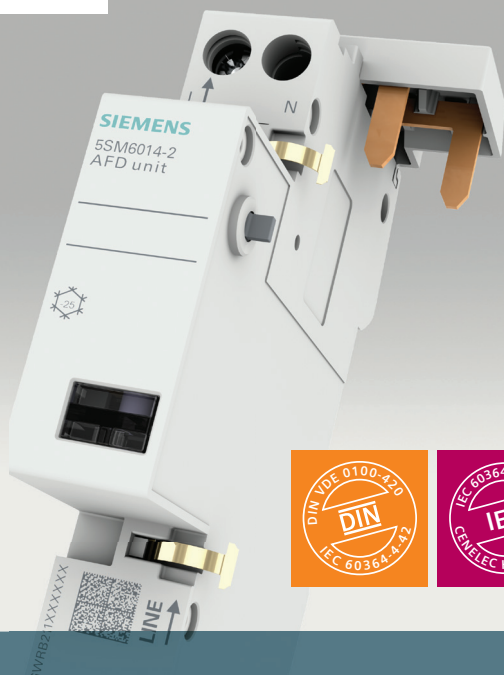


SIEMENS



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# 5SM6 AFD units

Technology Primer



Be it protecting, switching, measuring or monitoring – components for low-voltage power distribution from Siemens offer you just the right device for all applications in the electrical installation field. Whether for use in industry, infrastructure or buildings, these products guarantee a maximum of flexibility, ease of use and safety – helping you to keep the entire power supply safely under control.

Protection devices such as fuses, MCBs and RCDs have been tried and tested over many years, but they are not suitable for detecting arcing faults and particularly not those which are limited by an impedance. This safety gap is now closed by the 5SM6 arc fault detection (AFD) units. The 5SM6 AFD unit detects arcing faults which can arise at serial fault locations and unsecured contacts or as the result of insulation faults between one active conductor and another or between an active conductor and the protective conductor. This contributes very effectively to preventing fires caused by electricity.

In this primer we describe not only the physical properties of arcs but also the design and mode of operation of the AFD unit. We also present the various versions of the device and a number of application examples in order to make it easier for you to select the right unit and use it correctly.

<b>1</b>	<b>Introduction</b>	<b>6</b>
<b>2</b>	<b>Fire statistics and causes of fire</b>	<b>6</b>
<b>3</b>	<b>Protection devices</b>	<b>14</b>
3.1	Arcing faults and established protection devices	14
3.2	The expanded protection concept	16
<b>4</b>	<b>Ignition and burning conditions of the arc</b>	<b>17</b>
<b>5</b>	<b>Concrete examples of fault situations with serial arcs</b>	<b>19</b>
5.1	Fault situation range up to 3 A arcing current	20
5.2	Fault situation range from 3 A to 10 A arcing current	22
5.3	Fault situation range over 10 A arcing current	24
5.4	Impact of load current on the outbreak of fire	24
<b>6</b>	<b>Fault situation with parallel arcing faults</b>	<b>27</b>
6.1	Basic considerations	27
6.2	Shutdown behavior of overcurrent protection devices	28
6.3	Assessment	30
<b>7</b>	<b>Detection of arcing faults</b>	<b>31</b>
7.1	Basic design of the 5SM6 AFD unit	31
7.2	Detection of serial arcing faults	32
7.3	Detection of parallel arcing faults	33
7.4	Prevention of unwanted trippings	34

<b>8</b>	<b>Standards and requirements for AFD units</b>	<b>38</b>
8.1	General principles	38
8.2	Product standard	38
8.3	Installation regulations	40
<b>9</b>	<b>Product description of the 5SM6 AFD unit</b>	<b>42</b>
9.1	Product versions	42
9.2	General properties	44
9.3	Special properties	45
<b>10</b>	<b>Guide</b>	<b>48</b>
10.1	Installation of the AFD unit	48
10.2	Procedure after the AFD unit has tripped	48
<b>11</b>	<b>Application examples</b>	<b>51</b>
<b>12</b>	<b>Outlook</b>	<b>52</b>
<b>13</b>	<b>Sources and literature</b>	<b>53</b>
<b>14</b>	<b>Appendix: PV AFD unit for photovoltaic systems</b>	<b>54</b>
A.1	System description	54
A.2	Product description	55
A.3	Operation	56
A.4	More information	57
<b>15</b>	<b>List of figures and tables</b>	<b>58</b>

## 1. Introduction

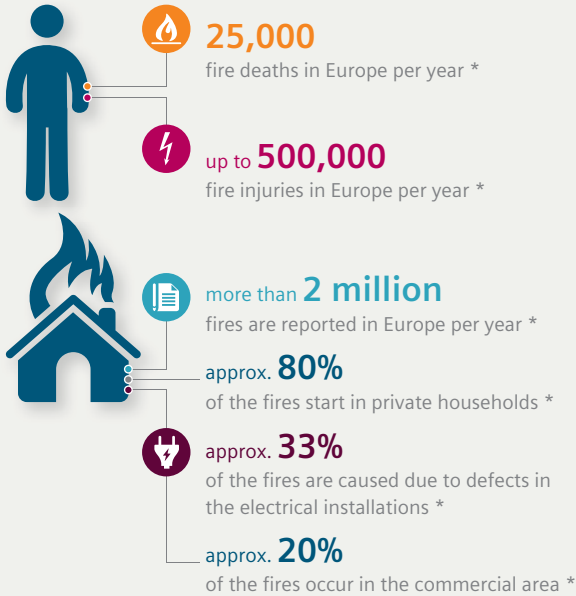
In the USA, the history of arc fault detection already goes back several decades. The first patents date back to 1983. In the 1990s considerable efforts were made to define suitable requirements and develop matching products for the detection of arcing faults. The step-bystep introduction of the AFCI (arc fault circuit interrupter) has been in progress in the USA since 2001. In 2005, the use of AFCIs in branch circuits with 15 / 20A in bedrooms was entered as a requirement in the national installation regulations. Since 2008, this requirement has been expanded to include the protection of branch circuits in all living spaces.

## 2. Fire statistics and causes of fire

More than 2 million cases of fire-related damage are recorded in Europe every year. On a more serious note approximately 500,000 persons are injured and 25,000 lose their lives due to fires. The fact that many fire victims are surprised at night in their sleep and that more than 90% die from the effects of smoke poisoning is particularly alarming. Most fires begin with a smoldering phase in which the rooms quickly fill up with smoke and combustion gases. Just a few breathfuls of these gases can cause a person to lose consciousness or even die.

Fires caused by electricity account for approximately 33% of all fires, and this percentage has hardly changed for many years. In 2014, for example, it was 34% (see figure 1). Ignoring those causes which cannot be influenced, e.g. arson and human error, the share of fires caused by electricity lies even higher at around 50%. In around 50% of these cases the cause of the fire lies in the electrical load, and in around 30% of the cases in the installation system.

### Fire statistics



\* Consumer fire safety (2009): european statistics and potential fire safety measures

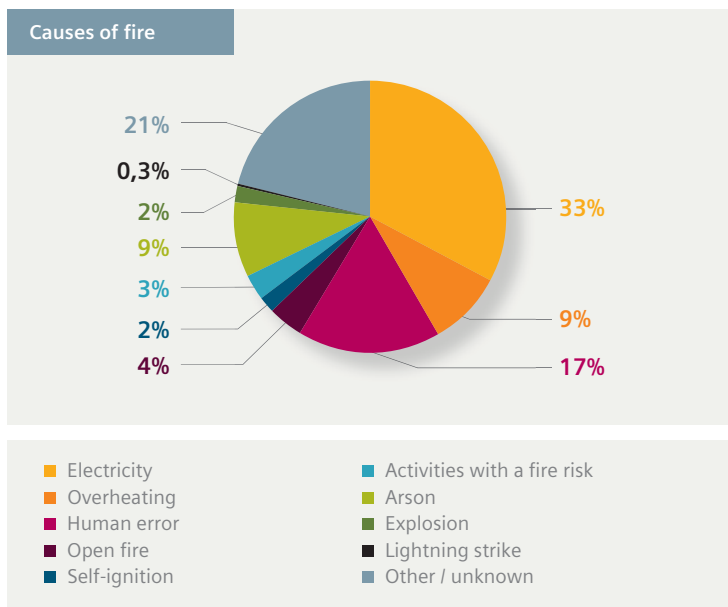
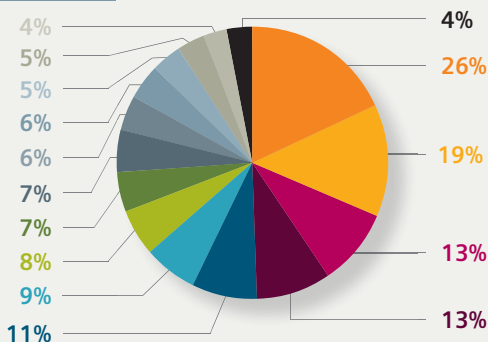


Figure 1: Causes of fire in Germany in 2014

It is also interesting to look at the defect statistics drawn up by VdS (VdS Schaden-  
verhütung GmbH) on the basis of more than 30,000 company inspections. Figure  
2 presents a breakdown of the more than 150,000 defects discovered. Multiple  
defects in the systems mean that totals can exceed 100%.



## Statistics of defects



- Technical documents not complete / not available
- Protection against direct contact not assured
- Wall and ceiling penetrations poor
- Equipment damaged
- Cables and cable routing poor
- Equipment poorly fastened
- Accessories (warning, safety and inscription labels, notices, maintenance manual, devices) missing / poor
- Conductor terminals and connections poor
- Protective conductor cannot be removed individually, is connected to N conductor
- Inscriptions, identification of electric circuits and electrical equipment unavailable / incomplete
- Cleanliness of the electrical installation inadequate
- Cable entries on electrical equipment poor
- Overload and short-circuit protective device unavailable / poor
- Equipotential bonding missing/poor
- Protection against indirect contact not guaranteed

Figure 2: VdS – Statistics of defects in electrical systems (2008)

With many of the discovered defects, e.g. poor cable routing or wall/ ceiling penetration, fires can also be caused by arcing faults which are not detected by the protection devices in place. The statistics published for Germany are applicable in similar magnitude to other European countries. However, there are differences in the way the data are collected and processed.

Figure 3 presents an example of fire statistics. Here again, fires can be caused by arcing faults which result from the discovered defects such as rodent damage, loose connections, aging or damage with moisture.

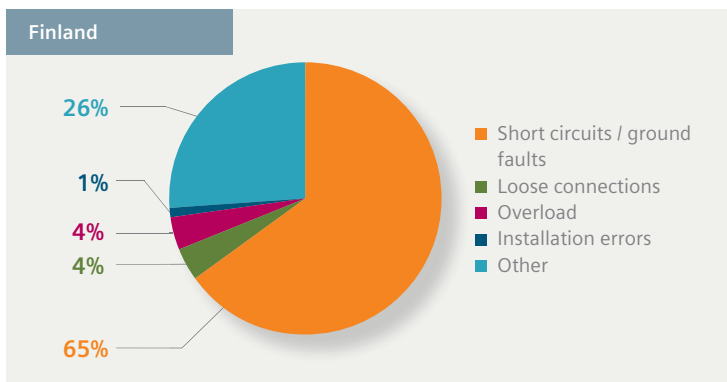
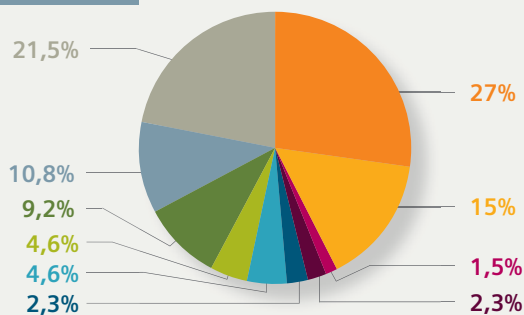


Figure 3: Fire statistics 2006; absolute number: 1,860 fires

Another study carried out in the USA (see figure 4) deals in greater detail with the effects which were noticed in the installation system before the fires broke out. Potential arcing fault types and causes can be assigned to these effects.

## USA

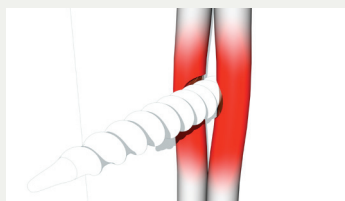


- Fuses blowing
- Other
- Lights going out
- Sparkling, arcing at outlet
- Radio sounding scratchy
- Bulbs burning out
- Appliances operating slowly
- Breaker tripping
- Lights dimming
- Lights flickering

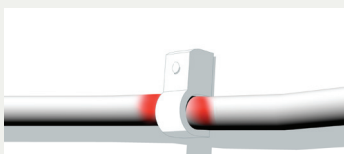
Figure 4: Observations made in the USA before the outbreak of fires caused by electricity

The fault situations indicated by the statistics are equally evident in practice. The following faults (and prohibited work practices) are frequently discovered in electrical installation systems and in the area downstream from the socket outlet.

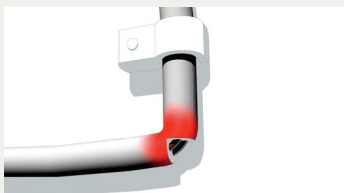
- a) Damaged cable insulation, e. g. due to nails, screws or clips
- b) Cables with too tight a bending radius are at risk of breaking
- c) Arcing faults can be caused in cables which are routed through open windows or doors and then crushed when the windows or doors are closed, leaving the insulation damaged.
- d) Damage or aging of the insulation due to environmental influences such as UV radiation, temperature, moisture, gases
- e) Rodent damage
- f) Loose contacts, e.g. due to too low a torque
- g) Conductors damaged by claw fasteners



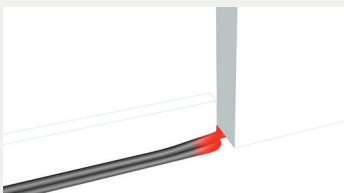
a) Nails or screws



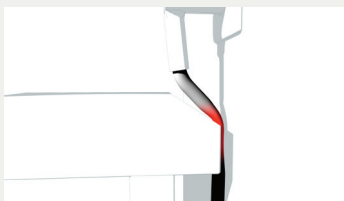
a) Overtight clip



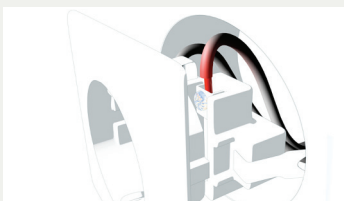
b) Too tight a bending radius



c) Crushed cable



c) Crushed cable



g) Conductors damaged by claw fasteners

The fire statistics, the defects observed and their effects are strong arguments for developing a suitable protection device such as the AFD unit as a contribution to reducing the number of fires caused by arcing faults.

### 3. Protection devices

#### 3.1 Arcing faults and established protection devices

Arcing faults can take different forms (see figure 5). The various fault types will now be considered in relation to the modes of operation of the established protective devices (RCDs and overcurrent protection devices).

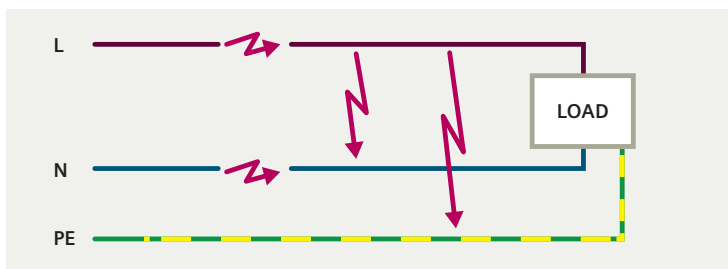


Figure 5: Types of arcing fault

#### a) Parallel arcing faults

Parallel arcing faults can be caused e.g. by aging of the insulation material or by the presence of conductive soiling between the line conductors.

#### Parallel arcing fault between a line conductor (L) and an earthing conductor (PE):

Current flows through the arc from the line conductor to PE. In this case an existing RCD with a maximum rated residual current of 300 mA can be used for fire protection purposes. This is expressly required for certain areas (e.g. "premises exposed to a fire hazard" according to IEC 60364-4-42; HD 384.4.482 S1). Overcurrent protection devices provide no protection in some cases because the impedances in the faulty circuit may be too high. It is then impossible to meet the shutdown conditions with the short times needed to limit the energy at the fault location to values which would prevent an outbreak of fire.

**Parallel arcing fault between one line conductor and another or between a line conductor and a neutral conductor:**

RCDs are unsuitable for protection purposes in this case because no current flows through PE or earth. Overload and short circuit protection devices such as MCBs can provide protection only under certain conditions. Success depends on the impedances in the faulty circuit, including the value of the arc voltage, and on whether the shutdown conditions for such current/time values are fulfilled, thus limiting the energy at the fault location to values which would prevent an outbreak of fire. High impedance values limit the current level and can prevent timely shutdown particularly at fault locations with high contact resistances or when extension cables are used downstream from the socket outlet (see chapter 6, page 27 et seq.).

**b) Serial arcing fault in an active conductor:**

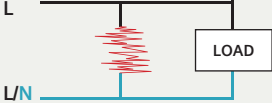

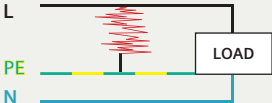

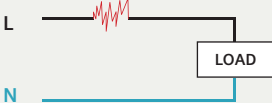

In this case no current flows to PE or earth, and the load current is even reduced on account of the arc voltage in series with the useful load.

RCDs and overcurrent protection devices can provide no protection therefore in this case.

To sum up it can be said that no protection at all exists for the case of a serial arcing fault, and that the protection level needs to be improved for parallel arcing faults between active conductors. To close these safety gaps, the Siemens protection concept for lowvoltage power distribution has been expanded to include the 5SM6 AFD unit.

3.2 The expanded protection concept for the prevention of fires

The 5SM6 AFD units from Siemens expand the existing protection concept for the reduction of fires caused by electricity, which is based on RCDs and overcurrent protection devices, and closes the safety gap which has existed up to now. Figure 6 shows the situation for the individual fault types with regard to protection devices according to UL standards (e.g. USA) and IEC or EN standards (e.g. Germany).

Type of fault	Protection options								
<p><b>Parallel (Phase-neutral/phasephase)</b></p> 									
<p><b>Parallel (Phase-protection conductor)</b></p> 									
<p><b>Serial</b></p> 									
<p>Figure 6: Fault types and protection devices suitable for fire protection</p> <table><tr><td>MCB</td><td>Miniature circuit breaker</td></tr><tr><td>RCD</td><td>Residual current device</td></tr><tr><td>AFD</td><td>Arc fault detection unit</td></tr><tr><td>RCBO</td><td>Residual current operated circuit breakers</td></tr></table>		MCB	Miniature circuit breaker	RCD	Residual current device	AFD	Arc fault detection unit	RCBO	Residual current operated circuit breakers
MCB	Miniature circuit breaker								
RCD	Residual current device								
AFD	Arc fault detection unit								
RCBO	Residual current operated circuit breakers								

The properties of arcs and the function and mode of operation of the 5SM6 AFD units are described in the following chapters.



## 4. Ignition and burning conditions of the arc

So-called “contact arcs” (see figure 7) can result from direct or indirect contact between metal parts at fault locations which are in motion or have little conductivity. Movement (vibration, thermal expansion) of the metal parts, which were originally in direct contact with each other, results in arcing, heating and ultimately a fused link. Through further heating and repeat breaking of the fused link, unstable arcs are formed briefly. The results are high temperatures on the metal parts (electrodes). The air is ionized, and after the arc is extinguished in the current zero crossing it is ignited again. Combustible materials in the vicinity (e.g. cable insulation) are carbonized.

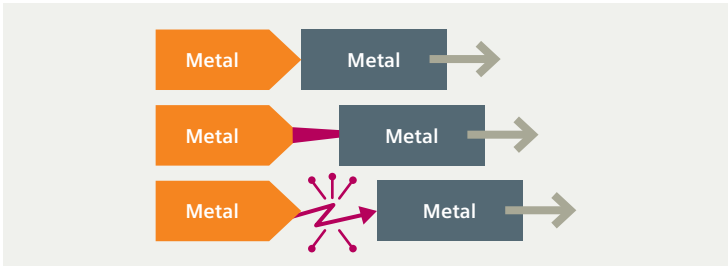


Figure 7: Contact arc

If the insulation between two conductors is damaged, parallel arcing faults can form over a conductive insulating clearance even without direct metal contact (see figure 8, page 18).

If there are materials between the conductors, the insulation properties can be impaired due to aging and chemical, thermal or mechanical loading. Leakage currents can form on surfaces which are contaminated by dirt or condensation. These leakage currents and short discharges can heat up and carbonize the plastics. High temperatures at the fault location can cause a part of the carbonized material to vaporize, greatly heating up the surroundings and igniting a stable arc. The carbonized path between the electric conductors enables the arc to be re-ignited after the current zero crossing, with further heating up to the outbreak of a fire.

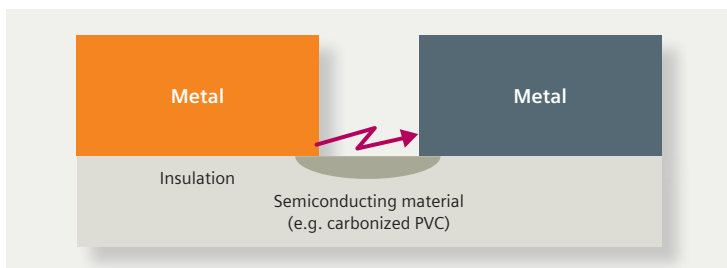


Figure 8: Arc over a conductive insulating clearance

The outbreak of a fire as the result of a serial arcing fault will be described using the example of a constriction in a cable. The current flow results in higher temperatures at the constriction. This increase in temperature causes hot copper to oxidize, leading in turn to an increase in resistance and even higher temperatures, and in some cases to melting of the copper. Gas is formed, particularly at the peak current point. This results at least briefly in an air gap with arcing. The insulation at the fault location is carbonized. Over this clearance it is possible for a stable arc to burn and for the resulting flames to cause a fire (see figure 9).

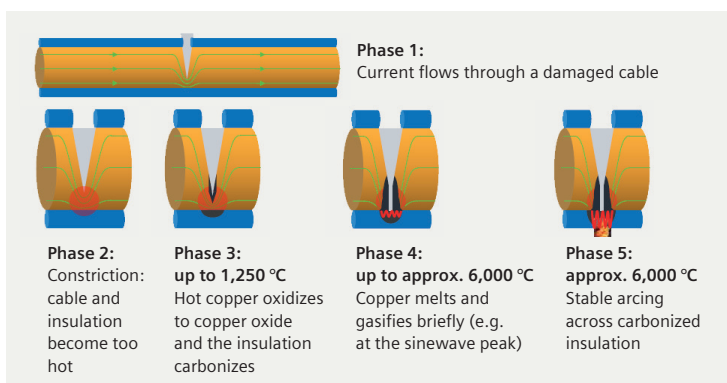


Figure 9: Outbreak of a fire due to serial arcs

## 5. Concrete examples of fault situations with serial arcs

Serial arcs were tested under laboratory conditions with various loads using 230 V to earth (the usual voltage in Europe) and NYM-J cable (the most widely used cable type in Europe). Definitions of terms used in the analysis and presentation of the conditions:

**a) Arc**

A luminous discharge of electricity over an insulating medium, which also causes partial vaporization of the electrodes. The electric arc subsequently creates a broad-band high-frequency noise.

**b) Arc stability**

The ratio of arc duration to observation time over 100 ms. Arc stability is always less than 100 % because of the zero crossings of the AC voltage.

**c) Incandescence (incandescent contact)**

A connection which due to poor contact in the current flow heats up the contact material and causes it to glow. No high-frequency noise is created, and the incandescent contact can be regarded as a serial impedance.

**d) First flame**

A flame which burns continuously for 5 ms

**e) Significant flame**

A flame which burns continuously for 50 ms

**f) Stable flame**

A flame which burns continuously for 500 ms

### 5.1 Fault situation range up to 3 A arcing current

The first graph (energy) illustrates the energy development over the observation time (see figure 10). Two energy values are presented. The black curve represents the total energy (total electric energy) which is released at the fault location mainly in the form of heat and radiation. The red curve represents the arc energy. The difference between total energy and arc energy is owed mainly to the incandescence. The development of the energy increase can be divided into two phases.

In the first phase, the "carbonization phase" (yellow section), it is impossible to create a stable arc if the fault location is not yet carbonized. Short arcs form only when the distance between the conductor ends at the fault location is small enough, i.e. at the moment of contact or interruption. As a result of the low arc stability (bottom graph), the mean value of the power is low and the total energy increases only slowly. During the carbonization phase, the cable sample cannot be ignited but the PVC insulation suffers continuous carbonization.

In the second phase, the "ignition phase" (red section), the fault location is carbonized enough and the arc stability increases rapidly to 80%. The arc becomes very stable, the energy increases rapidly, and flame formation begins (penultimate graph).

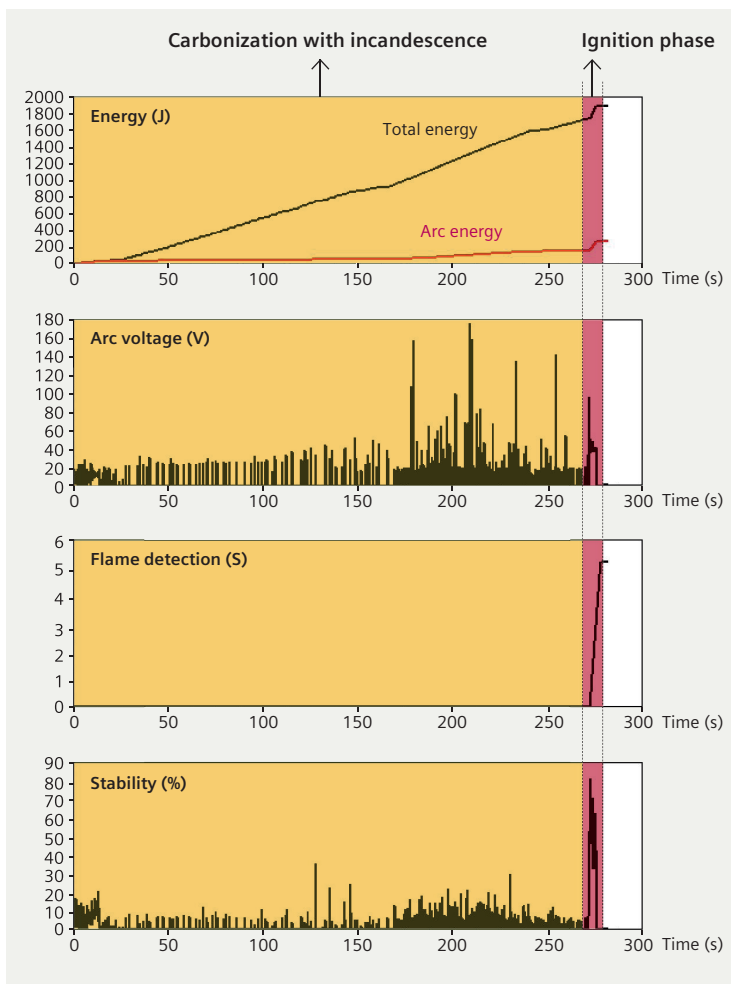


Figure 10: Development of the arc using the example 2 A / 230 V

### 5.2 Fault situation range from 3 A to 10 A arcing current

The graphs can also be divided into a carbonization phase and an ignition phase for these higher arc currents (see figure 11). Once again the stability of the arc is initially very low because the fault location is still not carbonized. As a result of the low arc stability, the mean value of the power is low and the total energy increases only slowly so that the cable sample cannot be ignited.

After a far shorter time than with lower currents, the fault location is carbonized enough and the arc stability increases rapidly to over 90%. The arc becomes very stable, the energy increases rapidly. After a few seconds the insulation is no longer able to withstand the heat and a flame is formed.

During the test the arc voltage is very low at around 15 V to 30 V. This is typical for an arc at low voltage because a serial arc can form only when the gap between the two conductors or electrodes is very small.

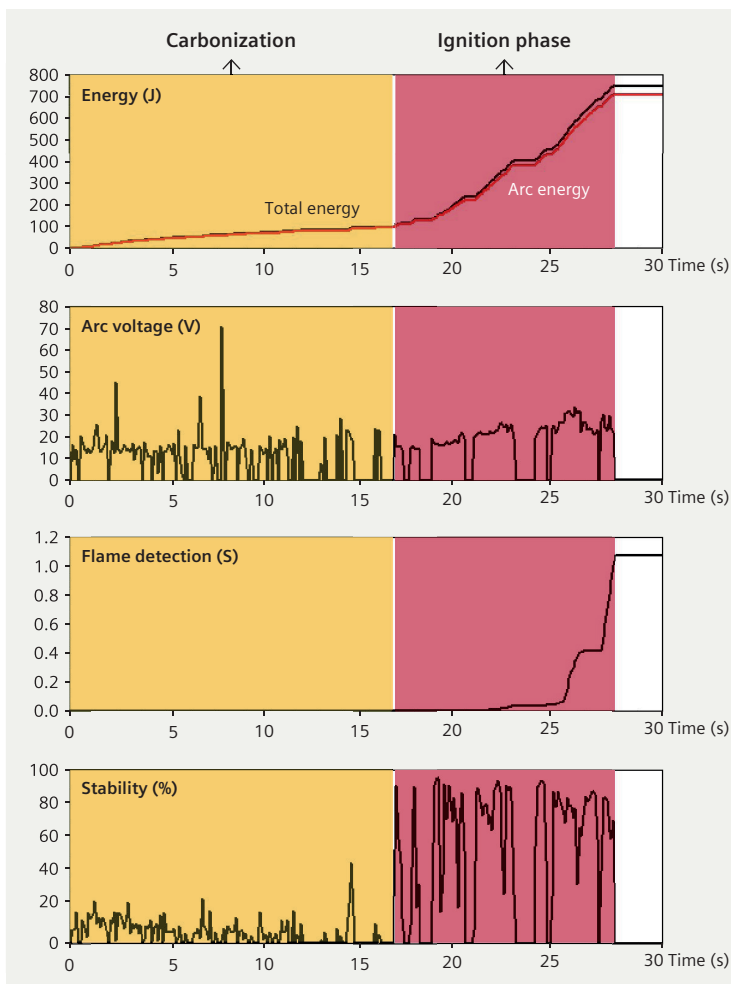


Figure 11: Development of the arc using the example 5 A / 230 V

### 5.3 Fault situation range over 10 A arcing current

In this range, the power of the arc is so high that flames occur very quickly and without carbonization. Evidently, arcs with high power are unsuitable for effective carbonization of the fault location. The reason lies with the vaporization of the already formed carbonized material, as a result of which the formation of a useful carbon path is prevented. Furthermore, serial arcs with high power are able to weld the two copper conductors together again, thus „healing“ the fault location.

### 5.4 Impact of load current on the outbreak of fire

Fire outbreak tests were conducted with load currents in the range from 1 A to 32 A. The following figures show mean values from 100 measurements.

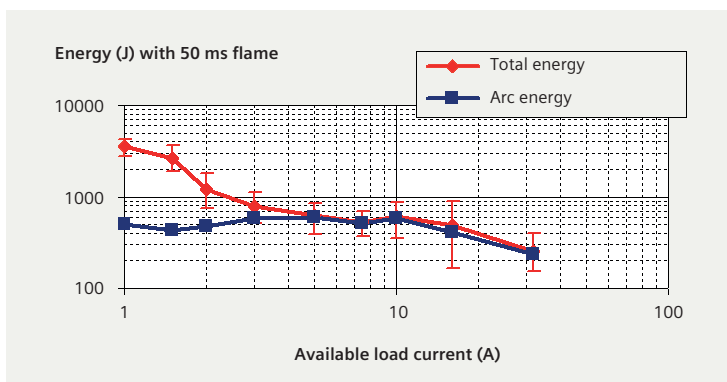


Figure 12: Energy of the significant flame as a function of load current



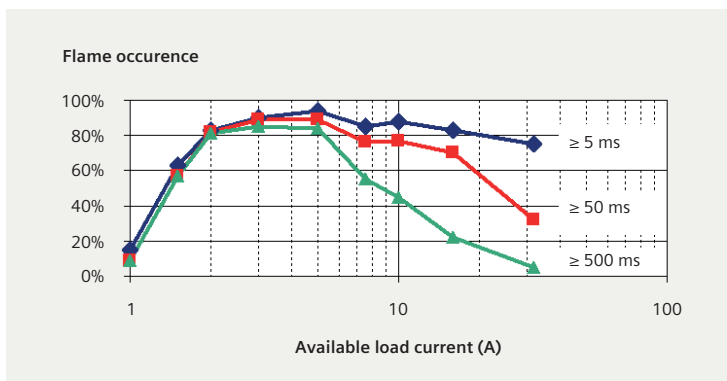


Figure 13: Outbreak of flames as a function of load current

In the low range (below 3 A), the total electric energy which is expended at the fault location mainly in the form of heat and radiation and must be used for the formation of the significant flame is two to three times higher than the energy released by the arc. This energy difference is caused by incandescence. Below 2 A, even a stable arc hardly has enough power to ignite the cable, so the probability of an ignition is greatly reduced.

The probability of arcing faults occurring is greatest in the medium range (3 A to 10 A), which is the category to which most common domestic electrical appliances belong. Here the arc energy is nearly as high as the total electric energy. This is underlined by the dominance of the arc over glowing in this range. In this medium current range, the amount of energy needed to ignite a PVC cable is evidently not dependent on the load current and lies relatively constant at approximately 450 Joule. Here the occurrence of first and significant flames lies at around 80%.

In the upper range (above 10 A), the power of the arc is so high that flames occur very quickly and without carbonization. Therefore, significant and stable flames occur more and more rarely. One reason for this is the vaporization of the carbonized material, which prevents the formation of a carbon path. The probability of stable flames drops below 5%. Similarly, arc stability also decreases notably with high load currents. The lower arc stability reduces the

power, hardly allowing reliable ignitions to occur. Moreover, high-power serial arcs can sometimes melt the two copper parts back together and “repair” the fault location. Even if stable arcs are rare above 10 A, the short and powerful flames which can occur in this range represent a serious danger.

## 6. Fault situation with parallel arcing faults

### 6.1 Basic considerations

Unlike serial arcing faults, for which no protection devices have been available up to now, parallel arcing faults are detected under certain conditions by other protection devices such as RCDs and overcurrent protection devices (see page 16, figure 6).

For the shutting down of parallel arcing faults by overcurrent protection devices it is necessary to consider the system conditions and their impedance values. In the following, the tripping conditions for the overcurrent protection devices (MCB and fuse) are examined to see whether they are sufficient in all cases for providing reliable fire protection.

Figure 14 shows the typical current and voltage curve of a parallel arcing fault. In addition to a stable arc, the current curve can also include rather long gaps without any current flow because the arc is not always reignited after the current zero crossing. There is no assurance therefore that the overcurrent protection device will be tripped via the thermal release. Given a high arc voltage in conjunction with a high system impedance, it is well possible for the current peak value to lie below the magnetic tripping current of the MCB.

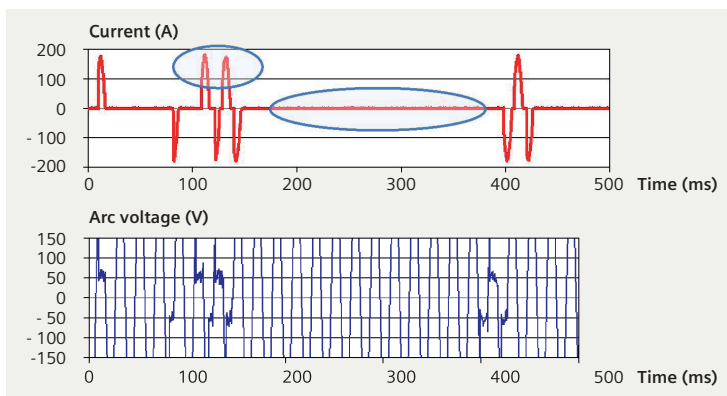


Figure 14: Current and voltage curve for a parallel arcing fault

The high arc currents in these cases, which can also exceed 100 A, and the arc voltages in the range of 60 V produce an arc power of several kW (e.g. with 100 A and 60 V the arc power would be 6 kW). This results in high power densities at the fault location, which can lead to rapid ignition of the insulation material and therefore to the outbreak of a fire if shutdown does not take place within fractions of a second.

### 6.2 Shutdown behavior of overcurrent protection devices

From measurements of prospective short circuit currents at socket outlets in office buildings and apartments it is known that the majority of current values lie between 150 A and 500 A. The magnetic quick tripping of the miniature circuit breaker B 16 (within 100 ms) is assured therefore in most cases.

If the fault does not occur at the socket outlet but on the supply line to the socket outlet, the situation will improve thanks to the then lower impedance and the resulting higher short circuit current. With faults in an extension cable, on the other hand, the impedance will increase and therefore the short circuit current will be notably reduced. The MCB is then no longer able to provide the desired protection.

In all cases, a high arc voltage can also lead to the reduction of the short circuit current and prevent magnetic quick tripping. Similarly, the shutdown times of the fuses can also be too long for fire protection purposes in critical conditions.

Overcurrent protection devices can work only when the conduction interval for a certain current level lies above the tripping curve of the respective overcurrent protection device.

Figure 15 shows the tripping curves of MCBs for the characteristics B, C and D, as well as the tripping curve of the 5SM6 AFD unit. The tripping times of AFD units offer both supplementary and improved protection against parallel arcing faults in some cross-over areas. As already explained, protection against serial arc faults is provided only by AFD units. MCBs are unsuitable in these cases.

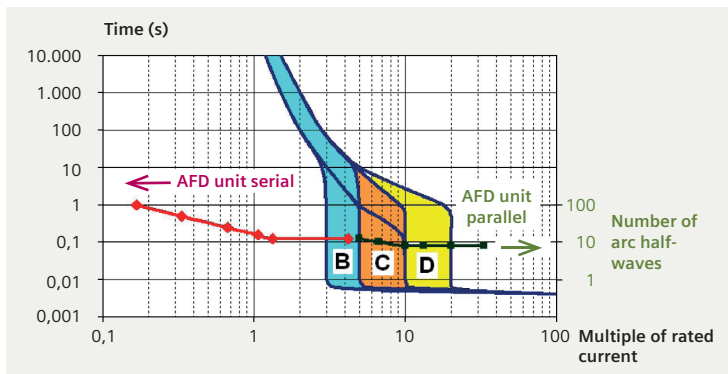


Figure 15: Protection by MCB

Figure 16 shows the tripping curves of a gL fuse and the tripping curve of the 5SM6 AFD unit. It is again evident that the tripping times of AFD units offer both supplementary and improved protection against parallel arcing faults in the cross-over area. For this reason, only the AFD unit provides comprehensive protection against serial arcing faults.

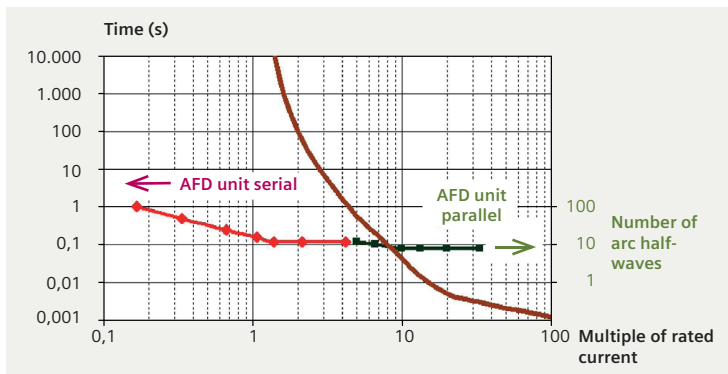


Figure 16: Protection by fuse

### 6.3 Assessment

Figures 15 and 16 show that upstream overcurrent protection devices provide sufficient protection against parallel arcing faults in most cases. Nevertheless, the AFD units can round off the protection in cross-over areas where there are special fault constellations.

The primary benefit of the AFD unit is its protection against serial arcing faults. Here the response times of MCBs and fuses, i.e. devices designed mainly for line protection purposes, are so long that they are unable to provide protection against fires.

## 7. Detection of arcing faults

### 7.1 Basic design of the 5SM6 AFD unit

Figure 17 shows the basic design of the 5SM6 AFD unit. For detection, all active conductors – in this case the line conductor and the neutral conductor – are passed through the unit and switched. The line conductor is passed through two separate sensors: a current sensor for detecting the low-frequency (line-frequency) signals and an HF sensor for detecting the high-frequency signals. Analog electronics prepares the signals for processing in the microcontroller.

The HF power of the current is scanned in the MHz range. In the following it is referred to as the RSSI (Received Signal Strength Indication) and represents the power of the arc at a defined frequency and bandwidth. When the microcontroller sees the criteria for an arcing fault as fulfilled, the tripping signal will be created and directed via a shunt trip to the switching mechanism. In the case of the 5SM6 AFD unit, a mechanical coupling link is actuated to work the mechanism of the mounted MCB (Miniature circuit breaker) or RCBO (Residual current operated circuit breaker). The mounted protection device is tripped along with its contacts, and the network is disconnected from the faulty part.

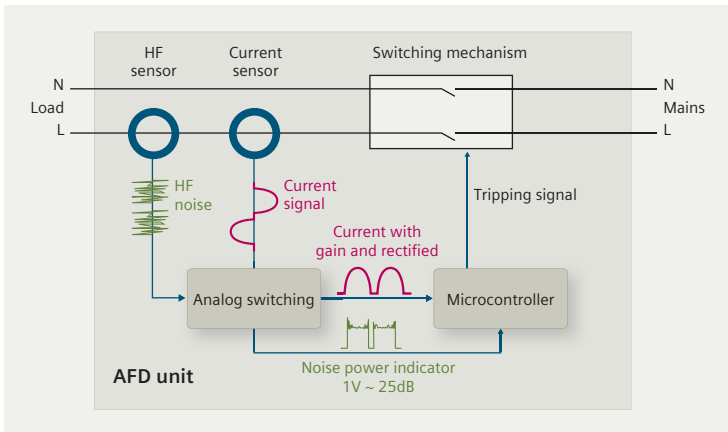


Figure 17: Basic design of the 5SM6 AFD unit

## 7.2 Detection of serial arcing faults

The detection of serial arcing faults accounts for approximately 80% of the overall calculation work performed by the microcontroller. The remaining 20% are taken up by the detection of parallel arcs.

The detection of serial arcing faults (see figure 18) is based on examining the RSSI on steep edges. The derivative  $dRSSI/dt$  is used to calculate a reference signal which is "uploaded" from  $|dRSSI/dt|$  when the edge lies in the zero crossing area of the current  $I$ . Two conditions must be fulfilled for the system to interpret a signal as an arc and consequently for the fault integrator to rise:

- reference signal > limit value G4 and
- RSSI reaches at least the threshold G2.

As soon as the fault integrator rises above the limit value G5, the microcontroller will send the trip command to the switching device.

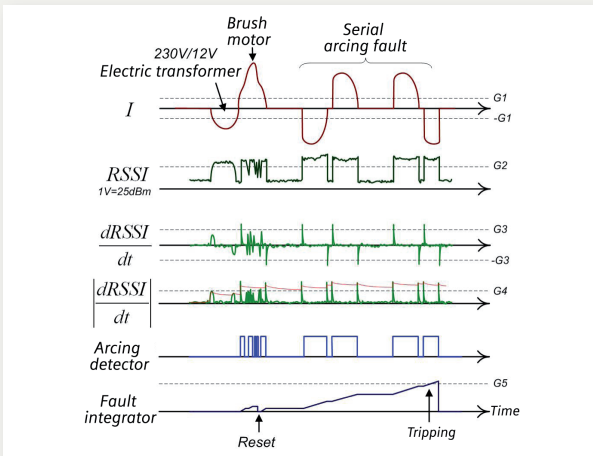


Figure 18: Signal processing for assessing serial arcing faults



To prevent unwanted shutdowns, a distinction must be drawn between arcing faults on the one hand and signals from loads such as brush motors and electronic transformers on the other, which in normal operation produce a high level of HF noise. This is achieved by the fault integrator being reset immediately to zero when certain “arc-untypical” events occur. A characteristic of such an event is for example that the RSSI shows interruptions in the signal curve.

### 7.3 Detection of parallel arcing faults

Serial and parallel arcing faults have different characteristics and are therefore analyzed in different ways. Figure 19 presents an overview of the signal processing.

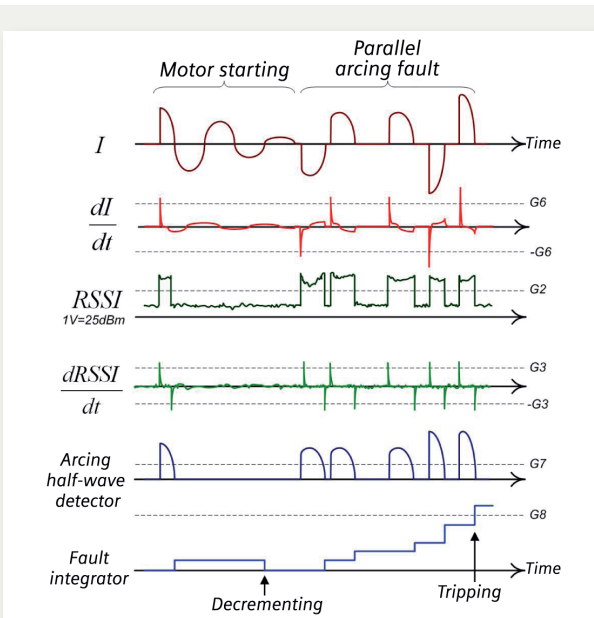


Figure 19: Signal processing for assessing parallel arcing faults

The calculation work required of the microcontroller to detect parallel arcing faults is relatively small compared to the overall algorithm, but this is not because less effort is needed to detect parallel arcing faults than serial arcing faults. The reason is rather that some of the signal variables which are calculated for the detection of serial arcs can also be used for parallel arcing faults.

The algorithm for parallel arcing faults calculates not only  $dRSSI/dt$  but also the current derivative  $dI/dt$ . The function for detecting parallel arcs does not become active until the value for  $dI/dt$  exceeds the threshold value  $G6$ . If  $RSSI > \text{limit } G2$  is also true, the current half-wave will also be interpreted as an arcing current and the fault integrator will be raised by a value proportional to the arcing current. If some time passes without another arc half-wave occurring, the fault integrator will be decreased again.

If a sufficient number of arc half-waves follow within a certain time window, the fault integrator will reach the threshold  $G8$  and the microcontroller will send the trip command via the mechanical coupling link to the mounted switching device (MCB or RCBO).

### 7.4 Prevention of unwanted trippings

For a protection device to be fully accepted, it must not only provide reliable protection against fires caused by electricity but also respond only when there are real faults. For the AFD unit this means that it must distinguish reliably between arcing faults, for which shutdown is required within defined limits, and the operational arcs of electric loads, for which no shutdown should occur.

The examples in figure 20 show a number of electric loads with highfrequency components in the current, which – particularly in the case of brush sparking on a power drill – lie very close to the signals of an arcing fault.

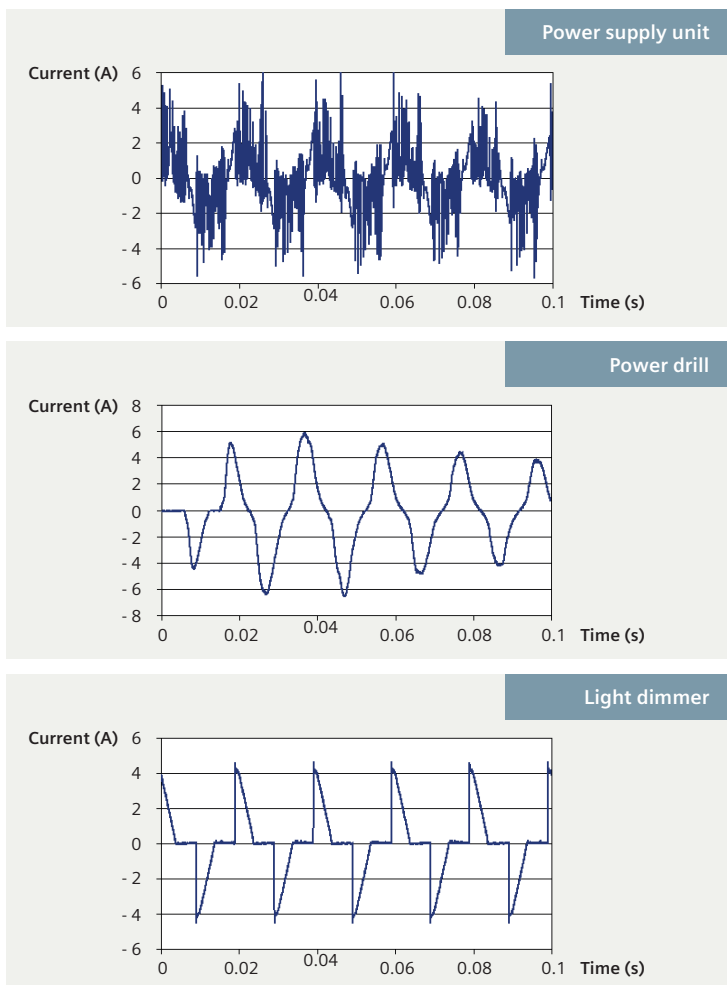


Figure 20: Examples of electric loads with high-frequency signals

Other operational faults are e.g.

- inrush currents of fluorescent lamps
- arcs through thermostat contacts, light switches, plug connectors

There should be no tripping of the AFD unit for any of these operationally created signals, nor for arcing faults in an adjacent circuit.

To reliably decide whether shutdown is necessary for an arcing fault, a number of factors are considered and compared with known fault signals (see figure 21).

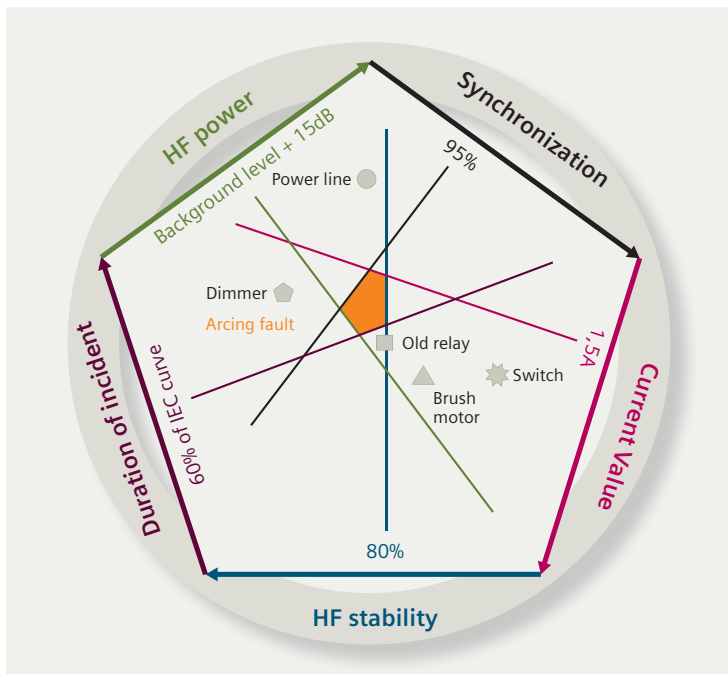


Figure 21: actors for the detection of an arcing fault

If the microcontroller analysis of the factors listed in figure 21 reveals that the signal does not lie in the red field for “arcing fault”, the decision will be “no shutdown”. What has been detected is an operational status of an electric load.

For greater reliability against unwanted trippings, the high-frequency background noise existing in installation systems was also taken into account. To achieve a high immunity to interference, the scanning is performed in the MHz range where there is an optimum difference in level between arc noise and system background noise.

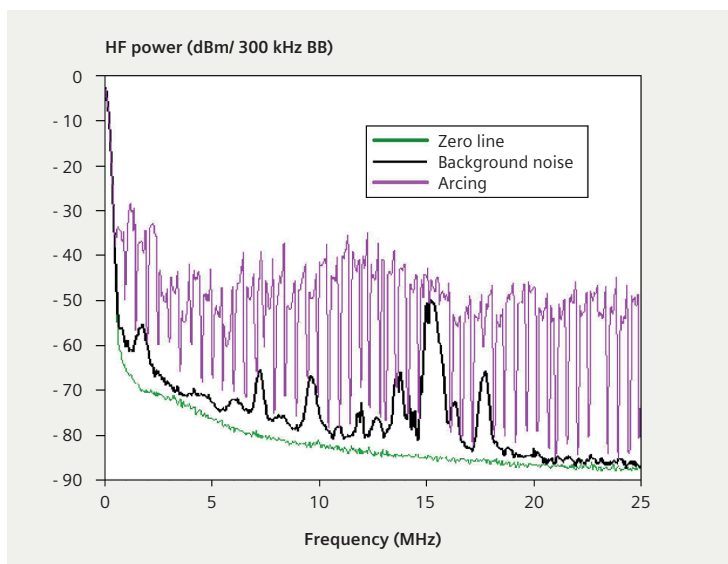


Figure 22: High-frequency noise: Background noise and arcs

The described analysis parameters and criteria are based on experience with AFCI in the U.S. and on comprehensive laboratory investigations and simulations. The applicability of the findings in practical conditions was confirmed in comprehensive field tests.

### 8. Standards and requirements for AFD units

#### 8.1 General principles

IEC 60364-1 / HD 60364-1 defines the area of application, purpose and principles which apply to the configuration of low-voltage installations. Section 131.3 "Protection against thermal effects" requires the electric system to be arranged such that it presents no risk of combustible material igniting as the result of high temperature or an arc.

This can only mean that protection must be provided against hazards which can result from arcs. In the past, a suitable protection device for this purpose was not available for circuits in low-voltage installations. This gap is filled by the AFD unit.

#### 8.2 Product standard

The product standard EN 62606 (VDE 0665-10) was drawn up for AFD units. The 5SM6 AFD unit was developed in accordance with this standard. The standard describes the usual requirements and tests, e.g. switching capacity, service life, heating and EMC, as applied for other protection devices (RCDs and MCBs).

Special test devices are described for testing the tripping in connection with serial and parallel arcing faults. The required shutdown times are then also tested under the defined conditions.

The shutdown times for small arcing currents (typical for serial arcs) are defined as a function of the arcing fault current level (see table 1)

Test arcing current	2,5 A	5 A	10 A	16 A	32 A
Maximum shutdown time	1 s	0,5 s	0,25 s	0,15 s	0,12 s

Table 1: Shutdown times for small arcing currents

With the values from 2.5 A to 32 A the tripping curve of the AFD unit for serial arcing faults lies far below the thermal tripping curves for MCBs and fuses (see figure 15 and 16). Fire protection is implemented using these low response values and short shutdown times.

The tripping curves for parallel and serial arcing faults are identical in this current range.

Test arcing current	75 A	100 A	150 A	200 A	300 A	500 A
Maximum number of half-waves	12	10	8	8	8	8

Table 2: Shutdown times for parallel arcing faults

The tripping condition defined for high arcing currents (see table 2) is not a fixed tripping time but a number of arc half-waves which are allowed to occur within 0.5 s. This is because of the often sporadic occurrence and unstable behavior of the parallel arcing fault with high currents.

As explained in Chapter 6.2, fuses and MCBs can also provide protection against parallel arcing faults at and above certain current levels, as long as their shutdown conditions are fulfilled.

In addition, special tests are performed on the tripping behavior during an arcing fault and simultaneous operation of various types of equipment in order to check that the unit works correctly. When the equipment is in operation, no shutdown must occur elsewhere if no arcing fault exists there.

### 8.3 Installation regulations

Standardization bodies have recognized the need for the use of AFD units, particularly for systems in which there is an increased risk of fire, where fire can spread easily, and where there is increased danger for people or valuable goods. With the publishing of the standard IEC 60364-4-42 the installation of AFD units should now be carried out in specific locations of use as the recognized state-of-the-art technology (see table 3)!

The AFD unit must be installed at the beginning of the circuit requiring protection. In future, after adoption of the respective european harmonization document (HD 60364-5-53), this will also be demanded in DIN VDE 0100-530 "Erection of Low-Voltage Systems – Part 530: Selection and Installation of Electrical Equipment – Switchgear & Controlgear" for vulnerable single- or double-phase AC branch circuits up to 240 V.

The international (IEC 60364-4-42:2010+A1:2014) and european installation regulations (HD 60364-4-42:2011+A1:2015) recommend the use of AFD units strongly for the locations listed in table 3.



Prescribed use for	Examples
Bedrooms and recreation rooms in care homes and daycare centers for children, disabled people and old people	Daycare centers for children, old people's homes
Bedrooms and recreation rooms in apartments with unhindered access in accordance with DIN 18040-2	Bedrooms and recreation rooms with unhindered access
Spaces or locations with a fire risk due to processed or stored materials	Barns, wood processing companies, paper factories
Spaces or locations with combustible building materials	Timber houses
Spaces or locations where irreplaceable goods are endangered	National monuments, museums, public buildings, railway stations, airports, laboratories, data centers
Bedrooms	Children's rooms, bedrooms, hotel rooms
Spaces or locations with fire-propagating structures	High-rise buildings with chimney effect
Branch circuits supplying consumer goods with high connected loads via socket outlets	Washing machines, clothes driers, dishwashers

Table 3: Locations in which AFD units are recommended in Europe and the IEC area

The AFD units must comply with the product standard EN 62606 (VDE 0665-10).

For Germany, the new version of DIN VDE 0100-420:2016-02 with the integrated supplement A1 is due to come into force on 01.02.2016 and is intended for immediate application to new electrical installations as well as to modifications and expansions of existing electrical installations. A transition period up to 18.12.2017 exists for electrical installations which are already at the planning stage or under construction.

### 9. Product description of the 5SM6 AFD unit

#### 9.1 Product versions

The 5SM6 AFD unit is offered in four versions for two mounting widths. Its rated voltage is 230 V and the rated current 16 A and 40 A. The 5SM6 AFD protection device is an AFD unit to which another protection device such as an MCB (Miniature circuit breaker) or an RCBO (Residual current operated circuit breaker) must be connected. It is this combination which then forms the AFD protection device.

- **5SM6011-1 ( $I_n$  to 16 A), 5SM6 014-2 ( $I_n$  to 40 A)**  
These AFD units are designed for mounting a compact 5SY60 or 5SY30 MCB (1+N in 1 modular width).

#### Benefits

**Compact design** in 2 MW overall width offers advantages during retrofits

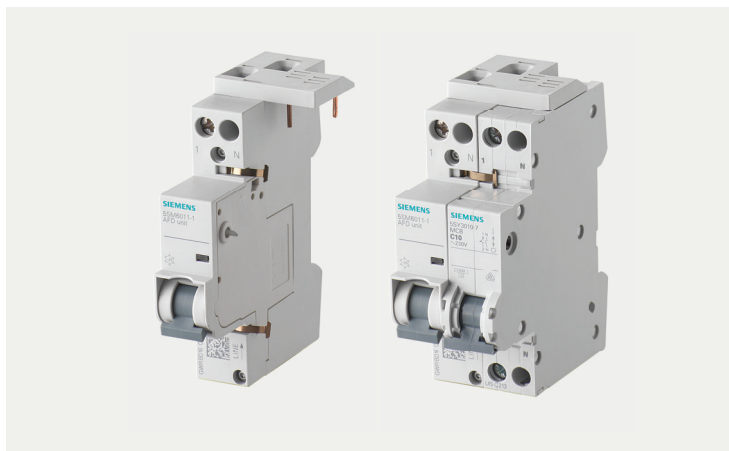


Figure 23: 5SM6011-1 AFD unit with and without a mounted 5SY60 MCB

- **5SM6021-1 ( $I_n$  to 16 A), 5SM6 024-2 ( $I_n$  to 40 A)**  
These AFD units are designed for mounting an MCB (1+N in 2 modular widths) from the 5SY and 5SL4 series or a 5SU1 RCBO (1+N in 2 modular widths).

### Benefits

The solution with an RCBO provides **complete protection** against overloads, short circuits, residual currents and fire.

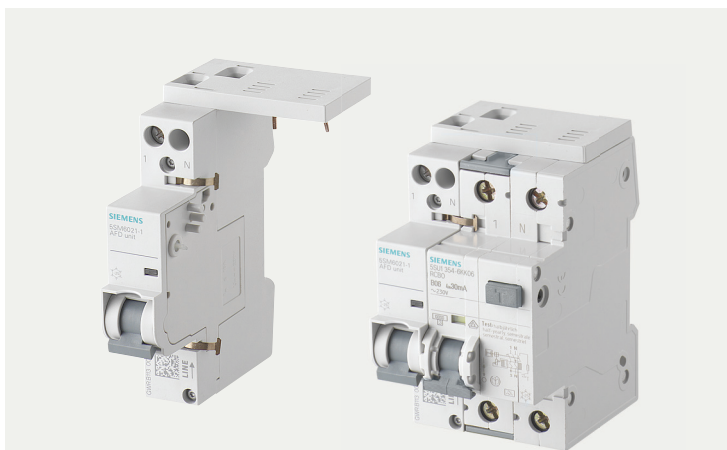


Figure 24: 5SM6021-1 AFD unit with and without a mounted 5SU1 RCBO or 5SY6 MCB

### 9.2 General properties

#### a) Assembly

The 5SM6 AFD unit can be completed on site with the required version of an MCB or RCBO and be mounted on a standard mounting rail easily, quickly and without tools. Many different versions with rated currents up to 40 A and various overcurrent characteristics and switching capacities can be fitted. This makes stock keeping far easier.

#### b) Tripping

The AFD unit detects and assesses the arcing fault. Tripping is performed via a working current relay, which trips the mounted MCB or RCBO mechanically via a coupling mechanism. This interrupts the circuit.

#### c) Infeed

Power is fed into the devices from the bottom. Infeed via a busbar network, for example, can provide a fast and reliable supply.

#### d) Additional components

Various additional components such as auxiliary current switches or fault signal contacts can be connected to the 5SM6 AFD unit. Connection to a higher-level control system is thus possible, and tripping can be reported to a central control room.

### 9.3 Special properties

#### a) Regular functional self-test

The 5SM6 AFD unit has an internal self-test function (for diagram see figure 25).

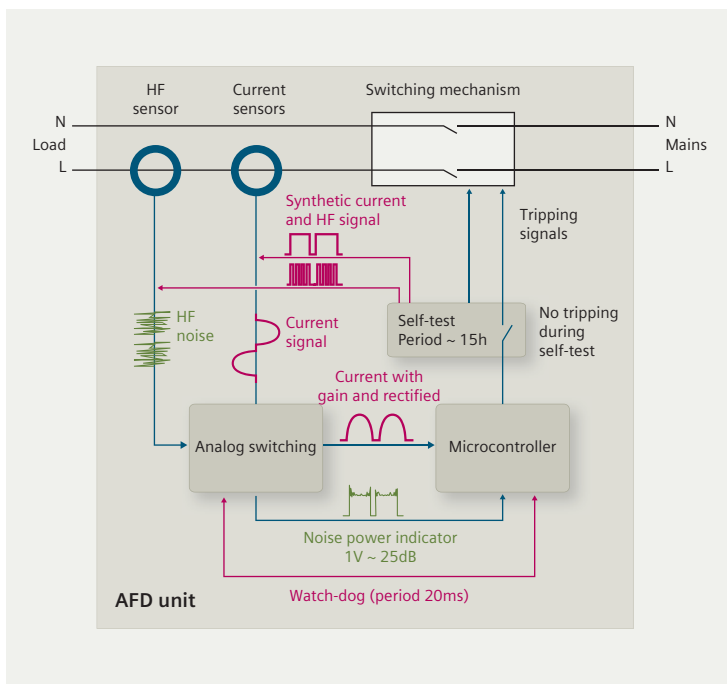


Figure 25: Diagram of the internal self-test function

This self-test is automatically initiated every 15 hours in order to test the analog electronics and the detection algorithms. The software in the microcontroller generates synthetic HF and current signals, which are similar to the signals of an arcing fault. These signals are fed into the system's detection path behind the sensors and are assessed by the analog circuit and the microcontroller. It is now imperative therefore for the microcontroller to create the trip command. During the self test the trip signal for the tripping relay is disabled for a short time (ms)

to avoid a real tripping of the device. After a successful test the tripping path is enabled again. A negative test result will cause the device to be tripped immediately. The self-test will be postponed, however, if there are initial signs of a real arcing fault or if the current consumption in the respective branch circuit is higher than the average. The test concept is rounded off by an external watch-dog which checks the program flow and the firmware integrity every 20ms.

### **b) Manually initiated function test**

A function test can be performed on the device at any time by actuating the Test/Reset button of the 5SM6 AFD unit in the normal operating state (illuminated indicator "red"). The AFD unit with the mounted MCB or RCBO must switch to OFF. After the unit switches on, the illuminated indicator must be lit "red" again continuously.

### **c) Reset button**

After the AFD unit trips and switches on again, the illuminated indicator of the Test/Reset button will indicate the reason for the tripping. This display can be reset by pressing the Test/Reset button.

#### *Note:*

A failed regular functional self-test (the display will blink yellow – red) cannot be reset.

### **d) Overvoltage protection**

If voltage increases between the line conductor and the neutral conductor occur due to system faults such as neutral conductor interruptions, the AFD unit will switch off at voltages above 275 V. The connected loads are thus protected against possible damage from overvoltage.

### **e) Operating state indicator:**

The LED of the Test/Reset button at the front indicates the operating state of the unit. This provides the user with simple and clear information about the reason for tripping (see figure 26, page 48).

### 5SM6 AFD unit fault indication



AFD unit switched on and in operation



Tripping: serial or parallel arcing fault



Tripping: overvoltage > 275V



AFD unit not ready



No voltage supply

Figure 26: Messages on the operating state indicator

In all cases in which the display of the AFD unit shows no standby signal, it is recommendable to notify an electrician who can investigate more closely the reason for the particular message.

The detailed notes in chapter 10.2 will help with an initial analysis of the trouble.

## 10. Guide

### 10.1 Installation of the AFD unit

The 5SM6 AFD unit is designed for the protection of branch circuits, in particular for lighting and socket outlets. It is installed at the beginning of the circuit in order to protect the entire circuit. It makes sense to assign the unit directly to an individual branching circuit.


#### **The following benefits are then possible:**

- The number of faulty loads and cable segments is limited
- It is easier to find the fault location
- Unwanted trippings due to superimposed interference are reduced

### 10.2 Procedure after the AFD unit has tripped

As explained in 10.1, clear assignment of the AFD units to individual branch circuits brings benefits when searching for the fault location as it enables an initial narrowing of the search field. The following troubleshooting procedure is recommended after the appearance of the message on the operating state indicator (see table 3, page 50).



Symbol	Meaning	Check / Cause	Measure(s)
	<b>Serial or parallel arcing</b>	<p>a) Smell test: "Smell of plastic"? Is discolored plastic visible (socket outlet, switch, load)?</p> <p>b) Switch on the AFD unit again. If tripping is repeated within a short time</p> <p>c) Switch on the AFD unit again → No repeat tripping within a short time: Does a load have a faulty switch or a damaged cable, or is discoloration visible on / in the wall (maybe in the neighboring room)?</p>	<p>a) Disconnect the faulty load from the network → Replace or have repaired</p> <p>b) Disconnect and switch off all the devices (lights) and switch on the AFD unit again  → <i>Tripping occurs again:</i>  <i>Notify an electrician</i>  → <i>No tripping:</i>  Switch on and plug in the loads one after the other until tripping occurs → Check whether the device is faulty (notify an electrician if necessary)</p> <p>c) Actuate the suspicious switch and wait for the reaction of the AFD unit  → Have it repaired by an electrician if necessary.  <i>If the cable is faulty:</i>  → Have it repaired by an electrician. In case of discoloration: Notify an electrician</p>




Symbol	Meaning	Check / Cause	Measure(s)
	<b>Over-voltage &gt; 275 V</b>	There was prolonged overvoltage between L and N.	If the fault reoccurs even after switching on the AFD unit once again, you should ask the power supply company whether it knows of any faults in the infeed. If no fault is known, arrange for an electrician to check the system.
	<b>AFD unit not ready</b>	AFD unit has an internal fault.	Call an electrician to test / replace the AFD unit.
	<b>No voltage supply</b>	<p>a) Check whether the general voltage supply is active or</p> <p>b) whether an upstream protection device has interrupted the supply.</p>	<p>a) Wait until the general voltage supply is active again</p> <p>b) Check the cause of the shutdown (notify an electrician if necessary) and switch on the protection device again after the cause is eliminated.</p>

Table 4: Operating states and recommended actions

## 11. Application examples

Brandschutzschalter sind am Beginn von Endstromkreisen einzusetzen. Um den gewünschten Schutz vor den Brandgefahren durch Lichtbögen zu erzielen werden im Fehlerfall Außen- und Neutral-Leiter vom Netz getrennt.

In addition to those locations mentioned in Chapter 8.3 where the use of AFD units is required or recommended in accordance with installation regulations, other applications can also benefit from the far higher protection provided by AFD units against the hazardous effects of arcing faults.

Here are more examples in which branch circuits should be protected by AFD units, particularly for socket outlets and lighting:

**a) The outbreak of a fire is detected too late or not at all and can result in mortal danger for persons in:**

- schools, universities
- hospitals
- cinemas

**b) In the vicinity there are readily flammable materials used in:**

- houses made of wood or ecological building materials
- light-weight structures and wood paneling
- loft conversions

**c) In the vicinity there are readily flammable materials stored in:**

- stables / barns
- joiner's workshops / bakeries

**d) A fire could cause damage to valuable buildings or objects in:**

- libraries
- listed buildings

In addition to these examples there are the general risks in older electrical installation systems where there is a particularly high likelihood of loose contacts or damaged insulation.

### 12. Outlook

The 5SM6 AFD unit is a new protection device for electrical installation systems, which effectively helps to reduce fires caused by electricity.

A first contribution is made by innovative products for protecting single-phase branch circuits. AFD units for three-phase current applications will follow in the future in order to provide protection against arcing faults in those areas too.

Standardization requirements in other countries are also likely to demand the use of AFD units in the future.

### 13. Sources and literature

The following sources, links and publications were among those used in drawing up this fire protection primer and can be consulted for additional information:

- [www.ifs-ev.org/schadenverhuetzung/ursachstatistiken/brandursachenstatistik](http://www.ifs-ev.org/schadenverhuetzung/ursachstatistiken/brandursachenstatistik)
- GDV (Gesamtverband der deutschen Versicherungswirtschaft e.V.):  
[www.gdv.de/Downloads/Schwerpunkte/GDV\\_Adventsbraende\\_in\\_Zahlen\\_2008-2009.pdf](http://www.gdv.de/Downloads/Schwerpunkte/GDV_Adventsbraende_in_Zahlen_2008-2009.pdf)  
[www.gdv.de/Presse/Archiv\\_der\\_Presseveranstaltungen/Presseveranstaltung\\_2001/Presseforum\\_Schaden\\_und\\_Unfall\\_2001/inhaltsseite12184.html](http://www.gdv.de/Presse/Archiv_der_Presseveranstaltungen/Presseveranstaltung_2001/Presseforum_Schaden_und_Unfall_2001/inhaltsseite12184.html)
- F. Berger, „Der Störlichtbogen – ein Überblick“, TU Ilmenau, VDE AKK-Seminar 2009
- vfdb Technisch-Wissenschaftlicher Beirat (Arbeitsgruppe Brandschutzforschung)  
[www.sachsen-anhalt.de/fileadmin/Elementbibliothek/Bibliothek\\_Feuerwehr/idf\\_dokumente/Kontextmen%c3%bc/Denkschrift\\_BS-Forschung.pdf](http://www.sachsen-anhalt.de/fileadmin/Elementbibliothek/Bibliothek_Feuerwehr/idf_dokumente/Kontextmen%c3%bc/Denkschrift_BS-Forschung.pdf)
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- John J. Shea, „Glowing Contact Physics“, Eaton Corp., IEEE 2006
- JM Martel, „Serielle Störlichtbögen in Elektroinstallationen im Niederspannungsbereich“, Siemens AG, AKK-Seminar 2009
- M. Anheuser, JM. Martel, Störlichtbögen in der Haustechnik, HDT- Seminar, München Dez 2011
- JM. Martel, M. Anheuser, A. Hueber, F. Berger, F. Erhardt, „Schutz gegen parallele Störlichtbögen in Hauselektroinstallation“, VDE AKK-Seminar 2011
- IEC 23E/742/CDV: 2012-02: IEC 62606 Ed. 1.0: General requirements for Arc Fault Detection Devices (AFDD)
- DIN VDE 0100-100:2009-06: Low-Voltage Electrical Installations – Part 1: Fundamental Principles, Assessment of General Characteristics, Definitions
- DIN VDE 0100-530:2011-06: Erection of Low-Voltage Installations – Part 530: Selection and Erection of Electrical Equipment – Switchgear and Controlgear

### 14. Appendix: PV AFD unit for photovoltaic systems

#### A.1 System description

The 5SM6 AFD unit for photovoltaic (PV) applications is a device for detecting serial arcing faults in photovoltaic systems. An arcing fault in a DC photovoltaic system is even more stable than in a system with alternating current (AC). The arc becomes more intensive and hotter, leading ultimately to a fire or fire damage in other system components unless it is detected and extinguished by interrupting the current flow.

The AFD unit for PV applications contributes very effectively to preventing fires caused by electricity in photovoltaic systems.

Intended for use as a detection device at line level, the 5SM6 PV AFD unit can also be installed for detection purposes at array and inverter level. Each system affects the effectiveness of the detection device. For this reason, different specifications must be considered when using the PV AFD unit in a particular system. Basically, it can be installed in the positive conductor (recommended) or in the negative conductor. As a rule, one PV AFD unit is required for each electrical circuit as the frequencies propagate throughout the cables connected within the system.

Using measurements taken on this conductor by the PV AFD unit, the device can determine whether an arc is forming. In case of an arcing incident, the PV AFD unit will emit an acoustic signal and an optical signal in the form of a blinking red LED. At the same time it will change the switching state of a relay (alarm output). This output can be used to initiate the correct measures if an arcing fault is detected.

## A.2 Product description

The 5SM6 094-1 from Siemens is a PV AFD unit which was developed and tested according to the requirements of UL 1699 – Sub B (PV AFD Type I). This means that the device detects serial arcing faults. After an arcing incident is detected, steps must be taken to ensure that the flow of direct current from the PV modules to the PV inverter is interrupted.

Table A.1 shows some of the technical rating data of a PV AFD unit


<b>Max. line voltage/current</b>	1.000 V DC / 40 A	
<b>Power supply</b>	24 V DC (+/- 10%)	
<b>Power consumption (passive)</b>	60 mA	
<b>Power consumption (active)</b>	120 mA	

Table A.1 Rating data of the 5SM6 094-1 PV AFD unit

The dimensional drawings are shown in figure A.1.

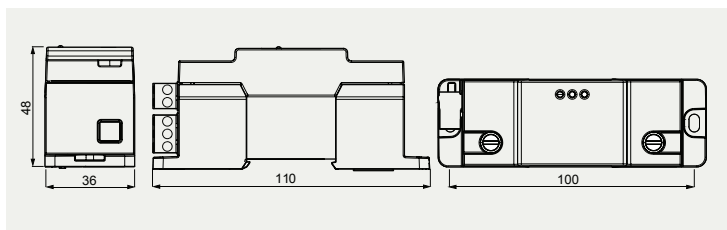


Figure A.1: Dimensional drawings of the 5SM6 094-1 PV AFD unit

### A.3 Operation

#### a) Starting

After the power supply is switched on, the PV AFD unit will start up and perform a self-test. There will be a short beep and the green LED indicator (power) will blink. When the self-test is completed, the green LED indicator will be lit continuously.

#### b) Normal operation

The PV AFD unit monitors the flow of current and analyzes the measured signal in order to determine whether there is an arcing fault. This proceeds without interruption until an arcing fault occurs and/or the DC power supply is interrupted.

#### c) Detected arcing incident

If an arcing incident is detected, the PV AFD unit will emit a signal in the form of a blinking red LED indicator (fault). At the same time an acoustic signal will be emitted for 30 seconds (after 30 seconds the acoustic signal will be emitted only once a minute).

The status of the alarm output will change. This ensures that every connected disconnecter unit will receive the signal to interrupt the DC supply between the inverter and the solar modules..

#### d) Resetting an arcing incident

The arching fault status can be reset by pressing briefly on the reset button with a pointed object (soft reset).



#### A.4 More information

Extensive information about the 5SM6 094-1 PV AFD unit, particularly concerning its function, use, troubleshooting and correction of faults, can be found in the "ADU Manual for Photovoltaic Systems 18, L1V30362803A".

**Link on the Internet (Industry Mall):**

[www.siemens.com/product?5SM6](http://www.siemens.com/product?5SM6)

## 15. List of figures and tables

<b>Page 8</b>	Figure 1:	Causes of fire in Germany in 2014
<b>Page 9</b>	Figure 2:	VdS – Statistics of defects in electrical systems (2008)
<b>Page 10</b>	Figure 3:	Finland: Fire statistics 2006; absolute number: 1,860 fires
<b>Page 11</b>	Figure 4:	Observations made in the USA before the outbreak of fires caused by electricity
<b>Page 13</b>	Figure a:	Nails or screws
	Figure a:	Overtight clip
	Figure b:	Too tight a bending radius
	Figure c:	Crushed cable
	Figure g:	Conductors damaged by claw fasteners
<b>Page 14</b>	Figure 5:	Types of arcing fault
<b>Page 16</b>	Figure 6:	Fault types and protection devices suitable for fire protection
<b>Page 17</b>	Figure 7:	Contact arc
<b>Page 18</b>	Figure 8:	Arc over a conductive insulating clearance
	Figure 9:	Outbreak of a fire due to serial arcs
<b>Page 21</b>	Figure 10:	Development of the arc using the example 2 A / 230 V
<b>Page 23</b>	Figure 11:	Development of the arc using the example 5 A / 230 V
<b>Page 24</b>	Figure 12:	Energy of the significant flame as a function of load current
<b>Page 25</b>	Figure 13:	Outbreak of flames as a function of load current
<b>Page 27</b>	Figure 14:	Current and voltage curve for a parallel arcing fault
<b>Page 29</b>	Figure 15:	Protection by MCB
	Figure 16:	Protection by fuse
<b>Page 31</b>	Figure 17:	Basic design of the 5SM6 AFD unit
<b>Page 32</b>	Figure 18:	Signal processing for assessing serial arcing faults
<b>Page 33</b>	Figure 19:	Signal processing for assessing parallel arcing faults
<b>Page 35</b>	Figure 20:	Examples of electric loads with high-frequency signals
<b>Page 36</b>	Figure 21:	actors for the detection of an arcing fault
<b>Page 37</b>	Figure 22:	High-frequency noise: Background noise and arcs
<b>Page 38</b>	Table 1:	Shutdown times for small arcing currents
<b>Page 39</b>	Table 2:	Shutdown times for parallel arcing faults
<b>Page 41</b>	Table 3:	Locations in which AFD units are recommended in Europe and the IEC area

<b>Page 42</b>	Figure 23:	5SM6 011-1 AFD unit with and without a mounted 5SY60 MCB
<b>Page 43</b>	Figure 24:	5SM6 021-1 AFD unit with and without a mounted 5SU1 RCBO or 5SY6 MCB
<b>Page 45</b>	Figure 25:	Diagram of the internal self-test function
<b>Page 47</b>	Figure 26:	Messages on the operating state indicator
<b>Page 50</b>	Table 4:	Operating states and recommended actions
<b>Page 55</b>	Table A.1:	Rating data of the 5SM6 094-1 PV AFD unit
	Figure A.1:	Dimensional drawings of the 5SM6 094-1 PV AFD unit

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