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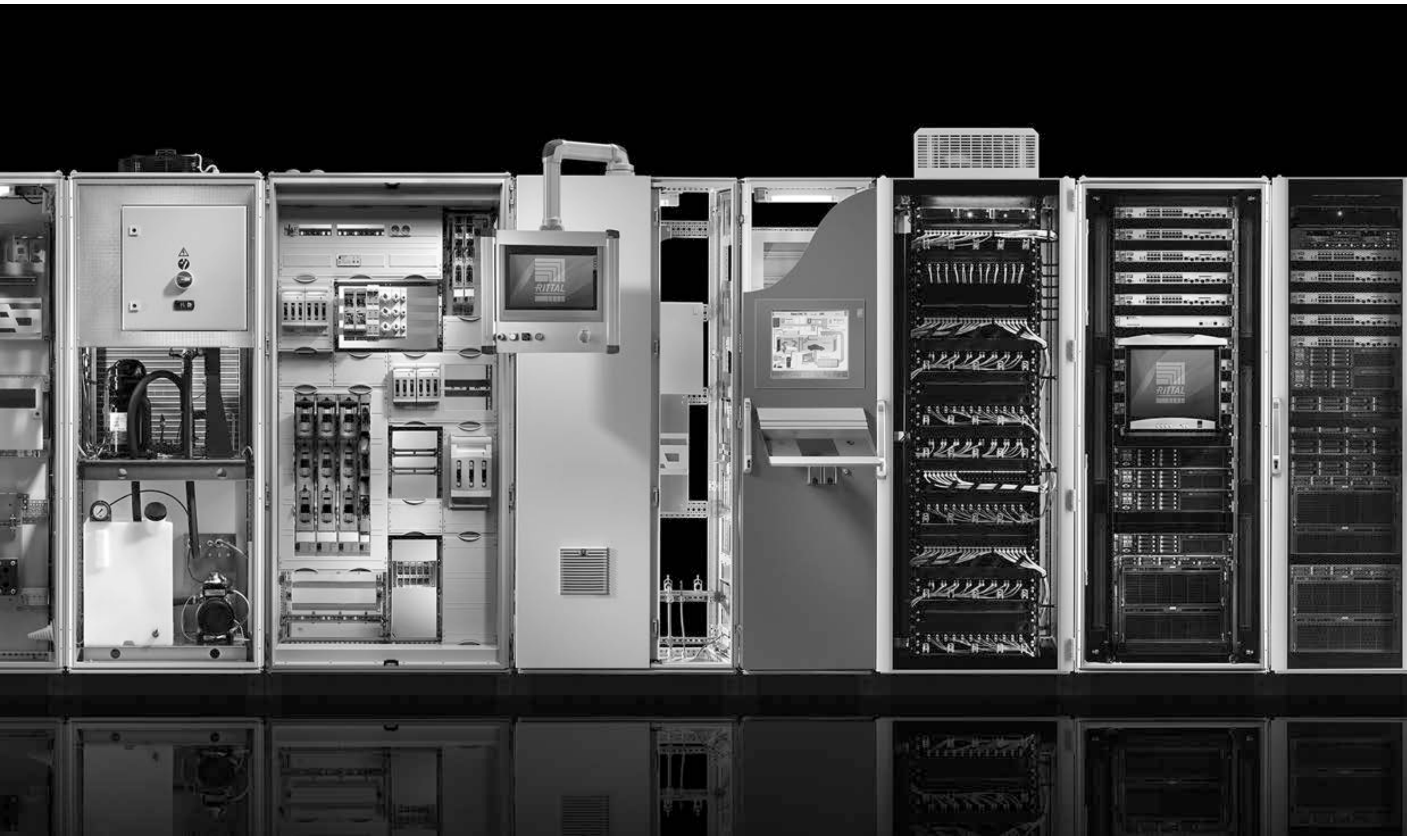

White paper:

Operator and system safety for low-voltage, control and switchgear systems in the event of internal faults with accidental arc formation

Michael Schell, MBA, Dipl.-Ing.
Head of Product Management Industry

SCHALTSCHRÄNKE | STROMVERTEILUNG | KLIMATISIERUNG | IT-INFRASTRUKTUR | SOFTWARE & SERVICE

FRIEDHELM LOH GROUP

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1. Introduction

The most severe damage that can occur to an electrical control or switchgear system is an accidental arc caused by an internal fault. The arc initially generates an enormous pressure rise and then burns as plasma column with a temperature of several thousand kelvin. Whereby, the arc travels through the low-voltage system and has a damaging effect. The damage can affect the internal equipment as well as the outer shell of the system. This removes the protective effect of the enclosure. Persons can be injured, possibly fatally, and material can be damaged severely.

Electrical low-voltage systems are planned so that protective devices shut down the affected circuit in the event of external faults. Consequently, when testing the protective function, e.g. a short-circuit test, the most extreme situation of an external fault is tested: a short-circuit directly at the tap-off terminals of a circuit. Further short-circuit tests are performed on the busbar system and the infeed of the low-voltage system. In the outgoing circuits, the immediate protection is provided by a fast shutdown. In the infeed area or on the busbar of the low-voltage system, an immediate shutdown is less desirable, because this results in a complete failure of the low-voltage system. Consequently, the infeed circuit and the busbars are frequently protected by a time-delayed protective device that in the event of a fault to ensure that a single circuit is shutdown before the complete low-voltage system.

The proven short-circuit resistance of a low-voltage system means a short-circuit capability is not assumed for normal operation within the low-voltage system, because the use of a tested unit consisting of busbars and the further power distribution technology, an adequate safety is taken as proven. However, there is a certain residual risk that, for example, because of material ageing, device defects, contamination, forgotten screws, forgotten tools or vermin, a fault occurs inside the low-voltage system that can change to an accidental arc when the short-circuit causer does not have an adequate current carrying capacity. The accidental arc can result from an accidental arc of a switching or protective device or from an electrically conducting connection that melts because of the high current, ionises and changes into a plasma column. A routine maintenance and cleaning of the low-voltage system can help with the early detection of such a fault cause.

Not every fault cause, however, can be detected early. When switchgear is installed in freely accessible areas (areas to which electrical novices have access), appropriate measures must be adopted to protect such persons from the dangers of the electrical system. Further measures are also desirable when a failure of the low-voltage system caused by an accidental arc can have major consequences for the operating company (production failure, etc.).

2. Formation of the accidental arc

The accidental arc in a low-voltage system can have various causes. Because of an equipment fault or as result of an arc. The arc results when switching an electrical switch contact on or off. If a minimum clearance depending on the operating voltage between the contact elements of the switch is undershot during the switch-on operation, an arc forms before the contact closes. Once the contact is mechanically closed, the arc vanishes because the arc voltage is set to zero when the contacts close. Every arc on the contact damages the contact surface and permanently impairs the contact property. Consequently, the switching operation should always be performed very fast.

An arc that also occurs for the switch-off operation of a contact similarly damages the contact elements. The electrically conducting connection is separated at the switch off. However, the current flow continues as arc until the minimum insulating clearance is attained. The arc is extinguished only when the arc voltage no longer suffices to form the arc because the insulating clearance is too large. In a switch, this extinguishing is accelerated by technical functionality such as a spark quenching chamber, because the switch-off operation should also be completed as fast as possible. In particular, heavy-duty circuit-breakers extinguish this switching operation by purging over the openings near the connection area. Because of this purging, each manufacturer defines a safety area around the switch in which no electrically-conducting metal may be located that could impair the discharge operation and so cause an unwanted accidental arc.

Not only the arc, but also other factors, can cause formation of an accidental arc. If an insulation fault because of material deterioration or a discharging conductor causes a minimum clearance to be undershot, an arc can also form. If the fault causes the arc to be bridged by short-circuiting with a good conducting material and a protective device initiates a shutdown, this fault situation is rectified fast. If, however, the fault causes the conductor to melt or no direct mechanical short-circuit results, the arc continues to burn if the arc current does not attain the tripping values of the protective device. It is certainly realistic that the distance between two potentials allows the arc voltage to be large enough for the arc to burn, whereby, an arc current of, for example, only 4 kA flows that is too low for a high-duty protective device to initiate a delayed shutdown. In this case, the arc can burn with consequential enormous damage to the low-voltage system.

When an accidental arc occurs, the pressure within the first 15 ms can reach several 100 mbar. This does not initially appear to be a high pressure. When, however, one considers that the switchgear is a closed housing, this rapid pressure increase can cause the housing to explode with the resulting deformation of the surface, dispersal of low-voltage system parts, opening of the side panels or enclosure doors. The pressure rise results by the formation of the plasma column that burns with very high temperatures (13 – 17,000 kelvin). This high thermal effect can make itself apparent on the outer side of a low-voltage system when the hot gases escape through the smallest openings or gaps. The accidental arc also tends to expand and so moves via the uninsulated conductors through the low-voltage system. Another behaviour often found is that the accidental arc travels from the current source (infeed) to the load side. For some faults, however, the arc travels to the infeed. Whereby, the ignition point is an important criterion. If the arc occurs at the end of an uninsulated conductor path, the arc remains there until the current source is switched on or finds another potential with which the accidental arc can continue to burn. If the accidental arc occurs at the end of a busbar system, it is possible that it ignites from there on an earthed part of the low-voltage system and burns a hole in the outer shell. The accidental arc path depends on the internal construction of a low-voltage system and the housing.

3. Consequences of an accidental arc for persons and systems

The enormous effects of an accidental arc greatly endanger people currently present in the direct vicinity of an affected low-voltage system. The previously described pressure increase can cause parts of the low-voltage system to fly off or doors to open. This can injure people if they are hit by the parts. Injuries are more severe when they are caused by hot gases that escape through even the smallest gaps and holes. These hot gases can result in severe burns to the skin. Injuries to the respiratory tract are also possible, because the accidental arcs also cause insulation materials to burn and so release poisonous gases. The unimpeded accidental arc has a devastating effect in the low-voltage systems affected by the accidental arcs.

Further operation of such a system is scarcely possible, because the accidental arc damages large parts of the busbars, devices and the housing, and the interior has severe soot deposits. Repair would be possible only by the complete replacement of the affected areas. Operation of the low-voltage system is interrupted, at least until the complete repair. This results in downtime costs. Total protection from accidental arcs does not currently exist. Targeted measures, however, give people the best-possible protection and limit damage. IEC TR 61641 describes requirements and test methods that prove the functionality of the measures.

4. IEC TR 61641

IEC TR 61641 is a regulation for testing low-voltage systems under accidental arc conditions. This test standard is originally derived from the earlier “PEHLA” regulation known from the area of medium-voltage systems. Whereby, “TR” is the acronym for “Technical Report” and so states that this document is not a standard, but rather a procedure description, in this case, how to perform tests. The third edition of the IEC TR 61641, published in 2014, for the first time contained the division of classes and also the definition of ignition locations for proving the functionality, unless agreed otherwise between the client and the manufacturer. The complete application of the IEC TR 61641 and the definition of the class to be achieved (and possibly the test parameters) are agreed between the client and the manufacturer.

5. Test criteria for proving the functionality of accidental arc safety

The test criteria for proving the operator and system protective measures have been taken from the previous version of the regulation, and are now described in detail. These criteria are evaluated after performing the accredited test and documented in the test report.

Criterion 1

The first criterion that the tester must evaluate after performing a test is the correct securing of all doors and covers of the enclosure. After the test, they must be secured so that nobody in the vicinity of the system can be injured by an opening door or cover. Damaged hinges and fasteners are also permitted, as are deformed panels. Although the original degree of protection also does not need to be specified, a minimum IP1X protection category must be ensured for the area in which people can linger.

Criterion 2

The second criterion ensures that nobody is injured by flying parts. The second criterion is satisfied when no part weighing more than 60 g flies from the low-voltage system. If parts fall vertically at the system and lodge between the indicator walls and the system, this is permitted.

Criterion 3

The third criterion proves the prevention of burning risk to anybody by an accidental arc that burns through the cover. This requirement applies to all accessible surfaces below a height of 2 m.

Criterion 4

Indicators must be provided in front of all accessible vertical surfaces of a low-voltage system. If the client does not specify any separation, the specification of 30 cm applies. These indicators should simulate the clothing of a person. This criterion is satisfied when no indicator has ignited after the test. If the planned installation location is a freely accessible area, the indicators are provided with a material with weight 40 g/m². This simulates normal summer clothing of a non-specialist. If the low-voltage system is located in a closed area to which only specialists have access, the indicators are provided with a material with weight 150 g/m². This simulates specialist clothing.

Criterion 5

The last person protection criterion requires that the protective conductor circuit still functions correctly after the test. If all five criteria are satisfied, the person protection in the accidental arc situation on a low-voltage system is given. The system protection provides extended protection in the accidental arc situation for a low-voltage system.

Criterion 6

The manufacturer can define an area for its low-voltage system that the accidental arc may not leave after being ignited. Hot gases or smoulder gases may enter neighbouring areas provided their effects can be removed with simple cleaning. This criterion is satisfied when these requirements are also satisfied after the test.

Criterion 7

This criterion is satisfied when after rectifying the fault or separating the affected area, the system can continue to be used in emergency operation. Whereby, before recommissioning, the dielectric strength must be tested to ensure that a minimum degree of protection IPXXB is given. All remaining system parts must be fully operational, both mechanically and electrically.

6. Assignment of classes

The third edition of the IEC TR 61641 describes the four different accidental arc classes (A, B, C and I), some of which are based on the previously described criteria 1 – 7.

Class A

A low-voltage system of the accidental arc class A provides person protection by satisfying criteria 1 to 5 and by accidental arc-protected zones, provided they exist.

Class B

A low-voltage system of accidental arc class B also provides person protection by satisfying criteria 1 to 5, system protection by limiting the accidental arc to a defined room, proved by criterion 6, and by accidental arc-protected zones, provided they exist.

Class C

A low-voltage system of accidental arc class C also provides person protection by satisfying criteria 1 to 5, system protection by limiting the accidental arc to a defined room, proved by criterion 6, and by accidental arc-protected zones, provided they exist. In addition, a low-voltage system of class C offers the option of further operating the system – at least in emergency operation – after a test, after a small repair or disconnection of the damaged area.

Class I

Class I offers a preventative form of accidental arc safety for a low-voltage system. For this class, the system is insulated so that the risk of occurrence of an accidental arc is minimised significantly. However, an insulation of all active parts of a low-voltage system requires derating of the current carrying capacity because the heat dissipation capacity of the busbars and of the equipment is impaired by the additional insulation. This must be considered specifically for the layout and evaluation of a low-voltage system.

7. Possible measures for minimising or limiting the effects of an arc

The effects can be best limited by preventing the occurrence of the accidental arc. For this purpose, there are currently various accidental arc extinguishing systems that with detection of the accidental arc via brightness and concurrent short-circuit current detection, extinguish the accidental arc with a short-circuiter; and the upstream protective device forces a shutdown. The short-circuiter establishes a severe short-circuit within just a few milliseconds and takes the arc voltage from the accidental arc that then extinguishes. The upstream protective device of the system shuts down the now saturated short-circuit. The resulting damage in the low-voltage system is extremely low and can normally be rectified by cleaning. The activated short-circuiter, however, must be replaced or disconnected from the circuit for further operation of the system. Unfortunately, these systems cannot reliably differentiate an accidental arc from a normal short-circuit shutdown of a circuit-breaker. When a short-circuit is shut down by a circuit-breaker, a shutdown arc results at the switch and a high current also flows. Namely, similar properties as for an accidental arc. Consequently, for the creation of an accidental arc extinguishing system, the areas around the circuit-breaker are excluded from the optical detection, because unwanted spurious shutdowns can occur. The replacement of the short-circuiter is also costly.

To summarise: In the event of a fault, an accidental arc extinguishing device is a very good protective measure to protect people from dangers and to prevent a total failure of the low-voltage system. However, an accidental arc cannot always be differentiated reliably from a normal short-circuit shutdown.

Lower cost measures that permit a reliable person protection and, with further optional steps, system protection, are possible as alternative. The types of the measures differ depending on the system rated voltage and the expected short-time continuous short-circuit current available at the low-voltage system or measured for the low-voltage system. A simple, but very effective measure to prevent doors or side panels from opening, is the opening of certain surfaces on the housing to release pressure at locations not dangerous for people.

These can be the roof area or the rear area of a low-voltage system. Whereby, it is important that appropriate space for escaping is available above or behind the system. The interior construction must allow the pressure to escape unimpeded by baffles or such baffles must provide a sufficiently large area for the air flow. In the event of a fault, the housing opens at appropriate rupture points and the pressure is released at this area so that the doors and side panels remain closed. For high rated voltages or short-circuit currents, additional door reinforcing and the attachment of further panels can be useful measures to ensure a safe pressure dissipation.

To prevent an accidental arc from burning through the outer shell, it is important for the switchgear that all live conductors are mounted at a larger distance from the outer surfaces and so inhibit the arc jumping from the outer conductors to the earthed shell. At tight spaces, the panels may need to be covered with insulation material or the arc “caught and held” intentionally with sacrificial anodes at defined locations.

To satisfy criterion 6 – limitation of the effect to a defined space of the low-voltage system – measures must be adopted to prevent propagation of the arc. Propagation of the accidental arc can be prevented with solid barriers. In particular for high currents, additional sacrificial plates can be a measure to concentrate and hold the accidental arc at a less dangerous location. For higher rated voltages, larger insulated paths can also be useful for preventing propagation of the arc.

8. Proof of accidental arc resistance

To prove the accidental arc-resistant function of a low-voltage system, IEC TR 61641 envisages various tests. For low-voltage systems without accidental arc extinguishing, tests are envisaged for which an ignition wire is laid successively at various locations and, as for a short-circuit test, fed with a short-circuit current. The short-circuit current flows over the laid ignition wire. The chosen wire diameter depends on the rated short-circuit current. This dimensioning ensures that the wire glows and an accidental arc ignites. This arc burns while the test object is being supplied with short-circuit energy.

Unless specified otherwise by the customer, the complete test should run for 300 ms. The size of the accidental arc current that actually flows is not relevant for the test evaluation. The criteria are evaluated after completion of the test. The test is considered to have been passed when all criteria are satisfied. If the accidental arc extinguishes before the end of the test duration, the test is considered initially to have not been passed. The test must then be repeated. If the accidental arc extinguishes again for the repeated test, the test is considered to have been passed.

The test must be performed at various locations of the low-voltage system. The following are envisaged as ignition points:

- Load side of an outgoing circuit
- Supply side of an outgoing circuit
- At the distribution busbar, when present
- At the main busbar
- The load side of the infeed for the low-voltage system
- The supply side of the infeed for the low-voltage system

If all tests complete successfully, the low-voltage system is considered to be an accidental arc-resistant low-voltage system.

If an accidental arc extinguishing system is used as active protective system, the function of all light sensors must be tested first. If all sensors function correctly, an arc is ignited at one location. Whereby, the system must function correctly and the accidental arc must extinguish successfully. This successful proof verifies the successful deployment of an accidental arc extinguishing system.

9. Proof of accidental arc class “I”

An accidental arc-protected low-voltage system is characterised by a best-possible insulation of all active conductors and equipment. The proof that a low-voltage system satisfies a reduced risk of accidental arc ignition by insulation must also be proved with a test. This test, however, only tests the insulation for its continuity. The deployed insulation material must satisfy the thermal and dielectric requirements of IEC 61439. The insulation must also satisfy degree of protection IP4X. Any deployed barriers must satisfy degree of protection of at least IP3X. Both degrees of protection must be proved with a test in accordance with IEC 60529. The function of the insulation properties must also be proved with a power-frequency voltage resistance test.

All procedures and tests must be documented in a test report.

10. Planning an accidental arc-resistant low-voltage system

For the planning of an accidental arc-resistant low-voltage system, the general standards for low-voltage systems always apply. The function of the accidental arc-resistance is optional and so an additional requirement must be defined in the functional specification of a low-voltage system. The general requirement for an accidental arc-resistant low-voltage system must be described in the quotation text with reference to the Technical Report IEC TR 61641. The same details as for the rated voltage, rated frequency and the rated short-circuit current Icw or Icc apply to rating the accidental arc resistance.

The duration of the accidental arc resistance must also be specified. The duration of 300 ms is usual; this is suggested as test duration in the Technical Report. It must also be defined who can linger in the area of the low-voltage system. The accidental arc class depending on whether person protection or system protection is required must also be determined. If class “B” or “C” is required, the area in which the accidental arc should be limited must also be defined. This area should best be a field of a low-voltage system because this can be replaced most easily.

11. Example of a description for a specification

The low-voltage system must be accidental arc-resistant in accordance with IEC 61641 and satisfy the following properties:

- Rated voltage: 400 VAC
- Rated frequency: 50 Hz
- Rated short-time short-circuit current Icw= Ip arc = 50 kA eff.
- Permissible accidental arc duration: 300 ms
- Accidental arc class: “B”, the accidental arc must be limited to a field.

For the design, ensure that a complete field can be replaced individually from a row of a low-voltage system. Any required pressure relief should be possible over the roof of the low-voltage system.

12. Summary

A fault in a low-voltage system that causes an accidental arc can have a large effect on the system, its surroundings and anybody in its vicinity. The design of a low-voltage system is decisive for the effects in a fault situation. Consequently, a representative design that considers the enclosure, the busbar system and the devices (at least to simulate the volume) is required for the test.

Provided maintenance and cleaning of a low-voltage system are performed correctly, the probability of an accidental arc is small. If frequent access to a low-voltage system is necessary or it is located in an area to which non-specialists also have access, the best-possible person protection that can also be achieved without an active accidental arc extinguishing system with small additional costs should, however, be deployed. If, however, a failure of the low-voltage system can lead to high failure costs of the operational production or of a data centre, a supplementary system protection should be considered and this possibly requested with the specification.

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RITTAL GmbH & Co. KG
Auf dem Stützelberg · D-35726 Herborn, Germany
Phone + 49(0)2772 505-0 · Fax + 49(0)2772 505-2319
E-mail: info@rittal.com · www.rittal.com