LOW VOLTAGE FUSES 1919-1991

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I am honoured to be asked to present the opening paper to this, the Fourth International Conference on Electric Fuses and Their Applications. These conferences are now established as an important event in the technical progress of fuses. The wide range of papers from an international assembly of authors reflects the extensive research which is continuing on what is probably the oldest electrical protective device - the fuse.

In contrast to the detailed academic content of the majority of papers to be presented during this conference, I intend to concern myself with an historical review, together with a somewhat practical assessment of present and future trends. I have concentrated on low voltage fuses because this has been my main interest, although, as the conference papers show, tremendous strides in the design of high-voltage fuses have, and are taking place, and there are now exciting developments in miniature fuses.

The first recorded discussion on fuses was in the early 1880's and in the first edition of the IEE Wiring Regulations in 1882, there is a reference to the fuse.

Regulation II 9 states

> "Every part of the circuit should be so determined that the gauge of wire to be used is properly proportioned to the currents it will have to carry, and changes of circuit from a larger to a smaller conductor should be sufficiently protected with suitable safety fuses so that no portion of the conductor should ever be allowed to attain a temperature exceeding 150^{o}F.
>
> NB.These fuses are the very essence of safety. They should always be enclosed in incombustible cases. Even if wires become perceptibly warmed by the ordinary current, it is a proof that they are too small for the work they have to do and that they ought to be replaced by larger wires".

I am sure all delegates to this conference will heartily endorse the sentiments expressed in the note but it is also an interesting fact that even in the first IEE Wiring regulations a major consideration was the thermal protection of circuit conductors, which, as will be discussed later, has always been, and still is a very important design parameter for the low voltage fuse.

The time scale of 1919 to 1991 given in the title of this paper covers a period from the first edition of the British Standard BS88 'Low-voltage fuses' to the present day.

Table 1 is a summary of the development of this standard from 1919 to the present time and it produces some interesting information on such subjects as :

Breaking capacity
Temperature rise
Minimum fusing current

What this summary does not reflect is the challenges which continuously arose during this period as electrical distribution grew and new applications emerged, testing the ingenuity of fuse designers, who as we know were proved equal to the task. Some examples of novel applications were fuses for warships, aircraft and rotating rectifiers. The shock, vibration and 'g' forces required to satisfy these applications are perhaps the most onerous to which any protective device is submitted and which few, if any, could equal.

The ability to interrupt modest over-currents on highly inductive dc circuits,(e.g., traction applications and aluminium pot-lines) required detailed investigation into the design parameters of fuses suitable for these duties. Here again, satisfactory designs emerged and are in widespread use. The protection of large capacitor banks, particularly series-parallel arrangements, posed particular protection problems in which the ability of the fuse to exhibit effective cut-off even on high discharge currents with a rate of rise of 10^{9}A/sec enabled satisfactory protection to be obtained.

Breaking Capacity

The summary of BS88 requirements (Table 1) shows that the cartridge fuse (or HBC fuse), first included in the 1937 edition, was only tested at I_1 (maximum prospective current). These requirements, both for ac and dc, have grown steadily more searching and more severe as knowledge of the various onerous combinations of voltage, current, and power factor (or time constant) emerged, until, with the present edition which reflects IEC 269, a very comprehensive and very reliable test series is specified which is adequate for the most onerous application requirements.

Let through current and I^2t

Breaking capacity alone however is not sufficient in modern installations: limitation of peak current and let through I^2t is essential for the protection of other components of the electrical circuit, particularly as they become more compact and efficient. The two outstanding examples of associated equipment which require precise protection are semi-conductor devices and the modern compact motor starter.

TABLE 1 Summary of requirements for fuses to BS88, showing how the standard has evolved between 1919 and 1991

Date	Title	Scope	Breaking Capacity	Temperature Rise	Minimum Fusing Current	Dimensions	Other Requirements
1919	Electric Cut-Outs for Low Pressure Type 'O'	Semi-Enclosed Fuses up to 100A	DC Test with no voltage or prospective current specified	None Specified	$2I_n$	Overall Dimensions	None Specified
1931	Electric Cut-Outs Type 'O'	As 1919 Edition	Various prospective currents up to 6500A DC at 260V	Fuse Contact - 60°C Terminal - 28°C	$1.9I_n$	None Specified	None Specified
1937	Electric Fuses up to 80A and 250V to Earth	Semi-Enclosed and Cartridge Fuses up to 800A and 440V	Test at 440V AC 33 kA or 250V AC 16KA, 500A 0.3PF also refers to DC testing at 250V. Recovery voltage 95% of test voltage. Tested in metal enclosure connected to earth via fine wire fuse.	Fuse Contact - 60°C Terminal - 35°C	1.4In for overload and SC protection. Higher values for SC protection only.	None Specified	Shrouding of Contacts Specified
1939	As 1937 Edition	As 1937 Edition	As 1937 but PF graded to duty and time constants specified for DC.	As 1937 Edition	As 1937 Edition	None Specified	As 1937 Edition
1947	Electric fuses for Low and Medium Voltage	Semi-Enclosed and Cartridge Fuses up to 1200A at 600V AC and 460V DC	As 1939 but with introduction of Test Duty 2 and point on-wave closure	Fuse Contacts - 55°C Fixed Terminals - 46°C	Fusing Factor Class P = $1.25\ I_n$ Class Q = $1.75\ I_n$ Class R = $1.75\ I_n$	None Specified	Arc Voltage limit introduced. Discrimination defined.
1952	Electric Fuses for Circuits of Voltage Ratings up to 660V	As 1947 Edition	As 1947 Edition	Fuse Contacts - 55°C Fixed Terminals: Up to 60A - 40°C Above 60A - 46°C	As 1947 Edition	Dimensions Of cartridge fuses included. Reference allocated to dimensions.	Test for determining time current characteristics introduced.
1967	Part 1 : Cartridge Fuses of Voltage Ratings up to 660 V Part 2 : Covers Fuse Holders	Cartridge Fuses Up to 1200A 660V AC and 500V DC	As 1947 but prospective current increased to 80kA	Tested In Test Rig Additional Temperature Rise - 30°C	Class P $= 1.25\ I_n$ Class $Q_1 = 1.5\ I_n$ Class $Q_2 = 1.75\ I_n$ Class R $= 2.5\ I_n$	As 1952 Edition	I^2t described
1975	Cartridge Fuses for Voltages up to and including 1000V AC 1500V DC. Part 1 : General Requirements Part 2 : Supplementary Requirements for Fuses of Standard Dimensions for Industrial Purposes	Cartridge Fuses up to 1250A 1000V AC and 1500V DC	Tests aligned with IEC 269 I_1 I_2 I_3 I_4 & I_5 for AC & DC Arcing Angle specified	As 1967 Edition	Class P and Q_1 Also $I_f = 1.6\ I_n$ $I_{nf} = 1.2\ I_n$	As 1952 Edition	Aligned with IEC269 - 1968
1988	As 1975 Edition	As 1975 Edition	As 1975 Edition	As 1967 Edition	Fusing Factors removed. $I_f = 1.6I_n$ $I_{nf} = 1.25I_n$	As 1952 Edition	Aligned with IEC 269-1986

Perhaps the most significant development during the period under review was the emergence of semi-conductor fuses for the protection of semi-conductor devices with their ever increasing capability and application. The parallel evolution of suitable fuses for the protection of these devices is one of the great success stories and the fuse industry can claim to be a major contributor to the continuing development of the application of solid state devices.

Papers included in this conference reflect the continuing development work on this subject.

The other example, the protection of the modern compact motor starter, is of more recent origin. With the advent of these designs of starters, the question of their proper protection in electrical installations has arisen, mainly due to the need to comply with the requirements of the IEC Wiring Regulations and rapidly increasing demands for safety in electrical installations in many countries (exemplified in UK by the introduction of the "Electricity at Work Regulations - 1989" which is a mandatory document).

The fuse is undoubtedly the best means of providing the most economical and efficient means of protection to motor starters. This fact is widely recognised and the efforts of the Low-Voltage Fuse Committee IEC SC32B/WG8 to determine internationally agreed parameters for let-through current and I^2t for fuses for such applications is to be commended. When this work is complete it will add to the IEC fuse standard limiting values of I^2t and I_p for L.V. fuses. This will improve the standard significantly and greatly assist the world-wide application of fuses to motor circuits, emphasising their superiority over other forms of protection.

Time current characteristics

Another significant achievement of IEC SC32B is the agreement reached on standardised time current characteristics for gG fuses in IEC269. This, coupled with the finalised agreements of I^2t and I_p, will result in complete electrical interchangeability of fuses complying with IEC 269. The benefits of this achievement to the Fuse Industry are very significant, and it is up to the industry to exploit this achievement. For example, the 16th Edition of the IEE Wiring Regulations (which aligns with the IEC Wiring Regulations) includes one set of characteristics for fuses to BS88 (IEC 269-2-2) and five sets of characteristics for MCB's. The five sets of characteristics result from a combination of the types 1, 2 and 3 characteristics of MCB's to BS 3871:1965 and types B and C characteristics of IEC 898 which are now included in a revision to BS3871.

A table of values of Z_s (earth loop impedance) for disconnecting times of 0.1, 0.2, 0.4 and 5 seconds is given for each type of MCB compared with one Table of Z_s values for fuses to BS88:Part 2 and Part 6 (Part 6 fuses are the compact types submitted to IEC 32B for inclusion in IEC269).

Therefore the simplicity of fuse application and interchangeability compares very favourably with the very complicated problem of interchanging MCB's. In fact, it is true to say that despite the great effort which the MCB Industry has made towards dimensional standardisation, the proliferation of time current characteristics, coupled with the other design variations, such as position of arc chutes etc, makes a nonsense of dimensional interchangeability of these devices. This must be to the advantage of the fuse.

Overload Protection

Perhaps the most controversial problem for the modern fuse concerns the overload protection of cables, one which was mentioned in the first edition of IEE Wiring Regulations. This problem is more theoretical than practical because there is no record to suggest that the modern low-voltage fuse properly applied does not provide adequate overload protection to cables. This is particularly true of installations complying with the IEC Wiring Regulations which specify that circuits should be so designed that they are not subjected to repeated overloads of long duration.

A study of the changes to minimum fusing current in the various editions of BS88 shows violent fluctuations, particularly in the earlier editions, until after considerable debate the values of $I_f = 1.6\ I_n$ and $I_{nf} = 1.25\ I_n$ were agreed and included in IEC 269 and reflected in BS88:1988. Even with the agreed value of I_f there is a need for an additional requirement to the fuse standard, called the conventional cable overload test, to prove that the fuse will protect a PVC insulated cable on a current of 1.45 I_z (I_z is the installation rating of cable) because this is a requirement of IEC364 'Wiring Regulations'. This agreement is now under further review in IECSC32B because the new MCB specification includes tripping currents of 1.45 I_n and this has produced a demand from certain countries that the fuse standard should be changed so that $I_f = 1.45\ I_n$.

This situation is further complicated by the fact that in IEC364 the rules of overload protection of cables still make reference to the characteristics of gI and gII fuses. It has already been agreed that these requirements must be reviewed in the light of the agreement now reached on gG fuses which replace the gI and gII types. The international cable overload protection problem is further compounded by the fact that the North American Code requires that overload protective devices shall have a fusing or tripping current of 1.35 I_n.

Against this background there is a simplistic view by some national users that the fuse should have an I_f of 1.45 I_n and various complicated test arrangements are being investigated in an attempt to achieve this objective and solve a 'non-problem'.

A review of the trends in cable insulation and overload protection requirements over the period covered in Table 1 produces some interesting information. Initially vulcanised rubber was used for low voltage cable insulation and the minimum fusing requirement was $\hat{=}$ 2 I_n. This was based upon the use of semi-enclosed fuses and is still valid today for the protection of PVC insulated cables by semi-enclosed fuses. Obviously the thermal capabilities of the cables were not fully utilised by this requirement.

With the introduction of the cartridge fuse and the achievement of lower minimum fusing currents without thermal penalties at rated current, the value was reduced to 1.4 I_n but later increased to 1.75 I_n, as higher temperature rises were permitted on terminals. It is not clear why such a large variation was permitted but what is certain is that with the introduction of PVC insulated cables the value acceptable for close protection of these cables was agreed as I_f = 1.5 I_n. Subsequent discussion in IEC32B resulted in agreement on the value of 1.6 I_n. This was a compromise based on existing fuse characteristics in the various national systems. The IEC364 requirement of I_f = 1.45 I_z permits fuses with an I_f = 1.6I_n to comply with the overload protection rules of IEC364 without the necessity of derating the cable. It utilises the fact that the I_z of a cable, is with few exceptions, larger than the I_n of the protective device. Therefore in practice the fuse with I_f of 1.6 I_n is used on an equal basis to the MCB for the overload protection of PVC insulated cables.

If we review the North American requirement of I_f = 1.35 I_n it should be noted that there is an exception which permits the use of the next highest rating of fuse if the cable and fuse-rating do not concide, thus effectively providing a much higher ratio between the I_f of the fuse and the installation current rating of the cable. I presented a paper on this subject to the 1984 International Fuse Conference in Trondhiem. This fact is being taken into account in the IEC32B discussions aimed at including some types of North American fuses into IEC269.

A further change is now taking place in the insulation used for low voltage cables. There is an increasing trend towards the use of cables with thermo setting insulation (XLPE) in preference to PVC in general wiring practice. Certainly in UK there is an increasing use of this type of cable which can run at 90°C compared with 70°C for PVC. Because of its greater fire resistance and reduced toxicity compared with PVC, this cable is being supplied without economic penalties because cable manufacturers, like other product manufacturers, have to consider the safety aspects of installations and their legal liabilities under modern safety regulations. There is no doubt that the use of thermo-setting insulation considerably reduces fire and toxicity risks, and cables so insulated are in increasing demand in a number of countries.

The problem of its increasing use to LV equipment manufacturers will in future not lie with the question of overload protection, but with the possible derating of cable or equipment required to avoid overheating in normal service. This is because all LV equipment is rated on the basis of the use of 70°C PVC insulated cables and terminal temperature-rises at rated current are limited to 70°C. The popular use of cables with 90°C thermo-setting insulation will bring with it the need to consider either the derating of equipment or the decision that the extra thermal capability of the cable can only be used for higher ambient situations. There is already a warning in the IEC Wiring Regulations concerning the use of higher temperature cables with low voltage equipment.

This aspect should figure largely in the future discussions of IEC TC64 when reviewing the rules for overload protection of cables. These may well reveal that an I_f = 1.6 I_n is a satisfactory value for the future, and there is certainly no case for making a further intermediate change to an I_f = 1.45 I_n to satisfy the simplistic view mentioned earlier. I cannot stress too strongly the importance of an effective presence from the Fuse Industry in this most influential IEC TC64 Committee because their decisions will affect future practice. I hope that the various national delegates at this conference will bear this in mind.

Alternative Protective Devices

In addition to the technical challenges facing the fuse arising from new applications and new materials, there is the challenge of alternative devices for the more popular applications, mainly the MCB and MCCB. There is no doubt that the MCB is the most popular device in new domestic installations because it is more user friendly than the fuse, and the modern current limiting MCB can quite easily cope with the fairly simple requirements of most domestic installations. In a number of countries, certainly in UK, it has apparent advantage over the semi-enclosed fuse which it is replacing. The increasing demand for residual current protection against electric shock is also more readily met with an MCB/ RCD package than with a fuse/RCD package.

There is now an increasing use of MCB's in industrial applications but in this area there are many pitfalls for the MCB. Inadequate breaking capacity and the inability to provide proper protection to motor circuits are examples. The first problem can and is dealt with by proper co-ordination with the back-up fuse. This is another application problem which should be thoroughly investigated. The second can only be solved by accepting damage to the starter on certain faults and the use of a cable of the same current rating as the MCB, which is a considerable economic disadvantage.

If the Fuse Industry is to fight back against these threats from alternative devices it must speak out more forcefully about the benefits of fuses.

The one thing that the MCB Industry has done very effectively is to advertise its products: this cannot be said of the Fuse Industry. As electrical installation practice becomes more precise and safety rules are more rigourously enforced, the advantages of fuses should weigh more heavily with the installers and users. For example :

1. Full electrical and physical interchangeability with fuses of any make complying with IEC269 and a given set of dimensions.
2. Simplified planning of discrimination and co-ordination with final decision on fuse dimensions made at a later date.
3. Unequalled limitation of damage at seat of fault. Now a very important consideration from the viewpoint of operator safety.
4. Discrimination with a ratio as low as 1.6:1 between major and minor fuse ratings.

With regard to 1 and 2, as stated earlier the MCB cannot be readily interchanged electrically because of the variety of characteristics available and the various forms of arc dispersion used in the standardised dimensional package and the user is effectively tied to one make of MCB.

With regard to 3, this is of great importance even within the breaking capacity of MCB's but absolutely essential in situations of high fault level.

With regard to 4, no mechanical tripping device can match this performance and it can produce many economies in circuit lay-out.

In the domestic application, fuse isolators dimensionally interchangeable with MCB's are emerging and becoming popular for those circuits where the MCB cannot provide the same reliability as the fuse. In the industrial sector the emergence of compact ranges of fuses for the 240/415V applications has offset one of the criticisms of low voltage industrial fuses, i.e., the relatively large dimensions compared with MCB's. Fuse combination units utilising these compact fuses, having dimensions comparable with MCCB's, are already on the market and increasing in popularity (see Figs 1 & 2). This trend is happening with all dimensional systems of fuses.

The Future

There is no doubt that, despite the improvements in the technology of low-voltage fuses, the threat from the MCB and MCCB in popular applications is serious. The work in IEC32B to standardise the characteristics of fuses has made fuse application much easier. This point must be made forcefully to the Installer and User.

Thought must continue to be given to ways of making the fuse more 'user friendly': for example, by ensuring safe and simple interchange of fuse-links by providing adequate shrouding of live parts. It is no longer acceptable to provide less shrouding on fuses for use by authorised persons than that provided on fuses for use by unskilled persons.

Modern safety legislation is producing an increasing demand for a high degree of safety to Operators in all situations.

One area of application which requires further exploration is the combination of an automatic overload tripping device with the fuse to combine the benefits of both the fuse and circuit-breaker. This is not a new idea with MCCB's but the problems of protecting modern motor circuits with MCCB's gives a new impetus to this arrangement and it could also apply to Fuse/MCB combinations. The economic benefits of compact fuses and fusegear is the subject of some papers at this conference and perhaps this theme can be developed further.

I have concentrated on low-voltage fuses with particular emphasis on practical aspects of applications, past, present and future. A similar picture could be presented on high-voltage fuses, where technical improvements are emerging at an impressive pace. The same can be said about the miniature fuse developments. All of these subjects will be discussed at length during this conference, from which we will gain further information and incentive to improve the technical excellence of the fuse and also improve appeal to the user.

Considerable steps along these twin routes have already been observed since the first conference and the subject matter of this conference indicates that progress will continue. It is however essential to recognise the competition faced in the international electrical industry from other protective devices and we must ensure that the achievements which have and will be made are well publicised so that fuses and fusegear will continue to enjoy the popularity they have had in the past. I look forward, as you all do, to the presentations and discussions which will take place during this conference. I am sure they will be both informative and challenging and hopefully will further promote the benefits of the fuse which, as long ago as 1882, was described as being "The Very Essence of Safety".

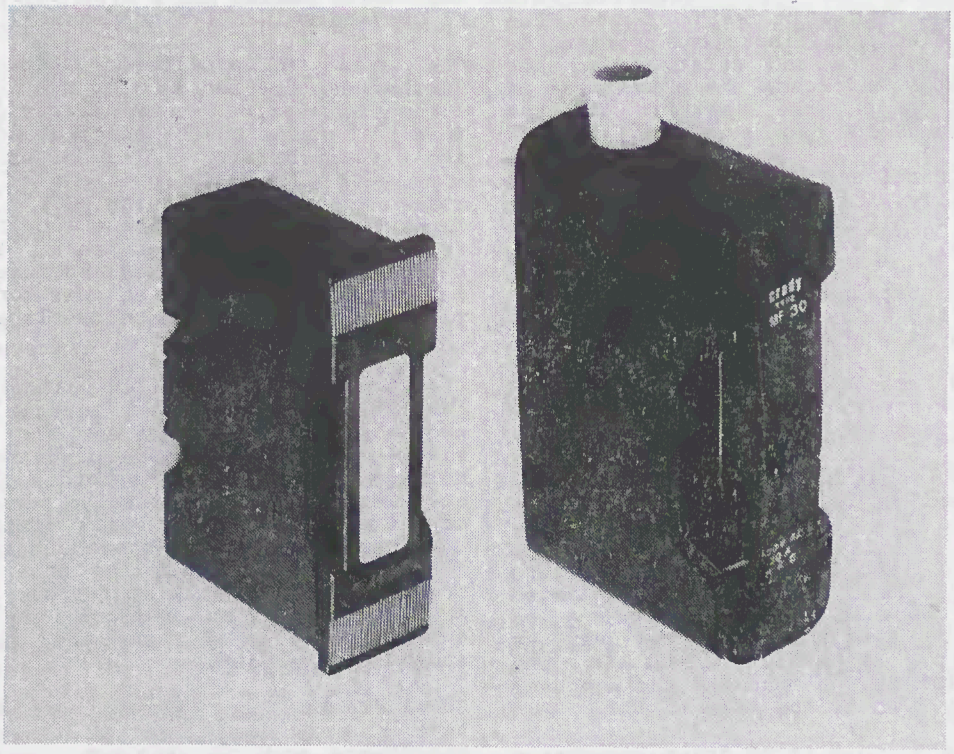

Fig.1 Comparison of 32A compact fuse (BS88:Pt 6) with 32A conventional fuse (BS88:Pt 2)

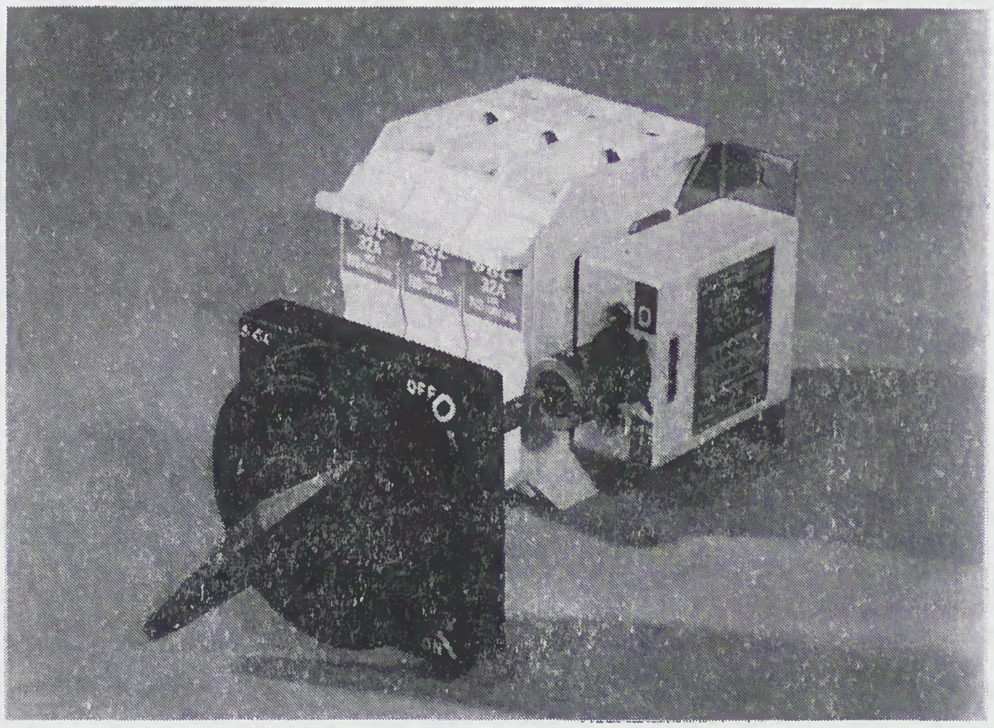

Fig.2 Compact 32A fuse combination unit with fuse-links to BS88:Pt 6

Session 1

FUSE DESIGN I