Tutorial and Guide for HV Fuses, IEEE and IEC Cooperation

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***Abstract*—In an unusual display of cooperation, the IEEE and IEC have worked to not only combine application information on typical North American and European type applications in two almost identical documents, but also to capture significant amounts of high-voltage fuse knowledge in the form of a tutorial, that does not require any extensive prior fuse knowledge. How this came about will be discussed as well as how the documents convey basic information about how HV fuses work and how they are coordinated.**

***Keywords*-- construction, coordination, fuse, high-voltage, operation.**

I. INTRODUCTION

At ICEFA in 2011 [1], the author reported that the HV Fuses subcommittee, SC32A, of the IEC Technical Committee on fuses was preparing a Tutorial and Application Guide ("Guide" for the rest of this paper) that included extensive input from IEEE HV fuse application documents. This came to fruition with the publishing, in 2013, of IEC Technical Report 62655. As was originally hoped, IEEE is now adopting this document, with certain changes, to replace the IEEE HV Fuse application guides IEEE Std C37.48 and C37.48.1. This paper will describe how such cooperation was achieved, summarize the content of the Guide, cover the basic construction and operational details of common HV fuse types, and give an example of how the Guides provide coordination rules for fuses in various applications. It should be noted that while the author started his career (50 years ago, in 1969) working with LV fuses, he has for the last 40 years worked almost exclusively with HV fuses. Therefore, the observations of this paper refer to HV fuses only.

There are a number of bodies that have developed HV fuse standards around the world. While cooperation between IEC and IEEE may be assumed as normal, this is not always the case. Clearly IEC should represent world-wide fuse practice, but as has been observed at ICEFA in the past [2], while "North American practice" is recognized as distinct from "European" practice in certain tables (preferred voltages for example), the substance of the standards regarding testing and, in particular, application guidelines have not always recognized the differences. As a result, the separately developed IEEE standards, while looking to IEC for general guidance, have often deviated significantly in an attempt to better reflect North American usage. This deviation is more than the "in country clauses" added by some IEC members when adopting IEC standards. Of course, other countries have also written their own standards when local requirements have been pressing (e.g. Australia adopting strong requirements concerning cutout exhaust gasses). However, because IEEE is an international organization (57% of its members reside outside the USA) and their standards are widely recognized around the world, there tends to be competition between IEEE and IEC sometimes leading to copyright disputes. For the last 40 years the author has attended IEEE fuse meetings and for 25 years IEC fuse meetings. As he progressed to leadership positions (recently Chair of both the IEEE and IEC HV Fuses Subcommittees, simultaneously) he has attempted to influence both groups to better reflect true worldwide applications, and significant differences between the two groups of HV fuse standards have been shrinking.

II. HISTORY – A TALE OF TWO DOCUMENTS

Work to develop the first HV Fuse "tutorial" type of document (IEEE Std C37.48.1) began because, in the 1970's, a new type of current-limiting (CL) fuse, the "full-range" fuse, joined the existing CL types "backup" and "general-purpose". In brief, while CL fuses excel at interrupting very high currents, their limitations when it comes to interrupting lower currents results in various classifications. Backup CL fuses can only interrupt currents higher than a defined value (rated minimum interrupting [breaking] current). General-purpose fuses can interrupt quite low currents, compared to backup fuses, but for convenience were tested at a current corresponding to a melting time of one hour. While this was acceptable for older fuse designs, new designs and applications, particularly at elevated surrounding temperatures in enclosures, required a new category with even lower current interrupting ability, termed "full-range" fuses. Unfortunately, since there was no standard definition and testing in IEEE or IEC standards, designs from different manufacturers could have different capabilities. IEC was contemplating a full-range fuse definition, and a US position was required. After some debate as to the need for a definition and testing, the IEEE HV Fuses Subcommittee set up a task force in 1986 to investigate this. The task force commissioned a survey of users and specifiers to determine if there was indeed confusion concerning the different fuse types, and whether changes to the standards were needed. The result of the 1988 survey was that, apparently, HV fuses were not well understood. For example, less than half of the responders (only 41.7%) knew that a backup fuse could only interrupt currents down to the "Current specified by the manufacturer and marked on the fuse" and knowledge concerning general-purpose and full-range fuses got even lower percentage correct answers. This caused significant concern in the task force and the HV fuses Subcommittee of the IEEE.

As a result of the concern, a Working Group was formed to a) revise existing IEEE standards to include full-range fuses, and b) produce a fuse tutorial to explain how different fuses work, together with expanded application information. Although the resulting tutorial was given at IEEE meetings, to ensure that the information would not be lost and would be continued to be updated, it became IEEE Std C37.48.1-2002 “IEEE Guide for the Operation, Classification, Application, and Coordination of Current-limiting Fuses with Rated Voltages 1-38 kV”. Although an IEEE application guide, IEEE Std C37.48, existed at the time, it assumed a quite high level of fuse knowledge; the new guide assumed relatively little knowledge on the part of the reader. The Guide covered current-limiting fuses, but because they are often used with expulsion fuses, a description of expulsion fuse operation was also included. Information on the coordination methods between the two types of fuses was expanded greatly compared to C37.48.

At this time in IEC practice, each HV fuse standard had a clause containing application information. There was also a freestanding guide for fuses for transformer circuits (IEC 60787). While looking for ideas for future work, the author suggested to the members of the HV fuses Maintenance Team 3 (CL fuses) that a worthwhile project could be to collect all available application material together in one place (drawing from both IEC and IEEE documents), and to also include tutorial information about fuses, as was done in IEEE Std C37.48.1. This was met with general agreement. Therefore in 2006 an ad hoc group was established to do preparatory work on a general HV Fuse User’s Guide. In 2009 this group became Working Group 6 of HV Fuses Subcommittee SC32A, tasked to produce a Technical Report (all IEC guides are technical reports). While the work was led by the convenor of WG6, Norbert Stein, as secretary the author did much of the work of combining existing application information. The scope of this document was larger than that of IEEE Std C37.48.1 in that it was to include expulsion fuse information to the same extent as current-limiting fuse information. This required quite a lot of new material to be written. In addition to information on the existing IEC “European practice” applications, North American practice applications were also included, furthering the author’s aim of having IEC recognize North American fusing practice as well as European practice. The resulting document was finished in 2012. Obtaining copyright permission from IEEE for their material proved something of a challenge (although they had approved the process in general terms before work started). Eventually, however, IEEE did give their approval, and IEC TR 62655 was published in 2013.

IEEE requires its standards to be updated within 10 years of publication so both C37.48 and C37.48.1 had to be revised. The IEEE HV Fuses Subcommittee concluded that, with most of the information in these documents contained in the IEC Guide, and with the Guide also including tutorial information on expulsion fuses, they should be able to use the IEC document to replace the two IEEE standards. However, as written, the IEC Guide did not lend itself easily to use by those only familiar with North American practice. It was decided that some changes were needed because, a) there are significant differences in terminology between IEC and IEEE standards, b) the IEC document gave priority to mentioning IEC practice and standards, and c) because one of the referenced documents, IEC 60282-1 the current-limiting fuse standard, was being revised itself, and would require that the IEC TR be subsequently modified also. As an example of the terminology differences see Fig. 1.

IEEE term	**IEC term**
ambient temperature	surrounding temperature
backup current-limiting fuse	Back-Up fuse
clearing	operating
cutout fuse support	cut-out fuse base
drop out	drop-out
full-range current-limiting fuse	Full-Range fuse
fuse, or fuse and fuse support	fuse
fuse, fuse unit	fuse-link
fuse link	fuse-link
fuse support	fuse-base (fuse-mount)
fuseholder	fuse-carrier
fuseholder and fuse support	fuse-holder
fuse cutout	distribution fuse-cutout
general-purpose current-limiting fuse	General-Purpose fuse
ground	earth
guide	technical report
interrupting (current)	breaking (current)
I^2t	Joule integral, I^2t
melting	pre-arcing
minimum fusing current	minimum melting current
Peak let-through current	Cut-off current
peak overvoltage	switching voltage
Rated Maximum Application Temperature (RMAT)	Maximum Application Temperature (MAT)
wye connected	Star connected

Figure 1. Comparison between IEEE and IEC terms

The HV Fuses subcommittee therefore proposed that a revision of IEC TR 62655, with as few changes as possible, be done to make it more suitable for use in North America, and that it be published as a revision of C37.48. IEEE therefore approached IEC for copyright permission, which was granted. The IEEE Revision of Fuse Standards Working Group (WG) was therefore tasked by the subcommittee to take the IEC TR and make such modifications as were required to make it suitable for IEEE use as IEEE Std C37.48-20XX. The WG decided that the primary focus would be North American practice regarding terminology, but that an equivalence table be included. In the same way, where equivalent or similar IEEE and IEC standards exist, the IEEE standard would be mentioned first. However, all references to IEC practice were left in place since it was felt important to compare and contrast areas that were similar and different, as well as taking the opportunity to educate readers as to other methods of achieving protection using fuses. The introduction states "As with the IEC Technical Report, it is felt that including both sets of practices will particularly benefit users located in areas where both practices are used, and where fuses primarily tested to one or the other, or both, standards are available."

III. THE STRUCTURE OF THE DOCUMENTS

Both IEEE C37.48 (draft document) and IEC TR 62655 are organized in the same way. Both emphasize that they contain no requirements and are informative only. The purpose states that it is to help prospective users and protection engineers to understand HV fuses, to illustrate the unique advantages of fuses, to minimize misapplication than could cause problems in the field, and to describe the many types of fuses in use and standards that apply to them, as well as types not covered by IEEE and IEC standards. Finally, there is a section on how to use the guide. The first point to be made is that if one were to read the whole guide start to finish, it provides an in-depth study of HV fuses. However, it is recognized that most readers will look at the section that contains information they desire, which leads to some duplication of material.

After the scope, references, and definitions, Clause 4 contains primarily "tutorial" style information, starting with a simple introduction to fuses. This points out that the most basic division of types is into "current-limiting" and "non-current-limiting". In IEEE both types are further classified into "Class A" and "Class B" (formerly in IEEE "Distribution Class" and "Power Class"), which generally indicates where, on an electrical distribution system, the fuses have been designed and tested to be used. The circuit conditions that differentiate Class A and B are X/R (power factor), Transient Recovery Voltage (TRV), and maximum available fault current, with "B" conditions being more severe than "A". Because CL fuses are generally quite insensitive to such conditions, in IEC CL fuses only have one class. Finally, the sub-classes of CL fuses that are based on their ability to interrupt currents lower than that producing a current-limiting action are mentioned, "backup", "general-purpose", and "full-range", together with common fuse terminology. There then follows lists of the advantages afforded by using fuses in general and then current-limiting fuses in particular. After the overview, the next subclauses look at individual types of fuse in much more depth. Descriptions of the most common fuse types are included, but also some of the less common types including some obsolete designs that may still be found in service. Only fuse types covered by standards have application information given.

Finally, Clause 5 and the Annexes provides application information divided into a) information common to nearly all applications, b) specific to typical, applications, c) concerning installation, operation, maintenance, and replacement of fuses, and d) additional information in the annexes. Annex A in both guides reproduces the current-limiting fuse temperature de-rating information previously published in the IEC current-limiting fuse standard, and Annex B, just in the IEEE guide, includes additional coordination information for reclosers from IEEE Std C37.48-2005. Early in the documents is the important statement "It should be emphasized that the information contained in this guide is intended to supplement information supplied by the manufacturer of a fuse and not replace it. If there is any doubt or conflict of information, the fuse manufacturer should be consulted." It may be noted that the tutorial section covers about 40 pages while the application section covers about 100 pages, so the Guides are quite substantial documents.

IV. COMMON FUSES AND HOW THEY WORK

The Guides provide a simple explanation as to how fuses work, and then go into more detail for different fuse types. Of course, fuses have been in use since the very beginning of electrical power distribution. One of their first usages was to protect fragile (and expensive) lamps from being damaged by excessive current due to fluctuations in voltage. From a simple "weak point" in the circuit they quickly became devices able to sense a current higher than normal and quickly interrupt ("break" in IEC terminology) that current, all in a self-contained easily replaceable unit. Fuses still provide the highest degree of protection for the lowest initial cost. A simple definition of a fuse is that it is a device that carries current through an "element" that melts by self-heating at an excessive current and initiates current interruption. All conventional fuses interrupt the current after some arcing across breaks formed in the element when it melts. Because there are few "mechanical" aspects to the melting process, fuses can have a very inverse time-current relationship as illustrated in Fig. 2. This enables extremely short melting times almost without limit (while time-current characteristic (TCC) – curves are normally drawn down to 0.01 s, there is no fundamental reason they could not be drawn to 0.001 s, or even less) and it is this apparently simple phenomenon that is primarily responsible for the universal success fuses have enjoyed for a very long time.

Fuses covered by standards all have three ratings, rated current, rated maximum voltage, and rated maximum interrupting current, all determined under prescribed conditions as set out in the standards. As we have seen backup current-limiting fuses also have a rated minimum interrupting current but more about that later.

HV fuses perform one or both of two primary functions. The first which virtually all types of fuse are designed to perform is to respond to quite high currents, normally termed "short-circuit" currents. In this case virtually all of the load has been bypassed, and the current can be very high. Fuses vary greatly in exactly how high a current they can interrupt, and this can be a significant factor in what fuse to select for a given task. It is high-current behaviour that causes fuses to be classified as “current-limiting” or “non-current-limiting”. Because almost all commonly used non-current-limiting fuses are expulsion fuses, “expulsion fuse” is usually the term used rather than “non-current-limiting”.

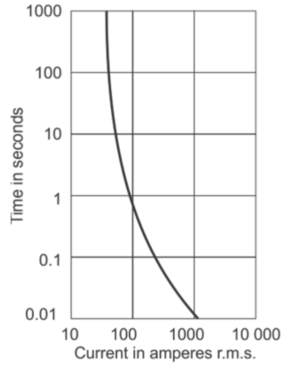

Figure 2. Fuse melting time-current characteristic curve

The second function, is to respond to moderately excessive currents, often called “overload” currents, up to about 10 times the rated current of the fuse. However, some fuses are designed only to operate at quite high currents and may arc at low currents until a second device interrupts the current, possibly resulting in physical damage to the fuse. They are therefore coordinated with a second device to interrupt low currents without damage to themselves. The ways fuses respond to high and low currents, as well as the ways they actually interrupt the current causes them to be classified in various ways. While all current-limiting fuses excel at high-current operation, their ability to interrupt lower currents leads to sub-classifications of “backup”, general-purpose” and “full-range”.

Current-limiting describes a class of fuse characterized by their behaviour when the current is sufficiently high to cause them to melt before the first peak of a fault waveform. When a CL fuse melts in this way, the arcing process introduces resistance so rapidly into the circuit that the current stops rising and is forced quickly to zero before it would naturally do so. Because the maximum prospective current is not reached, the fuse limits the magnitude as well as the duration of the fault which is where the “current-limiting” name comes from. The action is shown in Fig. 3a. The current-limiting action also produces a “spike” of voltage (the fuse peak overvoltage) into the system, and a maximum is specified by standards. However, this voltage does help support the system, reducing the duration of a voltage dip in parallel circuits, caused by the fault, just to the melting time of the fuse. The lowest current at which a fuse shows this current-limiting effect, called its “threshold current”, is usually about 20 to 30 times the fuse’s current rating.

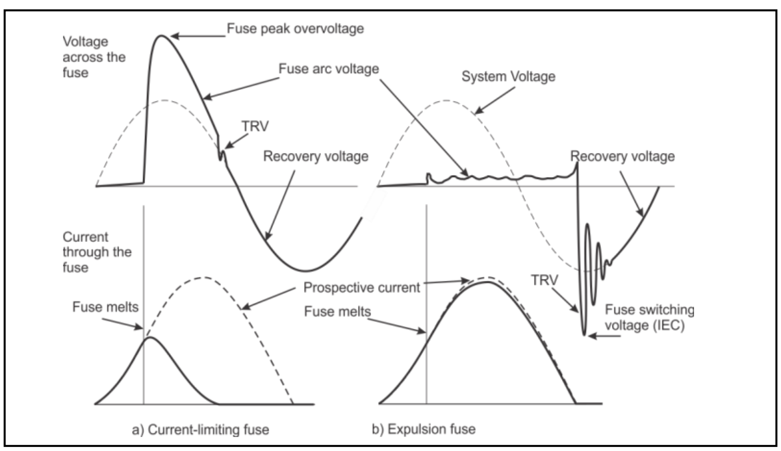

Figure 3. High current interruption by current-limiting fuse and expulsion fuse

An expulsion fuse, melting under the same circumstances as described, introduces only a small resistance into the circuit, so the current continues almost unchanged to the same peak as without the fuse. An expulsion action, that is where gas is generated by the arc and is expelled along with ionized material, produces a physical gap so that, at a natural current zero, the arc does not re-ignite and the current is interrupted. This type of fuse therefore limits the duration of a fault but not its magnitude, as shown in Fig. 3b. The figure shows the effect of transient recovery voltage (TRV). This is the brief transient oscillatory voltage that appears across an opened circuit, in this case across the fuse, after current interruption, and is due to damped current oscillation in the circuit inductance and intrinsic parallel capacitance. TRV is quite significant for expulsion fuses, but less so for CL fuses.

The basic principles that apply to all types of fuses are as follows.

a) In its passive or current carrying mode a fuse must be able to carry load current and permissible cyclic or transient currents without deterioration. The testing standards limit temperature rises, and the Guides advise on sizing fuses to avoid damage due to transient currents.

b) In its active, or fault-interrupting mode, more heat is generated than can be dissipated and the element melts. The relationship between a particular constant current and the minimum time required to melt the fuse is published in the form of a time-current characteristic curve (TCC curve). Upon melting a current interrupting process occurs that depends on the type of fuse, and a maximum clearing [operating] time-current characteristic curve is also published.

c) After interruption, a fuse must be capable of withstanding normal circuit voltage. Some fuses drop open to form a visible and physical “gap” (“drop out” fuses).

Current-limiting fuses: Fig. 4 shows the construction of a typical backup fuse having “DIN” dimensions (a European style fuse) and many features are common to other CL fuses. Fuses intended for outdoor use, or submerged in an insulating liquid will have special attention paid to sealing. The body and caps are required to have the attributes of a pressure vessel, capable of withstanding the combination of high pressure and very high temperature that occurs at the instant of fuse operation. The fuse elements are made of a very conductive metal, usually silver or copper, but aluminum has been used extensively as well as a few other metals. They are surrounded by granular insulating material, almost always compacted quartz sand of high purity and closely controlled grain size. The fuse shown, like many ratings, requires a fuse element length greater than the body length and so the fuse elements are wound in a spiral pattern around an inert former or "core". Element design is critical; its length is proportional to the voltage rating of the fuse while the total cross-section and number of parallel fuse elements determine the current rating. The shape of the fuse elements together with their spacing and configuration determine many of the electrical characteristics of the fuse. Fig. 4 shows a striker, and while they are seldom used in North American practice, they are commonly used in European practice to trip a series connected switch to interrupt low currents. Thermally operated strikers are also available to trip the switch before the fuse actually melts. By using a backup fuse and striker together with a switch, “full-range” current interruption is possible (i.e. from overload to short-circuit).

A current-limiting fuse introduces significant resistance into the circuit by having a long element with multiple pre-determined places where melting is initiated. At high currents all the restrictions melt simultaneously producing a controlled number of arcs. With continued current flow, the arcs elongate increasing the resistance and arc voltage. Eventually the arcs merge but by that time the current is low and close to zero. The combination of melted sand and element material is called “fulgurite” and is an insulator. Fig. 5 shows a “before and after” shot. It is of a full-range fuse but a backup fuse looks like the left-hand side. If the fuse were to try and interrupt against a slightly higher voltage than that seen in the illustration, the fulgurite would be much larger. A modest increase in fulgurite size can lead to failure (breakdown between the turns for example) so a CL fuse should never be called upon to interrupt a voltage higher than its rated maximum voltage (this is true also for low currents, for different reasons). The full-range fuse in Fig. 5 interrupts low currents by having an expulsion element (in a rubber tube) in series with a backup fuse element in the same body.

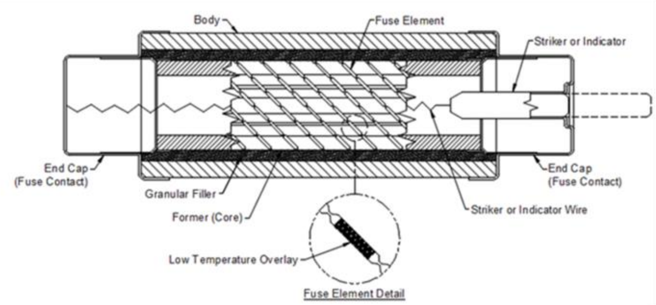

Figure 4. Construction of a typical backup fuse

Expulsion fuses: While there are many types of expulsion fuse, their primary characteristic is that they are vented devices in which, after their fuse element melts and arcs, the expulsion effect of the gases produced by the interaction of the arc with other parts of the fuse results in the current interruption in the circuit. Another common characteristic is that they are essentially non-current-limiting, having a low arc voltage. They extinguish current at a natural current zero so that anything that increases the magnitude of the first major loop of an asymmetrical fault current makes interruption harder. They are therefore very sensitive to fault current magnitude, system X/R, and degree of asymmetry. Because current is extinguished at a natural current zero, they are also very sensitive to TRV.

While expulsion fuses are not significantly affected by system voltage during arcing, it has a significant effect on recovery voltage so like CL fuses should never be used at a voltage higher than their rated voltage. Because of their typical applications, expulsion and other types of non-current-limiting fuses have been designed to interrupt any current from the overload current at which the fuse element melts up to their maximum fault rating. Particularly in North American practice, they are often paired with backup current-limiting fuses to provide “full range” performance to higher fault currents than an expulsion fuse alone can handle.

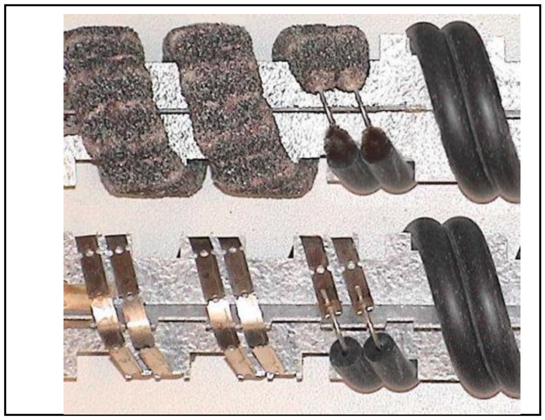

Figure 5. Fulgurite formation due to high current interruption

Because the circuit conditions that make Class A and B different significantly affect the performance of expulsion fuses, the construction and operation of Class A and B fuses tends to be different, and so the two types are treated separately in the guides.

The most common type of "Class A" expulsion fuses are fuse cutouts (previously “distribution fuse cutouts”). Fig. 6A shows the components of a typical fuse cutout. The insulator has traditionally been ceramic but increasingly is made from polymer material with a bracket in its middle. The pivoted fuseholder includes a tube lined with gas-evolving material, which contains the fuse element, typically mounted in a replaceable fuse link (Fig. 6B). Other Class A expulsion fuses include open-link cutouts (just a fuse link mounted in tension), enclosed cutouts (all live parts enclosed in a housing), and liquid-submerged expulsion fuses in which insulating liquid takes the place of air.

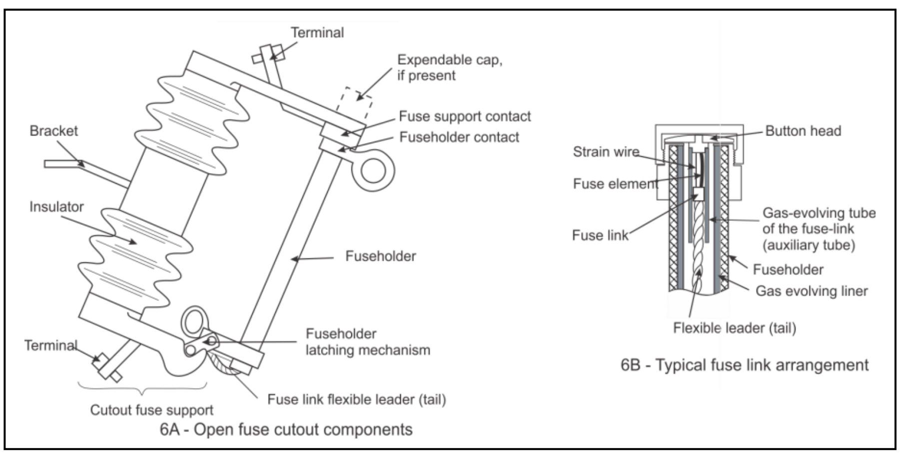

Figure 6. Fuse cutout construction

The most common type of Class B expulsion fuse is shown in Fig. 7A. Arc interruption is assisted by use of a boric acid liner to the fuseholder tube giving them a higher interrupting capability, under more onerous circuit conditions, than Class A expulsion fuses. They have a more complex internal structure than cutouts, Fig. 7B, that includes a main bore for high-current interruption and, in some designs (not shown), a smaller, parallel, bore for low current interruption. They have a rather short fuse element with parallel strain wire connected to an arcing rod attached to a compressed spring. When the fuse element and strain wire melts, the arcing rod draws the arc through the boric acid block. This increases the arc length and length of boric acid exposed to the arc. Gasses produced by the arc are primarily water vapor, which cools the arc and produces a deionizing effect. Some Class B expulsion fuses can use an exhaust-control device to condense the water vapor and virtually eliminate the effect of these gases allowing their use indoors and in enclosures. Class B fuses can be drop out fuses, like fuse cutouts, or remain in the fuse clips after operation like most current-limiting fuses.

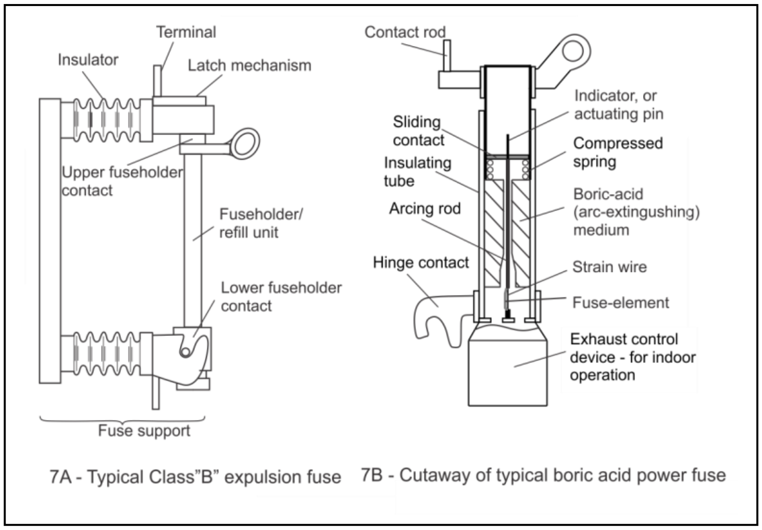

Figure 7. Class B expulsion fuse

V. Coordination Between Fuses

The primary aim of coordination is to isolate faults and keep as much load connected as possible. In general, therefore, one wants the "down-stream" device to operate leaving the "up-stream" device intact and undamaged. Fig. 8 explains these terms.

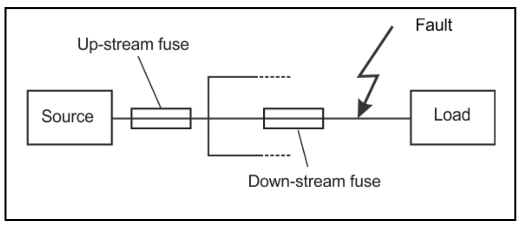

Figure 8. Description of the terms "up-stream" and "down-stream" fuses

The fuse characteristics that are primarily used for coordination purposes are time-current-characteristic (TCC) curves (minimum melting and maximum clearing) and I^2t characteristics. The primary method is to compare TCC curves for the minimum melting (pre-arcing) of the upstream fuse to the maximum clearing (operating) characteristics of the downstream (smaller) fuse. Both curves take into account variations resulting from manufacturing tolerances and represent performance under specific conditions. If nominal curves are published, they must be shifted to take account of the manufacturer's tolerances.

Generally speaking, curves are used for times greater than 0.01 s, the lower limit that curves are normally plotted to, while I^2t is used for shorter times. At high currents and very short melting times, the clearing I^2t of current-limiting fuses tends to a minimum value (the fuse's maximum clearing I^2t) that is published, and may be used in determining coordination with other devices. For non-current limiting fuses, clearing at high currents cannot occur until a current zero, so clearing curves for such devices are horizontal at a time corresponding to the duration of one loop (the clearing I^2t of an expulsion fuse therefor rises with rising fault current, so is not normally used for any purpose). As a result, the clearing curve of a non-current-limiting fuse will always cross the minimum melting curve of any larger fuse when these devices are compared for coordination purposes. Coordination is thus only possible if the available fault current is less than the value at which they cross.

The down-stream fuse must clear the maximum fault current at its location before the upstream fuse is damaged. To prevent damage to the up-stream fuse, the clearing time of the down-stream fuse should be less than 75 % of the minimum melting time of the upstream fuse for all current up to the maximum prospective current where the downstream fuse is located. In the case of I^2t coordination, the maximum clearing I^2t of the down-stream fuse should be less than 75% of the minimum melting I^2t of the upstream fuse.

A typical coordination example from the Guides is shown in Fig. 9 where a 125A full-range current-limiting fuse is to coordinate with a 65A general-purpose fuse at location A (an alternative location, that will also be examined, is shown at position "B").

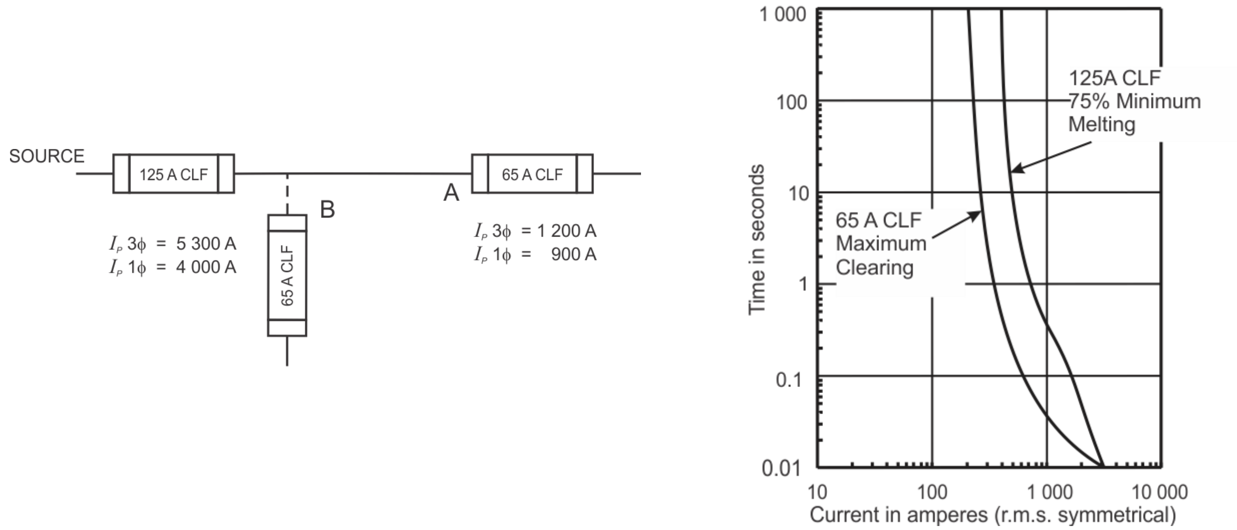

Figure 9. Current-limiting fuse/current-limiting fuse coordination example

The TCC curves for this combination are also illustrated in Fig. 9. However, before comparing the fuse TCC curves, we need to verify that the 125 A CLF has adequate reach, that is it can operate with a fault at the 65A fuse. At this fuse the phase to ground prospective current I_P is 900 A, assuming a bolted fault (that is one in which the fault impedance is essentially zero). A full-range CL fuse can interrupt any current that causes it to melt, so it will operate with a current corresponding to the top of its published minimum melting TCC curve. However, a fault persisting for hours would not be desirable so a utility will likely pick a shorter time for which they would like fuse operation. If a time of 300 s is chosen as a desirable maximum, the 300 s current for the 125 A fuse is 300 A. Since the phase-to-ground fault current at the 65 A fuse is 900 A, the fuse will melt in less than 300 s. However, another consideration is the fact that actual fault currents will be somewhat less than the calculated value, as a result of fault impedance. In this example, the current could be one third less (a "reach margin" of 3) and still operate the fuse in less than 300 s.

To check TCC curve coordination between the 125 A and 65 A fuse, for the 125 A CLF draw the minimum melting curve at 75 % of the melting time, to prevent damage to the up-stream fuse, and the maximum clearing curve for the 65 A CLF. Note that the curves intersect at approximately 3 100 A, and at a time below 0.01 s. Therefore, since the maximum prospective current at the 65 A CLF does not exceed 3 100 A, time coordination exists. Because the prospective current is less than the point at which the 125 A TCC curve crosses the 0.01 s line, I^2t coordination does not need to be checked.

Had the prospective fault current at the 65 A fuse been higher, 4 000 A for example (position B in Fig. 9), then I^2t coordination would have to be checked because the current is higher than the 0.01 s point on the TCC. The maximum clearing I^2t for the 65 A fuse is 100 000 A^2s, while the minimum melting I^2t for the 125 A fuse is 100 800 A^2s. In this case, I^2t coordination at 4 000 A would not be achieved (100 000 A^2s > 0.75 × 100 800 A^2s = 75 600 A^2s). If a 150 A fuse could be used instead of the 125 A fuse (with a melting I^2t of 136 000 A^2s) then this would be acceptable (100 000 A^2s < 0.75 × 136 000 A^2s = 102 000 A^2s). Reach would still be acceptable because although the 300 s current would be higher for the 150 A fuse (at 350 A) the prospective fault current is also higher. Coordination of the larger 150 A fuse with up-stream protection would also need to be checked.

VI. Conclusion

When completed, the “twin” standards IEEE Std C37.48-2020(?) and IEC TR 60282 will represent a, possibly unique, example of cooperation (including copyright agreements) between IEEE and IEC. We have produced equivalent, but different, standards containing essentially identical application information, but with each designed to maximize the convenience to their respective audiences or “stakeholders”. In this particular case a “dual-logo” document or “joint development” would not have produced a document that would have been best attuned to the needs of those anticipated to use it, largely because of historical differences in terminology and references to other standards. I hope that both organizations will be able to take inspiration from the procedures followed by the HV Fuses Subcommittees of both groups, and use this model for similar situations in order to allow the “customer to come first”, the hallmark of all successful undertakings.

References

[1] Leach J. G.: “Standardization and Electrical Safety”. In *ICEFA Maribor, 2011, p. 9*
[2] Leach J. G.: “The impact of HV fuse design and application on the development of international standards”. In *ICEFA Gdansk, 2003, p. 65*