

# A VIEW ON INTERNAL ARC TESTING OF LOW VOLTAGE SWITCHGEAR

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**Abstract** - Safety and downtime are the critical factors in petrochemical installations. In this respect, possible internal arc faults have also become a more important issue in user's specification, dimensioning, operating and maintenance of Low Voltage Switchgear and Controlgear Assemblies. Preventing internal arc occurrences in switchgear assemblies is of paramount importance and an increasingly more important consideration for the design engineers.

The paper compares the user's perception of Arc Proof switchgear against the manufacturer's way of marketing it's Arc Proof switchgear. This results in an assessment of the guide for testing under conditions of internal arcing - the IEC/TR 61641 – and suggestions for evolving this Technical Report in order to match the user's and the manufacturer's perception. Furthermore the paper gives a manufacturer and test house perspective on the practical value of the internal arc testing, and how the results are assessed and interpreted in order to conclude that a design is arc proof. The latter is in the perspective of safety during operating and maintenance.

Conclusions: for the user there is a need for more stringent rules in testing, possible classification and clearer reports in order to make switchgear of different makes comparable.

*Index Terms* — Switchgear assembly, Internal arcing test, Arc Free zone Arc Proof zone, Arc Proof assembly. TR (short for Technical Report or IEC/TR 61641)

## I. INTRODUCTION

Internal arc testing for Low Voltage Switchgear Assemblies is not a mandatory test under the IEC standard. The current IEC technical report (TR), for testing under internal arcing conditions is only a guide for testing and requires the users consent with respect to the way the tests should be performed and how the assessment of the results is interpreted. This is the theory of the TR. In practice, in many cases, the manufacturer applies the TR much more generic like it is a standard. He is encouraged to do so because many users lack the time to specify Internal Arcing capabilities for the switchgear they need and internal arc testing is a too costly business to perform on each switchgear arrangement that is manufactured.

This raises the question: Whether the current TR and the way it is practiced cover all the needs and expectations of the end user? For instance: does it make sense to only test the switchgear assembly in a static state in optimal condition with the doors closed, while we know arcing faults tend to happen as the result of a change of state caused by somebody operating the switching devices, performing maintenance or inspection. For example it is far less likely that an internal arc is triggered by vermin or whiskers in a static state.

For this reason there are some end users who specify tests in addition to the suggested locations for application of the fuse wire as per the TR. E.g. Initiating an arc on the engagement of the main terminals of a withdrawable unit or device like an Air Circuit Breaker while racking it in!

Although the probability of the occurrence of an internal arc fault is low, the impact of such an incident is devastating. Because in today's market more end-users value the importance of internal arc testing, there is a need for ways to compare the different makes of switchgear assemblies objectively.

Within the IEC technical committee there are discussions whether this TR should become more stringent and be included as normative annex to the product standard, IEC 61439-2. What is the argument for such a requirements? Do all switchboards need to be arc proof or can we set an acceptable maximum to the prospective exposed arc fault energy coming from a switchboard at an internal arc incident?

Chapter II describes an historical introduction on how the TR evolved from the high voltage switchgear assembly product standard.

Chapter III, discusses Internal Arc needs and expectations from a user perspective.

Chapter IV discusses a critical view on the TR as it is and how it could evolve further to the benefit of both the user and manufacturer.

Chapter V presents several solutions to achieve an Arc Proof switchgear design that can pass the tests and the assessment according to the actual TR. Passing the tests that are suggested in the guide and maybe some additional tests specified by the customer requires an Arc Proof design of the switchgear assembly.

The manufacturer makes the choices concerning the design of the system in order to pass the criteria in the Technical Report. This can be an enclosure existing of thick steel with exhaust-gas openings, etc., allowing the internal arc to be contained for a longer time.

Another design direction is to make the design in a way that the arc duration is limited and the arc will be confined in the compartment of the enclosure where it was initiated.

Chapter VI on Internal Arc Testing describes the perspective of the test station. Current testing according IEC/TR 61641 will be explained.

## II. HISTORY OF INTERNAL ARC TESTING

The first document regarding arc fault tests was the German PEHLA guide No. 2 issued in 1969. The document describes the method for testing switchgear under conditions of internal arcing and gave the criteria for accepting an arc resistant construction, with the focus on personal protection. An essential outcome of the research that was done for the test method is the typical indicators

for burning risk assessment, which are still in use. The properties of the indicators resemble the ignition temperatures of different types of fabrics used for working clothes and for general summer clothes.



Fig. 1 Typical set-up with indicators for an Internal Arc test

This guide was the basis of Internal Arc testing prescribed as optional type test for Medium Voltage Switchgear and Controlgear and as guidance for internal arc testing in Low Voltage Switchgear and Controlgear.

The IEC/TR 1641 “Enclosed Low-Voltage Switchgear and Controlgear assemblies - Guide for testing under conditions of arcing due to internal fault” was first issued in 1996. This first edition focused on personal protection. In the second edition, IEC/TR 61641: 2008 assembly protection was added to personal protection amongst other new items.

The arc fault test for medium voltage, now in IEC 62271-200, is further developed and is today an optional type test which needs to be performed only if a manufacturer assigns a rating of the Internal Arc Classification (IAC). The test set ups, specimen and ignition point are well prescribed with the aim to have a defined/standardized test method.

The rules for arc fault tests on Low Voltage Switchgear assemblies according to IEC/TR 61641 are due to the common roots similar to those in the IEC 62271-200, but not as much detailed and are not normative. While Low Voltage Switchgear assemblies in many cases are customised to the specification and local requirements of the user the rules are merely guidelines for testing and the interpretation of the results are subject to agreement between manufacturer and user. Nevertheless in segments of the market (mainly petrochemical industries and other big international companies, power plants, etc.) the tests are regarded as type tests and mostly required for assemblies according to IEC 60439-1 / IEC 61439-2.

In practice this means that the interpretation of the result is left to a third party, being a recognised laboratory or certification body. Highest priority is to prove personal protection, but also the requirement for assembly protection (continuous energy supply) is specified more often.

In other segments of the market and for other products in the IEC 61439 series, arc fault testing is not usually considered.

### III. INTERNAL ARC TESTING FROM A USER PERSPECTIVE

Employers are responsible for the safety of their employees, but they are also keen on continuity of their production facilities. Continuity in this case translates to reliability. In this perspective when – regrettably – an internal fault occurs, the owner wants the damage on the switchgear to be limited to a minimum, so they can resume production as soon as possible.

#### A. The necessity for Arc Proof switchgear

From a personal safety perspective, the focus has traditionally been on electrical touch safety and the mechanical withstand of through going short circuit currents. Arc flash hazards on the other hand were treated as of minor importance or negligible occurrence. This focus has now changed, switchgear is operated more frequently and safety requirements are taken more seriously, therefore professionals have come to realize that arc flash hazards pose a serious danger with regard to both physical injury and damage of the switchgear, and last but not least interruption of the production process.

From an equipment reliability / availability perspective, the focus has always been on bolted short circuits, i.e. assuming the fault is likely to occur on the load side of the switchgear. Testing of those short circuit properties has been known for many decades, and is a proven technique. But when a short circuit occurs inside the switchgear assembly, it is very likely to develop as an internal arc and generally causes serious damage to the hardware, resulting in downtime of the equipment.

When the protection capability of switchgear is not known, there are methods to determine what Personal Protection Equipment (PPE) should be used to protect personnel from the danger that one could be exposed to at the occurrence of an arc flash while operating the switchgear. The US IEEE has developed a standard to calculate the Arc Flash energy that can be released as a result from a fault. The incident energy is categorised in five Hazard/Risk Categories (HRC) in the US safety standard NFPA70E and is expressed  $\text{cal/cm}^2$ . The use of proper PPE is related to the HRC categories.

#### B. The merits of Internal Arc testing

Now arc flashes are an important issue from both personal protection and switchgear availability perspective. Employers/owners want to be sure that the equipment they will be operating is safe, reliable and have a high availability rate.

To prove these characteristics, uniform and representative testing is required. ‘Uniform’ means an internationally recognized and standardized method for testing. ‘Representative’ means that the tests to be

performed simulate the physical effects taking place during an internal fault in an installation as close as possible to reality.

Arc flash testing is a reasonably new phenomena and less well understood compared to the 'classic' short circuit testing. The test specimen required by the TR are fully equipped switchgear assemblies. However in low voltage there are numerous configurations and arrangements that have been derived from a limited number of tested standard constructions and arrangements. The end-user has to be well aware of this, and verify if his configuration sufficiently resembles the tested construction and judge whether the results of the performed tests on it, apply.

Especially customer-specific equipment or adjustments of protection units can affect the performance of the switchgear construction. Therefore serious attention should be paid to the required protection settings for the users application and settings that are valid for the test results, and more important safeguard the integrity of the whole assembly.

#### IV. CRITICAL VIEW ON THE TR

In this part a critical view on the TR from the users perspective to what a manufacturer can declare according to the document and what the real performance is of the tested assembly

##### A. Is the current TR a clear and complete document?

Manufactures want to specify their equipment in a concise way. To the user that is not familiar with the subject this concise specification could imply more than he really gets.

Some examples of the TR not being clear and complete.

1) *An example of a manufacturers declaration:* A switchgear assembly is declared Arc Proof having a permissible current rating of  $I_{p\ arc} = 50\text{ kA}$  and an associated arcing time of  $t_{arc} = 0,3\text{ s}$  for an operational voltage of  $U_e = 415\text{ V}$ , complying with criterions 1 to 7.

When a manufacturer specifies 300 ms, this is the ultimate tripping time for the users protection device that protect the switchgear assembly, either in the low voltage part or in the medium voltage part of the installation.

Without detailed information on the settings and the results of the tests that have been executed, one may interpret this declaration as the assembly is arc fault tested with a test current of 50 kA and the arc remaining for 300 ms. While in fact from this condensed specification one cannot tell whether the arc remained or the short circuit current was interrupted or the arc extinguished by itself in a fraction of the declared time.

Only the complete test report will tell the exact test data and thus the true performance of the switchgear assembly.

2) *Does the TR cover all situations?:* The TR only covers incidents that originate from static situations while most incidents happen while operating or as a result from maintenance on the switchgear. It is tough to protect the person in front of the switchgear when the covers of the enclosure are open and circuits are only behind a finger touch safe cover or readily

accessible. The TR does not consider operating actions on the switchgear with all covers in place, like for example:

- Racking in a functional unit with all covers closed;
- Operating a device

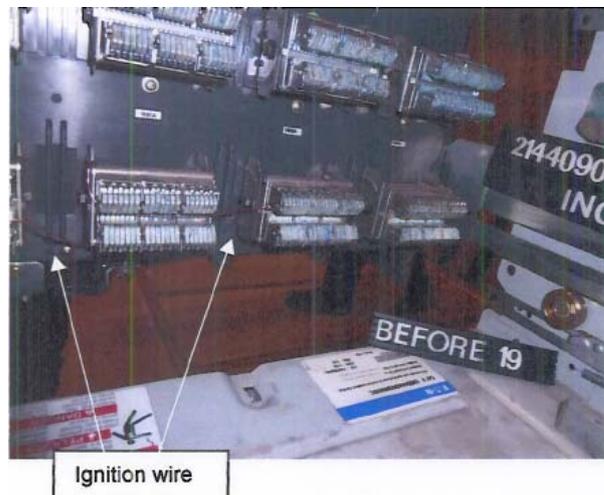


Fig. 2 Preparation on an Internal Arc test on an ACB

These are daily practices of users with their equipment and therefore there is a logic to consider this in the TR.

##### B. Shortcomings of the TR

Only users that are knowledgeable enough to understand the extent of the TR are able to come to an agreement with the manufacturer of what tests and what circumstances satisfy his needs and how to assess the outcome of the tests.

The above examples and the explanation shows that presenting the results of internal arcing tests according to the current TR leaves a lot of questions and makes it very hard to compare switchgear of different manufacturers and not necessarily meets the users demand.

From a manufacturers point of view the TR gives sufficient rules for rating the tested quantities, which and how tests should be performed and how they are assessed. Also for test laboratories there may be sufficient guidance on how to set-up the test, how to ignite the arc, how to assess the result of the tests and how to record the results of the test.

What changes could lead to more clarity and thus more security for the user?

Some shortcomings from the perspective of the user:

- Tests only in static situations, while arcing incidents may very well happen when someone is operating the equipment or otherwise working on the switchgear.
- The report does not identify the Arc Free locations where no test has been performed and it also lacks an assessment the Arc Free zones.
- The defined quantities are limited which can lead to a summary report on the tested ratings. For example the reported test duration may not necessarily be the actual duration of the arc during the test.

- And no normative testing nor classification?

### C. Suggestions for improvement of the TR

1) *Normative testing yes or no?*: Would switchgear assemblies become safer when Internal Arcing testing would become a normative test as part of the product standard? This would probably be unnecessary, while the majority of the switchgear assemblies is not big enough to pose so much danger from an internal arcing incident.

So the user has to consider the possible danger relative to the protective devices in the circuits.

The manufacturer faces a lot of costs making a switchboard design Arc Proof and performing the tests to prove it. Each test may require complete and new test objects, etc.

Since the market is very competitive and many parties in the market are not willing to pay for this expensive feature it is a big dilemma. What are the options?

Depending on how the user wants to handle his switchgear, one may not necessarily require an Arc Proof assembly. When the user only wants to do switching and control operations whilst the equipment is live and leaves the maintenance and care to a professional party that only performs maintenance works while the equipment is completely dead, there is little danger of an internal fault. When the user wants to do maintenance works on the assembly while it is partly live (frequently) because he cannot permit downtime to his process, then the risk of an internal fault increases.

Conclusion primarily a normative test would increase the price of switchgear assemblies. Secondly it is not necessary for all equipment from a safety perspective since not all switchboards pose the same danger nor all switchgear need to be operated and worked on whilst live.

Next step is to find a method for how to know and how one can distinguish the performance one needs, how to specify and what to expect from it.

2) *Classification of switchgear assemblies*: The end-users would be helped with an overview and comparison expressed in classification like in the product standard for High Voltage Switchgear and Controlgear.

It requires more stringent rules for manufacturers to specify their switchgear assemblies, in order for the user to compare the performance. Preferably rating of the performance is done through classification.

An assembly can be classified by:

- How it contains the internal arc: Definite arcing time  $I_{p,arc}$  or conditional  $I_{pc,arc}$ ; are there different ratings for circuits;
- Accessibility from one or more sides: for which sides is the switchgear assembly assessed;
- Protection: personal protection and assembly protection.

3) *Testing on manufacturer's own initiative*: In many cases a manufacturer wants to have a generic rating for internal arc safety without an agreement with the user. The TR now is not really fit for unilateral use. It lacks explicit rules on how to perform test that translates to comparable results for classifications.

While manufactures use the TR as it was a product standard it calls for changes that offer transparency and serves the expectations of the user.

4) *Improve the content of test report*: The test report should provide more information on the tested assembly parts, how the results are assessed (verified) and the tested ratings. Furthermore clear conclusion with respect to internal arc classification. In this way the user is able to compare different test reports.

## V. ARC PROOF DESIGN

There are no specific design requirements for an Arc Proof assembly from a standard point of view. The product standard IEC 61439 contains general requirements for dielectric integrity to prevent internal arcs rom occurring under normal operating conditions. Normal operating conditions means that the equipment is maintained well and the environmental conditions are steady without substantial pollution of the inside the assembly.

The TR is an addition to the IEC 61439 series to run tests under conditions of internal arcing and assess the safety for personnel and protection for the assembly itself. This TR allows several ways for an assembly to pass an internal arc test. These ways give the manufacturer options, how to adapt the design and construction of the switchgear assembly to achieve an Arc Proof design.

To obtain a positive test result to an internal arc test one has to meet certain criteria with regard to safety and operating readiness. The assessment does not only require one outcome of the test. Four ways to a positive assessed test are:

- either the arc exists for the full duration of the applied power, or
- the energy to the arc is interrupted premature for the duration of the applied power, or
- the arc dies through self-extinction, or
- it is not possible to initiate an arc at all.



Fig. 3 Pressure relief flaps

### A. No premature interruption of the current

In the first case the maximum arc energy is stressing the assembly which requires an almost bomb-free enclosure or predetermined routes for the arc within the enclosure, exiting the hot gasses through pressure relief flaps (see figure 3) in the top, in a way that it is released

that is not harmful to the operator or other persons in the vicinity of the assembly.

It is very likely that the assembly suffers a lot of damage risking the supported processes to come to a standstill, which in turn could be dangerous. One has to realize that in 300 ms an electric arc can ruin the complete switchgear assembly.

Complete destruction of the switchgear assembly can be prevented by designing the switchgear in a way that in case of an internal arc, the arc is quenched as soon as possible, and preferably be limited to the compartment of its origin. The following three design options B, C and D show how this can be achieved.

### B. Interruption of the short circuit current

In this case arc extinction can be established through:

1. Interruption by a overcurrent protection device;
2. Arc quenching device.

#### 1) Interruption by a overcurrent protection device:

The effects of an internal short circuit to the assembly can be limited through the application of a short circuit device. The fast acting quality of a short circuit protection device (SCPD), a fuse or a circuit breaker, can be used to interrupt the current in the circuit within a quarter of a cycle (less than 5 ms), taking away the energy and stopping the arc from growing and causing (more) damage to the switchgear assembly. One has to realize that the bigger the current and evidently the SCPD the more energy is let through and the longer it takes to interrupt the current in the circuit. A Molded Case Circuit Breaker (MCCB) may take 5 to 10 ms to interrupt the current, an Air Circuit Breaker (ACB) usually requires 40 to 50 ms interrupting time when operating in instantaneous mode. The MCCB will cut-off the current before it reaches its peak while the ACB not only lets the peak pass but requires more than two cycles for its operation mechanism to open its contacts.

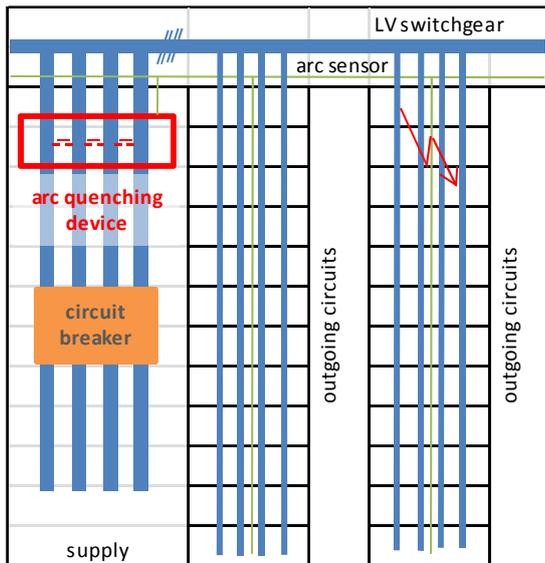


Fig. 4 Assembly with Arc Fault detection

2) Interruption by an arc quenching device: An arc quenching device has a quite different way of operating. The principle is shown in figure 4. The arc is instantly sensed through detecting the light of the arc flash. An

electronic circuit checks for an overcurrent in the main circuit.

Then a new current path is created, with the quenching device, to commutate the fault current to a controlled circuit (red box in figure 4). At this moment the arc will extinguish and the main incoming circuit breaker will trip and interrupt the short circuit current. Making the new current path takes a few milliseconds, interrupting the short circuit current depend on the type of circuit breaker that is used in the incoming circuit.

### C. Self-extincting design

This option is to design a circuit to extinguish in case of an internal arc. Self-extinction can be caused by the fact that the short circuit cannot gain enough energy available to maintain the arc, or the arc length is too long to remain for the available arc voltage. In either case the requirements, like temperature and *fuel*, for the plasma to remain, will cease to be available, the resistance will increase and the arc will no longer exist. This option works good for moderate voltages, for example 415 V. For voltages over 600 V this becomes harder since it is easier for the arc to remain. Figure 9 shows a oscillogram of such a phenomenon.

### D. Arc Free design

Where the option of big clearances and creepage distances is not feasible because of the available physical space one can chose to create an arc free zone to prevent an arc from occurring at all.

Assemblies or parts of an assembly that have no accessible active parts, either by application of insulation or through barriers that fully enclose the active parts, are referred to as Arc Free zones (see figure 5). In terms of testing this means that it is not possible to apply a fuse wire between any poles and earth to initiate the internal arc.

In this case the result of the assessment by the test station is that no fuse wire could be attached. Consequently no test involving an arc can be performed, therefore no ratings in terms of arcing current ( $I_{p\ arc}$ ), and arcing duration ( $t_{arc}$ ), nor rated voltage ( $U_e$ ) can be claimed.

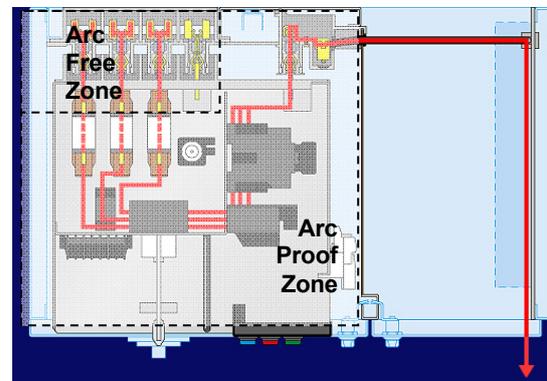


Fig.5 Top view of a motor starter unit with Arc Free zone

## VI. INTERNAL ARCING FROM A TEST HOUSE PERSPECTIVE

The performance of low-voltage switchgear assemblies under conditions of arcing due to an internal fault is tested in a high power laboratory.

The main purpose of the simulation of the internal arcs in the high power laboratory is to verify the protection of personnel, e.g. an operator, who is in the presence of the switchgear in the field in case an internal fault occurs. Although measures may be taken in the design of switchgear to prevent internal arcs from occurring. There can always be a minimal chance of an unexpected occurrence that impairs the insulation of a random part or a component that develops in an internal arc.

The ratings to be tested are specified by the assembly manufacturer.

An example, the manufacture requires the following ratings to be tested:

- The permissible current under arcing conditions ( $I_{p\ arc}$ ) and the associated arcing time ( $t_{arc}$ ) is 80 kA – 300 ms.
- The permissible conditional current under arcing conditions ( $I_{pc\ arc}$ ): 80 kA.

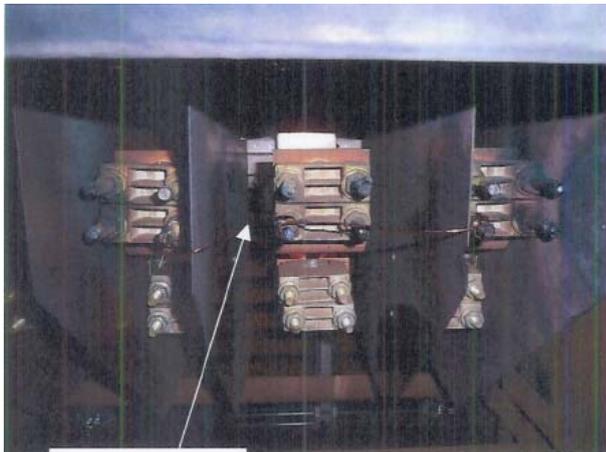


Fig. 6 Ignition wire connecting three phases

Tests are conducted with a 3-phase supply and the arc is initiated by a thin copper wire that connects the 3 phases (see figure 6).

The  $I_{p\ arc}$  rating is the more severe of the two tests, and is often done in main horizontal and vertical busbar compartments. The arc may stay on for 300 ms and a lot of energy is released (explosion) in the busbar compartment. A pressure relief flap can be employed as part of the enclosure to release the pressurized gasses from the top or the back of the assembly into the surrounding area, preventing the cotton indicators placed at 30 cm distance from all operator accessible sides of the assembly up to a height of 2 meters, from igniting. See figure 7 for more details. This is one very important compliance criterion for personal protection.

The impact of the explosion may be so severe that one may survive, but be in shock. Many experienced personnel in the field never having experienced an internal arc and who witness internal arc tests in a laboratory for the first time are very impressed, almost shocked by the released energy. It shows the real danger of electricity, and this would be a good lesson to anybody

involved in such installations. There are 5 criteria in the category personal protection:

- cotton indicator may not ignite
- doors, covers etc. may not open,
- parts causing a hazard may not fly off,
- the arc may not cause holes in accessible enclosure parts and
- the protective circuit for accessible parts of the enclosure shall still be effective.

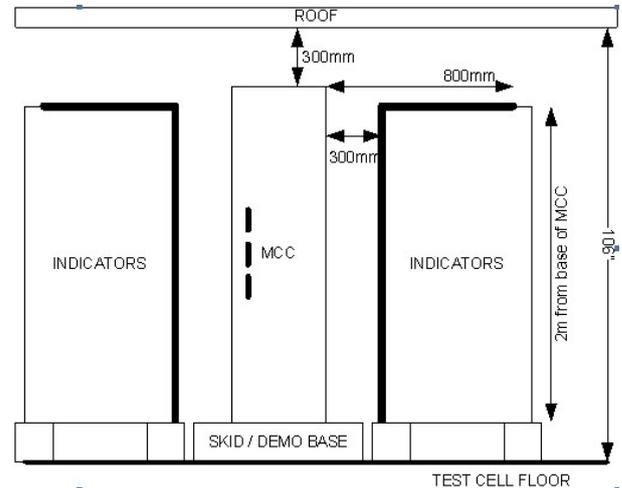


Fig. 7 Front view of a test set-up

Testing of the permissible conditional current rating ( $I_{pc\ arc}$ ) is less severe, because an overcurrent protection device in the circuit, such as a circuit breaker or a fuse, will limit current and clear the fault often within one cycle. This is most times the case for outgoing units of an assembly. Than there is little damage through the internal arc. When the assessment shows that the arc is confined to the defined area i.e. there is no propagation of the arc to other areas, criterion 6 is met. This is called assembly protection. Limited continued operation of the assembly, criterion 7, is verified through successfully conducting an additional dielectric strength test. In practice after this test the assembly can be taken back in operation again, in order to proceed the activities.

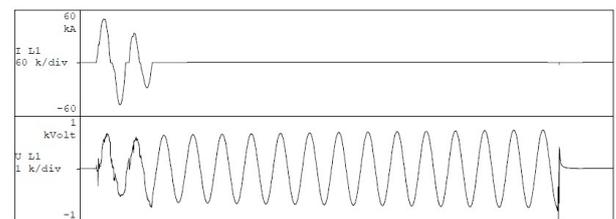


Fig. 8 Oscillogram of arcing fault test (ACB interrupted)

Figure 8 shows an oscillogram of an internal arc test at a prospective current of 80 kA. The actual current through the resistance of the arc is lower with a peak of 65 kA. The current (upper trace) is interrupted after approximately 2 cycles through the short circuit protection device (an ACB in this case), while the voltage (low trace) from source, the test generator is retained for the full 300 ms to enable re-igniting of the arc.

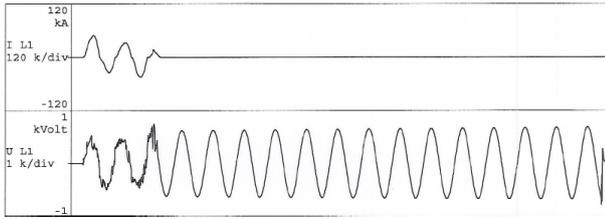


Fig. 9 Oscillogram of arcing fault test (self-extinguished)

Because the assessment according to the TR is an agreement between user and manufacturer different interpretations of the criteria are possible. The user may even ignore one or more of the 5 stated criteria. For example, how do we check that the protective circuit is still intact after the test? Obviously one can verify this according to IEC 61439 but in fact the TR is not clear about this. Or if doors may not open, may they bend and leave openings that give access to live parts? What is acceptable to the customer is relevant?

The number of tests and areas to be tested of a given assembly, are in most cases defined by the manufacturer. The TR only indicates that internal arc tests are not required for Arc Free zones.

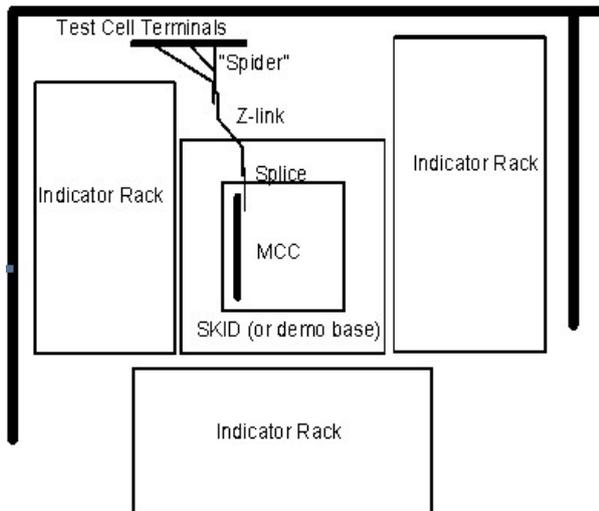


Fig. 10 Top view of a test set-up

The procedure for the test that test house follow is as follows:

1) *Arrangement of test object*: The test object is insulated from the floor, the object is grounded as in normal service. The PE is connected directly to the neutral point of the test current source. A neutral conductor is not present in the tested assembly.

Optional: A ceiling is constructed above the test cell with a maximum distance of 300mm from top of test sample to ceiling (see figure 7). Not required by the standard though.

2) *Supply circuit*: The arcing test is carried out as a three-phase test and the test samples are supplied corresponding to the normal service arrangement.

The applied voltage of the test circuit is 105 % of the rated operational voltage  $\pm 5\%$ .

Tests are conducted at 50 Hz cover also 60 Hz and vice versa.

3) *Arc initiation*: The arc is initiated by means of a small copper wire short-circuiting the three phases. This fuse wire should be small enough to evaporate to create a current path through a plasma in a matter of tenths of milliseconds.

The TR gives guidance for the wire size based on the peak let through values at in this case 65 kA.

4) *Duration of the test*: The application of the supply is set for the arcing time that is specified by the manufacturer e.g. 300 ms. If during the test the arc extinguishes within 150 ms, then the test is repeated using the same point of initiation. Regardless of the arcing time, a further repetition is not required. At tests for conditional current under arcing conditions, the recovery voltage is maintained for at least 10 cycles to allow for re-igniting of the arc.

5) *Test samples*: For each of the tests conducted a new sample may be used, however the manufacturer can allow for multiple testing on one sample risking a failure as a result of a previous test. The test samples are deemed to be fully equipped.

## VII. CONCLUSIONS

1. It is not realistic that each user specifies his own requirement with respect to Internal Arcing capabilities of the Switchgear assembly he needs.
2. Normative testing should not become mandatory. However more stringent rules for generic testing is helpful to the user.
3. Classification (in addition to more stringent rules) makes the Internal Arcing capabilities of Switchgear assemblies of different make more comparable for the user.
4. The test report should provide more information e.g. tested ratings and classification to enable the user to compare different test reports.

## VIII. ACKNOWLEDGEMENTS

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Thanks to our peers from the PCIC organization: Peter Freeman and Terence Hazel.

## VI. REFERENCES

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## IX. VITA

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Graduated in 1982 from the HTS Arnhem, the Netherlands with a bachelor degree (BSc) in Control Systems Engineering. Started at KEMA, Arnhem, The Netherlands in 1986, as Project Manager Testing of Low Voltage Products for the North American market, CSA and UL. Switched over to the KEMA High Power Laboratory by the end of 1989, and became Test Observer for short-circuit testing of Medium and High Voltage Equipment. From 1996 onward, changed to Team Manager Control Systems in the same High Power Laboratory, and obtained a Degree in Control Systems Engineering. Started in 2005 at the KEMA Low Voltage Laboratory, KEMA Quality, as Project Manager Industrial Components, with main focus on IEC Standards. In 2009 KEMA Quality was taken over by DEKRA, and from that time onward it is DEKRA Certification B.V.