



Paper Information

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Summary

The explosive nature of arcing faults in exposed cable components can inflict significant harm to people and property by fire, arc-flash and explosions. Furthermore, such faults can cause extensive damage to cables and nearby equipment, which can even lead to a snow-ball effect of secondary failures. Arcing faults in electrical equipment are highly chaotic, dynamic and intermittent. However, test methods of arcing faults in cable components for R&D and type testing are presently insufficient to design components that fail safely. In this paper, we describe the hazards of arcing faults and explore the idea of arc safety design rating for cable accessories in exposed environments. Furthermore, this paper reviews how the industry has currently addressed the issue, and how standardised short-circuit tests ensures safe failure modes in other equipment. We follow this up with a review of common and uncommon test methods employed in laboratories to investigate the behaviour of insulation breakdown and arcing in cables and accessories as examples for future standardised test methods. We discuss the impact of materials and geometry of accessory components on arc behaviour, and thus on test specifications. We conclude with future steps to arrive at test methods that produce reproducible results.

Keywords

Arcing, Fault, Cable, Accessory, Insulation, Hazard, Design, Test, Measurement, High Current, Experiments.

1 Introduction

Cable arcing faults can be hazardous to people, property and equipment. Some measures have been taken by individual companies to reduce the impact of such faults. However, much is still to be done to integrate safe failure modes into the design of accessories. In this paper we explore the idea of arc safety design rating for cable accessories in exposed environments combined with appropriate robust test methods.

Work done so far by the industry to mitigate hazards from failure modes to address the issue of arc hazard to workers, has included for instance implementation of design features (i.e., pressure relief device), or required use of temporary barriers and personal protective equipment (e.g. arc blast blankets in vaults) to allow work to proceed around live accessories. In some cases, the protective barriers and PPE are not sufficient or turn out to be inefficient, as in the example Figure 7. Therefore, first and foremost, hazards should be ‘engineered out’, meaning safety features are integrated into the design of the accessory. We believe robust short-circuit test specifications are required to verify the accuracy of such designed safety features.

Robust type test methods for verifying behaviour of arc faults in cable accessories designs are therefore essential to design such cable accessories with safe failure modes. Cable standards such as the IEC cable system standards IEC 60502, IEC 60840 and IEC 62067 as well as the IEEE accessory standards IEEE 48 and IEEE 404 do not include short circuit tests to ensure a safe mode of failure, as such these are lacking the essential requirements and guidance to minimize the arc fault hazards through safety in design, as discussed in section 4, unlike arc flash containment and associated tests for equipment such as switchgear and lightning arresters [20], [21].

To achieve the creation of robust type test methods, a structured and thorough survey of standards, laboratory experiments and field tests is needed to distil guidelines for robust test methods from existing test methods and their shortcomings. The CIGRE study committee B1 has approved a task force to explore user requirements for arcing fault hazard mitigation, which will likely include guidelines on testing, design and pass/fail criteria for arcing faults in cable components. The contribution of this paper is a survey of test methods that could be incorporated into a CIGRE technical brochure and future test standards.

Cable arcing faults in both public spaces and in controlled spaces can be hazardous to members of the public, workers, and/or nearby equipment, and these are well-known hazards. The explosive nature of such arcing faults is viewed with increasing concern in cable circuits of all voltage classes in the power industry, because the intensity of an arc, and thus its consequences, is related to fault current level and duration, rather than voltage class.

1.1 The impact of complex arc behaviour on developing robust test methods

Arcing faults in general are complex because of the chaotic, intermittent behaviour of the arc. Arcing behaviour in cable (component) insulation is further complicated by its dynamic behaviour; its chaotic nature changes as the arc burns through the insulation changing its local environment. The rates of change of the arc dynamics depends on the materials and configurations and construction of the specific accessory type. Test guidelines and requirements therefore must take into account the specific configuration of the component under test.

Apart from its dependence on its materials, geometry, arcing fault initiation and development within a cable component depends on its surroundings and exposure to the energy produced by the arc which is a result of the non-linear arc characteristics expressed in voltage and current.

Arc fault behaviour is thus complex, and creating model(s) for cable components is further complicated due to the wide range, materials and construction. The arc intensity, incl. the heat it produces, is determined by the source, surrounding electrical network (incl. transients), clearing time, state of arc channel. The arcing fault model describes arc fault behaviour. However, the arc fault models are not yet sufficiently accurate to use in simulations and design.

Finally, the impact of arcing on cable (component) insulation depends on the energy converted to heat determined by the non-linear voltage-current characteristic and driven by the source voltages, electrical impedances and transient behaviour in the network. The arc voltage-current characteristic is a function of the energy used in burning away material in the walls of the arc, the arc cooling. Considering that different materials require differing amount of energy to vaporize, the arc voltage is related to the materials heating characteristics.

A safety rating on accessories would be useful to guide selection of accessories for exposed situations, such as joints at eye-height in a tunnel, or porcelain terminations. “Accurate arc models combined with accurate protection will allow accurate forecasting of effect of an arcing fault on the components in a circuit” [6]. Accurate arc models thus will support the selection of a suitable safety rating.

1.2 Arc fault models for accessory design software packages

Accessories need to be designed to fail safely in certain circumstances, such as cable tunnels. Parameters that could influence the behaviour of the component during the fault event include physical parameters such as arc intensity, electro-magnetic forces, and those parameters influencing the risk such as exposure to the potential effects. Material specific arc fault models could simulate the arc behaviour and its impact on the specific materials, based on V-I characteristics as are being developed in [14]. Such models might be helpful to be incorporated in design software for accessories mimicking FEM used in mechanical models of materials at desktop design.

The state-of-the-art model for arcing contained within (cable) insulation is the ablation model [4], [5]. However, neither this model, nor other models known to the authors can simulate the response of specific materials and their dimensions combined with other surrounding materials. For instance, “cable arcing faults typically burn through the containing sheath, [and at that time] dramatically change the arc behaviour and electrical characteristics. Parameters of the ablation model are not yet published for all common types of cable components.” [6] Similarly, the appropriate parameters have not been developed for the various materials used in these cable components. Thus, the models available at present are understood to be limited, and the gap in the research is how a short circuit path develops from electric tree to free-burning arc.

Developing empirical arc models related to different types of material and construction of accessory requires understanding the physical behaviour of existing designs, and would provide means of simulating the behaviour of future designs. This would give the designer the ability to adapt the geometry to desired behaviour.

A mechanical finite element model (FEM) could be created to study the mechanical stresses inside a component during an arcing fault. Such a study would allow, for instance, a desktop design to incorporate mechanical rupture points to vent gasses in a safe direction.

“Studying the behaviour of cable components during arcing faults allows the development of appropriate behaviour. The study of arc behaviour in MV cable components can be found as early as 1992, with some examples given below. The experiments include both radial arcing (in cables and accessories), as well as interfacial arcing (in accessories).” [6]

Previous experiments and laboratory and field measurements, as listed in Table 1 and Table 2, ranging from LV to HV, and from low current to high current. The V-I characteristics measured in these experiments are useful to inform the range of potential voltages and currents for the cable components [6]. However, the relationships between V-I characteristics, the electro-thermo-chemical reactions of the materials and the arcing channel, and their dynamic behaviour over time are not yet available. Further experiments are anticipated to be required to develop a model of those relationships.

2 The hazards of arcing faults in exposed cable components

Arcing faults in exposed cable components can be hazardous because they can lead to explosion of the accessory, leading to venting of hot gasses, blast shock waves, and fire. The motivation of this work is to prevent arcing faults from endangering personnel and bystanders, property and equipment. [7] These hazards are similar to the hazards of surge arresters as described in [22] as we will show in the following paragraphs.

The explosive nature of such arcing faults are well-known hazards and are viewed with increasing concern in cable circuits of all voltage classes in the power industry. Extensive damage to equipment has been caused by arcing faults in cable accessories, as shown in the examples below. These examples include different voltage levels from high voltage 230 kV through to low voltage 230 V.

Similarly, the hazards of arcing faults in surge arresters strongly depend on their geometry and materials determining their failure modes and arc behaviour. Soft materials like polymers, for instance, allow an arc to “tear or burn its way its way through the polymer material, permitting the arc, along with any resultant gases, to escape quickly and directly”, while hard materials, like epoxy resins, ceramics, and even hard plastic bodies, can “violently shatter” [19], [22]. Many of the “general criteria” for “safe short-circuit performance” of surge arresters, as listed by [22] are considered relevant to our discussion on cable components, as discussed at the end of this section.

2.1 The hazard of proximity to arcing faults in exposed cable components

An arcing fault in a cable component can be hazardous to people (and property) that are in proximity to the arc if it turns into a free-burning arc. The hazard of a fault in an LV underground pit, such as shown in Fig. 2, is higher in densely populated areas because of the increased probability of someone being in proximity to the arc during its occurrence.

The example in Figure 1 shows a polymeric termination, which is similar in housing as surge arresters; “a vast improvement over porcelain housings in that they are non-fragmenting, but when they fail along the interface, the venting is uncontrolled.” [7] In this example the fault occurred following the deterioration process of “initially surface tracking, then partial discharge and electrical treeing through the main insulation, then flash-over underneath the red termination tubing and then finally a flashover when the termination tube was sufficiently destroyed.” [7], examined in detail in [6].

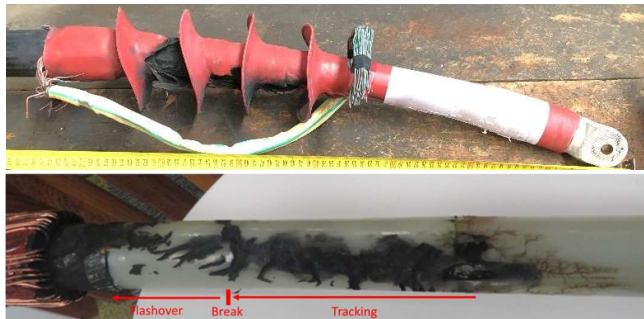


Figure 1. “example of an uncontrolled arc: termination flash over” [7], [CUPPEN-24PESGM] before removal of red tube (top) and after (bottom))



Figure 2. Underground arc fault from an LV pit in the UK [17] (video at 0:36)

2.2 An arcing fault causing extensive damage by projectile explosion

Arcing faults can launch large and heavy objects as shown in Figure 3. where “a set of outdoor 230 kV cable terminations in a substation experienced a failure, and the housing was ejected from the structure” [7]. The termination was designed with a pressure relief feature in case of a fault. But the pressure relief device did not operate as intended, and the termination was launched. The impact of such a large projectile could have caused additional damage, or hurt people nearby.



Figure 3. “230 kV Composite Housing Ejected From the Structure” [7]

2.3 Violent shattering into sharp projectiles

An arcing fault in solid epoxy can cause extensive damage or harm by violently shattering into sharp projectiles. The example in Figure 4 shows a set of PILC to XLPE transition modules installed at head and chest height in a distribution substation basement. These devices have multiple possible failure modes, in the metal bell, the epoxy body and the deadbreak separable connectors. Of greatest concern is the possible fragmentation of the solid epoxy should it experience a dielectric failure. [7]



Figure 4. “example of MV PILC/XLPE transition joint containing multiple failure modes of multiple materials: compound filled copper bell, epoxy and EPDM.” [7]

2.4 An arcing fault can lead to a cable fire

An internal arcing fault can heat cable insulation to ignition, which in turn can lead to a building (substation) fire. In Oct 2014 a fault in a medium voltage cable joint caused an extensive outage in New Zealand because it resulted in a fire in a cable trench affecting 19 cable circuits, including some high voltage circuits, see the evidence of arcing in Figure 5. Figure 6 shows an example of an oil-filled 33kV cable joint and the degree of damage possible when there is a delay in protection operating.

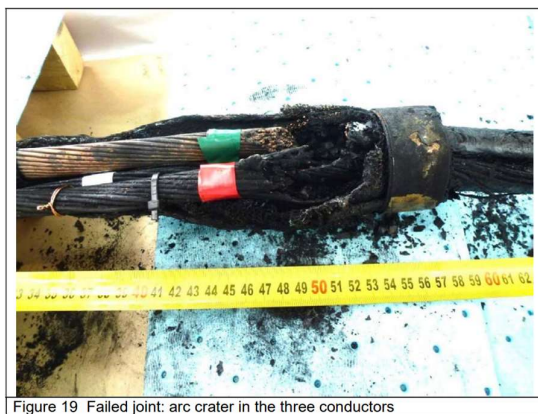


Figure 19 Failed joint: arc crater in the three conductors

Figure 5. Example of failed joint with arc craters (reproduced from [9]) causing a cable fire which in turn lead to a substation fire



Figure 6. Example of a faulted 33kV oil filled joint with extensive damage from an arcing fault. [7]

2.5 Example of live equipment in a cable tunnel

Arcing faults in a confined space can be particularly harmful. The hazard of an arcing fault in vaults and tunnels is due to the potential proximity of workers to the effects of an arcing fault in nearby live apparatus in such a confined space. The people in the confined space might get engulfed in flames and hot gases since these cannot dissipate in a large volume of space.

The example in Figure 7 shows a tunnel carrying two cable circuits. Access to the tunnel would be needed for inspections and maintenance of the ancillary equipment, such as the racks, the grounding circuit and monitoring equipment. In the event of a joint failure, longer access is needed to effect a repair. In case of repairing fault damage, the in-service equipment is often identical to what they are repairing. Since the nearby joint is of the same type, the probability of failure is raised because failing from the same failure mode, thus posing an increased risk.

However, there is increasing pressure to perform this work with the cables energized. “It is desirable for the joints not only to be non-fragmenting but also to vent their arcing gases in a safe direction.” [7]



Figure 7. 230 kV Joints in a tunnel showing the location of joints at chest and face level indicating the risk to workers should such a joint fail causing an explosion or an arc-flash [7]

2.6 Discussion of the hazards identified above

The impact of a hazard depends on its proximity to people and property. “Arc flash describes the intense light and heat generated during electric arcing, while the term arc blast can be used separately to refer to the pressure wave created from an electric arc.” [24]

The direct hazards associated with short-circuit arc currents include the shockwave from an arc blast which can cause severe and fatal organ damage, the intense light and heat from arc-flash which can cause blindness and severe burns, and if the arc current flows through the body it can cause severe internal burns and electric shock. [24]

Indirect hazards associated with arc currents include ejection of hot gasses and fluids, explosion of the component, which can cause violent shattering of the housing sending out fragments across a wide area. The fragments can be from the cable component housing or sheaths, and possibly internal components.

Finally, fire of the component or cable can cause a secondary fire, or hot ejected particles can ignite surrounding materials.

2.7 The hazards determine requirements on the test methods

The designs of different types of surge arresters (such as open and closed type polymer-housed arresters) show that solutions found by different manufacturers are successful because they fulfil “some basic requirements” [22]. The list of requirements can be summarised as follows:

1. no pressure build-up that can lead to explosive propulsion of sharp and/or heavy objects;
 - a. “The internal pressure must be able to be relieved quickly through the enclosure.”
 - b. the arc “must be commutated to the outside as quickly as possible” and
 - c. “the arc should not be allowed to be established nor stay within the enclosure” to prevent pressure build-up.
 - d. note that the above two basic requirements contradict with the requirement that people must be safe in proximity to an arcing fault occurring within a cable component
2. expelled materials must not cause surrounding materials to ignite
 - a. “The materials shall be self-extinguishing.”
3. ejected materials must not cause harm to people or extensive damage to equipment and property
 - a. “Block (and other) pieces of hard material must not be expelled through the enclosure.”
 - b. “The enclosure must be held together as much as possible.”

External surge arresters are typically installed out of reach of people providing a safe area for an external arc. However, cable components such as joints and indoor terminations used in tunnels and enclosures can be installed where people can be near, either workers or others.

An additional requirement could be

4. arc blast must be smothered or directed away from people (and property) in proximity

2.8 A safety rating for certain cable component designs can be based on its intended environment

The risk depends on the impact radius of a hazard, the proximity of people and property to the hazard, and the consequence of a particular hazard to the subject. As such we could define a required safety rating that reflects the three before-mentioned parameters. We propose the following list of safety ratings based on potential proximity of people and equipment.

- A. Very low: direct buried or in sealed pipes
- B. Low: Submarine, overhead line
- C. High: Switchyard
- D. Very high: Enclosed space such as cable tunnel, basement, vault

3 Short-circuit tests are needed to ensure cable components can be designed to fail safely

Short-circuit tests should show that no failure mode results in hazards, as discussed by [22] for surge arresters, relevant to the specific environment. Standardised short-circuit test protocols are included in the standards for surge arresters, both in the IEC standard [23] and the IEEE standard [19].

The IEEE Std C62.11-2020 [19] covers test methods for two types of interest:

1. Short-circuit test [19, section 8.15] “The test shall be performed in order to show that an arrester failure does not result in a violent shattering of the arrester housing ...”
2. Deadfront arrester failure mode test [19, section 8.17] “The purpose of the deadfront arrester failure mode test is to verify that metal-oxide disks are not ejected through the body of the arrester, but are either contained or ejected in a controlled manner from the bottom of the arrester.”

Short-circuit test included in the IEC 60099.4:2014 Subclause 8.10. The test shall be performed in order to show that an arrester failure does not result in a violent shattering of the arrester housing, and that self-extinguishing of open flames (if any) occurs within a defined period of time.

As far as the authors are aware current standards, such as the IEC 60840:2020 (30 kV – 150 kV), do not incorporate robust methods and requirements. Existing test methods and requirements, such as section 7.12 in [27] which refers to the HD 632 S2:2008 Part 2 (shown in Fig. 8), are not specific enough to address the real situations in which the components are installed. This utility standard requires a “3 m” pass criterion, which the authors believe is not specific enough to cover user requirements for, for instance, personnel safety in vaults and tunnels and other installations with tight spacing.

As such, the authors believe there are no test protocols in international cable standards to robustly test the safety features integrated in the cable component design. The authors have not found conclusive test guidelines nor the information required to create robust short-circuit test methods for cable components to study the hazard of arcing faults in specific accessory designs. Therefore, realistic type test and pass/fail criteria requirements need to be developed based on both component design and expected installation configuration to verify if component design achieves the intended safety level.

“At this time, there is no consistent means of specifying mode-of-failure requirements for accessories, or standard testing to evaluate performance. Such guidance does exist for other types of power equipment, but not for cables. Even though some manufacturers have developed pressure relief systems to prevent cable accessories from fragmenting and vent arcing gases safely, there is no consistent safety rating system nor suite of tests to ensure accessories fail in a safe manner suitable to the environment in which these are installed. The result is that manufacturers and users apply accessories that have insufficient safety ratings for particular situations and thus are either subject to broad outages to have the work completed, or must subject

their workers to exposure to high-consequence failures.” Problem description from [6]

7.12 Internal arc withstand test				
Only for cable-air terminals with composite casing.				
The test must be carried out in accordance with Standard HD 632 S2:2008 Part 2 paragraph 6.1.7, using the test parameters shown below.				
Nominal tension	(kV)	87/150	127/220	220/380
Short circuit current	(kA)	31,5	31,5/50	50/63
Time period	(s)	0,5	0,5	0,5
Asymmetry: time constant ≥ 44.8 ms				
The test is considered positive if there is no projection of material constituting the insulator at a distance of more than 3m from the object under test.				

Figure 8. Section 7.12 Internal arc withstand test as per Italian standard [27]

4 Developing suitable short-circuit test methods

This paper specifically focuses on defining tests to confirm safety level of failure modes in cable component designs, which is not currently addressed in other publications. Various studies published by CIGRE and IEEE provide valuable information about failure modes to develop standardised short-circuit test methods. A brief overview of such publications, with a summary of valuable info that can be found in each is given in the paragraphs below. These are used in research test facilities into failure modes supports developing robust type tests. This paper specifically focuses on defining tests to confirm safety level of failure modes in cable component designs, which is not currently addressed in other publications. Various studies published by CIGRE and IEEE provide valuable information about failure modes to develop standardised short-circuit test methods.

The research into failure modes and test methods supports developing suitable short-circuit test methods. Thus, a brief overview of such publications, with a summary of valuable info that can be found in each is given in the paragraphs below.

4.1 Designs of future standardised test methods

Since arcing faults are so complex, the test method needs to take into account these potential variables to verify the suitability of the design of accessories specific to the required safety level dictated by the environment.

Methods to initiate electrical treeing and arcing, shown in the figures below, include:

1. Electrical treeing followed by interfacial arcing by reduced pressure, as per Figure 9

2. Radial and interfacial arcing by fuse wire, as per Figure 10 and 11.
3. Electrical treeing followed by arcing fault by needle, as per for instance ASTM D3756-18

A selection of cable arcing tests and experiments performed previously are listed in tables 1 and 2 below. These examples of test methods used in research test facilities for studying failure modes can thus support developing future robust type tests.

Note in Figure 11 that although the geometry and materials of the two joints are similar, the arc behaviour is very different because of the difference in construction and layer thicknesses, as discussed in [1]. “It may be seen that for XLPE cables and type B splices the arc voltage waveshape may be considered to be virtually flat-topped, while for type A splices this is only a very rough approximation. This difference in the arc voltage waveshape is due to the different equipment design which entails different environmental arc-burning conditions” [2].

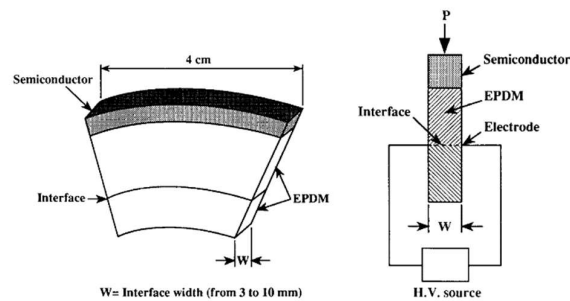


Figure 9. Interfacial tracking and arcing experiment setup: Joint body sample description source: [1] Fig. 1 (left) Experimental set-up (right), source: [1] Fig. 2 (Reproduced from [6])

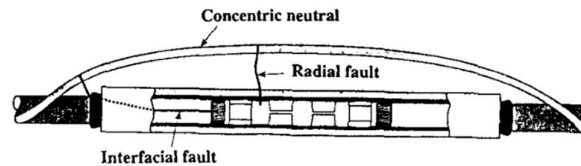


Figure 10. “Position of the interfacial and radial faults on a heat shrink type splice. Source: [2], Fig. 3” (Reproduced from [6])

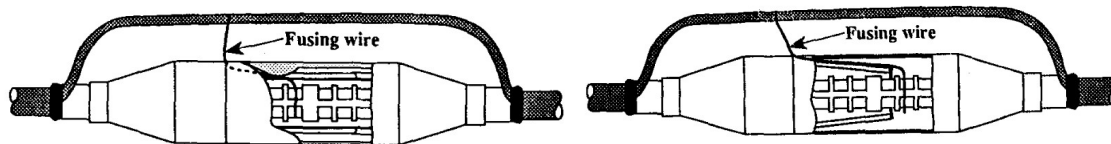


Figure 11. Type A (left) and Type B (right) joints. Source: [2]. Although similar in dimensions and materials, these exhibit very different arc behaviours.

Table 1 - Case studies with references to pictures and brief description: joints

Case study ID	Component build	Component type	Direction	Short description of relevant finding	v-i measurement/ component picture	ref.
K93-A	separable EPDM	joint	interfacial	The joint “opens very quickly under internal pressure, and the arc becomes virtually free-burning in air, while influenced however by the decomposition gases from nearby organic materials.”	Fig. 7-2) / Fig. 1	[2]
K93-B	separable EPDM	joint	interfacial	“its waveshape is more regular than for type” K93-A	Fig. 7-3) / Fig. 2	[2]
K93-Ci	heat shrink	joint	interfacial	shows “stabilizing effect of a narrow discharge channel”, “intense cooling and thus high arc voltage”	Fig. 8-1),2) / Fig. 3	[2]
K93-Cr	heat shrink	joint	radial	“arc voltage remained flat-topped, the average arc voltage was only about 740V”	n/a / Fig. 3	[2]
K93-D	cold applied	joint		“nozzle effect was also observed” similar to arc in PILC	Fig. 9-1) / Fig. 4	[2]
K93-E	cold applied	joint		“nozzle effect was also observed” similar to arc in PILC	Fig. 9-2) / Fig. 5	[2]

Table 2 - Case studies with references to pictures and brief description: terminations and unknown cable components

Case study ID	Component build	Component type	Direction	Short description of relevant finding	v-i measurement/ component picture	ref.
K14-1	unknown	unkn	unknown	“Arc cooling decreases the ionization rate and as a result the arc resistance value increases.” ... “Once the temperature increases with the increase in the AC current magnitude, the voltage flattens out. Presence of high odd harmonics makes the arc voltage waveform resemble a distorted square wave shape.”	Fig 2. / n/a	[13]
K14-2	heat shrink	term	radial	“the arc voltage and the arc voltage peak both increase from one half cycle to the next after three half cycles of stable arc voltage.” [14]	Fig. 7 & Fig. 8 / n/a	[13]
W17-1	unknown	unkn	unknown	Multi-cycle incipient arcing fault, noting that the “incipient fault is likely to ignite near the voltage peak.”	Fig. 2. / n/a	[15]
C24-1	oil-filled cable	joint	series, then radial	“The arc voltage remains steady while the arc voltage peaks decrease from one half cycle to the next from the start of stable arcing.”	Fig. 5. / Fig. 4.	[14]

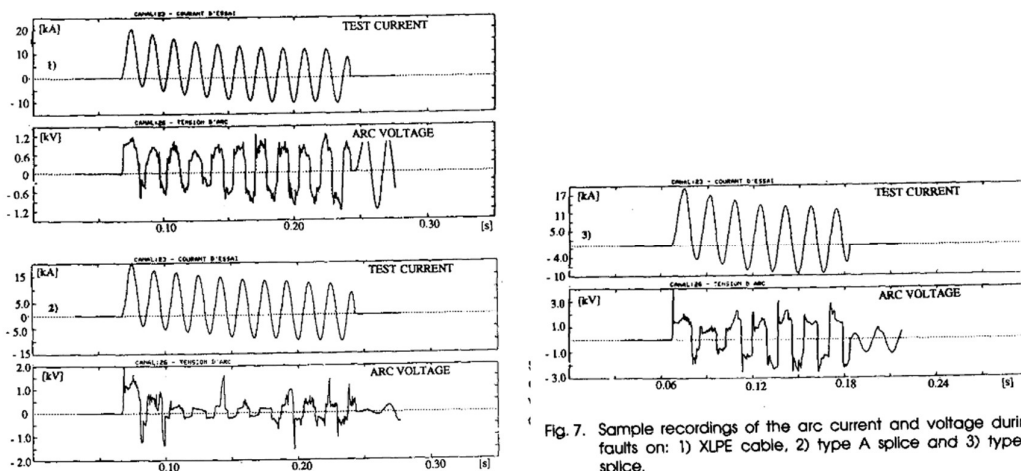


Fig. 7. Sample recordings of the arc current and voltage during faults on: 1) XLPE cable, 2) type A splice and 3) type B splice.

Figure 12. showing difference in arc voltage burning behaviour between XLPE cable, splice type A and splice type B. source: [2]

4.2 Overview of relevant CIGRE technical brochures

Cable failure studies provide knowledge of failure modes and the process from fault to consequence. CIGRE B1.89 “Guidance for conducting cable systems failure analysis” [10] is a working group “Focused on causes of failure and not on the specific consequences to personnel in the vicinity.” [7]

Specific work on failure mode evaluation of XLPE cable accessories can be found in [11]. This CIGRE Technical Brochure “recognizes the safety risk, that short-circuit behaviour (both internal, and through-faults) is not addressed in IEC standards and suggests a test protocol of drilling a hole for a fuse wire, and a very simple pass criterion of “no solid debris shall be observed at a distance of more than 3 metres from the termination or joint,” While this is a significant step in the right direction, both aspects in both the test design and pass criteria require further development to cover user needs.” [7]

Guidelines to identify and evaluate hazards associated with maintenance on cable systems are in [12] which “discusses safety of testing and repairs with regards to exposure to shock from induced voltages from adjacent circuits, but not about arc flash/arc blast hazards.” [7]

Failure analysis on other equipment, such as instrument transformers [16], can be helpful to better understand arcing failure modes in cable components.

The CIGRE technical brochures discussed here highlight the need for short-circuit test methods to verify if cable components fail in a safe manner.

5 Results and discussion

The observations from the tests listed in Table 1 and Table 2 show that the path of the arc through the samples determines the behaviour of the arc, among other parameters. The path can be radial (across the insulation) or interfacial (along two layers of insulation). The different paths through the samples determine a different response of the sample to the effects of the arcing current, and thus different dynamics of the V-I characteristics.

For instance, the example in Figure 11 shows joints that are, at a superficial glance, very similar. However, the difference in geometry of the parts of the joints shows that the one design is sufficiently stiff to contain an arc so that it needs to burn through the material, whereas the other design will split open and let the arc out. Another example is that the K93 PILC and its components quickly turn into an open burning hole with nozzle effect under a phase to ground fault because of the lead that quickly melts and does not contain the arc. However, in a belted PILC construction and a steel box termination type, to have a phase-to-phase fault could cause the box or bell to explode instead.

The examples shown in this paper and discussed here show that it is therefore important to take into account the geometry and materials in design of the test setup.

Currently, CIGRE TF B1.96 is preparing a scope of works for future CIGRE Working Groups on short-circuit test methods for HV, MV and LV accessories, as well as a joint WG on mitigations of hazards post failure, such as barriers.

6 Conclusion

In this paper we reviewed various test methods to study arcing faults in cable accessories at different voltage levels and current levels. We found that arcing faults on cable components have led to dangerous situations, and that no tools exist to model electro-thermal-chemical behaviour of arc with regards to specific materials and their geometry. Even though some measures have been taken by various users and utilities, no document with collective experience such as a guide or standard is available.

The existing test methods for verifying the pressure relief capabilities of cable accessories are inadequate, and not integrated into international standards. Test methods can be considered robust when designed based on 1) a holistic or conclusive set of arcing fault outcomes in accessories, that is the manner in which various types and brands of accessories fail, and how they respond to different levels of fault current and time until de-energisation and 2) a holistic or conclusive set of test requirements or test cases to guide the creation of common test guidelines or standard, and 3) capability of test equipment and how certain tests verify suitability of test object to object requirements.

Standardised tests are required to confirm performance of designs compared with the required safety rating. Experiments performed in labs show a wide range of electrical behaviour, visual observations and physical responses to the arc behaviour, see Table 1 and Table 2 containing summaries of V-I measurements of arcs in joints and of terminations.

The contribution of this paper is a review of test methods that could be considered to be incorporated into CIGRE technical brochures and future test standards.

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