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TECHNICAL REPORT

colour inside

Low-voltage switchgear and controlgear – Fire risk analysis and risk reduction measures

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR – FIRE RISK ANALYSIS AND RISK REDUCTION MEASURES

FOREWORD

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 63054, which is a technical report, has been prepared by subcommittee 121A: Low-voltage switchgear and controlgear, of IEC technical committee 121: Switchgear and controlgear and their assemblies for low voltage.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
121A/115/DTR	121A/155/RVDTR

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

As fire-ignition hazards are inherent with electricity, installation rules and product standards for electrical equipment are aimed at providing risk reduction measures and minimizing residual risk without compromising product safety and function.

Residual risk of low-voltage switchgear and controlgear compliant with IEC 60947 relevant publications is generally low and, when selected, installed and used according to manufacturer instruction and installation rules, do not ignite fire in normal operation or reasonably foreseeable fault conditions.

This document, in accordance to ISO/IEC Guide 51 and IEC Guide 116, describes the fire risk analysis of electrical equipment and risk reduction measures in IEC 60947 relevant publications. While intended to apply specifically to low voltage switchgear and controlgear, it is suggested that other product committees may find this information useful.

The fire hazards, namely the flame ignition mechanisms, relevant for low-voltage switchgear and controlgear are reviewed and discussed. The related risk reduction measures included in IEC 60947 relevant publications are subsequently reported for each of those mechanisms.

These measures are based on a system approach, not limited to construction materials requirements and include design rules and type testing to ensure equipment do not cause fires in normal operation or due to reasonably foreseeable faulty conditions.

LOW-VOLTAGE SWITCHGEAR AND CONTROLGEAR – FIRE RISK ANALYSIS AND RISK REDUCTION MEASURES

1 Scope

This document applies to the fire risk analysis of low-voltage switchgear and controlgear (hereinafter referred to as "equipment") referring to the IEC 60947 relevant publications, where the following applies:

– only the case where a fire originates (typically under fault or misuse conditions) within the equipment;
– only equipment installed in normal environments. Hazardous environments, for example in presence of combustible materials, is not to be considered;
– only the case of products selected, installed and used according to the manufacturer instructions and installation rules.

In addition, the following cases are not considered:

– faults addressed by IEC TR 61641;
– risks due to smoke emissions;
– double faults, i.e. multiple phenomenon, potentially combined.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC Guide 116:2010, *Guidelines for safety related risk assessment and risk reduction for low voltage equipment*

IEC 60695-1-10:2015, *Fire hazard testing – Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60947-1:2007, *Low-voltage switchgear and controlgear – Part 1: General rules*
IEC 60947-1:2007/AMD1:2010
IEC 60947-1:2007/AMD2:2014

IEC 60947-2, *Low-voltage switchgear and controlgear – Part 2: Circuit-breakers*

IEC 60947-3, *Low-voltage switchgear and controlgear – Part 3: Switches, disconnectors, switch-disconnectors and fuse-combination units*

IEC 60947-5-1, *Low-voltage switchgear and controlgear – Part 5-1: Control circuit devices and switching elements – Electromechanical control circuit devices*

IEC 60947-6-1, *Low-voltage switchgear and controlgear – Part 6-1: Multiple function equipment – Transfer switching equipment*

IEC 60947-7-1:2009, *Low-voltage switchgear and controlgear – Part 7-1: Ancillary equipment – Terminal blocks for copper conductors*

IEC 60999-1, *Connecting devices – Electrical copper conductors – Safety requirements for screw-type and screwless-type clamping units – Part 1: General requirements and particular requirements for clamping units for conductors from 0,2 mm^2 up to 35 mm^2 (included)*

IEC 60999-2, *Connecting devices – Electrical copper conductors – Safety requirements for screw-type and screwless-type clamping units – Part 2: Particular requirements for clamping units for conductors above 35 mm^2 up to 300 mm^2 (included)*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
fire risk
probability of a fire combined with a quantified measure of its consequence

[SOURCE: IEC 60695-1-10:2016, 3.5, modified – Note 1 to entry deleted.]

3.2
electrical fire
fire caused by electrical equipment or installation

3.3
spark
electric spark
small luminous electric arc of short duration

[SOURCE: IEC 60050-121:1998, 121-13-16]

3.4
electric arc
high-temperature luminous electric discharge across a gap or through a medium such as charred insulation

[SOURCE: NFPA 921:2014]

3.5
discharge
electric discharge
discontinuous movement of charge carriers through part of an otherwise insulating medium, initiated by electronic avalanche and supplemented by secondary processes

[SOURCE: IEC 60050-121:1998, 121-13-11]

3.6
tracking
progressive formation of conductive paths, which are produced on the surface or within a solid insulating material, due to the combined effects of electric stress and electrolytic contamination

[SOURCE: IEC 60050-212:2010, 212-11-56, modified – Note deleted.]

4 Ignition modes for electrical fires

4.1 General

Physical effects occurring in electrical equipment that can potentially cause fires are listed in Table 1 below, inspired by Table 1 of IEC 60695-1-10:2016.

Table 1 – Ignition phenomena in electrotechnical products

Phenomenon [a]	Origin	Consequential effects
Abnormal temperature rises	Overcurrent in a conductor Defective contacts Leakage currents (insulation loss and heating) Failure of a component, an internal part or an associated system (for example, ventilation) Mechanical distortions which modify electrical contacts or the insulation system Seizure of a motor shaft (locked rotor) Premature thermal ageing	The temperature rises are gradual and at times very slow[b]. Therefore a significant accumulation of heat and effluent in the vicinity of the product may result, sufficient to support fire as soon as ignition occurs Accumulation and diffusion of flammable gases in air may give rise to ignition or an explosion, especially inside hermetically sealed products
Short-circuit	Direct contact between conductive live parts at different potentials (stray conductors from loose terminals, ingress of conducting foreign bodies, etc.) Gradual degradation of some components causing changes in their insulation impedances After sudden failure of a component or an internal part	The rise in temperature is significant after a very short time[c] and is quite localized Possible arc-flash and emission of smoke and flammable gases Release of glowing materials or substances
Accidental sparks and arcs[e]	Cause external to the product (overvoltage of the system network, accidental mechanical action exposing live parts or bringing them together, etc.) Internal cause (switching operations with gradual degradation of internal components and/or ingress of moisture) After sudden failure of a component or an internal part	Possible emission and ignition of flammable gases[d], with consequent flames Ignition may occur locally in surrounding components
High transient peak current	Defect in the electrical circuit	The rise in temperature is significant after a very short time[d] and is quite localized However ignition or explosion are unlikely

NOTE The protective devices can include thermal, mechanical, electrical or electronic types.

[a] Mechanical distortions and structural changes induced by anyone phenomenon may result in the occurrence of one or more of the others.

[b] At start, protective devices may interrupt the current after a variable length of time according to a predefined tripping curve.

[c] The protective devices are activated.

[d] The protective devices may not always be activated.

[e] Some products produce arcs and sparks in normal operation.

A quantitative analysis of the probability of those phenomena and the severity of their consequences is overwhelming. An alternative approach is using fire statistics.

Even though fire statistics usually do not report the physical mechanism that caused the fire, some authors [6][1] have classified and ranked those mechanisms according to common field experience (see Table 2 below).

Table 2 – Root causes of electrical fires according to [6]

Mechanism	Frequency
Poor connections	most
Arcing across a carbonized path	↓
Arcing in air	
Excessive thermal insulation	
Overload	
Ejection of hot particles	
Dielectric breakdown in solid or liquid insulators	
Miscellaneous phenomena	least
NOTE Other possible miscellaneous phenomena are incompatible metals (e.g. Cu/Al), worn plating, ionic conduction, fungus and water treeing.	

Table 3 below lists the possible ignition modes from Table 1 that are relevant for low-voltage switchgear and controlgear, ordered according to the frequency ranking of Table 2.

Table 3 – Potential failure modes for low-voltage switchgear and controlgear

	Potential ignition modes and effects
1	Overheating at the connection point resulting in ignition of the insulation supporting or adjacent to the terminals (termination)
2	Overheating of a power conductor creating ignition of a component supporting a current carrying part
3	Operational and fault arcs (e.g. between the terminals), including ejection of hot particles
4	Ignition starting from an electronic component

All these ignition modes will be discussed in the following subclauses together with the most relevant mitigation measures.

4.2 Overheating at the connection point due to loose connections

4.2.1 General

Terminals (terminations) and internal connections are those points in electrical equipment where two different conducting materials are in close contact to provide electrical conductivity.

As the heat dissipated at the connection depends on the contact resistance, which is a function of the normal mechanical load applied across the mated contact surfaces, a loose connection may result in overheating, glowing, arcing and/or potential fire ignition [8].

According to Table 2, "loose connections" or "poor terminations" seem the most usual cause of overheating, even more critical than "overloads" and electric arcs. In the case of low-voltage switchgear and controlgear, there are two possible explanations:

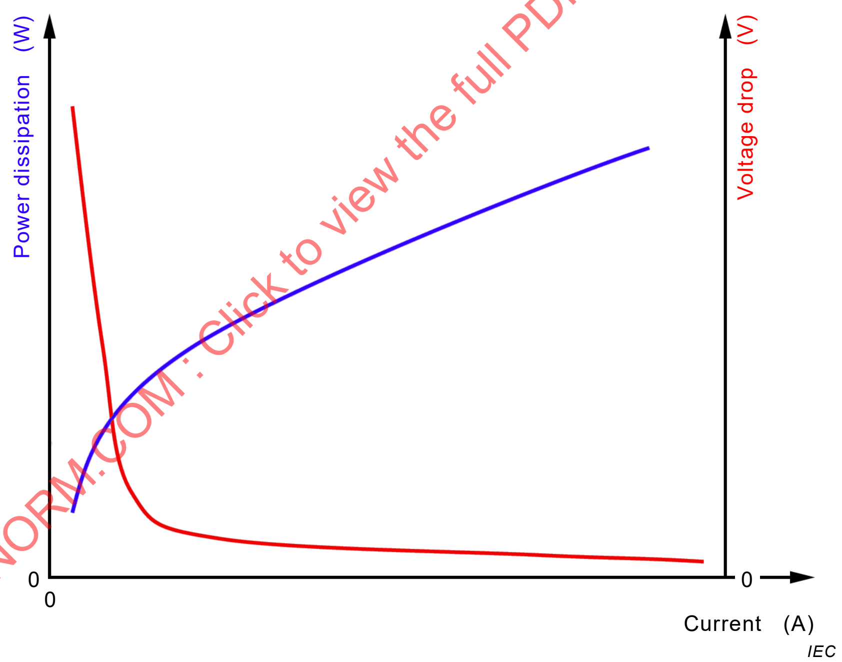
1 Numbers in square brackets refer to the Bibliography

– power dissipation and local temperature-rise are typically larger for poor connections than for overloads;
– protection devices (e.g. those integrated in the equipment) are designed in such a way that they provide protection against overloads, in particular severe overloads, whereas poor connections are typically not cleared by such protection devices and may result in long-term heating.

4.2.2 Ignition mechanisms

Babrauskas [5] reviewed scientific investigations about power dissipation, glowing and ignition from high-resistance loose connections. Even though there are quite a few studies and the phenomenon is not completely understood yet, the following conclusions can be drawn:

– wire-glowing can occur for quite low currents (< 1 A) and voltages (3 V to 4 V);
– for low values of current in the order of 1 A, in the vicinity of the glowing tip (at a distance of 10 mm), the wire temperature can be 200 °C to 350 °C;
– typical temperature on the glowing region can exceed 1 200 °C;
– power dissipation magnitude is of the order of 15 W for 1 A and 25 W for 2,5 A and depends on contact materials but not on supply voltage;
– the voltage drop across poor connections decreases as the current increases, so that the power dissipation trend versus the current is illustrated in Figure 1, and not quadratic as in normal connections with low and constant contact resistance value, it is not dependent of the supply voltage;



NOTE a more detailed chart describing glowing voltage and power can be found in [9], Figure 6.

Figure 1 – Voltage drop and power dissipation versus current values (schematic) [5]

– no indication of the minimum power dissipation required to ignite a plastic material has been reported.

4.2.3 Loose connections mitigation measures

4.2.3.1 Classification according to IEC Guide 116

IEC Guide 116 categorizes mitigation measures in three classes:

– inherent safety measures: consisting of design measures and type tests, aimed to ensure mechanically-tight low-resistance connections can be achieved and maintained over the entire service life of the equipment;
– technical safety measures: consisting of material requirements for the insulating parts, aimed to avoid or delay fire ignition in the case a loose connection results in overheating;
– information for use, including product marking, catalogues and installation and maintenance instructions provided by manufacturers. In addition, low-voltage switchgear and controlgear are intended to be used by skilled people, required to be familiar with installation rules, standards and codes.

4.2.3.2 Inherent safety measures

Countermeasures against poor connections within switchgear and controlgear include:

– use of materials to ensure low and stable contact resistance for the clamping unit;
– adequate mechanical properties through design, also accounting for stress relaxation effects;
– use of terminal materials, including surface plating if used, suitable for the environmental conditions and the conductor material to be connected.

Binding constructional requirements for clamping units to be used with copper conductors are given in group safety publications IEC 60999-1 and IEC 60999-2. The standards restrict the choice of material and surface treatment of current-carrying parts, to ensure mechanical strength, electrical conductivity and resistance to corrosion are adequate for the intended use. This restriction excludes the use of poor materials, which may lead over years to increasing voltage drop across the connection. Other design and construction requirements intended to avoid inadequate insertion of the conductor and undue damage to the conductor are included. Finally, IEC 60999-1 contains examples of clamping unit design.

In IEC 60947-1, type tests include specific tests to validate the design of the terminals. Flexion and pull-out tests are intended to verify mechanical strength of the terminals by simulating mechanical stress occurring for instance in case of poor handling of the connection. The temperature-rise requirements and tests are aimed to ensure that materials in the terminals are not exposed to excess temperature causing premature deterioration and instability of contact resistance. Screw-type terminals are tested with a tightening torque according to the standard or at 110 % of the torque specified by the manufacturer, whichever is bigger. Annex D (informative) of IEC 60947-1:2007, IEC 60947-1:2007/AMD1:2010 and IEC 60947-1:2007/AMD2:2014 includes examples of clamping unit designs from IEC 60999-1.

IEC 60947-7 (all parts) for terminal blocks add further requirements and tests on terminals, including resistance to abnormal heat and fire, short-time withstand current, temperature-rise in normal service conditions, handling test and an additional flexion test. The manufacturer is required to state if the tests are performed after any preparation of the end of the conductor. An additional requirement for terminal blocks with rated cross-section between 0,2 mm^2 and 35 mm^2 is that the clamping unit is designed to accept not only conductors of the rated cross-section but also smaller conductors within a defined range, defined in Table 4 of IEC 60947-7-1:2009 and called rated connecting capacity.

4.2.3.3 Material requirements for insulating parts

IEC 60947-1 categorizes insulating parts in two different groups with respect to their fire risk:

– parts necessary to retain current-carrying parts – including terminals – in position;
– other parts.

As overheating of connections and power conductors are the highest-ranking causes of ignition for low-voltage switchgear and controlgear (see Table 3), parts in the first group are deemed to have bigger impact on the fire risk; therefore, all such material has to undergo fire tests with higher severity. Whereas other parts shall exhibit basic ability to withstand fire, to guarantee that even in the unlikely event of a fire, its spread inside switchgear and control gear is restricted.

IEC 60947-1 allows manufacturers to choose between two different testing methods:

– glow-wire test (on equipment);
– flammability, hot wire ignition and arc ignition tests (on materials) (Annex M of IEC 60947-1:2007, IEC 60947-1:2007/AMD1:2010 and IEC 60947-1:2007/AMD2:2014).

The glow-wire (GW) test (see IEC 60695-2-11 and IEC 60695-2-12) reproduces the real situation occurring on the material in contact with overheated current-carrying parts. Unfortunately, no direct correlation can be established between the testing temperature and the electrical parameters of the devices. In addition, the glow-wire test is not intended for characterizing the ignition properties of the materials.

Even though a testing procedure for glow-wire ignition temperature on materials (specimens) has existed for many years, attempts to extend the GW test on end-products (GWEP) to evaluate ignition properties have failed. Other tests methods proposed for evaluating ignition due to contact with glowing wires were dropped because of poor repeatability (e.g. IEC 60695-2-3 withdrawn in 2003). An attempt to improve the hot wire coil ignitability (HWI) test (IEC 60695-2-20 and ANSI/ASTM D3874) is demonstrating the same problem. Different test procedures for evaluating ignition properties of materials are reviewed in IEC 60695-1-21:2016, only the tests previously mentioned seem to be suitable. For the above reasons, the glow-wire test, even though not perfect, is currently the best choice for assessing the ignition risk of the insulating materials supporting the terminals and other current-carrying parts.

The appropriate test temperature is defined in each product standard after conducting a risk analysis of failure of current carrying parts due to inadequate response to abnormal heat due to overcurrent fault, to ignition and to spread of fire, and the consequences to be expected as a result of such a failure. Switchgear and controlgear are considered in unattended, permanent load, fixed installation and industrial conditions. The glow-wire testing temperatures are listed in Table 4 below.

Table 4 – Function of the equipment and glow-wire test temperatures

Function	Current-carrying parts	Other insulating parts	Product standards
Short-circuit protection and switching at the origin of an installation	960 °C	650 °C	IEC 60947-2, IEC 60947-3, IEC 60947-6-1 (PC and CB types)
Control and protection of a load	850 °C	650 °C	IEC 60947-4 (all parts), IEC 60947-6-2
control circuit[a, b]	750 °C	650 °C	IEC 60947-5-1[b]

[a] The glow-wire temperature can be reduced to 550 °C if it can be demonstrated that the residual risk of fire is acceptable, for example in case of low-power circuits, fire enclosures, and small parts.

[b] In IEC 60947-5-1, small parts, with mass lower than 2 g or complying with definition 3.15 of IEC 60695-2-11:2014, do not require any testing.

As an alternative to glow-wire testing, IEC 60947-1 allows manufacturer to select materials based on their flame class according to IEC 60695-11-10 (V-0, V-1, V-2 and HB) and their ignitability evaluated with the hot wire ignition test (HWI) and the arc ignition test (AI) according to Annex M of IEC 60947-1:2007, IEC 60947-1:2007/AMD1:2010 and IEC 60947-1:2007/AMD2:2014. The HWI test assesses the ignitability of a material sample wrapped by an electrically heated coil (HWI).

Materials used for components necessary to retain current-carrying parts shall meet the requirements in Table M.1 of IEC 60947-1:2007 and IEC 60947-1:2007/AMD1:2010, describing the minimum HWI and AI performances depending on the flame class: higher flame class allows lower HWI and AI performances and vice versa.

In the same way, Table M.2 of IEC 60947-1:2007 and IEC 60947-1:2007/AMD1:2010 establishes similar but less severe requirements for components not supporting current-carrying parts.

IEC 60947-7-1 and IEC 60947-7-2 product standards for terminal blocks do not apply the IEC 60947-1 approach. In those, resistance of insulating materials to fire ignition is assessed by performing the needle flame test (IEC 60695-11-5) on the product housing.

4.2.3.4 Information for use

Even if all the requirements and tests in IEC 60947 (all parts) ensure the terminals are fitted to ensure a good and reliable connection, the major factor for poor connections is the actual quality of the termination, which is mainly dependent on the user. Such unwanted poor connections may occur for example due to inappropriate installation procedures, improper modification of wiring or not anticipated modifications of service conditions (e.g. higher loads, voltages and environment). Also, inadequate choice of clamping units, which are not suitable for the actual application, may be a reason for loosened connections. For example, it may have a big impact on a clamping unit, if stranded wires or solid wires are connected to it, even if they both have the same current carrying capacity. Also, the clamping unit shall be suitable to the conductor material used, like copper or aluminium.

To reduce the risk of inappropriate installation and/or inadequate choice of clamping units, product standards require manufacturers to provide technical information in catalogues, installation instructions or on the packages, or through marking on the product, about selection of the appropriate clamping unit for a given application as well as for the correct installation (e.g. the tightening torque, for screw-type terminals).

In addition, manufacturers may require service and preventive maintenance measures aimed to reduce risk of loose connections, for example regular measurement of temperature or voltage drop. For some connection types (namely screw-type terminals), periodic adjustment of tightening torques may be necessary if the manufacturer states this in the manuals (see also 4.11.4, last paragraph of IEC 62477-1:2012: "When screw terminal connections are used, the resulting connections may require routine maintenance (tightening)"). Other measures like regular thermal screening of connections under load are also common in industrial electric installations to detect poor connections well before a fire risk may occur.

4.3 Overheating of internal power conductors

Overheating of internal power conductors may occur in case an internal conductor is undersized due to poor design or subjected to elevated current under fault conditions.

Temperature rise and overload tests performed during type testing prevent equipment with such a problem to pass type tests.

Technical safety measures described in 4.2.2 also apply to this case.

4.4 Arcs

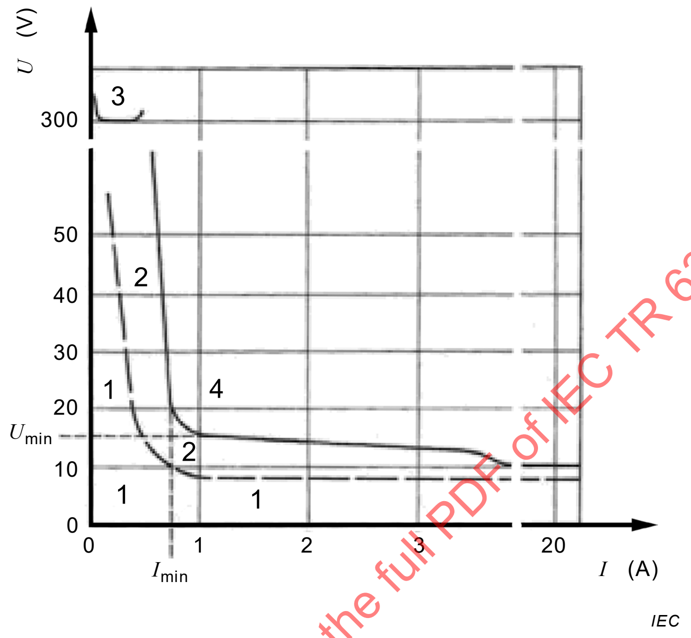
4.4.1 General

As temperatures within the arc are in the range of several thousand degrees, depending on current, voltage drop, medium and electrode materials, arcs are serious potential sources of ignition for surrounding materials. In low-voltage switchgear and controlgear, arcing caused by switching is controlled and contained, and typically so brief that the released energy is not enough for ignition.

The different types of arc ignition mechanisms that may occur in low-voltage switchgear and controlgear are described and discussed below.

4.4.2 Breaking and making arcs

Breaking and making arcs, also called "parting arcs" (e.g. in NFPA 921), are produced by separation and joining of contacts when the switched current exceeds about 1 A at a voltage above 10 V to 20 V (see Figure 2).



Key

1 arcless switching

2 short unstable arcs without plasma

3 glow-discharge

4 full electric arcs

Figure 2 – Current and voltage conditions for switching arcs (schematic) [10]

Such arcs are typically restricted within the device housing. Requirements in the type testing procedures (e.g. in making/breaking tests, overload and short-circuit tests) ensure the amount of energy released outside the device is not enough to ignite the insulating materials and adjacent equipment. In IEC 60947-1, a metallic screen is used to check that arcing does not extend outside the product and that any leakage current is limited to a very low value. The minimum size of the enclosure defines the distance at which the metal screen shall be placed. The device shall be installed according to the manufacturer's instructions.

In IEC 60947-2, during short-circuit tests, an additional polyethylene film is used to check the heat (and the hot particles) released is very low (not enough to melt a low-melting thermoplastic film).

NOTE That does not apply to equipment installed in combustible and explosive atmospheres, which are out of the scope of this document.

4.4.3 Arcs occurring at loose connections

Arcs may occur at loose connections, either in case of very poor and unstable contact or as the evolution of arc-free high resistant connections as metals melt due to the local heating.

Basic mechanisms and mitigation measures are discussed in 4.2.

4.4.4 Arcing through char and tracking arcs

Tracking is defined as the progressive formation of conductive paths, which are produced on the surface or within a solid insulating material, due to the combined effects of electric stress and electrolytic contamination. Such conductive paths typically consist of carbonaceous decomposition residuals. When the conductive path does not occur on the surface only but also in the bulk, the phenomenon is called "charring" and the carbonaceous track is called "char".

A voltage applied across a track or char results in a current consisting of high frequency bursts of arcing [8]. Such phenomenon has been observed at voltage as low as 30 V. If those arcs persist long enough, they can cause ignition.

The risk is mitigated through design rules supported by type tests. To minimize the risk of tracking, IEC 60947-1 defines minimum creepage distances based on material tracking characteristics (comparative tracking index – CTI). Dielectric tests after every test sequence, including short-circuit, making and breaking tests, electrical endurance and overload tests, ensure that the equipment is still able to withstand foreseeable voltage stresses without tracking.

4.4.5 Sparks

According to definition 3.3, a spark is a small luminous electric arc of short duration. Actually, for purposes of fire investigations and risk analysis, the term "sparks" is more commonly used for solid particles spattered from the electrodes when the arc melts the metals.

Sparks are typically too small and low-energy to cause ignition of surrounding materials, and their effects are, anyway, evaluated by the use of the above-mentioned metallic screen.

As described in 4.4.2, in IEC 60947-2 a polyethylene film is used to check that hot particles are not emitted by the equipment under testing during short-circuit tests.

4.4.6 Arcs due to excessive overvoltage

The equipment may be exposed to voltages higher than their rated voltage due to different causes, such as high rate switching in highly inductive circuits or accidental contact with a circuit operated at higher voltage, for example in the case of a 24 V rated switch connected to a 380 V network. The dielectric tests performed on switchgear and controlgear in a new state and after the applicable test sequences ensure those conditions do not result in arcing.

The impulse voltage withstand test required in IEC 60947-1 further ensures that any reasonably foreseeable lightning surge, between poles or between poles and ground, will not cause arcing.

NOTE The case of low-voltage equipment accidentally connected to high voltage grid is not considered.

4.5 Failure of electronic components

4.5.1 Basic description of the ignition mechanism

A failure of electronic components can lead to melting, fire or explosions. The main reason is a thermal runaway which can be induced by inherent defects, e.g. impurities and particles due to the manufacturing process, and by various stressing factor in the electronic circuits (high temperature, high current or voltage, radiation, mechanical shock, stress or impact, tin whiskers, ESD, etc.).

The failure of the package of the semiconductor may cause failures due to contamination and oxidation. A sudden fail-open fault can cause multiple secondary failures if it is fast and the circuit contains an inductance; this causes large voltage spikes, which may exceed 500 V. A broken metallisation on a chip may thus cause secondary overvoltage damage and can lead to fire spread. Overloaded components can also ignite printed circuit board. Some electronic components contain ignitable materials, such as dielectric fluids or polymeric films.

4.5.2 Mitigation measures

Fire safety of intact, unimpaired electronic circuits at different electrical operating points and temperatures is extensively assessed during type testing.

Further risk reduction measures, addressing abnormal operating conditions resulting from breakdown of electronic components or insulation, is under consideration in SC 121A for inclusion in future edition 4 of IEC 60947-4-1[2].This procedure consists of two steps:

– preliminary analysis to identify the electronic components likely to breakdown;
– analysis or testing of the effects of short-circuit and open-circuit conditions of those components.

Possible technical measures to reduce the risk of fire spread due to failure of electronic components are:

1) limited power source of the secondary circuit (see IEC 62477-1);
2) fire enclosure: metallic or 5V plastic (see IEC 60950-1);
3) the combination of both, after a fire hazard assessment based on an FMEA of the electronic circuits.

5 Conclusion

Table 5 below lists the most relevant potential sources of ignition for low-voltage switchgear and controlgear and the risk reduction measures required by IEC 60947 (all parts).

2 As a first step, then later on introduced in future edition 6 of IEC 60947-1.