21st CENTURY GUIDANCE USING INTERNATIONAL STANDARDS

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Abstract: The paper highlights the considerable amount of application guidance, which can be found within the International Electrotechnical Committee, IEC, Fuse Publications. Although there are some "stand-alone" Application Guides either on fuse systems or specific topics, additional information can be found within the Fuse Standards including Annexes. Salient information is brought together with respect to low voltage, miniature and high voltage fuses, and it shows many common principles in all three areas. The paper thus gives a framework for further reading to assist in the understanding of the use of fuses in modern installation applications.

Keywords: electric fuse, application guide, fuse standard.

1. Introduction

Fuses [1] have been used for over 100 years and can be considered as mature products, with the exception of modern developments such as "chip fuses", fuses for the protection of power semiconductors and full range high voltage fuses. Significant progress has been made on International Standardisation on fuse performance and restricting dimensional variants. The vital "SECURE" role of fuses in circuit protection, their performance and application are not generally covered in technical educational establishments and "taken for granted". This presents problems for the new generation of electrical technicians, installers, planners and specifiers.

The main task of IEC Standards is to formulate test requirements to cover a wide variety of needs. Having achieved this, the fuse Standards are now mostly finalised rather than subject to radical new revision. However, recently attention has been focussed on "Application Guides" and information to assist the user. In addition, within the IEC Fuse Standards, particularly in the Annexes, there is a lot of useful information relating the standardised test requirements to practical applications.

Such information is often overlooked and this paper will highlight and bring together such information and steer the user to useful application information. Although the information in the paper will relate to specific Standards or Guides, in many cases the same principles can be applied to other fuses. The paper will cover fuses in the following areas:

- Low Voltage fuse types.
- Semiconductor Protection fuse types
- Miniature fuse types
- High Voltage fuse types
- Temperature Rise considerations

2. Low Voltage Fuses

2.1 Scope

IEC 60269 Standards are applicable to fuses incorporating enclosed current-limiting fuse-links with rated breaking capacities of not less than 6kA, intended for protecting power frequency a.c. circuits of nominal voltages not exceeding 1,000V or d.c. circuits of nominal voltages not exceeding 1,500V.

IEC 60269-1:	General
IEC 60269-2:	Supplementary requirements for fuses for use by authorised persons
IEC 60269-2-1:	Examples of standardised fuses
IEC 60269-3:	Supplementary requirements for fuses for use by un-skilled persons
IEC 60269-3-1:	Examples of standardised fuses.
IEC 60269-4:	Supplementary requirements for fuse-links for the protection of semiconductor devices.
IEC 60269-4-1:	Examples of standardised fuse-links.

Fuse-links for the protection of semiconductor devices are covered in Section 3.

2.2 IEC 60269-1

2.2.1 I^2t Calculations (Annex B)

For 50Hz a.c. symmetrical circuits, it is not possible to obtain a pre-arcing time of 0.01 seconds due to the heating and cooling of the element during the first half cycle [2]. However, pre-arcing I^2t values may be found useful in the short-time region and are specified in Table 6 of IEC 60269-1. Annex B gives a method of determining these values from test points more easily obtained and for smaller current ratings in a homogeneous series.

A future amendment Annex B3 is in the final stages of preparation, showing how to estimate the operating I^2t at reduced voltage.

The operating I^2t values can be estimated at lower voltages than those measured during tests 1 and 2 of Table 12a, using the following formula:

$$\text{Operating } I^2t \text{ at reduced voltage } V_r = \left\{\frac{\text{Operating } I^2t \text{ at test voltage } V_t}{\text{prearcing } I^2t}\right\}^{V_r/V_t} \times \text{prearcing } I^2t$$

The experts on the IEC fuse committee refer to this as the "Henry Turner Formula" in memory of one of the pioneers in fuse technology.

2.2.2 Ambient Temperature and Surroundings (Annex D)

This gives some general guidance for example:-

An increase in ambient temperature will produce a similar temperature rise and therefore a predictable increase in actual temperature of the fuse. If this exceeds any specified limits, then a de-rating will be required.

The effect on fusing and non-fusing current will be minimal.

The installation conditions such as enclosure, mounting surface, adjacent heat generating devices and cross-section and insulation conductors, can affect the operating conditions.

2.3 Application Guide, IEC 61818TR

2.3.1 General

By the time this ICEFA Conference is held, this Technical Report should have been published. It gives information on the application of fuses, which are not always covered, as well as important facts, which are sometimes difficult to locate in Standards. The guide also makes reference to other IEC Standards and publications.

2.3.2 Benefits

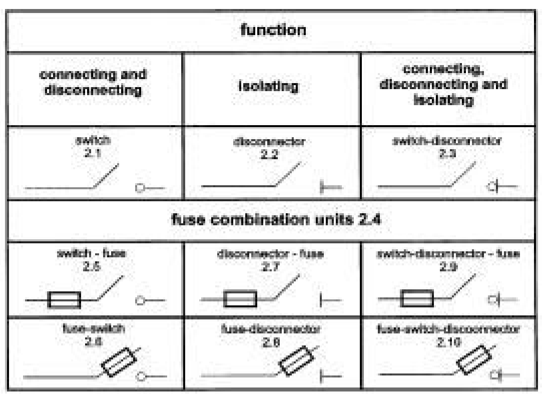
This section summarises the important benefits of current-limiting cartridge fuse-links. Most of these benefits are well documented. However, the following are considered to be of topical interest.

- Safe, Silent Operation – no emission of gas, flames, arcs or other materials when clearing the highest levels of short circuit currents. In addition, the speed of operation at high short circuit currents, significantly limits the arc flash hazard at the fault location. The award winning paper [3] in the previous ICEFA Conference covered the subject of Arc Flash Hazard. This is becoming of increasing concern, particularly in the USA.
- Improved Power Supply Quality – current-limiting fuses interrupt high fault currents in a few milliseconds, minimising dips in system supply voltage. This is important for sensitive electronic equipment and components.
- The ability of the fuse to handle very high fault current allows for easy and inexpensive system expansion without the need to upgrade protection.

2.3.3 Fuse Combination-Units

It is important to differentiate between the various types of fuse combination-units, see Table 1 and note the modern terminology, replaces "isolator" by "disconnector".

Table 1. Definitions and symbols of fuse-combination-units



2.3.4 Fuse Selection and Markings

Types of low voltage fuses are designated by two letters, as shown in Table 2.

Table 2. Fuse application

Type	Application (characteristic)	Breaking Range
gG	General purpose mainly for conductor protection	Full range
gM	Motor circuit protection	Full range
gN	North American general purpose for conductor protection	Full range
gD	North American general purpose time delay	Full range
gR, gS	Semiconductor protection	Full range
gU	Wedge tightening fuse for Utilities	Full range
gL, gF, gI, gII	Former type of fuse for conductor protection (replaced by gG type)	Full range
aM	Short circuit protection of motor circuits	Partial range (back-up)
aR	Semiconductor protection	Partial range (back-up)

- The first letter describes the breaking ranges: **a - partial range** : all currents between the lowest current indicated on its operating time – current characteristic and its rated breaking capacity.
  g - full range : all current which cause the melting of the fuse element up to its rated breaking capacity.
- The second letter describes the application (characteristics or utilisation category).

This information is "buried" within the Standards and is difficult to locate.

2.3.5 Wiring Regulations

The guide highlights the principles of conductor protection both in accordance with IEC 60364-5-52 and the National Electric Code in the USA, thus covering most global market requirements.

The subject of protection by automatic disconnection of supply in IEC 60364-4-41 is illustrated covering TN, TT and IT systems. Examples are given showing the calculation of the "fault loop impedance".

2.3.6 Power Factor Correction Capacitors

A useful section is included on a subject not widely found on low voltage fuses. This recommends a fuse-link value of 1.6 to 1.8 times the rated current of the capacitor unit or capacitor bank and takes into account the following:

- Inrush currents must not melt or deteriorate the fuse element.
- Potential over-currents must not lead to premature operation of the fuse-links.

2.3.7 d.c. Applications

Guidance is given on this subject, which is generally poorly documented. This shows the d.c. voltage rating is dependent on the time constant and that the operating times can vary considerably with the time constant.

2.4 Fuses and Contactors/Motor Starters

2.4.1 General

This is an important application area for fuses. In view of their high current limiting properties, maximum utilisation of contactors/motor starters can be achieved by fuses compared with other circuit interrupting devices. In 1996, IEC 611459 was published, this was produced by IEC low voltage working group with input from a contactor/motor starter expert. The principles of co-ordination are also summarised in IEC 61818TR (2.3)

2.4.2 IEC 60947-4-1

IEC 611459 outlines the tests specified at three levels of prospective current.

I_c crossover current (intersection of the mean time/current characteristic of the fuse and overload relay of the starter)
I_r Intermediate fault current
I_q Rated conditional short circuit current.

The criteria for co-ordinating these three currents are described in detail and the publication then illustrates co-ordination methods to give type 2 co-ordination for I_q and I_r.

2.4.3 Survey of Type Testing

A survey is presented of the rated currents, I^2t values and cut-off currents of fuses correctly chosen according to the ratings of the starters they protect, based on the results of successful type testing throughout the world. The studies revealed that there is no major difficulty in achieving satisfactory co-ordination at the most exacting of the levels with modern contactors.

Examples of typical fuse-link ratings used for motor starter protection are shown in table 3 for an average motor-starting duty of a motor full-load current of 28A. This illustrates how the type of fuse-link can influence the optimum current rating.

Table 3. Fuse types and ratings

Fuse Type	Origin	Suitable Rating
gG	General purpose IEC fuse	63A
gM	Motor circuit fuse	32M63
aM	Back-up fuse	32A
gN	North American general purpose fuse	70A
gD	North American time-delay fuse	40A

3. Semiconductor Protection

3.1 General

Fuse-links for the protection of semiconductor devices were introduced in commercial numbers some 40 years ago and still evolving to meet the developments in semiconductors and their applications. Manufacturers specialising in the fuse-links, supply comprehensive information and there have been many papers written on the subject at previous ICEFA conferences.

Within the IEC Standards there are two useful references for the application of fuse-links for semiconductor devices.

- Appendices of IEC 60269-4
- IEC 60146

3.2 Appendices of IEC 60269-4

3.2.1 Object

The object of this guide is to explain the performance to be expected from the fuse-links in terms of their ratings and in terms of the characteristics of the circuits of which they form a part, in such a manner that this may form the basis of the selection of the fuse-links.

In essence it relates the standardised test conditions to practical situations. Appendix A covers the following:-

- Current carrying capabilities
- Voltage characteristics
- Power dissipation characteristics
- Time current characteristics
- Breaking Capacity
- Commutation

Attention is drawn to the effects of “cyclic” loading or repetitive duty currents. For both rated and overload currents under such conditions fuse-links should not be operated too close to their time-current characteristics. The concept of a conventional overload curve is introduced, see Fig. 1. (X and Y are points of verified overload capability)

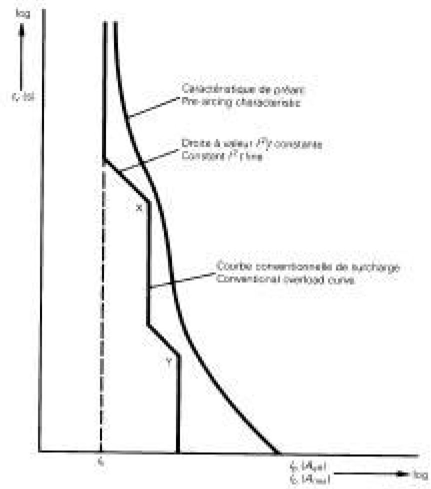


Figure 1: Conventional overload curve

In practice manufacturers supply multiplying coefficients for common cyclic duties to simplify the assessment in practical application.

Appendix A also draws attention to the effects of frequency and d.c. conditions, which can significantly influence the performance.

Appendix B gives a survey or checklist of 17 items on information to be supplied by the manufacturer in his literature (catalogue).

3.3 IEC 60146

This application guide covers the protection of semiconductor converters against over currents by fuses.

The object of the guide is to advise on the specific fuse features and on the specific converter features, which are to be observed to ensure correct application of semiconductor fuses in converters and to give specific recommendations for trouble free operation of converters protected by fuses.

The guide is limited to commutated converters in single way and double way connections for non-regenerative and regenerative loads. It covers the voltage capacity required for fuses in the above connections, for example in a regenerative load in a three-phase double-way connection for a conduction through (shoot through) or firing fault in practice the rated a.c. voltage of the fuse should be greater than

$$U_{ac} + \frac{U_{dc}}{\sqrt{2}}$$

In addition, the fuse should be capable of clearing U_{dc} with the time constant of the fault circuit.

4. Miniature Fuses

4.1 Scope

IEC 60127 Standards relate to miniature fuses for the protection of electrical appliances, electronic equipment and component parts, thereof normally intended to be used indoors.

IEC 60127-1	:	General
IEC 60127-2	:	Cartridge fuse-links
IEC 60127-3	:	Sub miniature fuse-links
IEC 60127-4	:	Universal modular fuse-links, UMF.
IEC 60127-5	:	Guide for quality assessment
IEC 60127-6	:	Fuse-holders
IEC 60127-10	:	User guide

A miniature fuse-link is an enclosed fuse-link of breaking capacity not exceeding 2kA and which has at least one of it’s principal dimensions not exceeding 10mm. (Principle dimensions are length, width, height and diameter).

Cartridge fuse-links to IEC 60269-2 are nominally 5 x 20 mm or 6.3 x 32 mm and up to 250V a.c.

The case (body) of a sub-miniature fuse-link has no principle dimensions exceeding 10 mm. The standardised terminations are either radial or axial leads.

Universal modular fuse-links are adapted for direct electrical connection to printed circuit boards or other conductive substrates, incorporating features designed to provide a degree of interchangeability where necessary, the fuse-links can be through hole or surface mount. Standardised products specify the terminal spacing.

IEC 60127-5 is a guide for quality assessment of miniature fuse-links. It gives a guide for tests for assessing the quality of miniature fuse-links, other than type tests, for the case where there is no complete agreement between the user and the manufacturer on what such tests should be. It provides guidelines and limits generally acceptable for quality control purposes by large scale users and manufacturers of miniature fuse-links, typically of lot sizes of 10,000 or more.

IEC 60127-6 covers fuse-holders up to 16A, accepting cartridge fuse-links according to IEC 60127-2 and sub miniature fuse-links according to IEC 60127-3. It covers a wide variety of unexposed or exposed fuse-holders, for example:-

- Types of mounting
- Methods of fastening
- Methods of insertion of fuse carrier into fuse base
- Types of terminals
- Protection against electric shock

4.2 User Guide

This user guide, IEC 60127-10, was published in January 2002. The object is to introduce the user to the important properties of miniature fuse-links and fuse-holders and to give some guidance in applying them.

The properties of miniature fuses are highlighted:-

- Protecting upstream, isolating downstream and diagnosing fault location
- Wide range of fuse-links and holders
- Lower cost and small dimensions
- Wide range of tamper-proof and reproducible characteristics
- Discrimination (selectivity)
- Safe and reliable

Attention is drawn that the characteristics of fuses conforming to other Standards, such as CSA – C22.2 No. 248.14 or UL 248-14, could be quite different from the IEC 60127 characteristics. Additionally, these other Standards may not specify the same characteristic definitions or precise time gates. Accordingly, the definitions of speed of operation, FF, F, M, T, TT are left to the individual fuse manufacturers and can vary widely.

Unlike power systems it is often difficult to calculate the maximum potential fault current of a circuit/application. Often it is an assumed theoretical value, assigned by a safety agency. In some cases, the suitability of a fuse's breaking capacity is determined by testing the fuse in the end product, under short circuit conditions.

The guide has tables of standardised fuse-links in IEC 60127-2, 3 and 4, giving salient properties for ease of reference.

Some good general guidance is provided on fuse selection and is usually dictated by three basic categories of criteria:

a) Electrical requirements of the application, including I^2t and d.c. requirements.
b) Conformance to published safety standards.
c) Mechanical properties/physical size.

Attention is drawn to the selection of the thermal rating of the fuse holder. It is based on the maximum power acceptance of the fuse holder, taking into account the local thermal conditions. The maximum **sustained** dissipation of the fuse-link shall be less than, or equal to, the admissible power dissipation of the fuse holder.

The guide advises that consideration should be given when fuse-links are used at extra low voltages, i.e. the range of 10V, especially for fuse-links of low rated current, see Fig. 2.

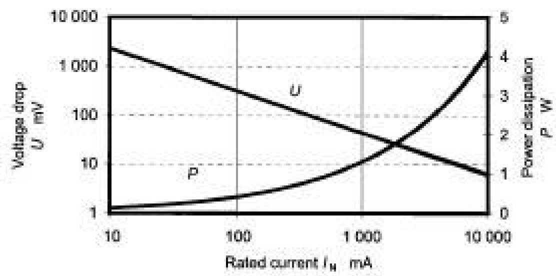


Fig. 2: Power dissipation P and voltage drop U according to rated current I_n.

Due to the non-linear increase of the voltage drop when the fuse element approaches melting point, care must be taken to ensure that there is sufficient voltage available to cause the fuse-link to operate when an electrical fault occurs.

5. High Voltage Fuses

5.1 Scope

High Voltage fuses covers all types of fuses designed for use outdoors, or indoors on alternating current systems of 50Hz and 60Hz and of rated voltages exceeding 1,000V:-

IEC 60282-1 : Current Limiting Fuses
IEC 60282-2 : Expulsion Fuses

In addition, there are three publications which have been produced and maintained by the IEC High Voltage Fuse Committee:-

IEC 60549 : External protection of shunt capacitors
IEC 60644 : Motor circuit applications
IEC 60787 : Transformer circuit applications

5.2 Current Limiting Fuses

The 2002 edition of IEC 60282-1 was editorially changed, so the clause numbers aligned with the switchgear Standards, thus making it more user friendly.

Application Guides are given in Clause 8 and presents suggestions on application, operation and maintenance as an aid in obtaining satisfactory performance with high voltage, current-limiting fuses

It cautions that high voltage fuses should be handled with at least the same degree of care as any other precision made item of equipment (such as a relay). In addition, if during internal installation and service, fuses are subjected to severe mechanical stresses, then special tests may be agreed by the user and manufacturer of the fuses and the switchgear. For switch fuse combinations, see IEC 60420.

A section includes the selection of the rated current of the fuse-link, although as will be seen in 5.4, 5.5 and 5.6, the chosen rated current for the fuse-link in applications are generally dictated by transient phenomena in the circuit related to switching, such equipment as transformers, motors or capacitors.

However, fuse-links are inherently and invariably mounted in more adverse thermal conditions than the standardised test arrangements, for example, in enclosed fuse "pods". A typical de-rating can be 25% of the rated current, so in such applications the service current carrying capability of the fuse-link has to be assessed.

The selection of the rated voltage should be selected with regard to:-

- **Three Phase Solidly Earthed Neutral Systems** the highest line-to-line voltage
- **Single Phase Systems** 115% of the highest single phase system voltage
- **Three Phase Isolated Neutral Systems** testing is necessary at higher than the 0.87 times the voltage rating of the fuse, as specified in the Standard
- **Capacitive currents** in phase-to-earth faults

With regard to operation, special care should be taken to see that the fuse-link is securely locked in the service position. It is also advisable to remove and insert fuses when in an off-load or de-energised condition.

Section 8.3.4 covers selection according to class: backup, general purpose or full range and minimum breaking current.

The Standard has a number of "normative" and "informative" annexes. The "informative" annexes are:

Annex B: Reasons which led to the choice of TRV (transient recovery voltage) values for test duties 1, 2 and 3.
Annex C: Preferred arrangements for temperature rise tests of oil-tight fuse-links in switchgear.
Annex D: Types and dimensions of current limiting fuse-links specified in existing National Standards.
Annex F: Determination of de-rating when the temperature surrounding the fuse exceeds 40^{o}C. This gives a worked example that is worthy of examination and could well apply to low voltage installations.

5.3 Expulsion Fuses

Application Guides are given in Clause 11 of IEC 60282-2 and presents suggestions on the application, operation and maintenance as an aid in obtaining satisfactory performance with expulsion and similar fuses.

The reader is reminded that drop-out fuse carriers that remain in the open position for prolonged periods of time, may accumulate water and pollution in their internal parts, which may result in the degradation of their operational properties.

Fuses should be mounted in the position specified by the manufacturer and precautions taken for the high noise level and emission of hot gasses. Like current limiting fuses, the current rating of expulsion fuses are generally dictated by transient current phenomena in the circuits they are protecting.

There are three classes of fuses based on the protection of the associated transformers, capacitor banks and feeder circuits.

Class A: Remotely placed from major substations.
Class B: Close proximity to major substations.
Class C: Close proximity to major substations without parallel-connected loads.

Some National Standards include additional requirements, including special applications including:

- Spark production tests
- Robustness
- Forces required to open and close drop-out fuses
- Current surge withstand tests.

- The standard includes three “informative” annexes.

Annex A: Reasons for the selection of breaking test values
Annex B: Typical fuse-link dimensions
Annex C: Operating rods

5.4 Transformer Circuit Applications

The most common application for high voltage fuses is for transformer circuits. The object of the Application Guide IEC 60787 is to satisfy criteria for co-ordination with other circuit components and to give guidance with particular reference to their time/current characteristics and ratings. The guide covers current limiting fuses to IEC 60282-1 and not expulsion fuses to IEC 60282-2.

The characteristics relating to the protection of a HV/LV transformer circuit is shown in Fig. 3.

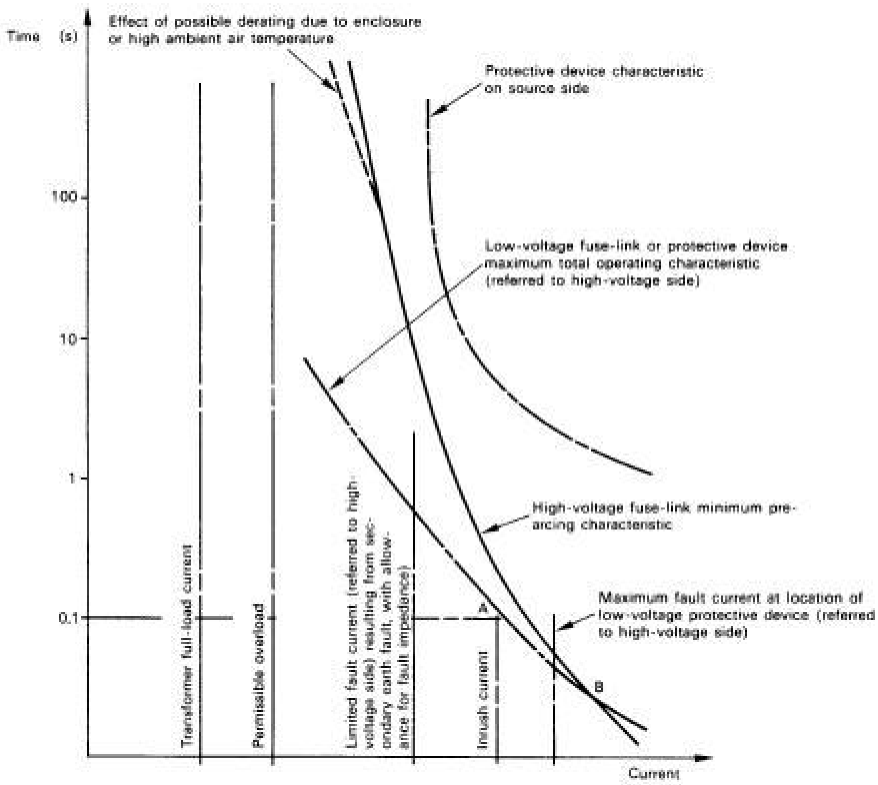


Fig. 3: Factors to be considered which are discussed in the guide.

The two major factors which determine the fuse-link rating are:-

- Transformer in-rush withstand current. Fuse-links require relatively high operating current in the 0.1 second region. For practical purposes this may be taken from 10 to 12 times the highest continuous current associated with the actual transformer size for duration of 0.1 seconds.

- Transformer permissible overloading

This can be up to 150% for a few hours and although the fuse-link current rating chosen for in-rush withstand is usually much higher than the full load current of the transformer, it has to be greater than the permissible overloading under abnormal service conditions. Such service conditions must also cover fuse-links mounted in an enclosure and for high ambient temperature. For example in some cases the fuse-link can be de-rated up to 25% (see 5.2).

5.5 Motor Circuit Applications

IEC 60644 gives additional pulse withstand tests and also guidance on selection.

In the case of motor circuits, the requirements are somewhat different to those in transformer circuits and special motor circuit fuse-links are marketed. These requirements include:

- Relatively high operating current (slow operation) in the 10 second region to withstand the motor starting current .
- Relatively low operating current (fast operation) in the region below 0.1 seconds to give short circuit protection to associated switchgear devices, cables and motors and their terminal boxes

The additional pulse withstand tests first introduces the ‘K’ factor. The ‘K’ factor defines an overload characteristic to which the fuse-link may be repeatedly subjected under specified motor starting conditions and other specified motor operating overloads, without deterioration.

The overload characteristic is obtained by multiplying the current on the pre-arcing characteristic by ‘K’ (less than unity).

This is very similar to the concept of overload characteristics for the protection of semiconductor devices (see Section 3.2.1).

Two sequences of withstand tests are specified and both are based on the pre-arcing current at 10 seconds.

5.6 External Protection of Capacitors

IEC 60549 is a Standard covering fuses which are intended to clear either faults inside a capacitor unit to permit continued operation of the remaining parts of the bank in which the unit is connected (unit fuses) or faults on the whole capacitor bank to isolate the bank ‘on the system’ (line fuses).

The Standard advises that the rated current of the fuse shall be at least 1.43 times the rated current of the capacitor. This takes into account harmonic currents and capacitor tolerance, but does not take into account the effects of charging in-rush currents, which may require a further increase in current rating of the fuse.

The tests in the standard cover:

- Capacitive breaking current
- Discharge (endurance and withstand)

6. Temperature Rise

IEC 60943 is a technical report covering guidance concerning the permissible temperature rise for parts of electrical equipment, in particular for terminals and was prepared by the Fuse Committee. It is more of a “classical” reference document covering the temperature rise in electrical assemblies, generally and not specifically to fuses The report is split into two sections:

- Theory
- Applications

and these are supported by additional information in the annexes.

The report is intended to supply: General data on the structure of electric contacts and the calculation of their ohmic resistance.

- The basic ageing mechanisms of contacts.
- The calculation of the temperature rise of contacts and connection terminals.
- The maximum “permissible” temperature and temperature rise for various components, in particular the contacts, the connection terminals and the conductors connected to them.
- The general procedure to be followed by Product Committees for specifying the permissible temperature and temperature rise.

7. Conclusions

The paper describes how the guidance given in the International Fuse Standards will assist the user to ensure that the SECURE over-current protection of electrical circuits is sustained into the twenty-first century. Please remember SECURE protection is:-

S Safe
E Economical
C Current-limiting
U Universal
R Reliable
E Effective

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