BEAMA GUIDE ON ARC FAULT MITIGATION IN LOW-VOLTAGE ASSEMBLIES

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ABOUT BEAMA

BEAMA is the long established and respected trade association for the electrotechnical sector. The association has a strong track record in the development and implementation of standards to promote safety and product performance for the benefit of manufacturers and their customers.

This publication provides guidance on arc fault mitigation in low-voltage assemblies.

This publication has been produced by BEAMA's Building Electrical Systems Sector operating under the guidance and authority of BEAMA, supported by specialist central services for guidance on UK Internal Market, European Single Market, Quality Assurance, Legal and Health & Safety matters. BEAMA's Building Electrical Systems Sector comprises of major UK manufacturing companies.

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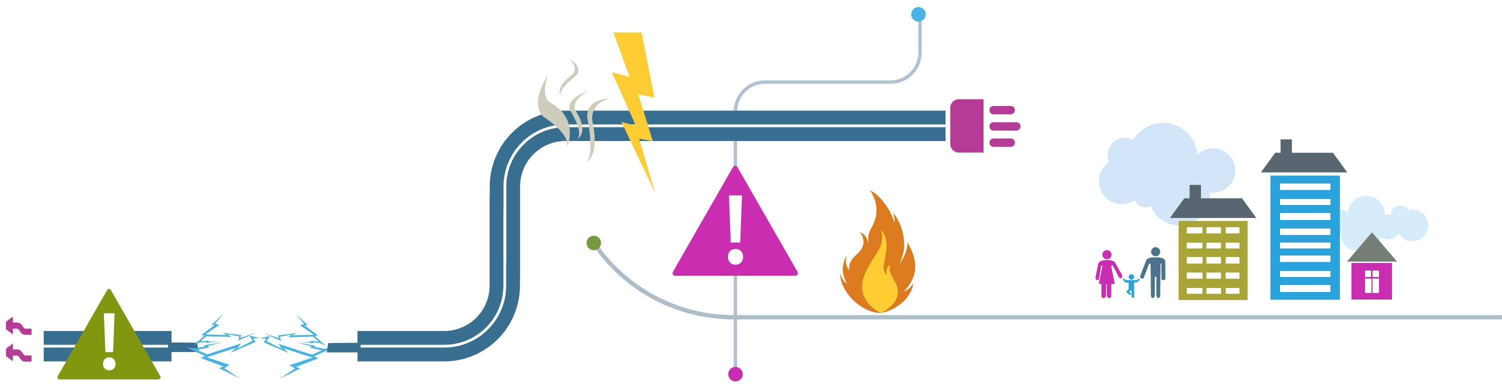


1. INTRODUCTION

The expectations for low-voltage assemblies continue to increase at an exponential rate. The quest for a greener environment, zero interruptions in supply and total personnel safety at times conflict. Margins in assembly designs are reducing due to the need to use less raw materials. Utilisation and pushing of assemblies to their limits is increasing as part of an overall drive for efficiency. As assemblies' transition from being dumb electricity distribution centres to integral and fundamental part of energy management systems, complexities are being added in abundance. Society's total dependence on electricity requires zero interruptions in supply. Added to these requirements is the desire for absolute safety, no one ever to be injured and everyone to go home safe each day.

Whilst internal arcing faults within well designed, constructed and maintained assemblies are extremely rare, when considering the new environment for assemblies, users are frequently asking what is the impact of an arcing fault within an assembly? How can it be reduced or eliminated? What might the benefits be if I specify an arc fault capability for an assembly? Unfortunately, there is no simple, one size fits all, answer. There are several options for reducing the likelihood and/or impact of an arcing fault, but due to the unpredictable nature of arcing fault, none are guaranteed solutions, and all offer different benefits.

To determine the most appropriate measures to limit the effects of an arcing fault within an assembly requires detailed consideration of the installation conditions, likely cause of an arcing fault and its consequences. As all the solutions available are circumstance dependent, choosing the most appropriate option is essential.

Arc Fault Detection Devices (AFDDs) conforming to BS EN 62606 are intended to mitigate the risk of fire due to the effect of arc fault currents in a final circuit of a fixed installation in household and similar applications such as offices, commercial premises, hospitals, public buildings, etc. BS 7671: IET Wiring Regulations have specific regulations relating to AFDDs. Therefore, AFDDs to BS EN 62606 are not relevant to this guide and are covered in the BEAMA Guide to Arc Fault Detection Devices (AFDDs).

This guide does not cover arc flash protection/analysis in accordance with IEEE 1584 where the intent is to protect operators via Personal Protective Equipment (PPE).

The purpose of this guide is to identify the possible causes of internal arcing faults within low-voltage assemblies, outline the measures that can be taken to reduce the likelihood of an arcing fault and/or its consequences, and assist the specifier in determining the most appropriate solution for their application.

2. RELEVANT DOCUMENTS

Several documents contribute to an understanding of and determination of the requirements for arc fault mitigation. These include:

- **IEC 60947-9-1:2019 Low-voltage switchgear and controlgear –** Part 9-1: Active arc-fault mitigation systems – Arc quenching devices
- **IEC 60947-9-2:2021 Low-voltage switchgear and controlgear –** Part 9-2: Active arc-fault mitigation systems – Optical-based internal arc-detection and mitigation devices
- **IEC 61439-0:2022 Low-voltage switchgear and controlgear assemblies –** Part 0: Guidance to specifying assemblies
- **IEC TR 61641:2014 Enclosed low-voltage switchgear and controlgear assemblies –** Guide for testing under conditions of arcing due to internal fault
- **IEC TS 63107:2020** Integration of internal arc-fault mitigation systems in power switchgear and controlgear assemblies (PSC Assemblies) according to IEC 61439-2
- **IEEE 1584:2018** IEEE Guide for Performing Arc-Flash Hazard Calculations
- **US Code NFPA 70E:2021** Standard for Electrical Safety in the Workplace
- **BS EN 50110 series –** Operation of electrical installations
- **BS 7671:2018 Requirements for Electrical Installations –** IET Wiring Regulations, Eighteenth Edition
- **Gambica Technical Guide –** Internal arc fault capability of assemblies in accordance with IEC TR 61641
- **AS/NZS 61439-2:2016** Low-voltage switchgear and controlgear assemblies Part 2: Power switchgear and controlgear assemblies (IEC 61439-2, Ed. 2.0 (2011), MOD)
- **Electricity at Work Regulations 1989**
- **Health and Safety Executive guide HSG85 –** Electricity at work: Safe working practices

3. CAUSES OF INTERNAL ARCING FAULTS WITHIN ASSEMBLIES

The cause of an internal arcing fault within an assembly can be one of many remote possibilities. For example:

- Insulation may breakdown following premature aging due to use of an unsuitable material for the conditions at its point of use within the assembly.
- There may be a build-up of contamination or moisture on the insulation leading to tracking and flashover.
- Faults in materials and workmanship.
- Loose or inadequate joints deteriorating and arcing as a result of load current, with the emitted ionised gas then bridging conductors to cause an arcing fault.
- Foreign objects, e.g. tools or hardware left in the assembly which, if they do not initially bridge conductors, may at some time in the future, move due to shock or vibration and cause a flashover.
- Lack of, or inappropriate, maintenance in which assemblies are not adequately cleaned, worn out parts are not replaced, etc.
- Inappropriate operating conditions, for example, an assembly providing protection in accordance with IP 31 is installed in a location where conducting dust is prevalent.
- Incorrect operation such as using a disconnector to break load currents or using any switching or fault interrupting device to interrupt a current larger than its proven capability.
- Vermin entering the assembly and bridging live conductors.
- Installing assemblies that have not been fully verified in accordance with the IEC 61439 series can lead to arcing within the assembly in service due to, for example, overheating, busbar and/or connection supports breaking as a result of short circuits, current interrupting devices flashing over between phases or phase to earth when attempting to break currents.
- Operator errors while maintaining or upgrading assemblies that are partially energised.

In reality all the foregoing can be avoided by due diligence in the design, manufacture, use and maintenance of assemblies. Unfortunately, errors and accidents do happen which can and do result in arcing faults within assemblies, mainly due to human error.

4. EFFECTS OF AN INTERNAL ARCING FAULT

When an internal arcing fault occurs within an assembly a large amount of energy is released in a fraction of a second. The amount of energy released is a function of the prospective short circuit current, the arc resistance, and the time it takes the protection upstream of the fault to operate, or the time taken for the arc to self-extinguish. Typically, with a 400 V system the arc fault current is 60 % of the prospective short circuit current.

An arc within an assembly creates a very high temperature, as high as 19 000 °C that will vaporise metals such as copper almost immediately and release a conducting ionised gas. Assuming the assembly is enclosed, the energy released causes a high gas pressure within the enclosure up to several tons per cubic metre within just a few milliseconds, often 'blowing' covers off or forcing doors open. Generally, the magnetic forces associated with the fault current drive the arc away from the source of the current and towards the extremities of the assembly. Unless the arc is blocked by robust barriers it will generally seat at the remote end of the main busbars or other main conductors. On some occasions the arc will self-extinguish before the upstream protection operates. Generally, it will cause significant damage to the main conductors and enclosure, allowing the emission of the high temperature ionised gas and vaporised metal. Gases and vapours emitted can, if a person is in the path of the emissions, cause serious burns and in extreme cases death.

It is well-known that arcing in low-voltage equipment is not totally predicable and consistent. Seemingly identical conditions may give different results. On one occasion the arc may self-extinguish, on others, it may persist until interrupted by the protection. Alternatively, the arc may propagate in different ways for no apparent reason. This has been clearly identified in the Australian Standard AS/NZS 61439-2 and its predecessors for many years. In a similar vein a note of caution included in Annex A of IEC/TR 61641; indicates that any internal arc fault tests on assemblies can only be regarded as indicative and that they do not cover all eventualities.

The afore mentioned references do however define rigorous tests to assess the ability of an assembly to limit the risk of personal injury and assembly damage with various options for classification.

BS 7671: IET Wiring Regulations has a specific regulation 532.5 in relation to internal arc fault protection in a switchgear and controlgear assembly. It prescribes that, where required for special applications, internal arc fault protection (e.g. optical detection system) detecting a fault arc together with a protection system can be selected in order to extinguish the arc. Alternatively, an assembly with arc ignition protected zone(s) can be selected to minimise the risk of an arcing fault.

Regulation 532.5 notes that internal arc fault protection is typically associated with a switchboard used in special applications. Electrical installation designers commonly consider the following as examples of special applications: oil refineries, data centres, car production lines, chemical process plants.

5. OPTIONS TO REDUCE AND/OR MITIGATE THE EFFECTS OF ARCING FAULTS

There are several methods of reducing the risks and effects associated with arcing faults. Each has differing merits, limitations and consequences. When deciding upon the approach to use it is vital to understand how each option relates to the specific needs of the application.

The different methods that can be employed to reduce and/or mitigate the effects of an internal arcing fault are as follows.

5.1 Reduce the magnitude and duration of the short circuit current

The energy released during an arcing fault is a function of the arcing current and its duration. This can be reduced by means of faster acting or fault limiting protection; if employed, such measures will reduce the damage to the assembly and the effect on personnel in the vicinity of the assembly.

With the trend towards the use of larger and/or parallel connected transformers this is increasingly difficult or impractical to implement to realise the benefit without compromising protection selectivity.

5.2 More sensitive protection setting

Where there is a desire to reduce the effects of an arcing fault while people are working on or near to an assembly, alternative and more sensitive protection setting that reduce fault clearance times significantly can be used during the period in which the work is undertaken. This will reduce the damage and improve safety during the work activity but of course selectivity is likely to be impaired.

5.3 Remote operation

One of the more sensitive operations in respect of initiating an arcing fault is that of closing a switching device to energise a circuit. Should there be an issue, an operator manually operating the device would not be in a good position with respect to the assembly. As has been good practice within some MV/HV substations for many years, the operator's situation can be improved by separating the operator from the device, and closing it remotely. Switching devices that are remotely operated, including remotely racked circuit breakers, are readily available.

Assuming an appropriate distance between the remote closing facility and the assembly, this approach provides total protection for the operator, but for all other aspects associated with internal arcing faults it has minimal benefit.

5.4 Arc prevention

As an alternative to managing the effects of an arcing fault, IEC TR 61641 (arcing class I) offers a 'prevention is better than cure' approach. This aims to prevent an arcing fault being initiated by covering all live conductors in insulation as one of several options. Whilst it is difficult to totally insulate all live conductors, in practice it can greatly reduce the probability of an arcing fault being initiated. However, in the extremely unlikely event that one occurs, the outcome is not dealt with in IEC TR 61641.

5.5 Arc fault containment

When considering arc fault containment, IEC TR 61641 applies. With this, the objective is to prevent the arc being emitted from the assembly in areas where an operative may be situated (front, sides and/or rear) and to vent the arc out of the assembly into a safe zone. Depending on the category selected (Class A, B or C), personnel safety (Criteria 1-5 = arcing class A) only may be considered, or additionally,

(i) **restricting the damage to one area of the assembly (Criteria 1-6 = arcing class B), or**

(ii) **damage restricted to one area and the assembly is suitable for limited further service (Criteria 1-7 = arcing class C).**

Noting that internal arc fault test results are not always repeatable, tests to IEC TR 61641 demonstrate that an operator adjacent to an assembly suffering an arcing fault is unlikely to be seriously harmed. However, the damage to all or part of the assembly, as determined by the categories within the TR, may be considerable.

IEC TR 61641 also assumes that all door and covers are closed and secured as in normal service. There is no consideration of one of the most sensitive situations, that of an operator having a door open and making some adjustment or similar within the assembly. Even assemblies built to the BS EN (IEC) 61439 series and operated under safe working practices can be subject to unforeseen circumstances or accidents.

5.6 Arc detection

Means for detecting arcs within assembles are readily available by using devices conforming with IEC 60947-9-2. The most basic devices detect the light emitted by the arc. If adequate precautions are not in place, such devices can be susceptible to torch lights and camera flashes resulting in erroneous operation. Alternative versions overcome the need for the additional precautions by detecting the arc using the light emitted by the arc plus measurement of the fault current.

Once an arc is detected a corrective action is initiated, usually within 1 ms or so of the arc being detected. IEC TS 63107 provides a means of verification of the position of the light sensors and requires that any blind spots, which can occur, are identified.

First issued in May 2020, IEC TS 63107 is a technical specification that describes the important steps for integrating and verifying an active arc mitigation system. This new specification covers:

- **Sensitivity tests (low energy arc tests)**
- **High energy arc tests**
- **Temperature-rise verification of related components**
- **Short circuit strength tests of connections to components**
- **Nuisance tripping tests**
- **Re-powering scenarios**

IEC TS 63107 also includes other mandatory requirements related to arc mitigation devices, their integration, and their operation to ensure the system is verified correctly.

5.7 Arc quenching

Once an arcing fault has been detected, an arc quenching device conforming with IEC 60947-9-1 can be used to extinguish the arc within a few milliseconds. Effectively arc quenching devices place a short circuit on the incoming terminals to the assembly, reducing the voltage to a level at which the arc cannot persist. With this process, damage to the assembly is minimal and the possibility that the assembly is suitable for further service is maximised. Also, the risk to individuals adjacent to the assembly is much reduced. However, a near maximum value short circuit is applied to the upstream equipment for the time it takes the upstream equipment to operate.

Following an arc quenching operation, the upstream equipment must be inspected and possibly maintained. In some instances, the upstream equipment may need to be replaced in order to restore the system to a condition where it can be certain to cope with another full value short circuit.

5.8 Arc interruption

As an alternative to arc quenching the arc detection equipment can be used to instruct an upstream circuit breaker to trip 'instantly'. This approach takes the tripping time of the upstream circuit breaker to extinguish the arc, of the order of 50 ms and longer than the time taken by an arc quenching device. Damage to the assembly with arc interruption is increased compared with arc quenching, but as arcing fault currents are of the order of 60 % of the prospective value, upstream equipment is far less stressed.

5.9 Personal Protective Equipment (PPE)

As required by the Electricity at Work Regulations, use of PPE to provide safety is the measure of last resort. The first choice should be to isolate all electrical equipment that needs to be worked on. When this is not possible, consideration should be given to separating personnel from the danger. Only if it is unreasonable to implement the foregoing should PPE be used to provide safety.

When PPE is the only option, IEEE 1584 provides useful guidance. IEEE 1584 gives a method of calculating potential arc energy, identifies zones of diminishing intensity at distances from the arc and recommend levels of PPE that will tolerate the arc flash. For intense arcs the PPE can be very cumbersome and greatly restrict the tasks that can be undertaken.

6. DETERMINING THE APPROPRIATE ARC FAULT MITIGATION MEASURE

As can be seen there is not a utopian solution when it comes to arc fault mitigation. Whichever approach is used to mitigate the effects of an arcing fault, in the unlikely event one occurs, there are issues to be managed following the fault, but the issues differ depending on the application and the means of mitigation employed. In order to determine the most appropriate approach to arc fault mitigation, a detailed assessment considering all aspect of the application including the most likely cause of an arcing fault, the likely effects of the arcing fault and the inconvenience of an interruption in electricity supplies needs to be undertaken.

When determining the appropriate arc fault mitigation measures considerations should include:

6.1 Electrical system and protection scheme

- Has the electrical system been optimised to minimise the prospective short circuit current at all points within the installation/assembly?
- Is current limiting protection used where practical?
- Are all protection elements set to the minimum that will allow selectivity?
- Is being able to reduce protection setting while working on the assembly beneficial?

6.2 Location

- Is the assembly located in a substation with access restricted to authorised personnel?
- Can ordinary persons access the exterior of the assembly?
- Can an exclusion zone around the assembly be effectively put in place?

6.3 Operation

- What operations will be carried out on the assembly when it is energised and in service?
- Can the assembly be de-energised before covers and doors are opened?
- Can the assembly be remotely monitored and operated?

6.4 Clothing and PPE

- What type of clothes will personnel adjacent to the assembly be wearing; normal clothes or work wear?
- Will personnel opening covers and doors be using PPE, if so what PPE?
- Will the guidance set out in IEEE 1584 be followed?

6.5 Arc prevention

- Can all energised conductors be protected with insulation such that the risk of an internal arcing fault is negligible?
- In the extremely unlikely event of an arcing fault, are the consequences manageable?

6.6 Arc fault containment

- If arc fault containment is employed, where is the arc going to be exhausted?
- If an arc fault occurs, will the damage be contained such that supplies can be restored in an acceptable time?
- What precautions will be employed if covers and doors are to be opened when the assembly is partially or fully energised and in service?

6.7 Arc fault quenching

- Are measures in place to ensure there will be no erroneous operation of the arc quenching device?
- Is it practical for the arc detection means to detect an arc in all places where an arc can occur?
- Is the upstream equipment able to support and interrupt a maximum prospective short circuit current?
- Will the upstream equipment need to be maintained or replaced before the circuit can be reenergised?

6.8 Arc fault interruption

- Are measures in place to ensure there will be no erroneous operation of the arc interruption device?
- Is it practical for the arc detection means to detect an arc in all places where an arc can occur?
- Can the arc be tolerated for the time it takes the upstream protection to operate 'instantaneously'?

6.9 Likely sources on an internal arcing fault

- Will doors and covers be opened, and work undertaken on the assembly when it is partially or fully energised and in service?
- If the assembly is located in dusty and/or humid environment is the IP protection such that there will not be deposits and tracking on insulation?
- Has the assembly been fully design verified in in accordance with the appropriate part of the BS EN (IEC) 61439 series of standards?
- Will the assembly be suitably maintained to ensure it remains in good condition?

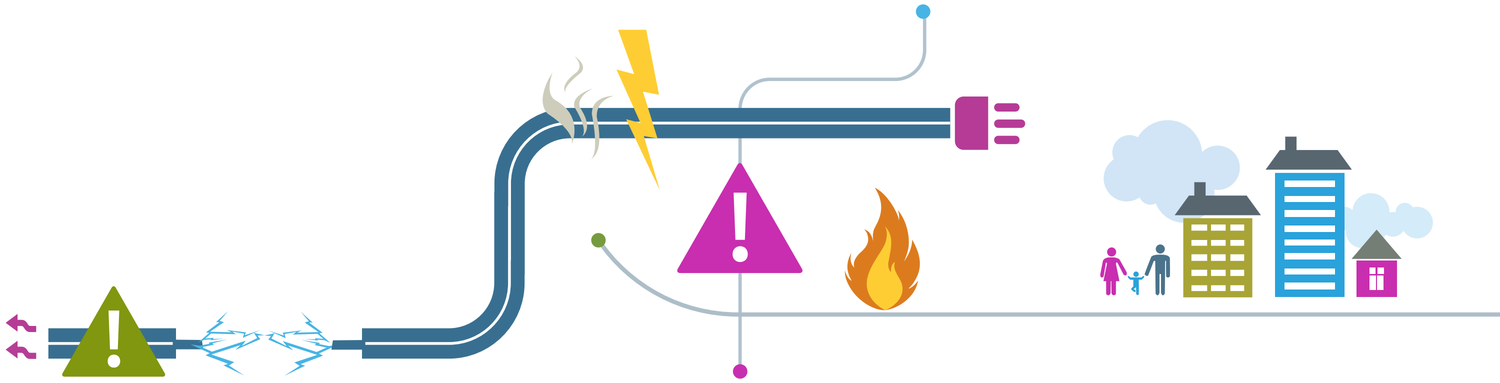
6.10 Consequences of an internal arcing fault

- What measures are necessary to ensure the safety of personnel?
- What is the impact of losing supplies for a time?
- Is limiting damage to the assembly or part of the assembly a priority?
- What measures are in place to ensure supplies can be restored in an acceptable time?

7. CONCLUSION

Once the attributes of the various methods of mitigating arcing faults and needs of the particular applications have been fully understood, a judgement on the most appropriate approach to mitigating the effects of an arcing fault can be made. It is not an easy decision, and some compromise will be necessary. It is also essential to note that internal arcing faults are not totally predictable and that none of the means of mitigating or preventing and/or eliminating arcing faults are perfect. There will be a small but residual risk associated with the nature of arcing faults and the particular mitigation method employed. However, giving full consideration to the unlikely occurrence of an arcing fault and significantly reducing the probability and/or the consequences of such a fault by the most appropriate means at the design stage is very beneficial to both personnel safety and supply availability.

It is the responsibility of the purchasers of LV assemblies which include internal arc fault mitigation, to always ensure that the assembly being delivered has internal arc fault mitigation measures in accordance with the representative design tested and that all other design verifications are in accordance with BS EN (IEC) 61439 series and remain valid.



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