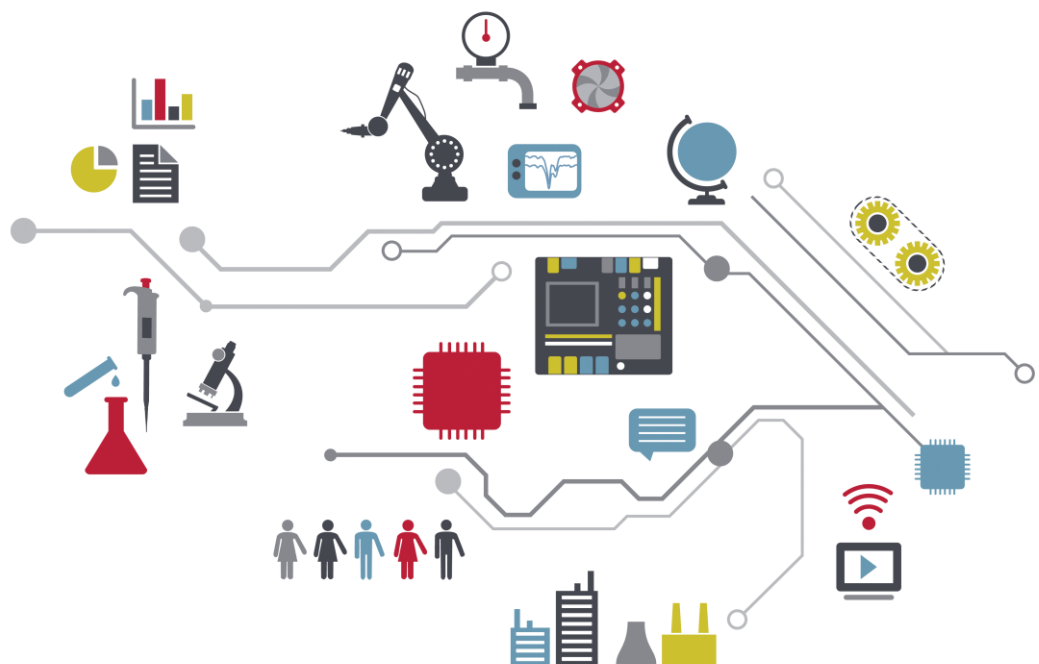


INTERNAL ARC FAULT CAPABILITY OF ASSEMBLIES IN ACCORDANCE WITH IEC/TR 61641

A GAMBICA Technical Guide



Internal arc fault capability of assemblies in accordance with IEC/TR 61641

If you specify an assembly as requiring an internal arc fault capability in accordance with IEC/TR 61641; what can you expect, what benefit will you get, are there more effective options for the particular application. Gambica provides some clarity.

Introduction

Assemblies that are correctly operated, properly maintained, well designed and verified in accordance with the IEC 61439 series very rarely incur an internal arcing fault in service. However, as fault levels increase, the potential consequences when such a fault occurs become more severe. This, together with the ongoing pursuit for ever greater safety, is bringing internal arcing faults within assemblies to the fore.

In the belief that their personnel will be 'safe', increasingly, users of low-voltage assemblies are calling for them to comply with IEC/TR 61641; Enclosed low-voltage switchgear and Controlgear assemblies — Guide for testing under conditions of arcing due to internal fault. Since the document is a TR (Technical Report) it cannot be 'complied with' in the way that a full Standard can.

Whilst in some circumstances specifying that equipment has to 'comply' with IEC/TR 61641 will lead to greater operator safety and reduced down time in the event of an arcing fault within an assembly, it is not a 'cure for all ails'. Before specifying 'compliance' with this requirement an objective assessment should be carried out considering the whole application to determine if 'compliance' with IEC/TR 61641 brings worthwhile benefits. The factors to be considered are varied and at times very subjective. They include: what enhanced safety does 'compliance' with IEC/TR 61641 offer for the application being considered; when is an internal arcing fault most likely to occur, and; are there better options for increasing operator safety and process security.

Making the right choice in respect of an assembly 'complying' with IEC/TR 61641 is complex. It requires a good understanding of the intended application for the assembly, knowledge of the design and use of assemblies and a detailed understanding of IEC/TR 61641. In addition, a skill in assessing risks is necessary.

Gambica has prepared this guide to assist users of low-voltage assemblies in making the right choice in respect of an internal arc fault capability for their application.

IEC/TR 61641



This document is an IEC Technical Report. It is also available as a Published Document from British Standards: PD IEC/TR 61641. Its focus is on internal arcing faults within assemblies in accordance with IEC 61439-2, but by agreement it can be applied to other assemblies.

As a Technical Report (TR), IEC/TR 61641 recommends good practice in respect of the testing of assemblies under arcing fault conditions. The requirements detailed in the TR are not sufficiently definitive, mature and robust for a Standard.

Certification bodies do not certify compliance with a TR, but they may conduct tests in accordance with it and issue some form of report detailing the results of the tests.

Terminology

Like most IEC documents, IEC/TR 61641 has determined a number of Terms and Definitions. These are not repeated in this guide, they are available from Clause 3 of IEC/TR 61641.

Causes of internal arcing faults

Internal arcing faults within assemblies occur for a number of reasons, for example;

- Insulation breakdown;
- Contamination or moisture on insulation leading to tracking;
- Faults in materials or workmanship;
- Load current arcing across a loose or deteriorating joint;
- A foreign object within the assembly, e.g. a tool;
- Lack of, or inappropriate, maintenance;
- Inappropriate operating conditions;
- Incorrect operation;
- Entry of vermin;
- Operator errors while working adjacent to live equipment.

None of the foregoing should occur. Virtually all internal arcing faults within an assembly are as result of some failing that can be avoided by other means.

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 400V system the arc fault current is 60% of the prospective short circuit current. If the prospective short circuit current is reduced and/or protection upstream of the fault operates quicker, e.g. current limiting type compared with the

definite minimum time protection, the energy released and the consequences of the arcing fault are significantly reduced.

An arc within an assembly creates a very high temperature and a conducting ionised gas. Assuming the assembly is enclosed, the energy released causes a high gas pressure within the enclosure, often 'blowing' covers off or 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 burn clear before the upstream protection operates. Generally, it will cause significant damage to the assembly; 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.

Note of caution

Unfortunately, low voltage arcs are not totally predicable. Seemingly identical conditions can give different results. On one occasion the arc can self-extinguish, on others, it can persist until interrupted by the protection. Alternatively, the arc can propagate in different ways for apparently identical conditions.

The Australian Standard for assemblies, AS/NZ 3439-1 has for many years included an annex detailing internal arc fault tests. This recognises that an internal arc fault is neither predictable nor repeatable. AS/NZS 3439-1, Annex ZD, states:

'It should be realised that it is not always possible simulate all the conditions that can produce arcing faults in service and that the arc does not always behave in a repeatable manner. Unfortunately, arcing faults are not totally predictable and repeatable.'

This statement has essentially been transferred into the recently published AS/NZS 61439-1. A similar note of caution is included in Annex A of IEC/TR 61641; indicating that any internal arc fault tests on assemblies can only be regarded as indicative and that they do not cover all eventualities.

Options within IEC/TR 61641

The current edition of IEC/TR 61641 is a considerable advance on the earlier issues. Previously only the effects of arcing at the front of the assembly were considered; now, unless the manufacturer advises otherwise, arcing on all sides (front, rear, left and right) must be considered. In addition, previously a manufacturer need only consider the effects of arcing on the load side of outgoing functional units. Now, the complete assembly must be considered. As a result, claims of meeting the requirements of the earlier versions of the TR need to be treated with caution.

Different installation conditions are considered within IEC/TR 61641. The TR recognises that assemblies can be installed in positions where they are accessible by people without specialist electrical knowledge (unrestricted access), or, in areas where access is limited to authorised persons (restricted access). With unrestricted access the TR assumes that anyone near the assembly can be

wearing light summer clothes, whereas with restricted access it is assumed personnel will be dressed in heavier work wear. Anyone specifying an assembly with an internal arc fault withstand capability should identify which type of access is applicable. Unless otherwise indicated, the manufacturer will assume the assembly is to be installed in a restricted access location, for example, a locked substation with controlled access.

To take account of different application needs the Technical Report defines three Arcing Classes for arc fault tested assemblies:

Arcing Class A: assembly providing personnel protection under the arcing conditions defined in the Technical Report.

Arcing Class B: assembly providing personnel protection and confining the arc fault damage within the assembly is limited to the zone within the assembly where it was initiated. (Effectively, a zone is defined as a circuit or compartment.)

Arcing Class C: in addition to meeting the requirements of Arcing Class B, the assembly, following isolation of the damaged circuits the remainder of the assembly is capable of emergency operation.

In addition, there is a further class; **Arcing Class I**. This takes a totally different approach. In the unlikely event of an arcing fault within an assembly Arcing Classes A, B and C focus on managing the effects of the fault, whereas Arcing Class I adopts the philosophy of 'prevention is better than cure'. Arcing Class I seeks to reduce the risk of an arcing fault being initiated by individually enclosing, as far as practical, each conductor in solid insulation.

The Arcing Class I can apply to parts or all of the assembly. Areas offering protection in accordance with Arcing Class I are termed 'arc ignition protected zones'. With some limited exceptions, the insulation must provide protection against contact with live conductors in accordance with IP 4X of IEC 60529 and withstand a power frequency dielectric test 1.5 times the normal test value for an assembly.

Limitations of testing in accordance with IEC/TR 61641

Internal arc fault testing of an assembly in accordance with IEC/TR 61641 is carried out with all doors and covers closed and correctly secured. Unless there is a separate agreement between the user and manufacturer, no consideration is given to the effects of any toxic gases or loud noises that may be emitted. Risks associated with maintenance when doors or covers are open and someone working inside the assembly, or personnel exposure to the top or bottom of the assembly, are not considered.

The principle focus of IEC/TR 61641 is, in the event of an arcing within the assembly, the safety of personnel adjacent to the assembly. The personnel may be operating external control devices, but the Technical Report assumes the assembly will be fully closed and that no one will be working inside the assembly at the time any arcing fault occurs.

Characteristics

A manufacturer offering an assembly as having an arc fault classification is obliged to provide details of its capabilities. The characteristics to be declared are set out in Clause 5 of IEC/TR 61641 and in general terms include, as applicable:

- Rated operational voltage.
- Arcing Class, A, B, C, or I.
- For Arcing Class B or C, the areas to which the arc will be confined.
- Prospective short circuit current at the incoming terminals of the assembly together with any upstream current limiting requirements.

Internal arcing fault tests

The prime aim of internal arcing fault tests on an assembly is to demonstrate, as far as reasonably practical, an improved level of safety for personnel in the vicinity of an assembly, should an internal arcing occur. The tests do not guarantee personnel in the vicinity of an assembly will not be frightened or suffer some injury as a result of the fault. However, it is expected the risk of severe burns, or worse, will be much reduced with an assembly that has been shown to have an ability to withstand internal arc faults.

During the test clothing of personnel is simulated by 'indicators' around the assembly. The indicators are made of different grades of cotton to simulate light summer clothes and workwear (unrestricted and restricted access).

A second reason for conducting internal arcing fault tests on the assembly is to demonstrate the impact of the fault on the assembly itself. In some instances, and as defined by the Arcing Class, there may be a requirement to confine arc damage to a part of the assembly, and in addition, with minimal maintenance, part of the assembly can be re-energised for emergency use.

The process of conducting internal arc fault tests within an assembly is relatively straightforward. In simple terms, the assembly to be tested is connected to a supply capable of delivering the required prospective short circuit current for an appropriate time. Indicators are placed a short but defined distance from all sides (front, rear, left and right) of the panel being tested. Fuse wire is used to bridge all phases of main conductors in a three phase assembly or between phase and neutral in a single phase assembly. This is placed at the point where the arc is to be initiated. The supply is then energised and the test carried out.



Fig. 1: Internal arcing fault test:

- Test panel mounted on a simulated cable trench
- Arc fault initiated on the incoming cable terminals;
- indicators for unrestricted access;
- result deemed to provide protection for ordinary persons in accordance with IEC/TR 61641

Noting that insulation on conductors is not removed to apply the fuse wire, sufficient tests are carried out on an assessed worst case basis to cover arcs initiated anywhere on the main conductor system;

e.g. incoming supply terminals, complete busbar system, load and line side of all outgoing functional units. Generally, the duration of an internal arcing fault test is limited to the time it takes the upstream protection to operate. Where details of the upstream protection are not known an upper limit of 500 ms can be applied to the duration of the test, but, the TR recommends 300 ms when HV protection is relied upon. (Modern protection seeing a major fault is expected to operate within this time).

For a successful test the indicators must not catch fire. In addition, a number of other criteria as determined by the Arcing Class and as defined in the Technical Report must be met, e.g. minimum IP, ejected parts must not exceed a maximum weight, door and covers must remain effectively in place even if some hinges and fixings are broken.

Other considerations

When considering the possibility of internal arcing faults within assemblies, other possibilities for increasing operator safety and/or limiting damage to an assembly may be worthwhile. These include quicker means of eliminating the arc than is possible with traditional protection and/or enhanced PPE for operators.

i) Arc detection

Relays are available that detect an arc within an assembly, generally through sensing a particular range of light frequencies and/or the rate-of-rise of the fault current. These relays operate within a millisecond or so. They can initiate 'instantaneous' tripping of an upstream breaker to isolate the fault much quicker than waiting for the normal short-circuit protection to operate. Alternatively, the operation of an arc fault mitigation device can be initiated.

ii) Arc fault mitigation

Arc fault mitigation devices are gaining prominence. Essentially they apply a short-circuit to the supply within 3 or 4 milliseconds of the arcing fault being initiated. This reduces the arc voltage to a very low level, extinguishing the arc. At the same time, it forces a short-circuit operation of the upstream protection.

This has the negative effect of stressing the upstream network and forcing a maximum level operation of the protection. However, the very fast operation of the fault mitigation device has several benefits;

- a) the probability and severity of injury to personnel in the vicinity of an assembly incurring an internal arcing fault is much reduced;
- b) damage to a low-voltage assembly suffering the internal arcing fault is vastly reduced;
- c) many of the additional assembly design measures necessary to make an assembly more robust, so as to withstand a full arcing fault, are not necessary; and
- d) the feasibility of returning an assembly to normal service, quickly, after an arcing fault is significantly increased.

It is worth noting that arc fault detection and arc fault mitigation devices must be operational and maintained in order to provide effective protection.

iii) Working on or near energised equipment

As previously noted, one of the most likely causes of an internal arcing fault is an 'incident' while maintaining or modifying a partially energised assembly; a tool might slip, something might drop

through a ventilation aperture in a barrier, a conductor might be presumed dead when it is energised, etc. These types of activities are outside the scope of IEC/TR 61641, but if they are contemplated other safety and legal obligations must be met.

In the UK, the Electricity at Work Regulations are particularly pertinent in regard to working on or near energised equipment. These Regulations prohibit work on or near live conductors unless it is unreasonable in all the circumstances for the equipment to be fully isolated. The Health and Safety Executive guide, HSG85 is a useful aid to determining if working with equipment partially energised cannot be avoided. It also gives some guidance on good practise when working on partially energised equipment.

Other useful references when contemplating working on partially energised equipment, whilst not legally binding in the UK, are;

- BS EN 50110 series: Operation of electrical installations
- The US code, NFPA 70E: Standard for electrical safety in the workplace.
- IEEE 1584: Guide for performing arc flash hazard calculation.

In combination these documents;

- i. Provide a means of calculating incident arc flash energy;
- ii. Identify various boundaries for arc flashes and personnel safety (qualified, unqualified, wearing a particular type of PPE, etc.) relative to the energised equipment; and
- iii. Define arc flash suits with various ratings that provide a measure of personnel protection against arcs of different incident energies.

iv) Network topology

In recent years there has been a trend towards the use of larger transformers or more transformers operated in parallel. As current rating of assemblies increases, so in general do the short circuit currents and the energy released under arcing fault conditions.

Subject to the many other conflicting needs, if at the design stage the magnitude and duration of the prospective short circuit can be reduced by, for example, using more and smaller transformers, wider use of current limiting protection, the effects of an internal arcing fault within an assembly can be correspondingly reduced.

v) Forms of separation

Forms of separation in accordance with IEC 61439-2 are intended to improve access to parts of an assembly while other parts remain energised. They might also assist in containing an arc to a compartment within an assembly, but this is not their intended function. They are not verified as having any arc containment capabilities.

Decision

Making the 'right' decision in respect of an assembly being arc fault tested is not easy; it is subjective, and confirmation that the right decision has been made might never be known.

Anyone specifying an assembly has to decide if the additional benefit and cost of an internal arc fault tested assembly is justified. This can only be objectively established for each individual application,

taking into account when internal arcing faults are likely to occur and if testing in accordance with IEC/TR 61641 would avoid any issue that may result. Anecdotal evidence is that, in the case of assemblies in locations with controlled access, the majority of arcing faults which result in injury occur when the assembly is partly energised and some form of work is being undertaken inside the assembly. At other times the assemblies are unattended.

When deciding if it is worthwhile specifying an arc fault tested assembly all the aspects given in Table 1 should be reviewed. Whilst most items to be considered are not definitive, an objective review of each of them will assist in reaching the most appropriate conclusion for the application. (As significant judgement is required, some form of scoring or ranking system can assist in reaching a conclusion.)

Consideration	Benefit of an arc classified assembly in accordance with IEC/TR 61641
Has the electrical system been optimised to minimise prospective short circuit currents and maximise the use of current limiting protection?	As the magnitude and duration of arc fault current is reduced, so too are the benefits of an arc tested design of assembly
Where is the assembly located? (The TR covers two options; restricted access and unrestricted access.)	Benefits are much reduced when the assembly is located in a controlled area and only assessable by authorised personnel (restricted access).
What type of environment is the assembly located in?	A clean dry environment much reduces the risk of an internal arcing fault and correspondingly the benefits of an arc fault tested design.
Can all operations (switching, racking, monitoring) be carried out remotely?	The safety benefits of an arc fault classification are much reduced with remote operation.
Will there be a need to open door and covers with the assembly partially energised, e.g. to carry out maintenance, connect additional outgoing cables)?	If yes, Arcing Class I may be of benefit. In addition guidance from HSG85, BS EN 50110, NFPA 70E, IEEE 1584 and other relevant sources may be applicable.
Will the assembly have regular, routine maintenance in accordance with the manufacturer's instructions?	Appropriate maintenance reduces the risk of an internal arcing fault.
Are personnel likely to be in the vicinity of the assembly in normal service (all doors and covers closed) if an arcing fault occurs?	If personnel are unlikely to be adjacent to the assembly at the time of an arcing fault, the benefits in respect of personnel safety are much reduced.
Is the prime concern the safety personnel in the vicinity of the assembly, if an arcing fault occurs?	If yes, Arcing Class A may be applicable
In the unlikely event of an internal arcing fault, is there a benefit in restoring some supplies very quickly?	If yes, Arcing Class B or C may be appropriate.
Bearing in mind the lack of total repeatability of arcing faults, is the added assurance of an arc fault tested design sufficient to reduce the risk of injury to personnel to an acceptable level?	If yes, Arcing Class A, B or C may be applicable. If not, consider remote operation and total separation of the personnel for the assembly while it is energised.

Table 1: Considerations for an arc fault tested assembly

Summary

Working on, or inside, an assembly while it is partially energised is outside the scope of IEC/TR 61641. If activities of this nature are being considered the appropriate legal obligations and safety practises should be followed.

Installing arc detection and arc fault mitigation devices can dramatically reduce the consequences of an internal arcing fault in respect of personnel safety, damage to the assembly and time to return the assembly to service. The cost of these systems must be weighed against the probability and consequences of an arcing fault and the impact their operation may have on the upstream system.

Specifying an assembly to be internal arc fault tested in accordance with IEC/TR 61641 is beneficial in some circumstances, but making the right decision for the application and ensuring the desired benefits are realised is very difficult. The benefits are subjective and depend on the application, probabilities, consequences for personnel safety and operational impacts. Claims of meeting IEC/TR 61641 must be thoroughly reviewed with respect to the extent and validity of testing performed.

There is a cost associated with providing an assembly in accordance with any of the Arcing Classes given in IEC/TR61641. The key question is; ***has the risk of an internal arcing fault within an assembly and the consequences of that fault been reduced to an acceptable level?***

Determining if an assembly should have an Arc Classification and which is the most appropriate Class needs serious consideration. Aspects to be considered and guidance on reaching the 'right' decision is given in Table 1 of this guide.

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