PROTECTION AGAINST ARC FAULTS

AFDD Technical Guide

Arc fault phenomena and functioning of AFDDs

- Complete protection against arc faults , overcurrent and earth faults
- Easy cross-wiring and installation
- Supply possible both from top and bottom side
- Family feeling in the System pro *M* compact® range
- LED for an easy troubleshooting of the network

AFDD Technical Guide
Arc fault phenomena and functioning of AFDDs

A wide range of ABB Low-Voltage DIN Rail products for electrical distribution supports users in terms of protection, measurement and control, while at the same time providing the highest standards of reliability, quality and safety in residential, commercial and industrial buildings.

Early detection of arc faults in the electrical installation can contribute to fire protection in residential and commercial installations, resulting in additional safety for people and valuable assets. Compliant with the international product standard "IEC 62606 – General Requirements for Arc Fault Detection Devices", ABB's AFDDs mitigate the risks of fires caused by faulty electrical installations.

The following guide will help application users to understand the physical phenomenon of an electrical arc, the functioning of the devices, the main features and benefits.

Table of contents

Definitions, Expressions, Abbreviation

AFDD	Arc Fault Detection Device
AFCI	Arc Fault Circuit Interrupter
MCB	Miniature Circuit Breaker
RCBO	Residual current operated Circuit-Breaker with Overcurrent protection
RCCB	Residual Current Circuit Breaker
RCD	Residual Current Device
SPD	Surge Protection Device
POP	Power frequency Overvoltage Protection

Introduction

The first Arc Fault Circuit Interrupter (AFCI) has been patented in 1980 in the United States. AFCI is a device designed to detect electric arc faults which was prescribed for use by the National Electric Code (NEC, US Wiring Regulation) in January 2008.

In particular, it prescribed the use of AFCI devices to protect all circuits from 15 / 20 A in some rooms of residential dwellings. The NEC describes it as 'A device intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected.'

At the beginning of 2012 the Arc Fault Detection Device (AFDD) began to be introduced into the IEC world, culminating in the publication of Technical Product Standards IEC 62606 in August 2013, which sets out the requirements for arc fault protection devices.

Fires

Phenomenology

Fire is the rapid and uncontrolled oxidation of material in the exothermic chemical process of combustion, which releases heat, light, and various reaction products. It requires three basic elements: something combustible (flammable), oxygen, and a suitable temperature. The different phases of a fire are shown below in Figure 1. Three minutes is all it takes for a fire to involve an entire room, because today we use more flammable materials than in the past. In the first ignition stage, vapors from combustible substances begin the combustion process, which is easily controllable. During the propagation phase, heat feeds the fire and determines a slow rise in temperature, and the emission of fumes. At this step the fire is not yet fully developed, but must be managed to avoid flashover. At that stage, there is a sudden rise in temperature and an increase in the amount of material involved in the combustion. The fire in fact reaches very high temperatures (exceeding even 1.000 °C) and combustion becomes uncontrollable as long as there is fuel and oxygen, before it finally reaches the extinction phase. It is therefore essential to control the fire before it reaches the flashover stage.

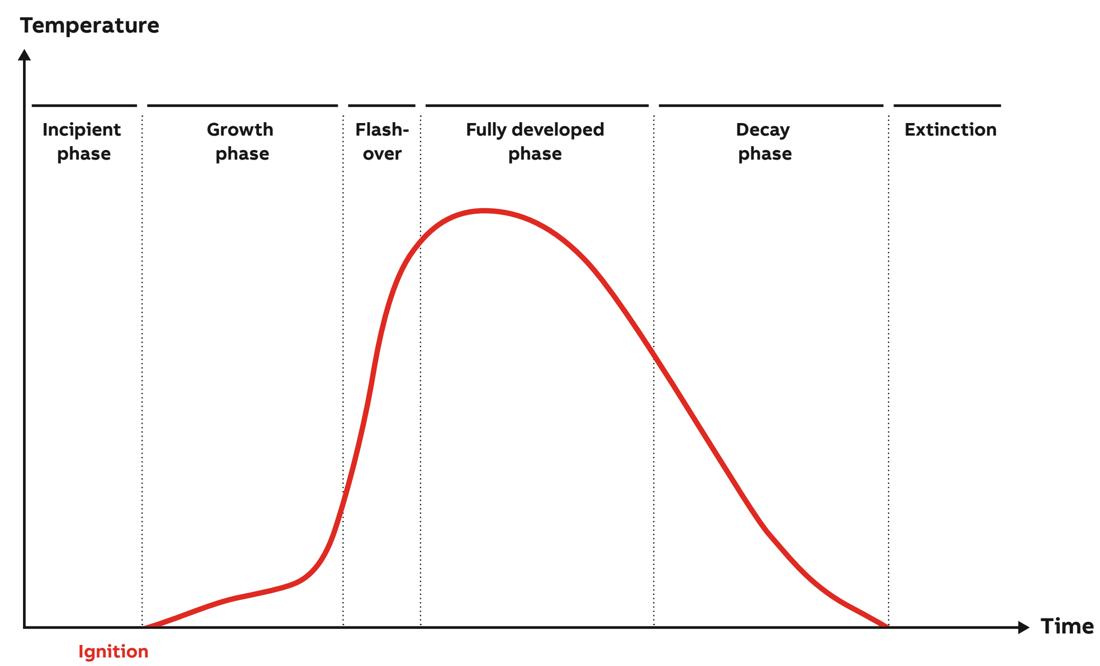


Fig. 1: Fire phases

Causes and statistics

More than 2,000,000 fires of various types are reported in Europe each year; on average, 90 % of them happen in buildings. Fires cause about 4,000 deaths each year in Europe, or around 11 per day, and send 70,000 people to hospital with severe injuries. (Source: firesafeeurope.eu)

Figure 2 shows the causes of fires in Germany (Source: 2016 IFS-ev.org): the largest number of fires (31.7%) were caused by electrical problems, particularly in residential environments. In 2015, electricity was the cause of damage in 230,000 fires (Source: GDV), as well as 343 deaths from exposure to smoke, fire and flames, and another 77 deaths from lethal contact with electricity. (Source: destatis.de)

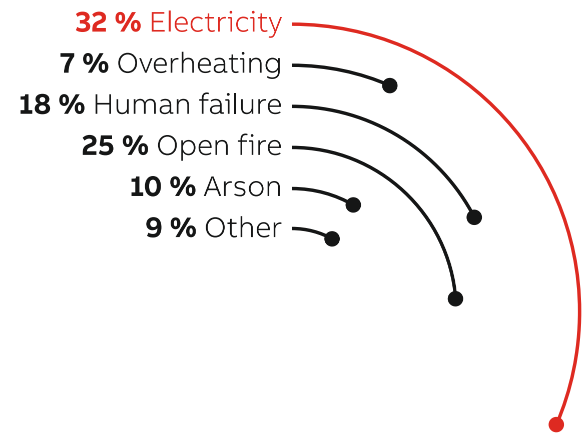
Faults in the electrical installations are the main cause of electrical fires, including:

Short circuits occur when two conductors come into contact and quickly create a high current draw that results in an explosion of the conductors, which can then ignite any nearby combustible materials.

Overload occurs when an electric circuit carries more current than it is designed to handle. An overheated conductor can damage its insulation and cause a fire by igniting any nearby combustible materials.

Transient overvoltages, or surges, related to lightning strikes cause the instant deterioration of certain loads, and can potentially start a fire.

Fig 2: Causes of fire in Germany (2015)



Overvoltages of long duration (from several seconds to several minutes) are voltages that may not be high but are long enough in duration to cause certain components in electrical equipment to overheat and even catch fire, if they have not been sized correctly to operate under such conditions. These overvoltages may be caused by faults in the supply network (break in neutral conductor, short-circuit to earth of high voltage network cable).

Damage to the insulation is an issue. New insulating material has very high surface resistivity to prevent the flow of tracking currents, but over time pollution leads to material deposits such as dust, various types of soiling, etc. If these deposits also absorb humidity they can turn the surface of the insulation into a conductor. If deposits remain dry surface resistivity remains very high, so there is no danger from tracking currents. But when the surface of the material dries, micro-arcs may appear locally (flickering), deteriorating the insulating material and producing local carbon deposits, which increase tracking current. If the current exceeds 300 mA, surface heating and the sparks produced are enough to ignite the carbon deposits. In some cases, current can flow through the PE conductor and be detected by a residual current device. Otherwise, a specific device such as an arc fault detector is necessary.

Non-compliant installations in old buildings such as improper use of multisocket adapters and extension cords is also an issue. Currently available protection devices, such as Miniature Circuit Breakers (MCB) and Residual Current Devices (RCD), Surge Protection Device (SPD), Power frequency Overvoltage Protection (POP) are able to guarantee effective tripping for overcurrents, leakage currents and overvoltages respectively. Damage to the insulation and non-conforming installations can cause an arc (also without the presence of the leakage current), which needs to be protected specifically by an arc fault device.

Electric Arc

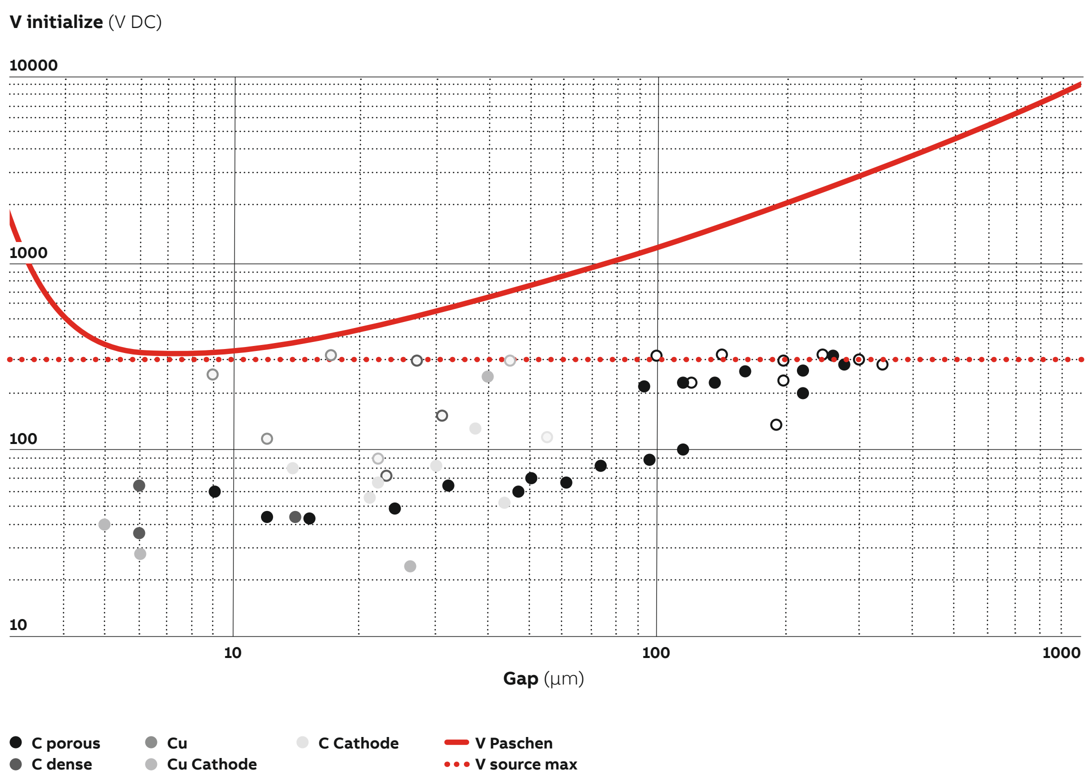
Phenomenology and structure

"Contact arcs" are generally related to two conductive parts at different voltages placed in direct or indirect contact through low conductive paths. For example, the conductive parts in this case can be the metal contacts of a switch. Furthermore, the arc fault constitutes an example of a fault characterized by an impedance different from zero, and not negligible. There could be two different types:

- **Parallel arc fault** – insulation breakdown between the conductive parts that are normally isolated
- **Serial arc fault** – the partial disruption and unintended release of an active conductor not normally interrupted

In the first instance, the arc is mainly composed of metallic vapors (primarily carbon) released by the contacts. The arc environment will be enriched by ionized particles as a result of collisions between them and the thermal regime instituted. Arc development is related to the voltage and distance between the two contacts, which is shown by the "Paschen Curve." This curve provides the trigger voltage in an ionized gas that is a function of the multiplication between the pressure and distance between the conductors. For example, as shown in Figure 3, it is obtained by the minimum breakdown voltage (to 101 kPa and for a distance of 7.5 µm) equal to 327 V DC, considering the air between the two conductors.

Fig. 3: Paschen Curve for air and other gasses



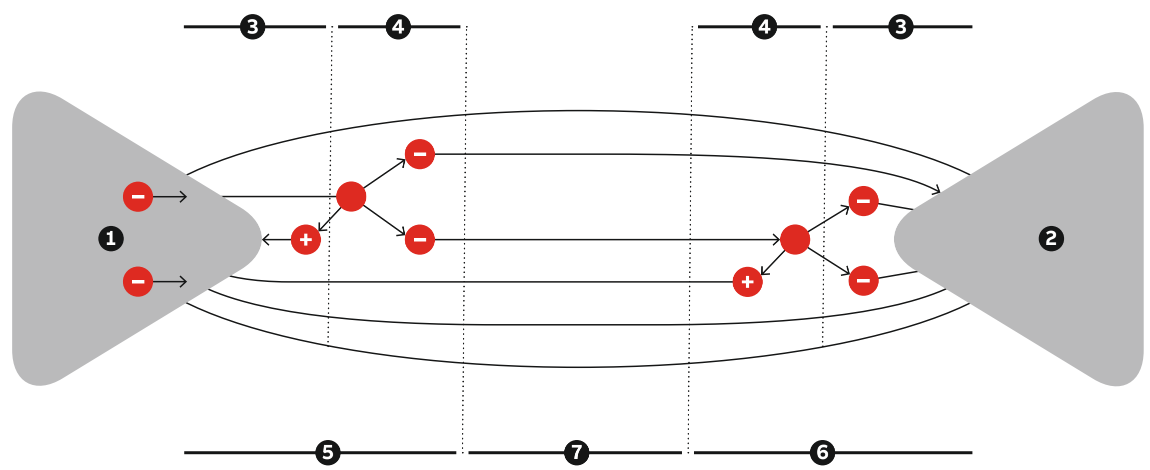
This might suggest that in a low-voltage circuit it would be impossible to start an electric arc at 230 V. However, it has been shown that the presence of carbon particles released as a result of the insulation melting process lowers the threshold, and consequently increases the possibility of arcing.

In fact, a damaged conductor could facilitate the creation of electrical arcs between the initial merged contacts. Considering this example, current flows through the damaged section, and as a result current density tends to increase. The increased heat in the affected area by the Joule effect starts overheating the insulation. The copper at this point oxidizes and subsequently merges, and starts to carbonize the insulation. Thus, an air gap condition between the two conductors exists, and small arcs begin to appear in the insulation.

The arc's physical structure is in general divided into three parts, as shown in Figure 4.

The extensions of the cathodic and anodic areas are reduced, while the positive column includes almost all of the electric arc length. In particular, the cathode area is in direct contact with the electrode at negative potential (cathode) and the anode with the one at positive potential (anode). Both are characterized by a transition zone, with the positive column (neutral zone) and a longer area in contact with the electrode called "sector of the space charge". In particular, the part adjacent to the cathode is characterized by a prevalence of positive ions, while the same adjacent to the anode by a prevalence of electrons.

Fig. 4: Electrical arc structure



1. Cathode
2. Anode
3. Sector of space charge
4. Transition sector
5. Cathodic zone
6. Anodic zone
7. Positive column

Waveforms and arc stability

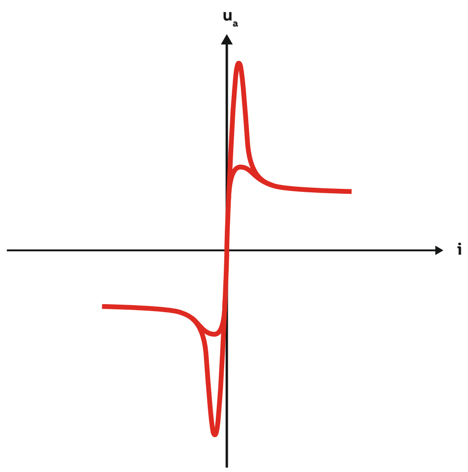


Fig. 5: Arc characteristic in sinusoidal steady state

An arc can be represented with a characteristic curve (voltage current), which shows the values of voltage required to sustain the arc to vary its current. A sinusoidal steady state arc characteristic assumes both positive and negative values as shown in Figure 5, where Ua is arc voltage, and I is current.

In particular, the first quadrant curve (corresponding to positive current values) at first increases and then decreases. This is mirrored in the third quadrant. The connecting portions between the curves of the two quadrants correspond to instants when the current reverses the sign. The arc current is also different from the ideal sinusoidal current. As shown in Figure 6, it assumes a shape with the "shoulders" at zero crossing the ideal current waveform. This is mainly because the power supply is unable to support the arch for those brief moments. The current and arc voltage waveform charts depicting a resistive load are also represented in Figures 6 and 7.

From the previous waveforms it is possible to see that the sinusoidal nature of the supply circuit is reflected in the arc characteristic at the zero crossing of both voltage and current, with consequences in terms of switching off and possible restrike.

Fig. 6: Differences between sinusoidal current and arc current (at 60 Hz frequency)

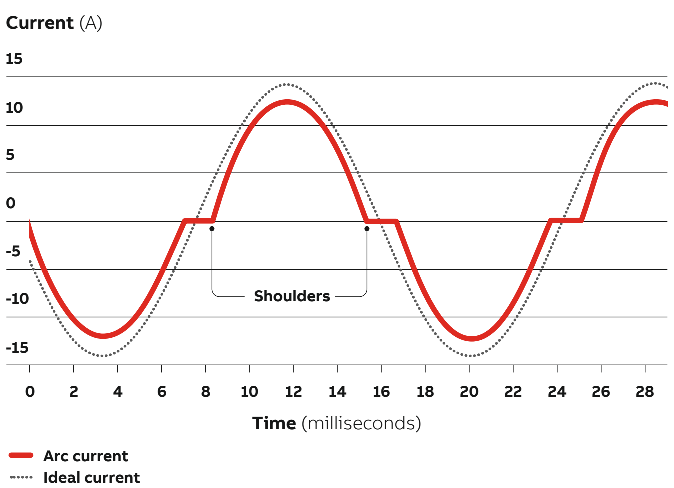


Fig. 7: Voltage and current arc waveforms (at 60 Hz frequency)

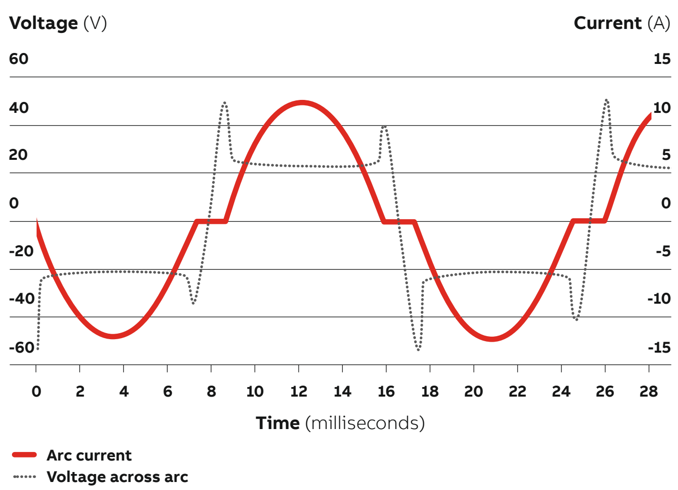


Fig. 8: Arc current in case of 115 V rms (top) **230 V rms circuit** (bottom)

It is generally difficult to predict the probability that an arc has formed, and its intensity, waveform and capacity to cause a fire depends on many variable factors, such as:

- voltage between the conductive parts
- distance between the conductive parts,
- electrical load (if any) in serial, or in parallel with the load
- local heat dissipation conditions
- adjacent materials that can combust, carbonize, or release combustible gases

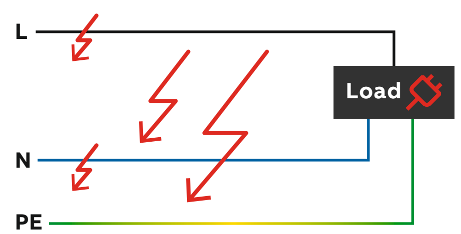
In particular, arc stability is widely enabled by increasing the voltage level (and thus the current). Consider for example two different levels of voltage – 115 Vrms and 230 Vrms. The arc current in the case of 230 Vrms increases more in comparison to 115 Vrms (see Figure 8), causing a higher thermionic emission of electrons and greater possibility of restrike after the zero crossing.

Protection devices and arc faults

Faults classification

Faults resulting from an electric arc generally involve at least one active conductor. The load mass is also always ground connected, which may be common (TN system) or independent from the transformer substation (TT or IT systems). The presence of the protective conductor PE is a necessary constraint for each system considered. Series arc faults between neutral and PE are omitted, as the current and voltage are not high enough to verify the presence of an arc. Assuming the exclusion of cases in which the neutral is shared, or is in common with a protective conductor PE, faults can be represented as in Figure 9.

Fig. 9: Faults in a generic distribution circuit



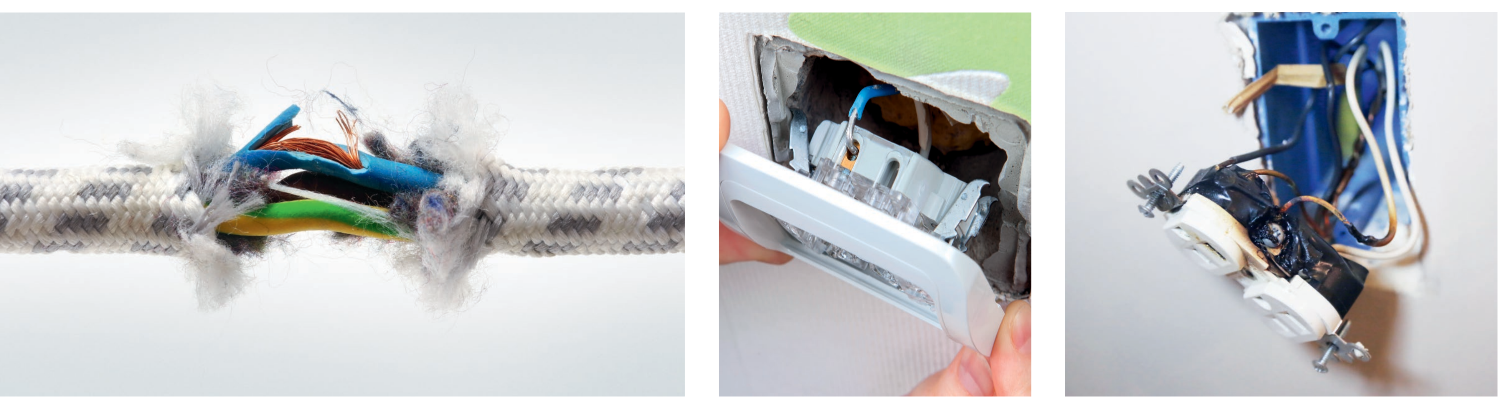
Parallel arc faults

In general, a parallel arc current is more intense than the typical currents used in domestic circuits. In fact, if the arc is in parallel with the load, the total circuit current will increase, typically from 50 A to the short circuit current. Generally the short circuit current value is not reached since it is characterized by negligible impedance. Thus, within limits, parallel arcs can also be detected and interrupted by standard overcurrent protection devices, such as MCBs, RCBOs and fuses. Normally they are caused by insulation failure, mechanical or accidental interference with conductive parts causing damage, as shown in Figures 10:

The following are some possible parallel arc fault situations:

- Line conductor L and neutral conductor N. Residual Current Devices (RCDs) cannot trip since the fault is not affected by a leakage current that flows through the ground conductor PE. MCBs, RCBOs and the fuses can trip only if their intervention time and current curves are compatible with the values of the current parallel arc fault. In fact, the parallel arc impedances may decrease current values, limiting MCBs and RCBOs functionality. ABB AFDDs of S-ARC1 and DS-ARC1 series are able to detect parallel arc faults and interrupt he circuit.

Fig. 10: Possible causes of parallel arc faults



- Line conductor L and ground conductor PE (earth arc fault). Fault current flows through the electric arc between the phase conductor and the ground (PE), or because of leakage current. In this case, RCCBs and RCBOs may ensure proper tripping based on their responsiveness, and also provide protection in the event of fire with sensitivity at or below 300 mA. MCBs and fuses are not able to trip, because the fault current value is in general rather low, especially in distribution TT systems. ABB AFDDs of S-ARC1 and DS-ARC1 series are able to detect parallel arc faults and interrupt the circuit.

Series arc faults

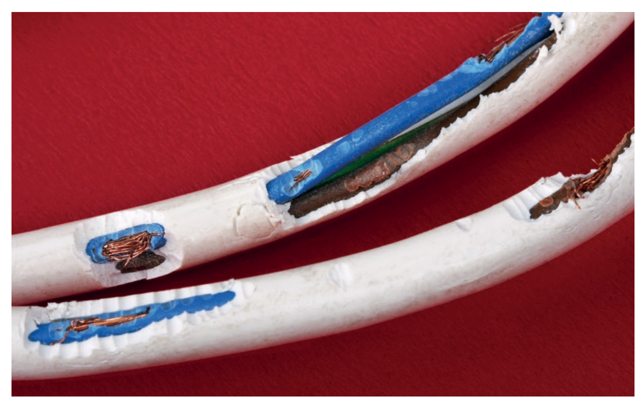
Series arc faults with a load resistor are localized along the conductor and may cause local overheating. Fault current is limited by the load, and it is therefore lower than the one of a parallel arc, but it can still start a fire because of high arc temperatures. However, series arcs are harder to be detected because their current value is lower than operational values, and a more sophisticated analysis of the fault waveform is required.

Causes might include a lack of conductor continuity (see Figure 11), which alternates states of complete contact interruption (false contacts), or high-resistance conductor states. It is also caused by defective switches (which do not properly close the poles); with terminals that are not tight; light bulbs that are not well tightened; and partially broken or poorly spliced cables.

Series arc fault currents can vary between less than 2.5 A (for 230 V AC circuits) up to normal operational domestic circuit currents. Furthermore, the total series impedance of the circuit tends to increase. MCBs, RCCBs, RCBOs are not able to detect this fault.

ABB AFDDs of S-ARC1 and DS-ARC1 series provide a complete protection also against series arc faults.

Fig. 11: Possible causes of series arc faults



Overview of protection devices

The concept of a protection device designed with the intention of detecting electric arc faults to mitigate the risk of fire was introduced in United States starting from 1980. In the USA, after some years fire protection became mandatory in all residential buildings with the installation of an AFCI, according to the product standard UL 1699.

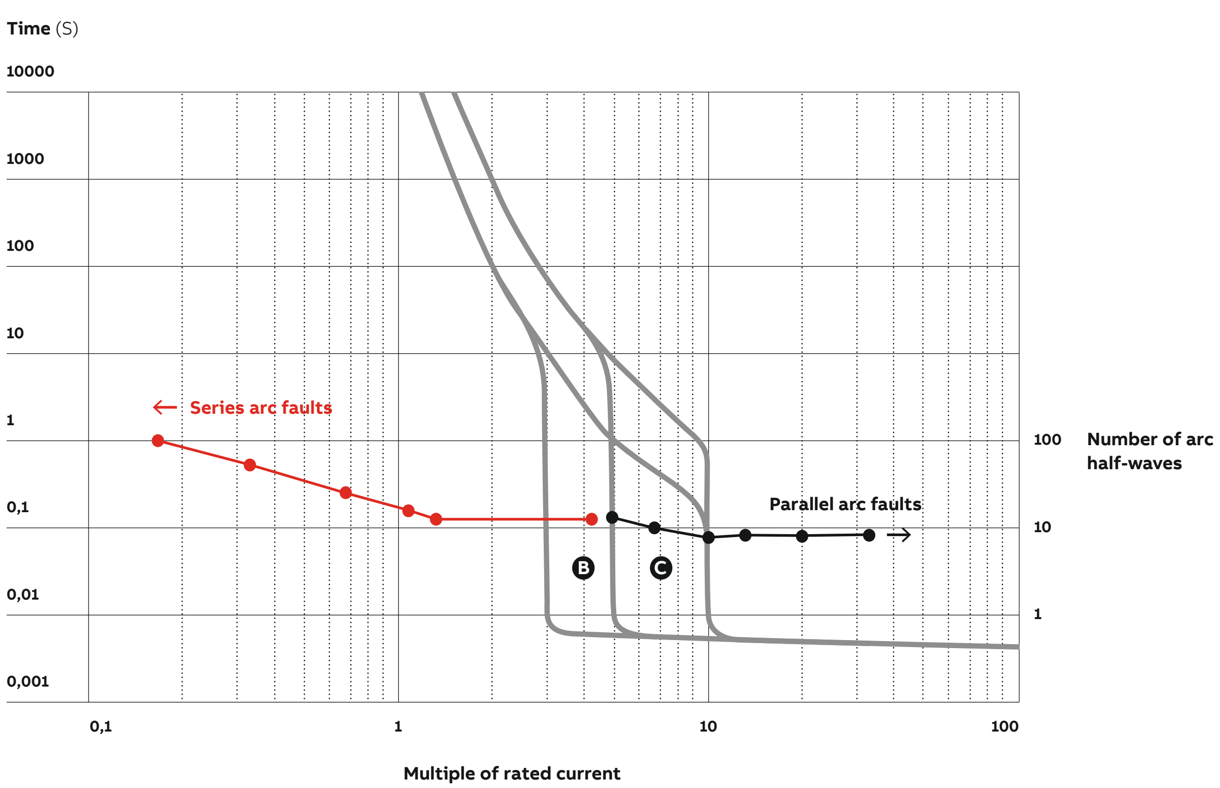
At the beginning of 2012 the concept of Arc Fault Detection Device (AFDD) was introduced into the IEC world, culminating in the publication of Technical Product Standards IEC 62606 in August 2013, which sets out the requirements for arc fault protection devices to mitigate the risk of fire.

As shown in Figure 12, an AFDD is providing protection against series and parallel arc faults which can occur outside of the tripping time area of standard MCBs (or RCBOs).
It is possible to identify three predominate areas:

- zone for currents lower than the rated current, characterized by high impedance faults (series arc) and normal operating currents. They are weak faults or series arcs similar to typical values of normal operating currents. These currents are absolutely undetectable for MCBs, while RCDs can detect them only in case of leakage current flowing to ground. An AFDD is able to interrupt the circuit in case of a series arc within the time described in the product standard IEC 62606 according to table 1 (reported here on page 19).
- zone for currents between the rated current and magnetic trip threshold (below the overload characteristic) are characterized by "weak" faults, in general typical of parallel arcs. In this area, in general, faults have values close to overload currents, and can be detected by MCBs according to their time/current curve. RCDs could detect these faults only in case of leakage current flowing to ground.
  As the fire risk is relatively high, with the installation of an AFDD, the fault can be detected faster than with an MCB (that interrupts the circuit in accordance to its tripping time characteristic). In this case the intervention time is not assigned to an AFDD, but the maximum number of half-waves affected by arc in 0.5 sec is considered, as described in the product standard IEC 62606 according to table 2 (reported here on page 19).
- zone for currents greater than or equal than the magnetic trip threshold are characterized by no impedance faults (short circuit), which can be detected and stopped immediately by MCBs, RCBOs or fuses. There is no risk of failure with these devices.

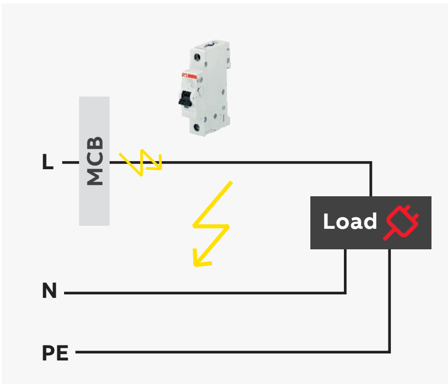
For complete protection against series, parallel and earth arc faults, an AFDD must be installed. Figure 13 shows the different level of protection provided by different devices.

Fig. 12:
Protection curve for AFDD and overcurrent protection devices according to standards IEC 62606 and 60898-1.



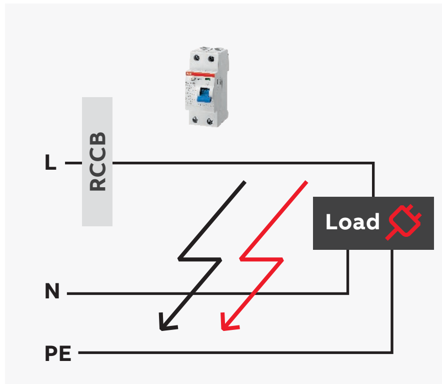
Overview of protection devices

01 MCB



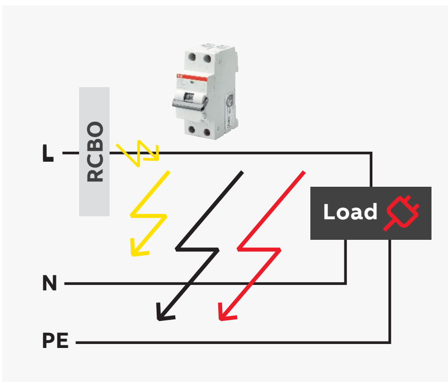
Protection against:
- Overcurrent (short circuits, overload)

02 RCCB



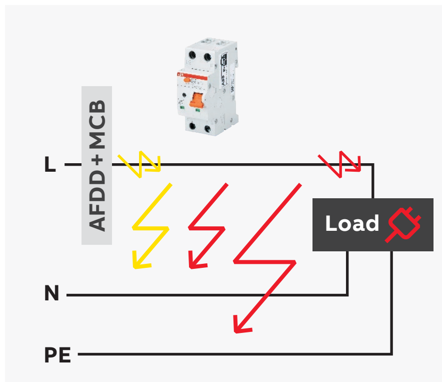
Protection against:
- Earth faults currents
- Earth arc fault

03 RCBO



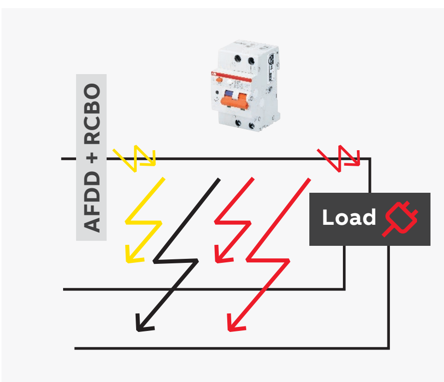
Protection against:
- Overcurrent (short circuits, overload)
- Earth fault currents
- Earth arc fault

04 S-ARC1 AFDD with integrated MCB



Protection against:
- Overcurrent (short circuits, overload)
- Series, parallel and earth arc faults

05 DS-ARC1 AFDD with integrated RCBO Maximum Protection



Protection against:
- Overcurrent (short circuits, overload)
- Earth fault currents
- Series, parallel and earth arc faults

Fig. 13: Overview of protection devices

Operational function of S-ARC1 and DS-ARC1

The basic structure of the ABB S-ARC1 and DS-ARC1 device is described in Figure 14.

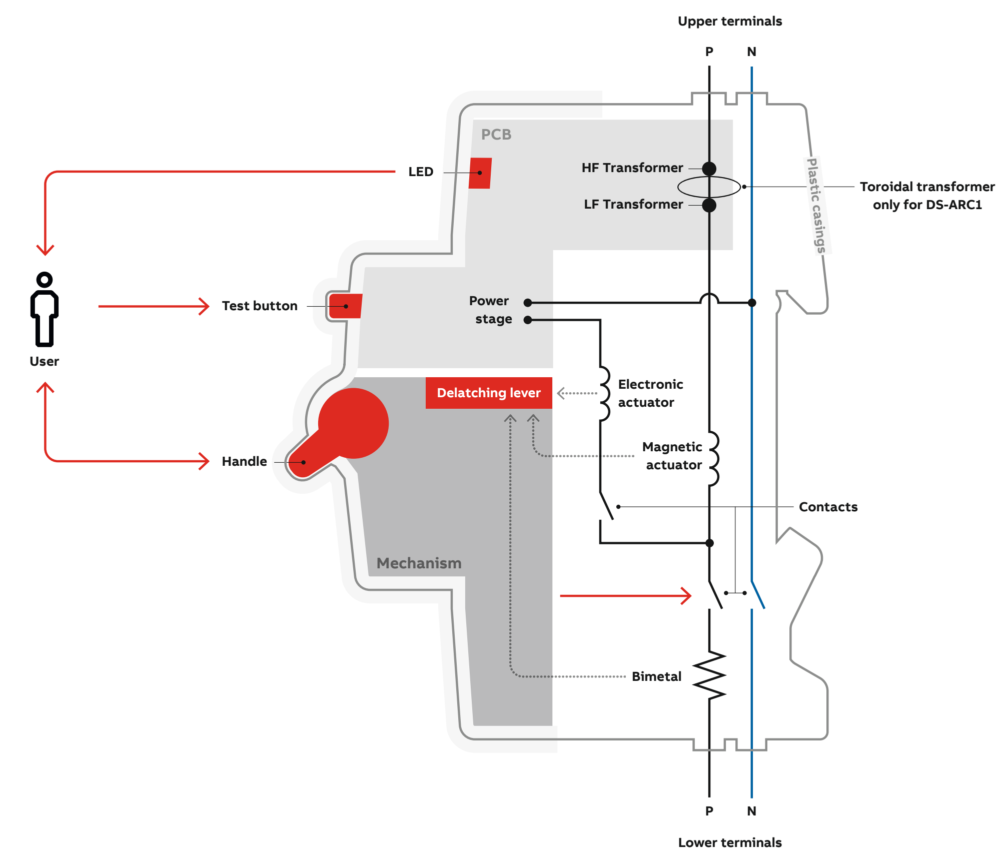
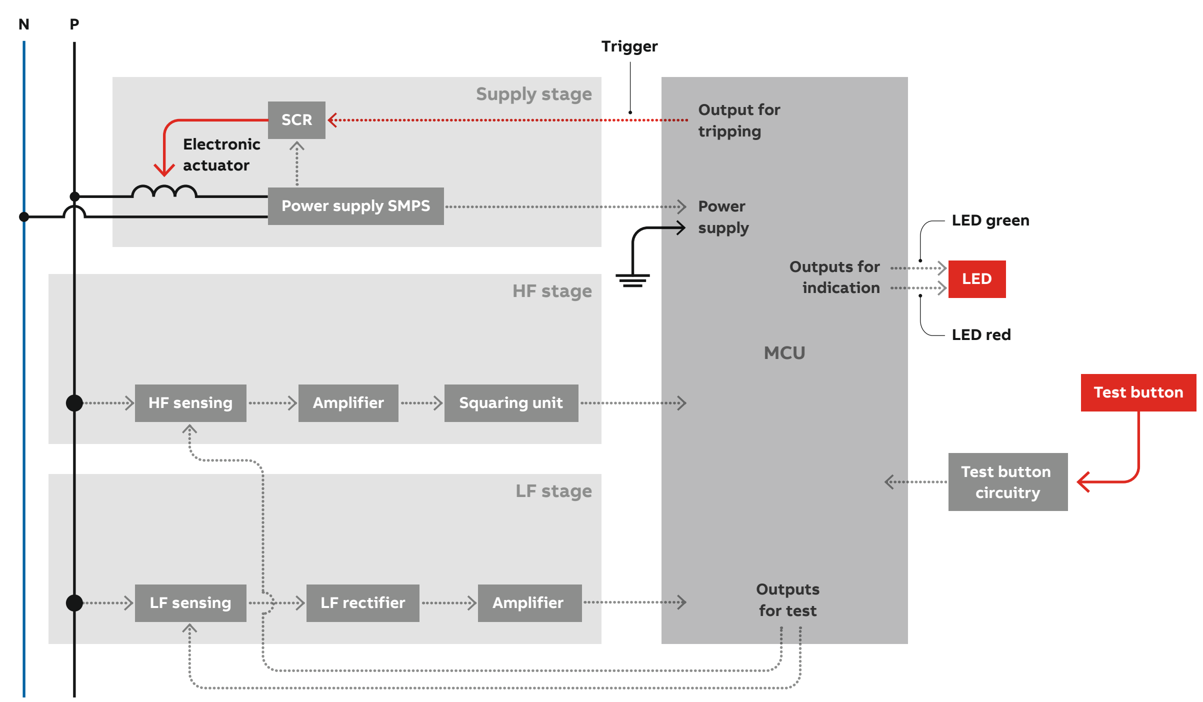


Fig. 14: Basic internal structure of S-ARC1 and DS-ARC1

Fig. 15: Basic operating mode of S-ARC1 and DS-ARC1



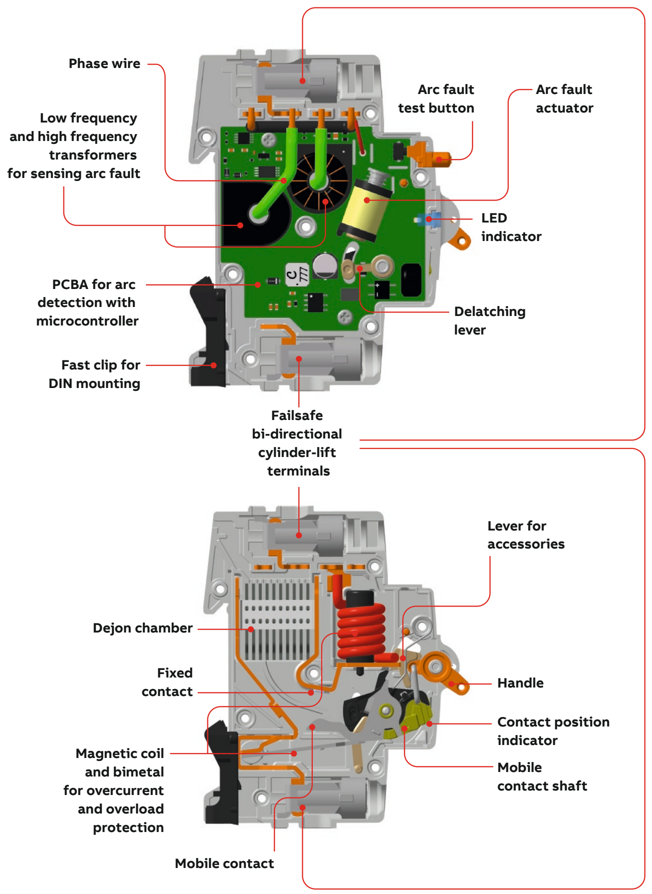
Operational function of the ABB S-ARC1 and DS-ARC1

S-ARC1 and DS-ARC1 have moveable contacts on both pole and neutral, and of two main functional groups can be identified.

- **The PCB section** (Printed Circuit Board, see also Figure 15) is sourced by a Power Supply SMPS (Switched Mode Power Supply). The S-ARC1 and DS-ARC1 are equipped with two main sensing stages to detect Low Frequency (LF) and High Frequency (HF) in a band of 10 MHz in the line current. The unit's dedicated sensors and analog circuitry handles electronic signals. A Microcontroller Unit (MCU) receives input signals from the LF and HF sensing stages and by means of appropriate algorithms continuously analyses the signals in search of unique features indicating the presence of an arc fault in the line. If an arc fault is detected, the MCU energizes an electronic actuator with a Silicon Controlled Rectifier (SCR), which trips the mechanism and opens the main contacts. This technology provides proper tripping for both series and parallel arcs, which are signaled by LED (always part of the MCU).

- **The mechanism section** includes the delatching lever, which can be actuated by the electronic actuator (MCU, in case of series and parallel arc faults); the magnetic actuator (in case of short circuits); and the bimetal (in case of overload currents) to open the main contacts. On DS-ARC1 also a toroidal transformer is present in order to detect leakage currents to ground.

Figures 16 and 17 show detailed views of the internal components of S-ARC1 and DS-ARC1, which have already been described.



—
Fig. 16 & 17: S-ARC1 and DS-ARC1 internal components

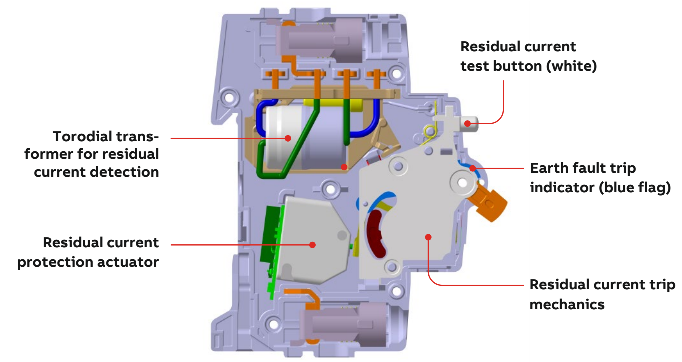
ABB's S-ARC1 and DS-ARC1 are equipped with two testing functionalities to verify the correct working conditions of the AFDD electronic circuit: an AFDD test pushbutton (orange) and an internal self-test. According to product standard IEC 62606, the device has to be equipped with at least one of these two solutions.

- **The test button** (see Figure 15) sends a signal to a MCU pin. The MCU generates electronic signals that mimic the characteristics of a real arc current at LF and HF levels. If the product is functioning correctly, the MCU arc detection routine recognizes the simulated arc and makes the device trip. When the toggle is reclosed, the LED will turn green. If there is an internal failure after pressing the test button, the breaker will not trip and the LED will start blinking red/green. A check by an electrician is required.

- **The internal self-test** involves the MCU continuously testing electronic components (i.e. analog circuitries, MCU peripherals, memory, etc.) that are crucial for arc detection. In particular, self-test routines are executed starting from power on, and throughout product run-time. If any error is detected by the internal self-test, the LED will start giving an indication with alternative green/red blinking without tripping in order to guarantee continuity of service.
In this case it is necessary to press the test button: if the device trips, it has recovered to normal behavior and the toggle can be reclosed; otherwise a check by an electrician is required

- **White test push button:** DS-ARC1 is also equipped with a white test pushbutton to be pressed every six months in order to check the RCD working conditions. The presence of this test pushbutton is mandatory according to product standard IEC 61009.

Figure 18 shows DS-ARC1 internal components for residual currents detection



—
Fig. 18: DS-ARC1 internal components

Regulatory framework

Introduction

IEC 60364 is the international reference wiring regulation for low-voltage electrical installations in buildings. As mentioned above, fires in residential buildings and other assets are mainly attributable to electrical malfunctions. The section IEC 60364-4-42, “Protection for Safety – Protection against thermal effects”, is dedicated to the protection against fires and thermal events created by malfunctions in low-voltage electrical installations.

IEC 62606, “General requirements for arc fault detection devices,” is a product standard that applies to AFDDs for household and similar uses in AC circuits.

Installation of AFDD according to IEC 60364

The use of AFDDs is currently specified in the international wiring regulation IEC 60364-4-42 “Protection for safety – Protection against thermal effects.” The amendment was published in 2014 and recommends the use of AFDDs to protect against the effects of electric arcs. The installation is recommended at the origin of final circuits in applications as:

- locations built with flammable material
- locations that contain flammable material
- rooms that have sleeping accommodation
- locations at risk of fire due to
  - processed or stored materials
  - combustible construction materials
  - fire propagating structures
- locations that contain irreplaceable goods

These applications are shown in Figure 19.

—
Fig. 19:
Possible applications for the AFDD use in buildings with flammable materials and workshops for wood processing and carpentry

Installation standard VDE 0100-420

The German wiring regulation VDE 0100-420 introduces points endorsed by IEC 60364-4-42, which became mandatory on 18/12/2017. In particular, the installation of an Arc Fault Detection Device (AFDD) is mandatory for all final circuits in single phase AC systems with less than 16 A in locations, such as:

- rooms with sleeping and living accommodations in homes and day care centers (for children, disabled and elderly), and barrier-free apartments
- locations at risk of fire due to processing or storage of materials
- combustible constructional materials
- locations that contain irreplaceable goods
- generally recommended for locations such as rooms with sleeping accommodation
- locations with fire propagating structures

Product standard IEC 62606

The reference standard for AFDD is the IEC 62606 – General requirements for Arc Faults Detection Devices – which describes the requirements and compliance tests of these devices. The Standard defines the product in the following configurations:

– As a single device, consisting of one Arc Fault Detection (AFD) unit expected to be connected in series with a suitable short circuit protection device declared by the manufacturer complaint with one or more of the following standards: IEC 60898-1, IEC 61009-1 or IEC 60269 series.

– AFDD “combined” as a single device, consisting of an Arc Fault Detection (AFD) unit integrated with a protection device in accordance with one or more of the following standards: IEC 60898-1, IEC 61008-1, IEC 61009-1 or IEC 62423.

– AFDD “assembled”, consisting of one Arc Fault Detection (AFD) unit and a declared protection device that is expected to be assembled on site.

In case of low arc current values up to 63 A, thus series arc faults, the standard defines the maximum tripping time for AFDD as shown in table 1.

Table 1:
Tripping time for low current values

Test arc current (r.m.s.values)	**2.5 A**	**5 A**	**10 A**	**16 A**	**32 A**	**63 A**
Maximum break time	1 s	0.5 s	0.25 s	0.15 s	0.12 s	0.12 s

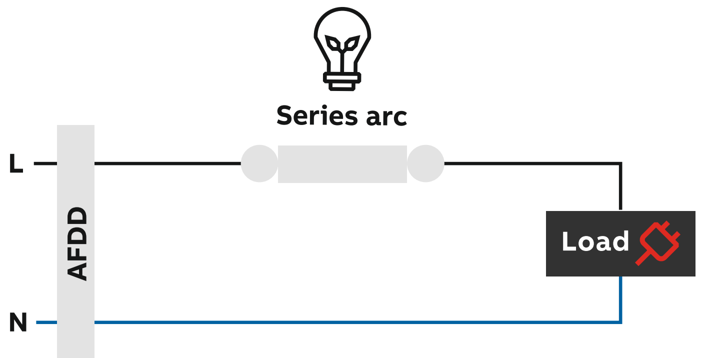
In case of high arc current values, thus parallel arc faults, the standard does not define the maximum tripping time for AFDD, but the maximum number of half-waves affected by arc in 0.5 sec., as shown in table 2. This is because parallel arc faults can sometimes occur with many missing half-waves.

Table 2:
Number of half-waveforms declared for high currents

Test arc current[a] (r.m.s.values)	**75 A**	**100 A**	**150 A**	**200 A**	**300 A**	**500 A**
N[b]	12	10	8	8	8	8

The standard also provides references for the execution of several tests, including the ones to differentiate series and parallel arcs. There are also tests to verify the correct not-trippings of the AFDD even in the presence of the current waveforms (masked) absorbed by the loads, that are very similar to arc faults current. In next pages, a short description of the different tests carried out is provided.

Fig. 20:
Cable specimen test

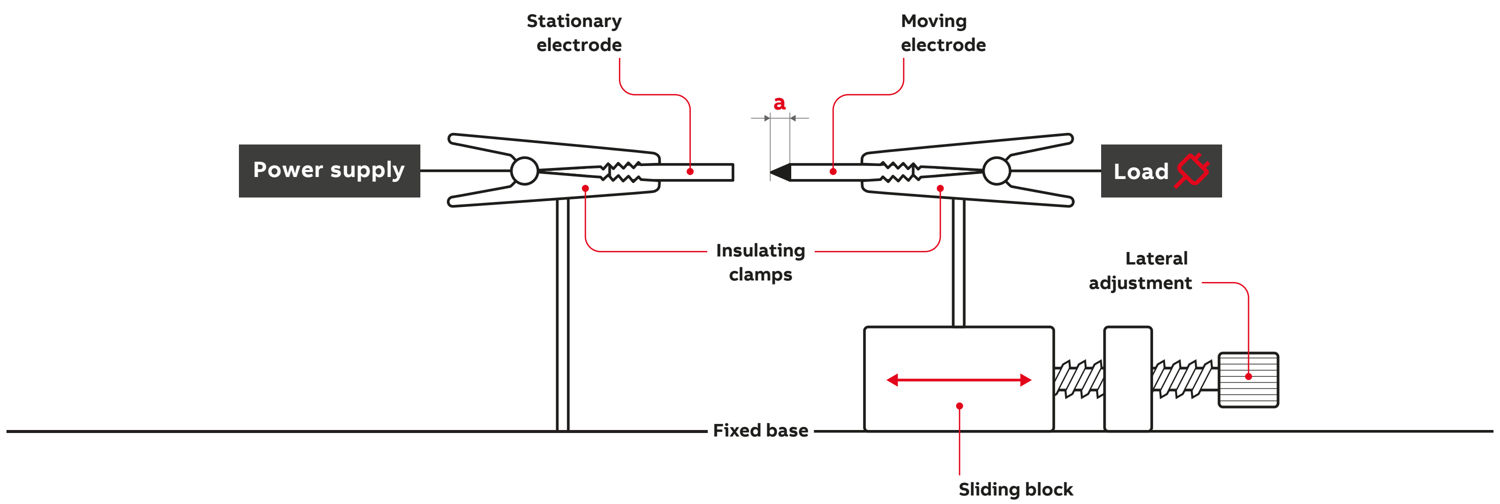


Test for the detection of series arc faults

In this test the S-ARC1 unit must trip within the timeframe specified in Table 1 (page 19), corresponding to the intensity of the arc current and considering the test voltage of 230/240 V and 50 Hz rated frequency. The test circuit (Figure 20) uses a cable specimen (by electrodes or pre-carbonized specimen) to create a stable carbonized path between phase and neutral. To verify the positive result of the test, an incandescent bulb connected in series should light up.

Another test called “arc generator” deploys an apparatus (see Figure 21) with a fixed and a movable electrode of standardized dimensions made of copper and graphite, respectively. The test is carried out starting with closed contacts, which are progressively separated to obtain a persistent arc. When the arc generator is used, the AFDD shall trip in less than 2,5 times the tripping time in Tables 1 (page 19). That’s because the arc energy resulting when arcing the carbonized path is in the range of 2,5 times the arc energy provided by the arc generator.

Fig. 21:
Arc generator test



Parallel arc test detection

The AFDD unit is able to trip for a parallel arc fault (characterized by higher currents compared to a series arc fault) if the number of half-waves in an arc period of 0,5 seconds is equal to those in table 2 (page 19). The test is performed using the circuit in Figure 22 where the impedance Z is regulated in order to obtain different test current values.
The test apparatus simulates a short circuit (with impedance different from zero due to the carbonized path), and can be:

- the same specimen cable from the series arc tests
- a “guillotine” apparatus (Figure 23) utilizing two different kinds of copper two-wire cable used in domestic environments. A conductive blade is slowly lowered and cuts the insulation, producing a zero-impedance contact with one of the two conductors, and a no zero-impedance contact on the other, resulting in the creation of an arc (continuous or intermittent).

The source voltage is equal to the AFDD rating (120, 240 V), the current (measured with a special instrument) is adjusted by acting on the upstream cable length in front of the guillotine (in this test adding resistors is not allowed). The test is positive if the AFDD trips and produces an arc of up to 8 half-cycles within 0,5 s. The test is negative if there is a period of at least 8 half-cycles within 0,5 s, but the AFDD does not trip. The test is indeterminate and must be repeated again if the AFDD does not trip within 8 half-cycles in 0,5 s. The following pictures exemplify current waveform on the guillotine current (see Figure 24). In particular, the curtain distortion increases the amplitude of the arc current.

Another test is also performed to check correct operation in the event of a parallel arc fault between the phase and PE conductor.

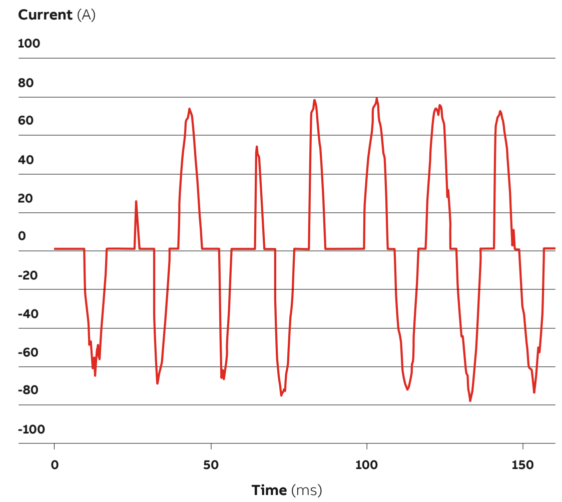


Fig. 24:
Parallel arc for guillotine test

Fig. 22:
Circuit used for parallel arc test detection

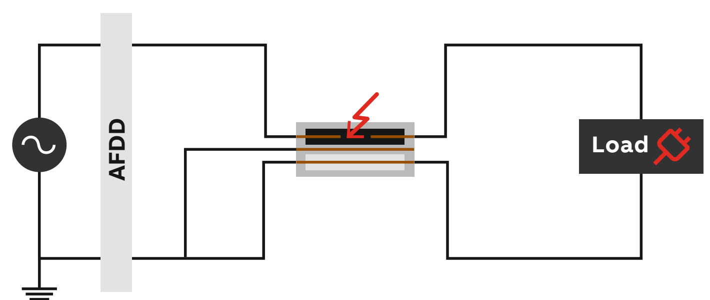
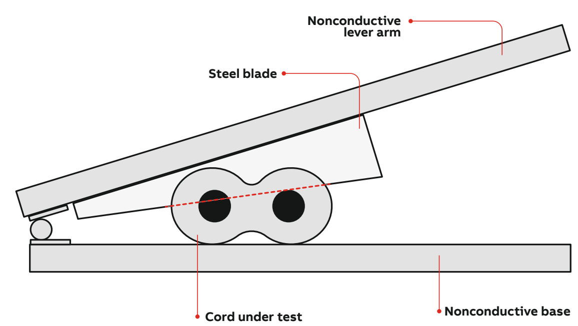


Fig. 23:
Guillotine apparatus



Masking tests and immunity tests

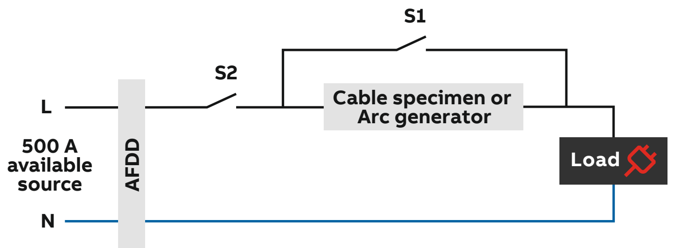
Correct AFDD operation must also be verified in cases where current waveforms (for example, absorbed by the loads) can be “confused” with waveforms typical of an arc fault (parallel or series). In particular, masking tests are done with the arc generator; immunity tests are done without the arc generator

The goal is to verify that the unit is operating effectively. The standard test done for series arc faults can be used, utilizing an arc generator or a test that determines a carbonized path to simulate the arch itself. As shown in Figure 25 the load to be considered is purely resistive, and current can be modulated by acting on it. The reference voltage usually must be equal to the AFDD rated voltage, testing three times the device to 2,5 A at 230 V, and 5 A for 120 V.

The test is performed in the presence or absence of the arc generator, and with different configurations. Listed below are loads for testing:

- vacuum cleaner
- switching power supply
- motor with starting capacitor (e.g., air compressor)
- electronic thyristor dimmer for incandescent lamps at 600 W tungsten (230 V) or 1,000 W (120 V), subjected to the specific operational cycles
- two fluorescent 40 W lamps and a resistive load that absorbs 5 A
- 12 V halogen lamps powered by an electronic transformer with a total capacity of at least 300 W with an additional resistance that absorbs 5 A
- drill at least 600 W

Fig. 25:
Immunity/Masking test circuit



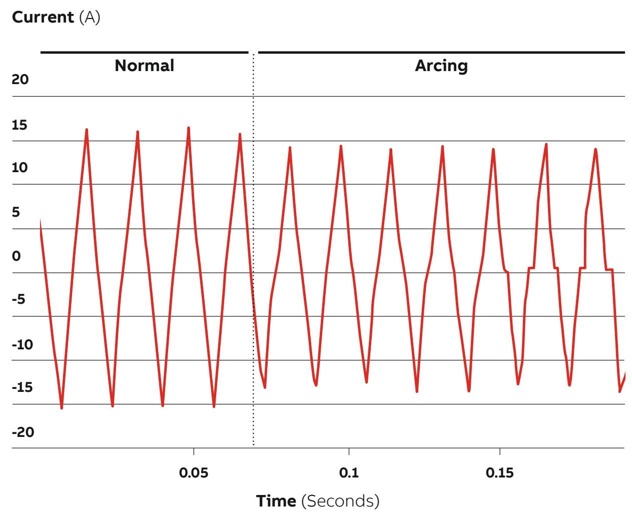


Fig. 26:
Current absorbed by a vacuum cleaner (Normal) **and from an arc** (Arcing)

Fig. 27:
Current waveform for immunity test with two 40 W lamps

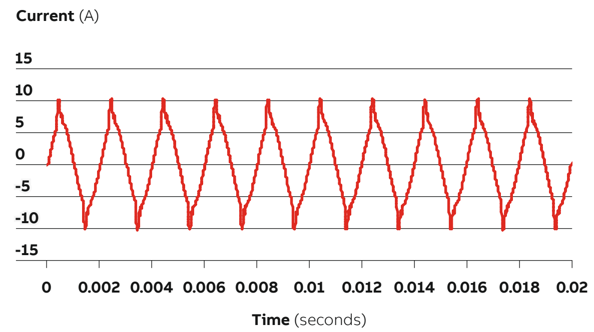
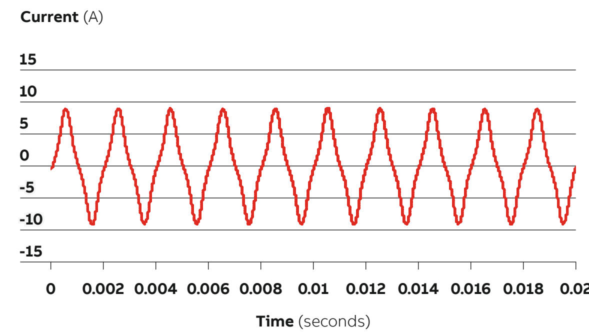


Fig. 28:
Current waveform for immunity test with air compressor



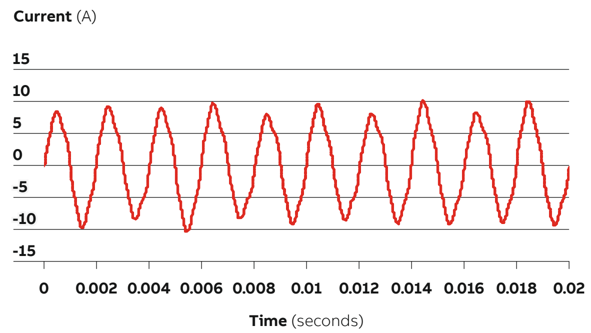


Fig. 29:
Current waveform for immunity test with 600 W dimmer

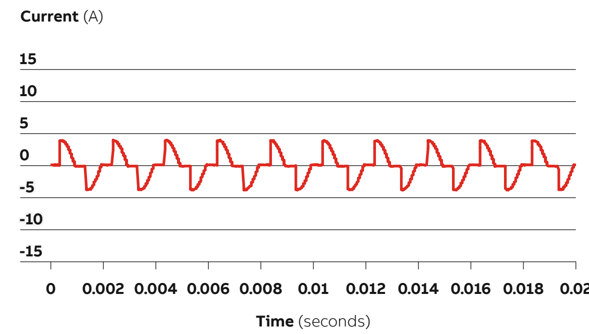


Fig. 30:
Current waveform for immunity test with vacuum cleaner

The current arc waveform has the so-called “shoulders” at the zero cross. However, the unique presence of the “shoulders” in a waveform of current is not a sufficient condition to justify the presence of arcs. Figure 26, for example, shows a series arc and a vacuum cleaner, and marks only a slight decrease of peak values (the series arc introduces additional impedance into the circuit, decreasing current amplitude), as well as the presence of the shoulders and rapid current jumps.

However, the AFDD has to be able to avoid tripping in the presence of masking loads, and to trip for the arc fault. Sometimes, as shown in the Figures 27, 28, 29 and 30, it can be difficult to detect differences between arc and load waveforms, but the ABB S-ARC1 is designed to operate for this purpose.

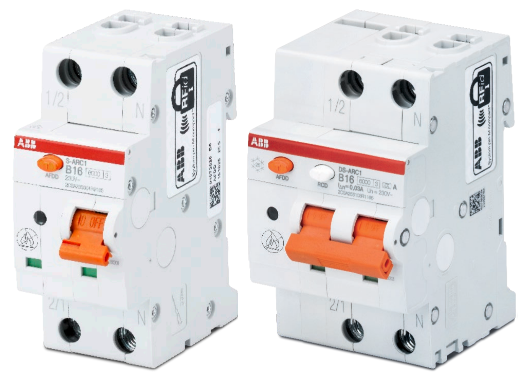
Arc Fault Detection Devices S-ARC1 and DS-ARC1

S-ARC1 and DS-ARC1 are the new 1P+N AFDD with integrated MCB and RCBO respectively, both available in 6 kA and 10 kA breaking capacity. With a total integration in the System pro M compact® profile, S-ARC1 and DS-ARC1 series offer a complete protection against arc faults and overvoltages, reducing the risk of fire.

With the integrated MCB, S-ARC1 is providing additional protection against overcurrent in only two modules width. An RCCB has to be installed upstream for residual current protection.

With the integrated RCBO, DS-ARC1 is providing a complete protection also against overcurrent and earth fault current in only three module width: compact solution for a complete protection of people and valuable assets.

In the table below the main characteristics of S-ARC1 and DS-ARC1 are summarized.



—
Fig. 31: AFDDs S-ARC1 and DS-ARC1

	S-ARC1	DS-ARC1
Standards	IEC/EN 62606, IEC/EN 60898-1	IEC/EN 62606, IEC/EN 61009-1, IEC/EN 61009-2-1
Poles	1+N	1P+N
Modules	2	3
Type	–	A
Sensitivity	–	30 mA
Tripping characteristics	B, C	
	6, 10, 13, 16, 20, 25, 32, 40 A	6, 10, 13, 16, 20 A
Rated short-circuit capacity I_{cn}	6 kA, 10 kA (S-ARC1 M)	6 kA, 10 kA (DS-ARC1 M)
Rated frequency	50/60 Hz	
Rated voltage	230 – 240 V	
Threshold for protection against overvoltage	275 V	
Dimensions H × D × W	85 × 69 × 35 mm	85 × 69 × 52.5 mm

Product features

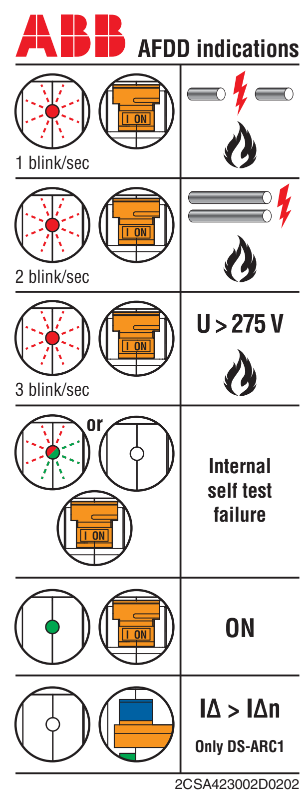
- Easy installation. Connection is possible both with cables (up to 25 mm²) and busbars (10 mm²) thanks to the presence of two different slots.

  Quick installation is possible in just a few steps using ABB System pro *M* compact® busbars (Figure 33, 34, 35).

- **Power feed from top or bottom.** Device supply is possible either from the top or the bottom, with cables or busbars. This guarantees highly flexible installation depending on the application. For correct operation, it is important not to reverse neutral and line conductors.

- **Accessories.** System pro *M* compact® accessories can be mounted quickly and easily, adding extra features to the product. Possible combinations include auxiliary contact, signal contact/auxiliary switch, shunt trip, undervoltage and overvoltage releases. Only for DS-ARC1 combination possible also with auxiliary for bottom fitting (fig. 33).

—
Fig. 32: Sticker for indications of S-ARC1 and DS-ARC1



Contact Position Indicator (CPI). Fast and easy identification of contact status thanks to the green/red window, independently on the toggle positions (green: contacts opened, red: contacts closed).

- **Integrated overvoltage protection.** S-ARC1 and DS-ARC1 offer protection against overvoltage higher than 275 V, mitigating the risk of fire due to the overheating of electrical equipment caused by overvoltage of long duration.

- **LED Operation.** S-ARC1 and DS-ARC1 are equipped with an LED to monitor the device's operation and provide easier troubleshooting of the network, as well as reduced downtime for maintenance in the event of tripping:

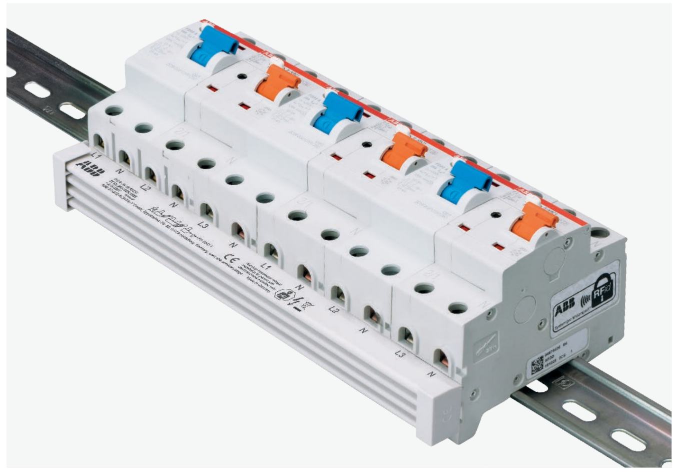
  - Standard working conditions (toggle ON): Green LED
  - Different indicators after tripping (after reclosing the toggle) include:

LED indication	
Green (permanent)	Manual trip, test button, overcurrent
RED Blinking (1 blink/sec for 5 sec)	**Series arc.** After 5 sec LED has to become GREEN
RED Blinking (2 blink/sec for 5 sec)	**Parallel arc.** After 5 sec LED has to become GREEN
RED Blinking (3 blink/sec for 5 sec)	**Overvoltage.** After 5 sec LED has to become GREEN

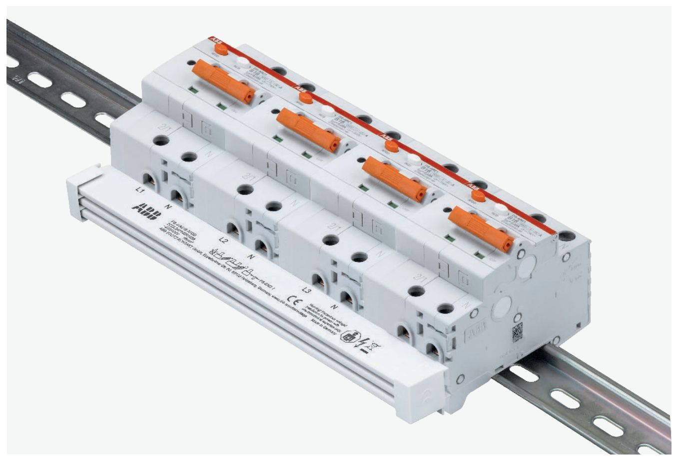
- Internal self test and AFDD test push button to check the correct working conditions of AFDD electronic unit as described at page 15
- Possibility to recall in memory (and to clear if required) the last LED indication due to arc fault tripping or overvoltage, with the aim of reducing the downtime for maintenance operations with an easier troubleshooting. The memory is kept even in case the power supply is interrupted.
- Only for DS-ARC1: presence of earth fault indicator (blue flag on the toggle) to identify earth fault trips.

- AFDD indications are also described with a sticker provided inside the packaging as shown in Figure 32.

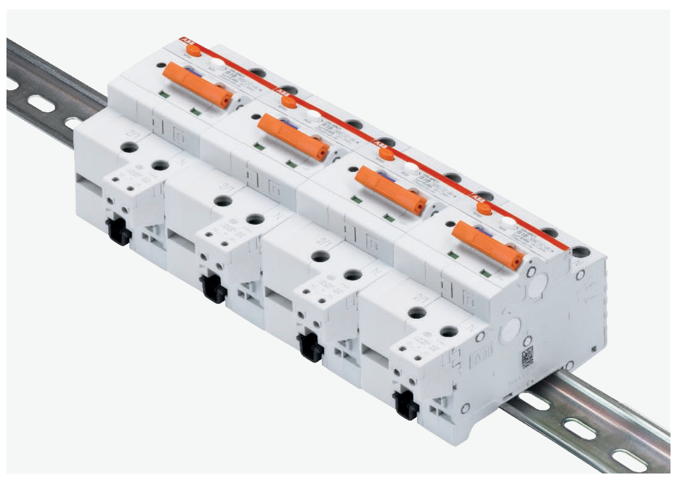
Installation examples S-ARC1 and DS-ARC1



—
Fig. 33: Wiring of S-ARC with 2-pole RCCB with busbar



—
Fig. 34: Wiring of DS-ARC1 with busbar



—
Fig. 35: Wiring of DS-ARC1 with auxiliary for bottom fitting

Sources and literature

The following sources, links and publications where used for this guide, and can provide additional information.

The University of Manchester: Fire Behaviour (http://www.mace.manchester.ac.uk/project/re-search/structures/strucfire/Design/performance/fireModelling/fireBehaviour/default.htm?p=)

Fire statistics:
firesafeeurope.eu (Europe), ifs-ev (Germany)

Carvou, E.; Mitchell, J.B.A.; Ben Jemaa, N.; Tian, S.; Belhaja, Z.;
"AC Electrical Arcs with Graphite Electrodes,"
Electrical Contacts (Holm),
2011 IEEE 57th Holm Conference on ,
vol., no., pp.1-6, 11-14 Sept. 2011

Università degli Studi di Cassino e del Lazio Meridionale:
"Impianti elettrici per media e bassa tensione: Capitolo III
Componenti dell'Impianto Elettrico, Apparecchi di Manovra"

A NEMA Low Voltage Distribution Equipment Section
Document, ABP 2-2011, Recommendations on AFCI/
Home Electrical Product Compatibility

Comparing 240 Vrms to 120 Vrms
Series Arcing Faults in Residential Wire,
John J. Shea, Senior Member IEEE Eaton Corporation

ANIE Conference
"Federazione ANIE – Associazione CSI Sottogruppo
Apparecchi di protezione October/November 2016"

IEC 23E/742/CDV: 2012-02: IEC 62606 Ed. 1.0:
General Requirements for Arc Fault Detection Devices (AFDD)

IEC 60364-4-42
"Protection for safety - Protection against thermal effects."

VDE 0100-420

Ed Larsen: Arc Fault Circuit Interrupters,
Presentation for IEC 23E / WG2,
New Orleans -November, 2007

—
ABB Group
Electrification Products Division
Business Unit Building Products

www.abb.com/lowvoltage

9AKK107045A8938 Rev B September 2018