

# Electrically ignited fires in Low Voltage Installations



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Powering Business Worldwide

## Author's foreword

This scientific publication is about *electrically ignited fires in low voltage electrical installations* and ways to avoid the risk of such fires by taking appropriate effective action when planning and erecting such installations.

It is primarily about conveying the best of knowledge within the scope of this publication of how electrically ignited fires (except for fires caused by lightning or the misuse of low voltage equipment) are caused, and which protection concepts are available nowadays to reduce the risk of such incidents.

The main focus of this publication is to show the essential correlations for domestic installations and similar applications. Requirements and detailed solutions for industrial or commercial systems are not part of this scientific publication, although there are many similarities.

This scientific publication neither can nor intends to replace comprehensive studies of the detailed applicable accepted rules of technology for the installation of low voltage installations and the corresponding technical measures to be taken in each country within Europe but it is about the practical familiarisation with this issue. The goal is to convey general knowledge up to a degree for anyone interested to continue further individual studies on this topic.

The deadline for this publication is 1 September 2016.



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## 1 Protection goals

### 1.1 Legal foundations for installations and equipment

EC Directives in general assume that the generally accepted rules of technology are applied on a voluntary basis. However, the EC Directives for products (e.g. electrical equipment) stipulate major safety requirements which must not constrain the marketing of the equipment if they are complied with.

Standards and technical stipulations, in particular *harmonised standards* (for electrical equipment), however, are very important because if they are complied with, the major safety requirements are deemed as met. In this case it is also said that they give presumption of conformity.

The legal requirements for the electrical safety of electrical installations and equipment are included in the Austrian Electrical Engineering Act (ETG)[14]. It uses clear wording with regard to the preparation of safety measures for electrical engineering.

#### Safety measures for electrical engineering

§ 3. (1) Electrical equipment and electrical installations in the whole federal territory must be set up, produced, maintained and operated in a way to ensure their operational safety, the safety of persons and objects, as well as the safe and undisturbed operation of other electrical installations and equipment in their hazard and interference area, as well as of other installations. In order to ensure the above, not only normal utilisation must be taken into consideration for the construction and production of electrical equipment but also any utilisation to be expected according to reasonable discretion. Stipulations included in other statutory provisions regarding the protection of the life and health of persons are not affected by these regulations<sup>1</sup>.

§ 3. (2) In the hazard and interference area of electrical installations and electrical equipment, those measures must be taken which are required for any interacting electrical installation and other installations as well as equipment in order to maintain electrical safety and uninterrupted operation.

The three main safety goals included in this legal text are summarised in Figure 1-1.

The generally accepted rules of technology for setting up, operating, modifying and maintaining electrical installations are officially stated in Austria in the so-called “Electrical Engineering Regulation”.

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<sup>1</sup> Translated from German to English by the author.

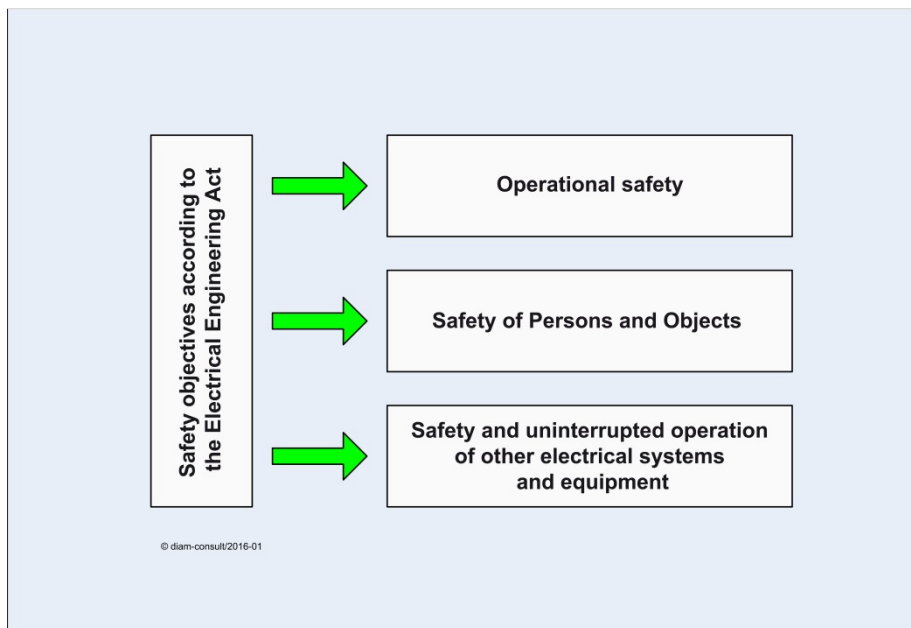


Figure 1-1 Safety objectives according to the Austrian Electrical Engineering Act [14]

In other European countries, this is accomplished (with regard to practical impacts) in a comparable way by reference to the corresponding electrotechnical rules (e.g. the VDE rules and standards in Germany, or the low voltage installation standard NIN in Switzerland).

## 1.2 Classification of electrical equipment and electrical installations

Compared to earlier versions of the Electrical Engineering Act, the definitions of fixed installations and electrical equipment were redesigned in the Electrical Engineering Act of 1992 and in the amendment of 2015. Thus, these terms are clearly classified.

§ 1. (1) *Electrical equipment* in terms of this Federal Act are objects which are, as a whole or in their individual parts, intended for the generation, transfer or use of electrical energy. The operational combination of several pieces of electrical equipment which are marketed as a structural unit and which are, at least at this point in time, portable as a structural unit, are also deemed as electrical equipment.

§ 1. (2) An fixed electrical installation in terms of this Federal Act is the stationary operational combination of electrical equipment, as far as this combination has not to be deemed as equipment in terms of section 1. Installations for equipotential bonding, earthing systems, systems for lightning protection and systems for protection against cathodic corrosion are also fixed electrical installations.

§ 1. (2a) *Movable electrical installations* are a combination of devices and further installations, if available, which are movable and which are intended for the operation at different places. With regard to safety, movable installations (operational combinations of electrical devices on vehicles, transportable buildings and flying constructions) are subject to the same provisions as fixed electrical installations.

## 1.3 Requirements for the accepted rules of technology

### 1.3.1 General information

A very basic requirement is to protect persons, livestock and objects against being inadmissibly heated which may be caused by electrical equipment or fixed electrical installations.

It is in particular necessary to avoid any ignition of, burning of or other damage to materials and to avoid burns (burn wounds). Above all, the safe function of installations must not be impaired [19], [20].

For example in Austria, the provisions of the standard series ÖVE/ÖNORM E 8001 and also the provisions of the standard series ÖVE EN 1 are presently applicable to the installation of electrical low voltage installations.

They include many requirements with regard to the prevention of electrically ignited fire; as generally for example in EN 1, part 2, section 25.2.1.

The equipment must be arranged and installed so that neither the temperatures reached during operation nor the temperatures reached in case of overload and short circuit will endanger the installation or the environment, i.e. the equipment must [...] comply with the applicable technical provisions and be suited for them [...]

or for agricultural and horticultural premises in E 8001-4-56, section 56.5

If neutral lines or residual current circuit breakers are used, a residual current-operated circuit breaker with  $I_{\Delta N} \leq 0.3 \text{ A}$  must be provided as fire protection.

### 1.3.2 Current international and European developments

In the last few years, regulations have been added to the accepted rules of technology of IEC<sup>2</sup> and CLC<sup>3</sup> for the installation of electrical low voltage installations which shall avoid the risk of fires caused by electricity [21], [22].

While this publication is being prepared<sup>4</sup>, some of these installation rules are (or were) adopted in the national accepted rules of technology, and some more national requirements were added [20].

This is applicable to the use of arc fault protection systems (see section 3.2) as well as to the use of arc fault detection devices (see section 4.4).

The latest issue of VDE 0100-420 [20] recommends the use of arc fault protection systems for permanently installed equipment which might generate electric arcs or sparks during its intended use if the installation is expected to require high availability.

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<sup>2</sup> International Electrotechnical Commission

<sup>3</sup> European Committee for Electrotechnical Standardisation

<sup>4</sup> Deadline: 1 September 2016

These protection devices must identify the light power of the electric arc and the increase of current in the line conductors, extinguish the electric arc within 5 ms and disconnect the electrical installation (or, if possible, the affected part of the installation) from the mains supply. This requirement is based on the knowledge that slowly reacting protection devices cannot prevent material assets from being damaged, thus avoiding the fast recommissioning of the installation.

However, arc fault detection devices<sup>5</sup> have also been adopted in the international, European and national accepted rules of technology for the installation of low voltage installations [20], [21], [22].

Since 1 February 2016, in Germany arc fault detection devices must be taken into consideration for the installation of new installations in certain circuits as well as after the change or extension of existing electrical installations<sup>6</sup> [20].

In Germany, there is a transitional period until 18 December 2017 for electrical installations which are currently being planned or constructed. Any other electrical installations which will be commissioned after this date are subject to the regulations of DIN VDE 0100-420 (VDE 0100-420):2016-02.

Arc fault detection devices have thus become an integral part of the accepted rules of technology. They require that AFDD are installed *in single-phase final circuits (alternating current)* with an operating current of max. 16 A for the following applications:

with an operating current of max. 16 A for the following applications:

- in bedrooms or recreation rooms of homes or day-care facilities for children and disabled or old people (e.g. nurseries, retirement homes)
- in bedrooms or recreation rooms of apartments equipped for the disabled<sup>7</sup>
- in rooms or places
  - with fire risk due to processed or stored materials<sup>8</sup>
  - with combustible construction materials<sup>9</sup>
  - with risks for irreplaceable goods<sup>10</sup>

Any accepted rules of technology for Europe published so far assume that only arc fault detection devices are used which comply with EN 62606 [10].

## 2 Causes of electrically ignited fire

As already known from literature and practical experience for many decades (see e.g. [5], [6]), fire risks in electrical low voltage installations arise in case of the simultaneous existence of

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<sup>5</sup> In German speaking countries, these protection devices are often also referred to as AFDD according to their English abbreviation.

<sup>6</sup> DIN VDE 0100-420 (VDE 0100-420):2016-02

<sup>7</sup> Apartments equipped for the disabled according to DIN 18040-02

<sup>8</sup> DIN VDE 0100-420: (VDE 0100-420):2016-02, section 422.3

<sup>9</sup> DIN VDE 0100-420: (VDE 0100-420):2016-02, section 422.4

<sup>10</sup> DIN VDE 0100-420: (VDE 0100-420):2016-02, section 422.6

- an ignition source
- combustible material
- oxygen

If one of the three components does not exist, there is no fire. From the electrical point of view, ignition sources are “hidden” e.g. in heat generators, lamps, terminals, inadequately maintained installations, overloaded cable systems.

In practice, the crucial protection goal in order to avoid fire ignited by electrical energy is to avoid ignition sources, or to identify ignition sources in due time before the energy acting on the defective area has become high enough to ignite the material/oxygen mixture.

The fire damage statistics for Austria<sup>11</sup> indicate 1150 fire events caused by electrical energy<sup>12</sup> in 2013. The amount of damage summed up to approx. 70 million Euro. This corresponds to 25 % of the total amount of damage caused by fire. Even if the trend regarding the number of fires as well as the amount of loss since 2003 is carefully interpreted, a slight increase can be identified (Figure 2-1).

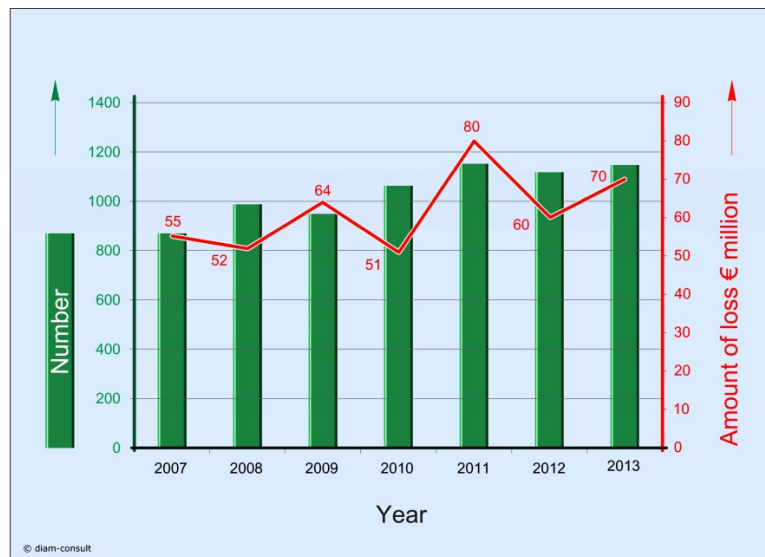


Figure 2-1 Number and amount of loss caused of fires caused by electrical energy; process from 2007 to 2013; source Austrian Fire Prevention Agencies (publisher), fire damage statistics 2013

In 2013 as well, more than half of all fires (approx. 52 %) affected *private households*. In the ranking of the most frequent cause of fire, “electrical energy” as ignition source was second.

Although the statistics available for each European country cannot be entirely compared with each other, there is expertise in literature, e.g. for Germany [18], which proves the significance of electrical energy as a cause of fire. Here as well, one of the main causes of fire is electricity with a share of 34 % in all causes of fire in 2010.

<sup>11</sup> Austrian Fire Prevention Agencies (publisher), fire damage statistics 2013

<sup>12</sup> These figures do not include minor damage (damage under € 2000, or for Tirol under € 1500), damage caused by heating devices, as well as indirect and direct lightning damage.

## 2.1 Harmonic currents in the neutral conductor

Harmonic currents in the neutral conductor of electrical low voltage installations, above all in old installations, are a potential ignition source.

A frequent cause of the generation of harmonics are rectification processes (e.g. in power supply units).

The so-called “non-rotating harmonics” or harmonics of the zero sequence system do not generate a rotating field. The reason is that these harmonics have a periodic sequence which exactly occurs in the pitch of the mains currents of the line conductors which are displaced by 120°.

Thus, the currents of the third harmonics ( $i_{3L1}$ ,  $i_{3L2}$ ,  $i_{3L3}$ ) have the same phase position in all three line conductors. This situation is shown in Figure 2-2.

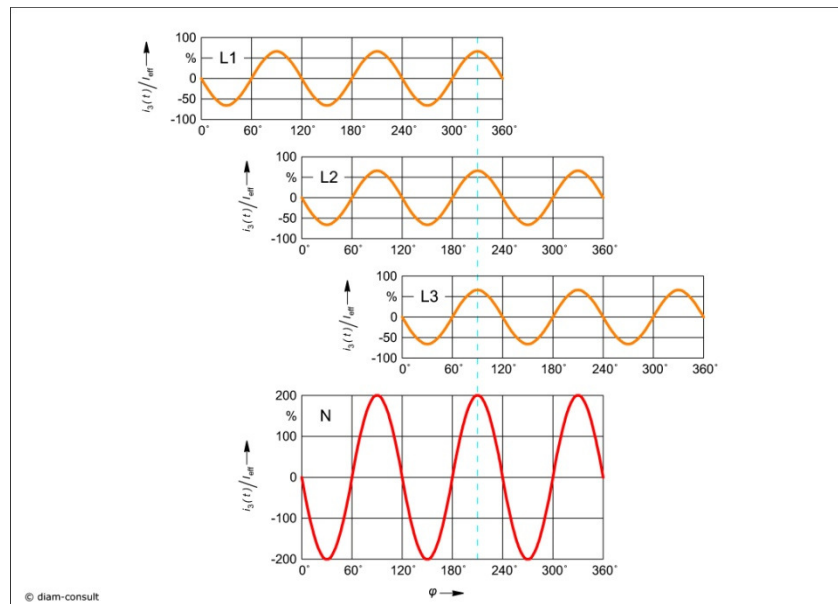


Figure 2-2 Overlap of the third harmonics in the neutral conductor; illustrated in percent of the effective value of the line conductor current

This means that the *supply frequency currents* (with basic oscillation, e.g. 50 Hz) of the line conductors add up to *zero* in case of symmetric load in the neutral conductor. The third harmonics in the neutral conductor, however, reaches three times its value<sup>13</sup> in case of symmetric load. Since many neutral conductors were designed with half the cross-section in the past, this situation may become thermally critical at the clamping points even if the line conductors are not yet overloaded by far.

This basically also applies to any harmonics with an ordinal number which can be divided by three (6., 9., 12., ...). The peak values, however, are in most cases much lower than each of the third harmonics.

<sup>13</sup> Phase shifts may occur even for 150 Hz currents; however this is a topic which is deliberately left out here.

## 2.2 Careless handling of equipment in the installation by the user

From years of experience in the use of the electrical energy in electrical installations we know that fire is caused in particular due to the following causes:

- electrical heating devices and lamps which are defective or not applied according to their intended use (e.g. fan heaters with blocked fans, or devices with inadequate stability, lamps used with light bulbs with excessive power, heaters covered with clothing)
- other electrical devices which are defective, or which become defective during their operation (e.g. TV sets)
- excessive heating of lines due to inadequate overcurrent protection or defective contacts (e.g. loose clamping)
- electric arc caused by short circuits with or without fault current to the earth (e.g. due to tracking)
- mechanical damage to lines (stationary installation lines bruised or damaged by drilling), also to extension lines for portable equipment
- ageing of lines and equipment
- environmental influences (temperature, UV radiation)
- highly loaded or overloaded mechanically damaged sockets or multiple socket outlets

## 2.3 Changed room utilisation without adjusting the installation and protective measures

In case of changed room utilisation, e.g. if dangerous amounts of combustible materials might get close to electrical equipment and the room is therefore considered as an area with risks of fire, the electrical installation must be adjusted to the changed conditions.

In these cases, lines and cables must be protected in TN and TT systems with residual current-operated circuit breakers with a rated residual current of  $I_{\Delta N} \leq 0.3 \text{ A}$  in order to avoid fires caused by defective insulation<sup>14</sup>.

Where resistive defects may cause a fire, e.g. ceiling heaters with surface heating elements, the rated residual current must be  $I_{\Delta N} \leq 0.03 \text{ A}$ .

If the low voltage installation is not adjusted accordingly, there is a permanent risk of fire due to electrical energy after the changed utilisation of the room.

## 2.4 Insufficient maintenance and inadequate repair (“eternally provisional arrangement”)

Operators of electrical low voltage installations are responsible for their safe operation (see also section 1.1 and [7]). This includes maintenance and repair measures to maintain a safe condition.

If the maintenance staff is not adequately instructed or not adequately trained, shortcomings in the implementation of their activities might increase the fire risk. For example if inadequate tools and installation materials are used.

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<sup>14</sup> See also ÖVE/ÖNORM E 8001-4-50:2001, section 50.5.7

### 3 Identification of possible ignition sources in the low voltage installation

In addition to optimising protective measures for the protection of people and animals against dangerous body currents, fundamental research and technical developments increasingly deal with the protection against hazards caused by electric arcs, often also referred to as *arc fault*.

#### 3.1 Residual current in low voltage switchgear assemblies, distribution circuits and final circuits

Residual current is the current which flows through a defective area due to defective insulation<sup>15</sup>. Residual current may not only directly endanger people and animals, e.g. ventricular fibrillation, but also present the ignition source for fire. This applies likewise to switchgear combinations, distribution circuits and final circuits.

These residual currents are nowadays mostly identified by protection devices which, in order to react, only identify the current which occurs in case of an error, evaluate it and disconnect the affected circuit if a certain “threshold value” is exceeded. (Exception: the system for the optical identification of arcs mentioned in sector 3.2.)

In the contemplation of short circuits or earth faults, serial and parallel electric arcs in final circuits have not been the focus of protective considerations so far (neither in national nor international standardisation)<sup>16</sup>. This is currently changing, not least due to the approval of an internationally applicable accepted rule of technology for arc fault protective equipment [10].

#### 3.2 Arc fault protection in low voltage switchgear assemblies

##### 3.2.1 Occurrence of arc faults

The following causes might be responsible for the ignition of arc faults in low voltage switchgear combinations:

- generation of condensate (humidity in the switchgear combination)
- contamination caused by foreign matter deposits on bus bars and switchgear parts
- transient overvoltage due to thunderstorms or switching surges
- early (unidentified) ageing of insulation material due to sporadic or permanent thermal overload
- loose connections, defective contact points
- working on parts of the switchgear

One of the possible consequences caused by arc faults is the complete destruction of the switchgear combination.

Due to the high internal pressure of up to 15 - 25 t/m<sup>2</sup> in case of electric arc impacts, the steel housing becomes a high risk for the environment *and the persons there*. Due to arc faults, side walls, doors, and built-in units are quite often expelled from the housing of the switchgear combination.

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<sup>15</sup> Definition according to ÖVE/ÖNORM E 8001-1:2010-03-01; In low voltage installations, this definition in particular specifies the current which flows into the earth due to defective insulation, and which triggers the protection device for error protection, if any.

<sup>16</sup> The only exception is North America. They have protection devices which enable the identification of parallel and later also of serial electric arcs in final circuits already since the 1990s.

Another possible impact of arc faults is the generation and distribution of so-called electrically ignited fires.

Arc faults occur very rarely in the work environment of such persons. It is, however, important to have reliable protection in case of their occurrence because they can be caused by incorrectly carried out operations.

Arc faults are not only caused by or as a consequence of a short-circuit but also if energised parts such as lines, cable lugs, switchgear, or fuses are disconnected under load without having taken special precautions<sup>17</sup> [23].

### **3.2.2 Arc fault protection systems**

A method for the quick identification of arc faults which has been used for some years in practice is to capture the light emitted by the arc [9].

In this process, electric arcs occurring in the switchgear assembly are captured within the first two milliseconds of their existence. Then the mains voltage supplying the electric arc is short-circuited with a pyrotechnical short circuiter in less than 2 ms thus taking away energy from the arc fault. This short circuit is then identified and switched off by the mains switch.

Consequences are reduced in case of quick arc extinction because the significant temperature increase caused by the electric arc prevents the switchgear assembly from reaching maximum temperature and pressure (Figure 3-1).

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<sup>17</sup> ÖVE/ÖNORM EN 50110-1:2014-10-01, appendix B. 6, [23].

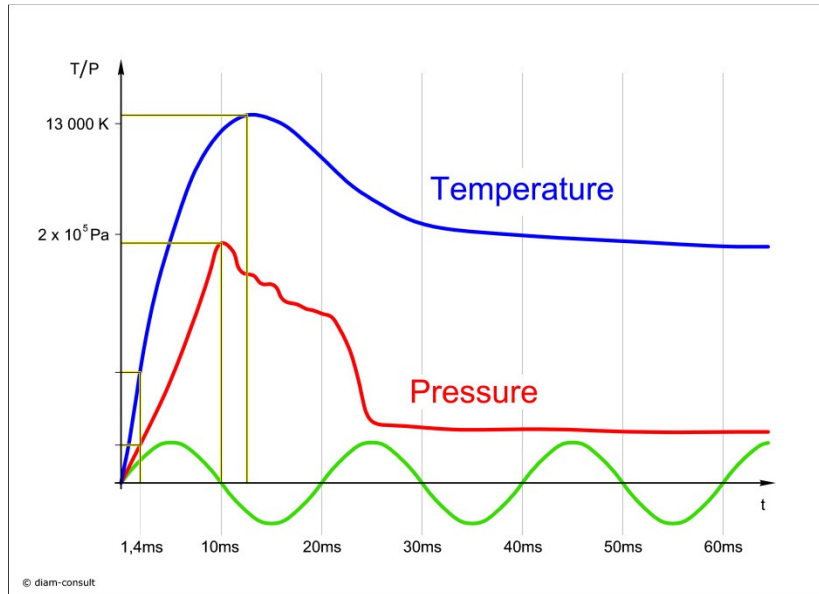


Figure 3-1 Pressure and temperature curve of a arc fault in a low voltage switchgear assembly; the quick interruption (here e.g. after 1.4 ms) of the power supply avoids the increase of pressure and temperature; schematic exemplary illustration.

A decision whether arc fault protection systems are actually used as a protection against or in case of the occurrence of electric arcs is usually not made until a risk assessment [24] has been carried out. Possible protection goals for the use of such systems might include the protection of persons and property or also the availability of electrical installations.

### 3.3 Serial and parallel electric arcs in final circuits

Fire caused by arc faults in low voltage installations might include the following causes:

- defective insulation between active conductors
- lines damaged or broken by external mechanical impacts
- terminals with increased resistance due to external influences or thermal overload

Serial and parallel arc faults in final circuits are sometimes also referred to as *low-current arc faults* [8]. Figure 3-2 and Figure 3-3 depict the schematic illustration of parallel and serial electric arcs.

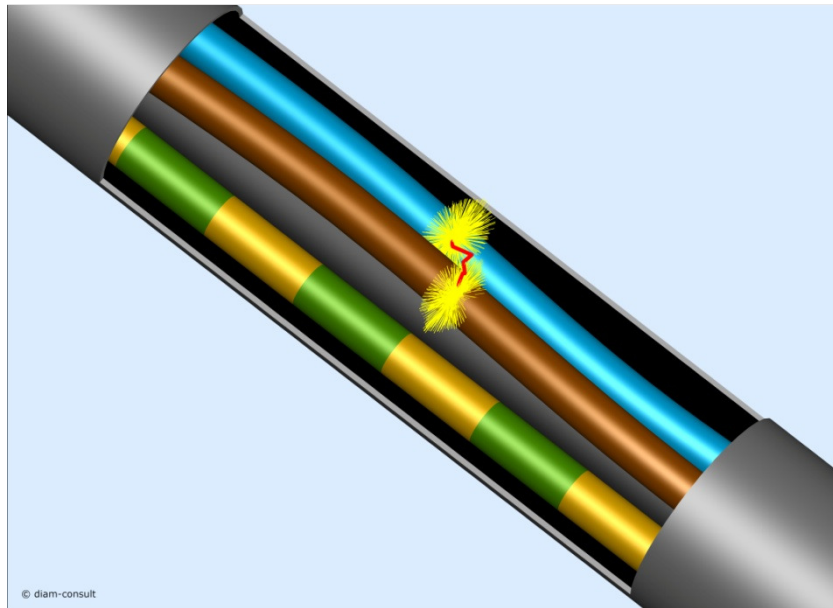


Figure 3-2 Parallel electric arc between L conductor and N conductor and serial electric arc at an L conductor in a plastic-sheathed cable or in a conduit; schematic illustration

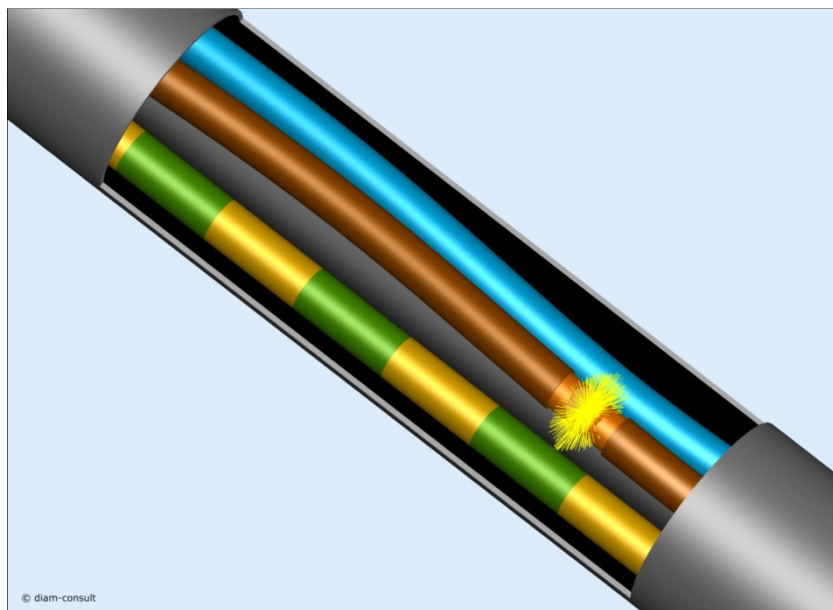


Figure 3-3 Serial electric arc at an L conductor in a plastic-sheathed cable or in a conduit; schematic illustration

A low-current arc fault is an electric arc with a total current flowing through the electric arc which is within the range of the nominal current of the circuit and/or the rated current of the protective equipment used.

Since the residual current is not significantly higher than the nominal current, or sometimes even below the tripping threshold of the residual current-operated circuit breaker, circuit breakers for overcurrent protection and residual current-operated circuit breakers do not (always) trip.

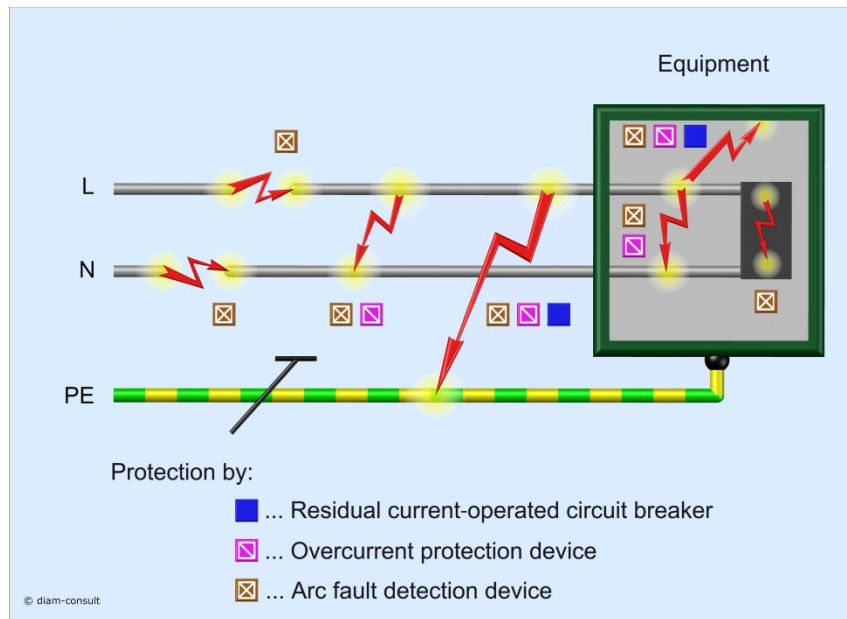


Figure 3-4 Parallel and serial arc faults occurring in a final circuit; schematic illustration

Figure 3-4 shows the options for parallel and serial arc faults to occur. Possible fault points are marked in the final circuit<sup>18</sup> and in the equipment. In case of low-current arc faults, the arc fault detection device adds to the protection provided by residual current-operated circuit breaker or to the circuit breaker for overcurrent protection.

#### 4 Protective measures in installations

A number of protective measures are included in the accepted rules of technology for the planning and design of low voltage installations which are to prevent electrically ignited fires.

Practically all these measures have in common that the professional and standard-compliant planning and erection of the installation and all protective measures as well as its responsible operation is the vital prerequisite for a possibly low residual risk with regard to electrically ignited fires. It must also be mentioned that recurring inspections carried out by electricians qualified for this purpose are indispensable.

The following sections include a compilation of some major measures to be taken to reduce the residual risk for electrically ignited fires to occur.

##### 4.1 Thermal design of switchgear assemblies and junctions in the installation

In the last few years, the accepted rules of technology and literature [3] have regularly pointed out to the necessity of the user-friendly design of switchgear combinations.

Especially the mechanical design of all joints (clamping points) in the installation, the use of appropriate clamps, wire sleeves and the crimp tools provided for this purpose etc., is very important.

<sup>18</sup> Beginning with the last device for overcurrent protection, the circuit supplying the equipment is termed “final circuit” (definition according to ÖVE/ÖNORM E 8001-1:2010-03-01, section 3.1.11.3).

## 4.2 Design of cross-sections and the selection of the wiring system and their overcurrent protection devices

Thermally overloaded cables and lines which are laid on the basis of an inadequate type of laying, e.g. excessive clusters, without taking into account the actual ambient temperatures occurring during operation as well as the non-compliance with the bending radii admissible for each type of line are potential risks for fire.

Exemplary for a number of further provisions, this is the quote<sup>19</sup> of a practically decisive requirement for the professional design of cable and line systems (emphases A.M.):

If systems are changed, or if lines or cables are added, the admissible permanent current  $I_z$  and the nominal current  $I_N$  of the protection device must be redefined *also for the section which is affected by the change or addition*.

It should only be pointed out to the use of circuit breakers for overcurrent protection which also protect the *neutral conductor* against overload and short circuit (circuit breakers for overcurrent protection with two or four protected poles). They also protect against thermal overload of the neutral conductor in case of harmonic currents.

## 4.3 Identification of differential currents using residual current-operated circuit breakers

Residual current-operated circuit breakers may be protection against electrically ignited fires which are caused by *currents to earth* (see Figure 3-4).

Residual currents to earth occur if

- there is an insulation fault between line conductors, and e.g. some of the (short-circuit) current flows via a creepage path to an earthed part in the vicinity, or if
- the insulation defect occurs directly between an active conductor (e.g. line conductor) and earthed parts.

Tests carried out in practice [5], [15] show that the residual power<sup>20</sup> from currents of approx. 300 mA is already high enough to ignite a fire if it acts inadmissibly long on a fault location.

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<sup>19</sup> ÖVE EN 1, Teil 3, § 41.1, last section

<sup>20</sup> The estimated value for the power limit for the risk of electrically ignited fire is below 100 W. The limit of 60 W is also often considered as “low enough for practice to avoid the risk of fire” [5].

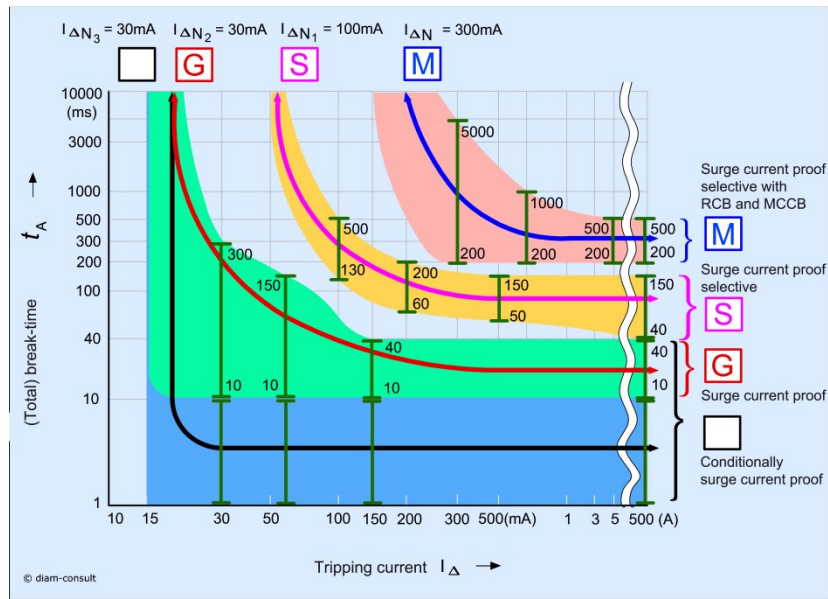


Figure 4-1 Residual current-operated circuit breaker, Type M; selectivity

They are, however, primarily designed for the protection against electric shock and must comply with precisely defined limits with regard to the maximum admissible (total) break-time due to electrophysiological reasons. Therefore, they switch off “quickly”. Depending on the value of the occurring residual current, the switch-off times are some tens of milliseconds up to 0.13 s (for S-Type).

The residual current-operated circuit breakers of the currently common tripping current / break-time characteristics<sup>21</sup> can principally protect against such risks.

This means that residual current-operated circuit breakers often switch off simultaneously with circuit breakers for overcurrent protection. This affects the availability of electrical energy and results in (not necessary) downtimes of electrical equipment (data loss, ...).

In order to avoid this unwanted tripping in case of simultaneous fire protection - or earth fault fire protection, to be precise - effective for the whole installation<sup>22</sup> (or part of installation), residual current operated circuit breakers of type M were developed [12]. They switch selectively with residual current-operated circuit breakers and line safety switches (see Figure 4-1).

<sup>21</sup> These are: Residual current operated circuit breakers of Type S, Type G and so-called “undelayed” FI switches (formerly also referred to as “conditionally search-current-resistant” breakers).

<sup>22</sup> For circuits with nominal currents above 32A.

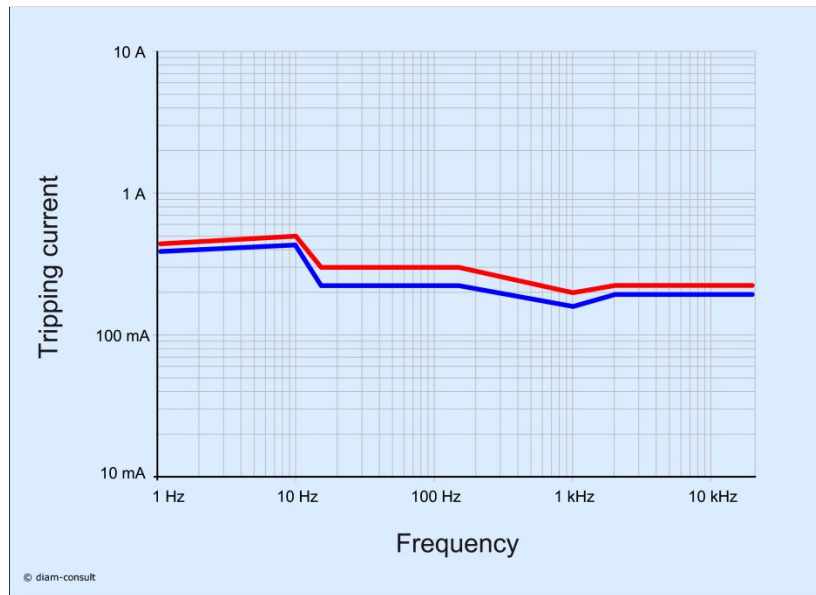


Figure 4-2 Residual current-operated circuit breaker, Type B+; tripping current / frequency range with tripping limits (maximum, minimum); data taken [13]

Also residual current-operated circuit breakers which cannot only identify sinus-shaped residual currents with a rated frequency of 50 Hz but also other residual current wave forms, are already available in designs which can be effectively used against electrically ignited fires. An example is given in Figure 4-2.

## 4.4 Identification of serial and parallel electric arcs in final circuits by means of arc fault detection devices

### 4.4.1 Basic information

As known for many decades, residual current-operated circuit breakers and circuit breakers for overcurrent protection are effective devices which reduce the risk of electrically ignited fires.

Residual current-operated circuit breakers and circuit breakers for overcurrent protection, however, are not able to reduce the risk of electrically ignited fires caused by serial or parallel electric arcs between energised conductors.

For serial arc faults, there is no current against the protective conductor. The impedance of serial arc faults reduces the operating current keeping it below the tripping threshold of the circuit breaker for overcurrent protection. Circuit breakers for overcurrent protection and residual current-operated circuit breakers cannot identify such faults.

In case of a parallel arc fault between the line conductor and the neutral conductor, the current is limited by the impedance of the circuit. Moreover, circuit breakers for overcurrent protection are not designed for sporadically occurring electric arcs.

ÖVE/ÖNORM EN 62606 [10] points out to the fact that the effective value of an earth fault current caused by a arc fault which may ignite a fire is not limited to the rated frequency of 50/60 Hz. This earth fault current may have a much broader frequency spectrum which is not taken into consideration in the currently available accepted rules of technology for the inspection of residual current-operated circuit breakers.

#### 4.4.2 Arc fault detection devices

Due to the above reasons, North-America has started developing protective devices for the detection of arc faults already in the 1990ies.

In Europe, the accepted rules of technology for testing arc fault detection devices<sup>23</sup> were only published in 2014 [10].

Arc fault detection devices (AFDD) are devices intended to mitigate the effects of arcing faults by disconnecting the circuit when an arc fault is detected<sup>24</sup>. Arc fault detection devices are used to limit the risk of fires ignited by electricity in downstream equipment.

Among others, AFDD are classified according to their design.

On the one hand, there are arc fault detection devices as one single device comprising an AFD unit<sup>25</sup> and opening means and intended to be connected in series with a suitable short circuit protective device declared by the manufacturer. This protective device must comply with one or more relevant standards<sup>26</sup>. (This AFDD design does not include any protective device.)

On the other hand, there are AFDDs as one single device comprising an AFD unit integrated in a protective device complying with one or several relevant standards<sup>27</sup>. This includes e.g. arc fault detection devices which are supplied by the manufacturer as a residual current operated circuit-breakers with integral overcurrent protection with an integrated AFD unit.

Moreover, there are AFDDs comprised of an AFD unit and a declared protective device, intended to be assembled on site<sup>28</sup>. Residual current protection switches, combined residual current protection switches/circuit breakers or circuit breakers may be used as protective devices.

Depending on the design, the current is disconnected either by disconnection devices or by protective devices which include an AFD unit, or by protective devices which are combined with an AFD unit.

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<sup>23</sup> In German speaking countries, these protection devices are often also referred to as AFDD according to their English abbreviation.

<sup>24</sup> Definition according to EN 62606:2013, section 3.3

<sup>25</sup> The AFD unit is part of the AFDD ensuring the function of detection and discrimination of dangerous earth, parallel and series arc faults and initiating the operation of the device to cause interruption of the current.

<sup>26</sup> EN 60898-1, EN 61009-1, IEC 60269

<sup>27</sup> EN 60898-1, EN 61008-1, EN 61009-1 or EN 62423

<sup>28</sup> The requirements of EN 62606:2013, appendix D are applicable to these arc fault detection devices.

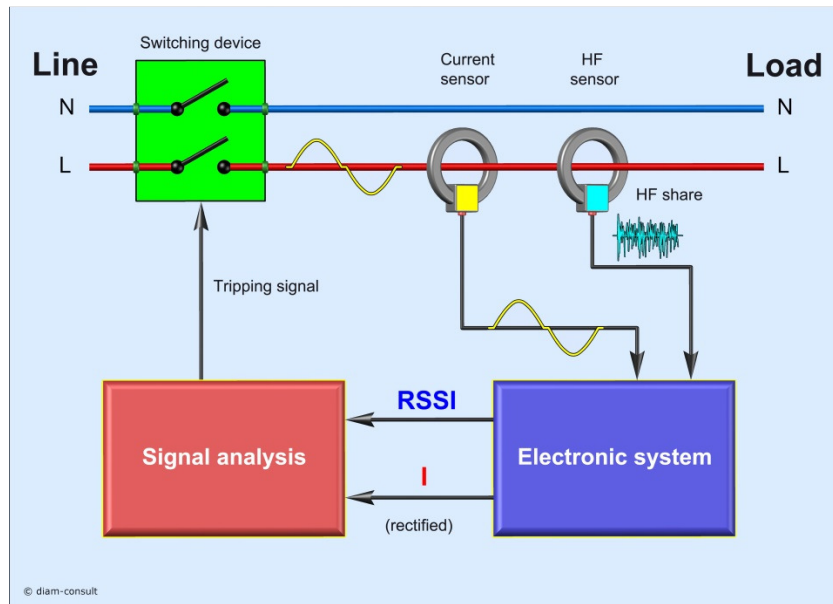


Figure 4-3 Arc fault detection device; schematic illustration; RSSI ... Received Signal Strength Indication (HF power of the current)

The schematic illustration of the layout of an arc fault detection device<sup>29</sup> is presented in Figure 4-3.

The operating current  $I$  is measured by two separate sensors and divided into a low-frequency and a high-frequency share via an electronic system.

#### 4.4.3 Protective effect

Arc fault detection devices divide the measured current of each final circuit into a low-frequency and a high-frequency share.

These two signals are used as the basis for the electric arc identification; they are analysed by a micro controller as to whether these are characteristic HF signals of a serial or parallel electric arc, or whether it is the HF noise of an equipment such as a brush motor or an electronic transformer. In the first case, the switch-off of the affected circuit is triggered, in the latter case, it is not switched off.

Depending on the AFDD design, it is of course possible to use e.g. an RCBO<sup>30</sup> (protective device with integrated AFD unit) as switching device. Thus it is possible to provide additional protection and arc fault detection in final circuits with sockets by only one single protective device.

Arc fault detection devices are protection devices which are not to be considered as an *alternative for residual current-operated circuit breakers and/or circuit breakers for overcurrent protection*. Arc fault detection devices are not able to identify insulation defects! As an author [11] aptly described it: “The arc fault detection device (only) “waits” for the HF signals from a arc fault.”

The (additional) protective effect of arc fault detection devices can be clearly illustrated by comparing the current-time-(half-cycle) diagrams of overcurrent protection devices and arc fault detection devices (Figure 4-4).

<sup>29</sup> The illustration is based on ideas from [25].

<sup>30</sup> Residual current operated circuit-breaker with integral overcurrent protection

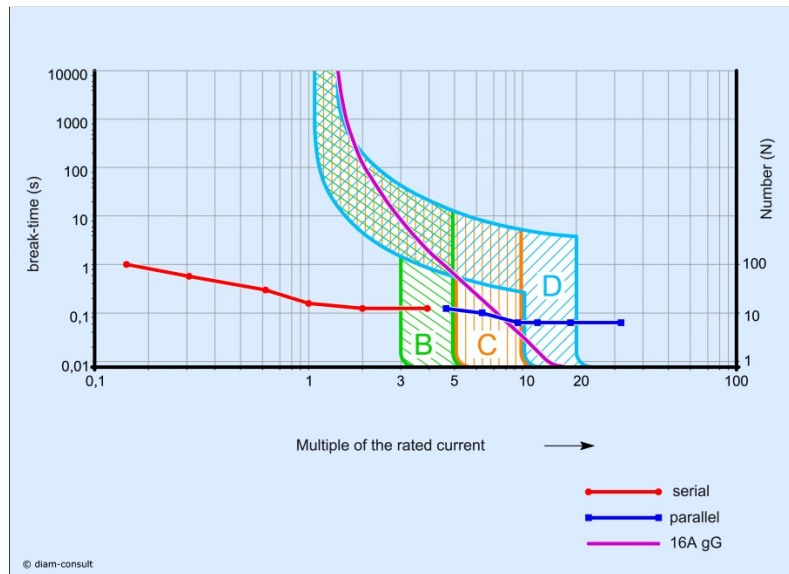


Figure 4-4 Current-time-half-cycle diagram of overcurrent protection devices and arc fault detection devices, schematic illustration; 16A fuse, gG, circuit breaker for overcurrent protection B, C, D; AFDD with characteristics for serial and parallel arc faults

The tripping characteristic of arc fault detection devices is defined for electric arc currents up to 63 A (typical for insulation errors of external conductors against earth or for occurring serial electric arcs) and more up to 500 A (typical for insulation errors of external conductors against earth or for occurring parallel electric arcs) (Table 4-1, Table 4-2).

For low currents, the tripping characteristic for parallel arc faults is identical to that for serial arc faults and is thus below the tripping characteristic of overcurrent protection devices. For high arc currents, [10] does not define a fixed tripping time but a number of arc fault half-cycles (N) which may occur within 0.5 sec. The arc fault detection device must switch off the arc fault if the number of electric arc half-cycles as defined in Table 4-2 occur within a period of 0.5 sec.

Arc current (r.m.s value) (A)	2.5	5	10	16	32	63
Maximum break-time (sec)	1	0.5	0.25	0.15	0.12	0.12

Table 4-1 Limit values of break-time for arc fault detection devices for low arc currents;  $U_N = 230\text{ V}$ ; taken from [10]

Arc current (r.m.s value) (A)	75	100	150	200	300	500
Number of half-cycles (N)	12	10	8	8	8	8

Table 4-2 Number of half-cycles for arc fault detection devices for high arc currents;  $U_N = 230\text{ V}$ ; taken from [10]

For serial electric arcs, the tripping time is significantly below every tripping time of circuit breakers for overcurrent protection.

#### 4.4.4 Installation of arc fault detection devices

Arc fault detection devices (product requirements see [10]) must be installed according to the manufacturer’s instructions at the beginning of the final circuit to be protected.

The standard requirements for the operation of AFDD must be complied with. If the manufacturer did not specify any requirements, the requirements according to Table 4-3 are applicable.

Influencing quantity	Standard range of the application	Reference value	Test tolerances <sup>f)</sup>
Ambient temperature <sup>a)g)</sup>	- 5 °C to + 40 °C <sup>b)</sup>	20 °C	± 5 °C
Altitude	Not exceeding 2000 m		
Relative humidity maximum value 40 °C	50 % <sup>c)</sup>		
External magnetic field	Not exceeding 5 times the earth's magnetic field in any direction	Earth's magnetic field	<sup>d)</sup>
Position	As stated by the manufacturer with a deviation of 2° in any direction <sup>e)</sup>	As stated by the manufacturer	2° in any direction
Frequency	Reference value ± 5 % <sup>f)</sup>	Rated value	± 2 %
Sinusoidal wave distortion	Not exceeding 5 %	Zero	5 %
<p>a) The maximum value of the mean daily temperature is 35 °C.</p> <p>b) Values outside the range are admissible when more severe climatic conditions prevail, subject to agreement between manufacturer and user</p> <p>c) In case of lower temperature, higher relative humidity values are admissible (e.g. 90 % at 20 °C).</p> <p>d) Additional requirements may be required if the AFDD is installed in the vicinity of a strong magnetic field.</p> <p>e) When installing the device, any deformations which could impair its functionality must be avoided.</p> <p>f) The specified deviations are applicable unless otherwise defined by the manufacturer.</p> <p>g) During storage and transport, maximum values of -20 °C and +60 °C are admissible and must be taken into account for the construction of the device by the manufacturer.</p>			

Table 4-3 AFDD; standard conditions for the operation according to EN 62606:2013; [10]

For any AFDD which is provided for the combination or integration or installation with one or several protective devices with standard conditions for operation and installation which are more severe than specified in Table 4-3, the standard conditions for the operation and installation of the most severe protective device standard must be complied with.

Arc fault detection devices are installed in final circuits. Figure 4-5 illustrates an example of a design for a low voltage installation with protective earth (TN system) as a protective measure for fault protection and additional protection for circuits with socket outlets.

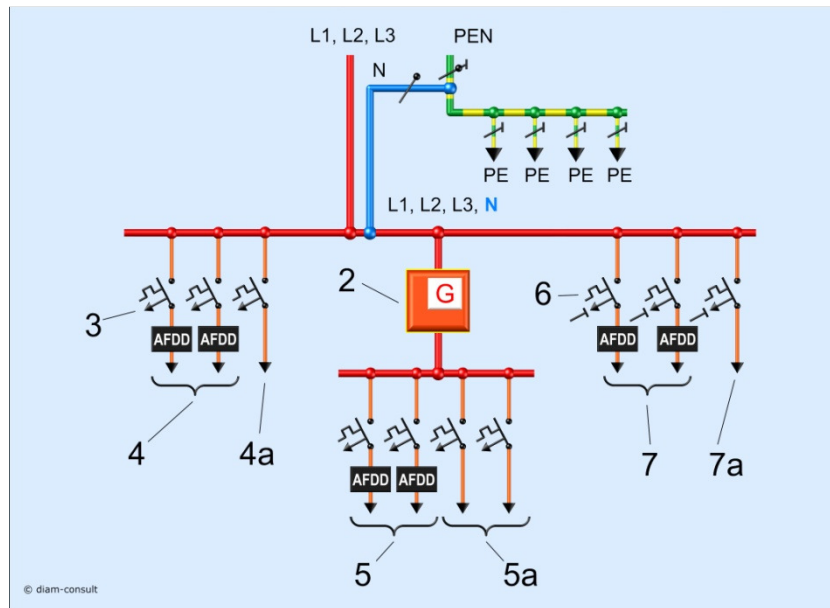


Figure 4-5 Installation of arc fault detection devices in final circuits of low voltage installations with protective earth (TN system) as a protective measure for fault protection, individual circuits with additional protection as a protective measure; example, schematic illustration

- 2 ... Type G residual current-operated circuit breaker (RCCB) according to ÖVE/ÖNORM E 8601:2015-02-01 for additional protection of circuits with socket outlets
- 3 ... Circuit breaker, also as combination of RCBO and AFDD
- 4 ... Circuits for permanently connected electrical equipment and protection with AFDD
- 4a ... Circuit for permanently connected electrical equipment
- 5 ... Circuits with socket outlets, additional protection and protection with AFDD, also as combination of RCBO and AFDD
- 5a ... Circuits with socket outlets
- 6 ... Combined circuit breaker / residual current-operated circuit breakers (RCBO) for the additional protection of circuits with socket outlets
- 7 ... Circuits with socket outlets, additional protection and protection with AFDD, also as combination of RCBO and AFDD
- 7a ... Circuits with socket outlets, additional protection

## 5 Summary

Fires caused by electricity and measures taken to avoid them are more and more the focus of national, European and international considerations with regard to protection. The installation-specific combination of the careful application of installation rules and state-of-the-art protective devices for protection against overcurrent, residual current protection and arc fault detection provides planners, installers and operators of low voltage installations with effective technical options to reduce the risk of damage to persons and property.

## 6 References

- [1] Ludwar, G., Mörx, A., Elektrotechnikrecht, Praxisorientierter Kommentar; ÖVE, FEEI, ON, Vienna 2007, ISBN: 978-3-85133-044-1
- [2] BGBl. 106/1993; Elektrotechnikgesetz 1992, BGBl. Version. I/129/2015, 6. November 2015
- [3] Henschl, T., Mörx, A.; Elektroinstallation in Gebäuden, new edition; Österreichischer Wirtschaftsverlag; 2012; ISBN 3-85212-116-5
- [4] Austrian Fire Prevention Agencies (publisher), fire damage statistics 2013
- [5] Schwenkhagen, Hans., Schnell, Paul.; Gefahrenschutz in elektrischen Anlagen; Verlag W. Girardet Essen, 1957
- [6] Hofheinz, Wolfgang; Fehlerstrom-Überwachung in elektrischen Anlagen; VDE publication series 113, VDE-Verlag GmbH., 2008
- [7] ÖVE/ÖNORM EN 50110-1 (EN 50110-2-100 incorporated):2014-10-01
- [8] Müller, Peter; Detektion von stromschwachen Störlichtbögen in Niederspannungsschaltanlagen, Dissertation Universität Stuttgart, 2014, Printed by Druckerei Hohlweg, 70182 Stuttgart, Germany, 2015, ISBN: 978-3-00-048762-0
- [9] Esser, W., Meyer, D.; Auslösekennlinien einstellungsspezifisch darstellen und ihr Zusammenwirken kompetent beurteilen; Moeller GmbH., Bonn, 2004
- [10] ÖVE/ÖNORM EN 62606: 2014 09 01; General requirements for arc fault detection devices
- [11] Schmucki, Josef; Schutz vor elektrisch gezündeten Bränden; Elektrotechnik 4/2015, elektrosuisse, SEV Verband für Elektro-, Energie- und Informationstechnik; CH-8320 Fehraltorf.
- [12] ÖVE/ÖNORM E 8603:2015-11-01; Zeitverzögerte Fehlerstrom-Schutzschalter des Typs M ohne eingebautem Überstromschutz zur Anwendung in Stromkreisen mit Nennströmen über 32 A, amendment of ÖVE/ÖNORM EN 61008-1
- [13] Eaton Industries (Austria) GmbH; xEffect - Schaltgeräte für industrielle Anwendungen; 2015
- [14] BGBl. 106/1993, Elektrotechnikgesetz 1992 in der Fassung BGBl. I/129/2015
- [15] Mörx, A.; Fehlerstellen in Niederspannungsanlagen und elektrische Zündung von Bränden; research protocol, diam-consult, Ingenieurbüro für Physik, Wien; 2007 (unpublished).
- [16] Mörx, A.; Brandschutz in Niederspannungsanlagen (Parts 1 to 3), elektrojournal booklets 9a, 10, 11, Österreichischer Wirtschaftsverlag, 2006
- [17] Mörx, A.; Brandschutz in Niederspannungsanlagen (Parts 4 to 6), elektrojournal booklets 3, 4, 6, Österreichischer Wirtschaftsverlag, 2008
- [18] Database of the IFS „Institut für Schadenverhütung und Schadenforschung“ der öffentlichen Versicherer e.V., Kiel; <http://www.ifs-kiel.de>; quoted in Martel, Anheuser, Hueber, Berger, Erhard; Schutz gegen parallele Störlichtbögen in Hauselektroinstallationen; VDE technical report 67; 2011
- [19] ÖVE/ÖNORM E 8001-1-23:2000-12-01; Installation of electrical systems with nominal voltages up to AC 1000V and DC 1500V, Part 1-23: Protection for Safety – Protection against thermal effects
- [20] DIN VDE 0100-420 (VDE 0100-420), February 2016; Low voltage electrical installations - Part 4-42: Protection for safety – Protection against thermal effects
- [21] HD 60364-4-42:2011 + A1:2015; Low-voltage electrical installations - Part 4-42: Protection for safety – Protection against thermal effects
- [22] IEC 60364-4-42:2010 + A1:2014; Low-voltage electrical installations - Part 4-42: Protection for safety - Protection against thermal effects

- [23] EN 50110-1:2013; Operation of electrical installations– Part 1: General Requirements
- [24] Mörx, A., Störlichtbogen in Niederspannungs-Schaltgerätekombinationen, Gefährdungsbeurteilung gemäß EN 50110-1:2014;  
[http://www.diamcons.com/images/stories/kostenlose\\_publicationen/0162\\_09\\_DACH\\_2016\\_Diskussionsbeitrag\\_Moerx\\_AT\\_V\\_03.pdf](http://www.diamcons.com/images/stories/kostenlose_publicationen/0162_09_DACH_2016_Diskussionsbeitrag_Moerx_AT_V_03.pdf)
- [25] Martel, Anheuser, Hueber, Berger, Erhard; Schutz gegen parallele Störlichtbögen in Hauselektroinstallationen; VDE technical report 67; 2011
- [26] ÖVE/ÖNORM E 8601:2015-02-01; Short time-delayed residual current-operated circuit breakers, Type G without and with overcurrent protection, supplement to ÖVE/ÖNORM EN 61008-1 and ÖVE/ÖNORM EN 61009-1
- [27] ÖVE/ÖNORM E 8001-1:2010-03-01; Erection of electrical installations with rated voltages up to AC 1000 V and DC 1500 V - Part 1: Definitions and measures against electrical shock
- [28] ÖVE/ÖNORM EN 61008-1:2015-12-01; Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCBs), Part 1: General rules
- [29] ÖVE/ÖNORM EN 61009-1:2015-12-01; Residual current operated circuit breakers with integral overcurrent protection for household and similar uses (RCCBs), Part 1: General rules

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Printed in Austria  
Publication No. BR003011EN  
Article number 188247-MK  
February 2018  
Graphics: SRA, Schrems

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