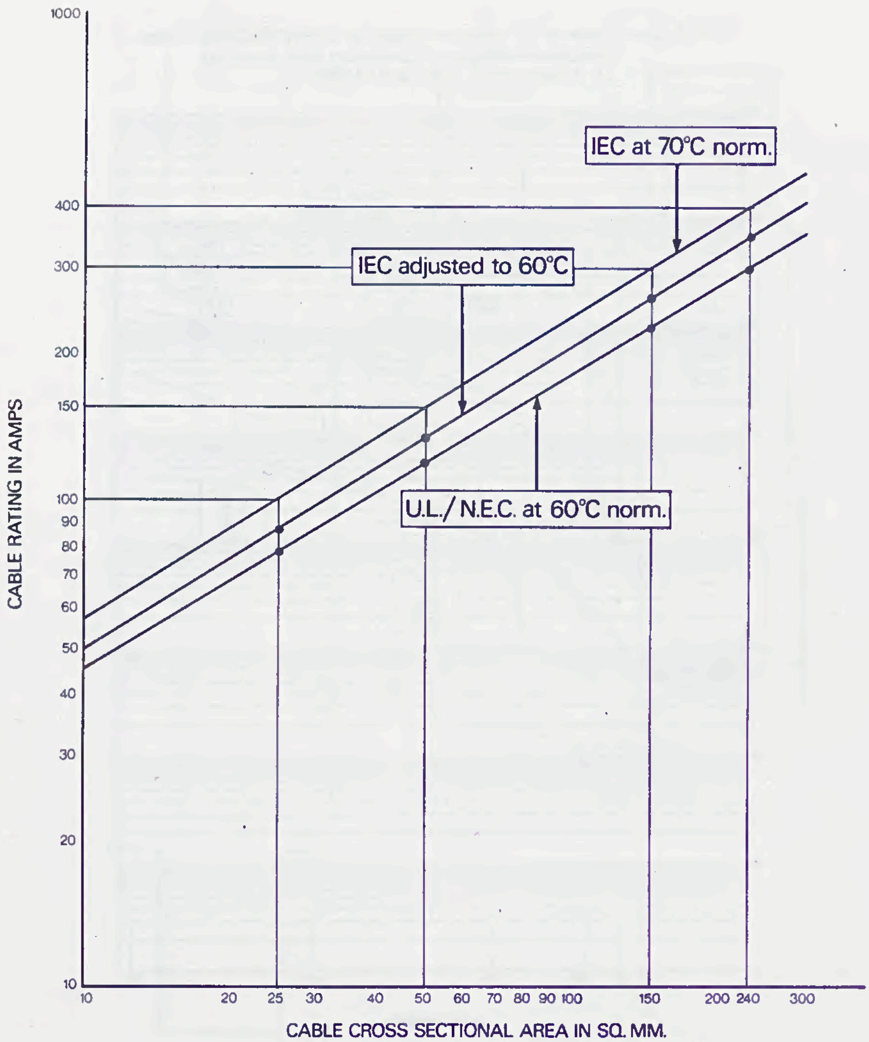


FIG.3: Comparison of IEC & NEC Current Ratings
for P.V.C. Insulated Cables

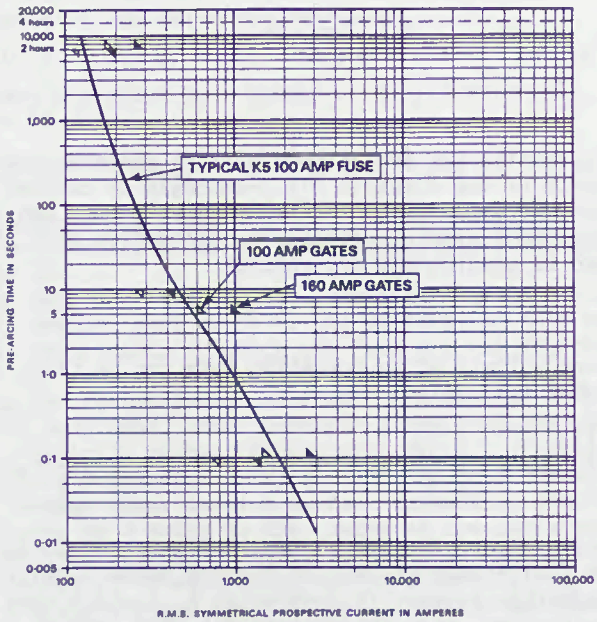


Fig. 4 COMPARISON OF TYPICAL K5 100 AMP CHARACTERISTIC WITH IEC269 GATES FOR 100 AMP AND 160 AMP FUSES