

**SIEMENS**



# 5SM Arc Fault Detection Unit for Photovoltaics

Totally Integrated Power – SENTRON

Manual

Edition

04/2015

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## SENTRON

### Arc fault detection units 5SM arc fault detection units for photovoltaic systems

Manual

|  |           |
|--|-----------|
| <u>Introduction</u>                                | <b>1</b>  |
| <u>Safety notes</u>                                | <b>2</b>  |
| <u>Description</u>                                 | <b>3</b>  |
| <u>Usage</u>                                       | <b>4</b>  |
| <u>Validation</u>                                  | <b>5</b>  |
| <u>Best practices</u>                              | <b>6</b>  |
| <u>Troubleshooting and fault<br/>rectification</u> | <b>7</b>  |
| <u>Technical data</u>                              | <b>8</b>  |
| <u>Dimension drawings</u>                          | <b>9</b>  |
| <u>Circuit diagrams</u>                            | <b>10</b> |

## Legal information

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#### **WARNING**

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#### **CAUTION**

indicates that minor personal injury can result if proper precautions are not taken.

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# Table of contents

|           |  |           |
|-----------|--|-----------|
| <b>1</b>  | <b>Introduction.....</b>                             | <b>7</b>  |
| 1.1       | Introduction .....                                   | 7         |
| <b>2</b>  | <b>Safety notes.....</b>                             | <b>9</b>  |
| 2.1       | General information - UL standard .....              | 9         |
| <b>3</b>  | <b>Description.....</b>                              | <b>11</b> |
| 3.1       | General information on arc detection.....            | 11        |
| <b>4</b>  | <b>Usage .....</b>                                   | <b>15</b> |
| 4.1       | Intended use .....                                   | 15        |
| 4.2       | String level detector .....                          | 16        |
| 4.3       | Array level detector .....                           | 17        |
| 4.4       | ADU operation .....                                  | 19        |
| <b>5</b>  | <b>Validation.....</b>                               | <b>21</b> |
| 5.1       | Validation of the ADU by customers .....             | 21        |
| <b>6</b>  | <b>Best practices .....</b>                          | <b>23</b> |
| 6.1       | Best practices .....                                 | 23        |
| 6.2       | False tripping/no detection.....                     | 25        |
| <b>7</b>  | <b>Troubleshooting and fault rectification .....</b> | <b>27</b> |
| 7.1       | Troubleshooting and fault rectification .....        | 27        |
| <b>8</b>  | <b>Technical data .....</b>                          | <b>31</b> |
| 8.1       | Technical data.....                                  | 31        |
| <b>9</b>  | <b>Dimension drawings .....</b>                      | <b>33</b> |
| 9.1       | Dimension drawings.....                              | 33        |
| <b>10</b> | <b>Circuit diagrams.....</b>                         | <b>35</b> |
| 10.1      | Circuit diagram.....                                 | 35        |

**Figures**

Figure 3-1 Typical setup of a simple PV system .....11

Figure 3-2 Typical noise in a 5 kW installation (frequency range) ..... 12

Figure 5-1 Arc generator (UL 1699) .....21

Figure 6-1 Cabling .....23

Figure 9-1 Dimension drawings .....33

Figure 10-1 Connections .....35

# Introduction

## 1.1 Introduction

The arc fault detection unit (ADU) is a device for detecting series arcs in photovoltaic systems. Arcs in electrical systems can cause fires. In DC photovoltaic systems, the arc is more stable than in a system with alternating current (AC). The arc becomes more intense and hotter, ultimately causing a fire or burn damage in other system components if it is not detected and quenched by interrupting the current flow.

This document contains all relevant information on arc fault detection in general and the best practices for using the SIEMENS arc fault detection unit for arc faults in photovoltaic systems.

Developed and tested in accordance with UL 1699 – Sub B (this standard contains the definitions, requirements and test methods for arc fault circuit interruption solutions).

Because of the random nature of arc faults with different types of arcs (series, parallel, etc.), it not possible to achieve a 100 percent detection rate. Following numerous tests with various rectifiers and application scenarios, we have achieved the highest possible detection rate. Using this technology for arc fault detection significantly increases the safety and reliability of PV systems.





## Safety notes

### 2.1 General information - UL standard

The UL standard applicable to arc fault circuit interruption is UL 1699 – Sub B, in compliance with the US National Electric Code. This standard contains the definitions, requirements and test methods for solutions for interrupting circuits in the event of arc faults.

The standard specifies three kinds of devices:

- The PV arc fault circuit interrupter (AFCI) which includes functions for detection and circuit interruption
- The PV arc fault detector (PV AFD), which only enables detection
- The arc fault interruption device (PV ID), which only includes interruption

Each of the devices mentioned in the standard can be listed as a type 1 device (series arcing) or as a type 2 device (series and parallel arcing).

#### Requirements

UL 1699 – Sub B explains that four types of series arcs need to be detected. The arcing conditions that need to be mitigated are:

- 300 W within 2.0 s with a current of 7 A and a gap of 1.6 mm
- 500 W within 1.5 s with a current of 7 A and a gap of 4.8 mm
- 650 W within 1.2 s with a current of 14 A and a gap of 3.2 mm
- 900 W within 0.8 s with a current of 14 A and a gap of 6.4 mm

Nuisance tripping tests are also required in addition to these arcing tests. The UL standard does not cover all the conditions encountered in practice to which a device will be subjected, however.



## Description

### 3.1 General information on arc detection

#### Typical system

Typical photovoltaic (PV) systems consist of a series connection of multiple solar panels, called a PV string, which typically have a voltage of up to 1000 V DC. These PV strings can be connected in parallel, called a PV array, to increase current flow. These PV strings or PV arrays are connected to a PV inverter, which converts the generated DC current of the PV panels into alternating current for feeding into the grid. A typical setup of a simple PV system can be seen in the figure. A number of different setups are possible.

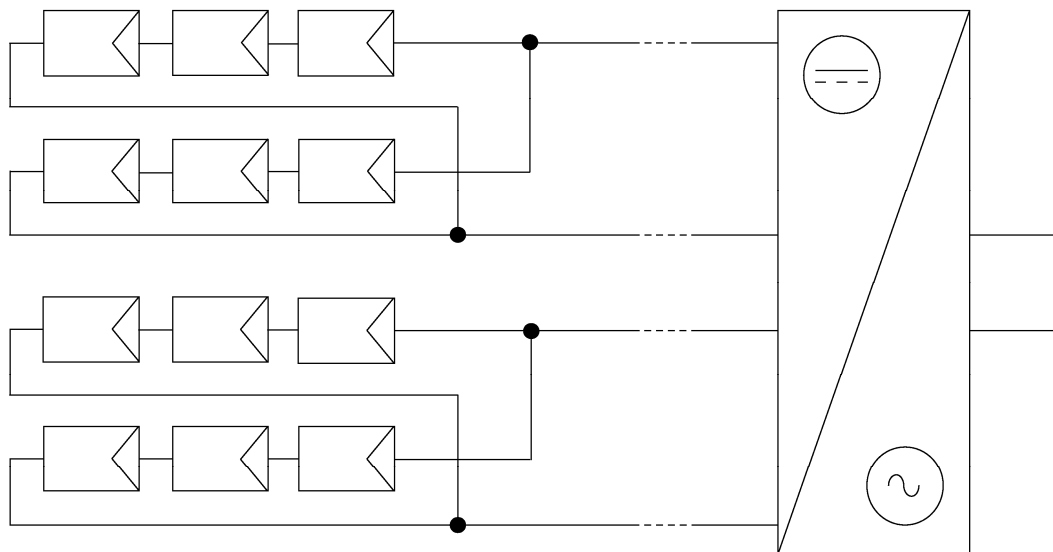


Figure 3-1 Typical setup of a simple PV system

#### Arc detection performance

To understand how the performance of detection devices is influenced throughout a PV installation, it is good to understand first of all what arcing is and how it can be detected.

### What is arcing?

An electrical arc is a current that flows from one conductor to another, with a gap between these two conductors. The arc generates heat, which can lead to a fire.

There are two kinds of arcing events that can occur in PV installations:

- Series arcing  
(arcing between two conductors connected in series to a load)  
This situation can arise, for example, if connectors or other cable connections are not fixed properly.
- Parallel arcing  
(arcing between two conductors connected in parallel to a load)  
This situation can arise, for example, if the insulation of two conductors of opposing polarity is damaged and the current begins to flow from one conductor to the other.

### How to detect arcing

All electrical circuits produce unwanted frequencies/signals, called noise. This noise can best be described as a sequence of random fluctuations of an electrical signal. The noise can be generated by numerous electronic devices with several different effects and the noise can also vary greatly. All forms of arcing also introduce additional noise into the electrical circuit.

In a PV system, the noise is detectable as different frequencies on top of the normal DC current/voltage. A device for detection of or protection against arc faults must be capable of distinguishing the system's normal "background noise" from a genuine arcing event. The technical solution to do this can vary, but basically all solutions come down to analysis of the frequencies. The figure shows a possible frequency spread in a simple two-string PV installation.

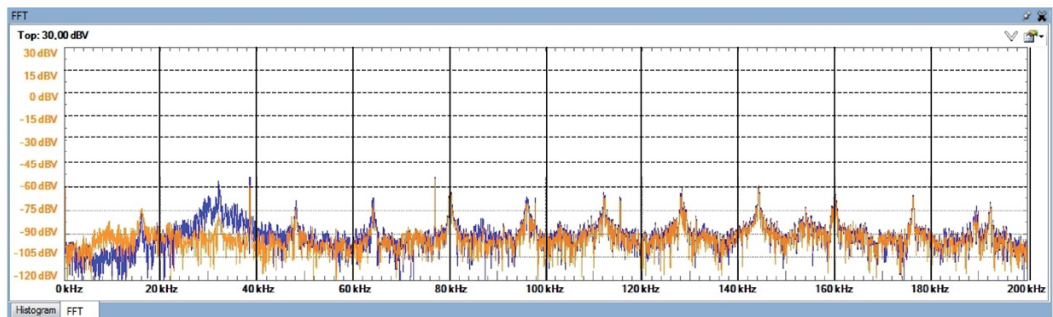


Figure 3-2 Typical noise in a 5 kW installation (frequency range)

### **Influences on detection**

The task of a protection/detection device is to detect an arcing event in the mix of all frequencies in the overall system. The inverter generates a lot of noise in a PV system during its constant search for the Maximum Point of Power (MPP). The way in which inverters search for the (optimum) MPP can vary from one manufacturer to another.

Besides the MPP tracking process, the inverter itself can also generate additional excessive noise during the inverter startup phase or during its self-test, during high solar irradiance at/over the inverter's maximum input, or during cloudy conditions.

To accurately detect an arcing event, all these possible disturbances generated must be considered in order to prevent false tripping of a protection/detection device.

Besides the noise generated by an inverter itself, the detection range (distance) between the arcing event and the detection device is significant. Arc detection works best with a high signal-to-noise ratio. The greater the distance between the device and the arcing event is, the lower the signal-to-noise ratio will be. The arc will be masked by the "background noise".

The UL 1699 – Sub B standard has incorporated tests for determining whether the AFCI or AFD is functioning correctly (detection). The tests consist of detecting the arcing wattages – mentioned further above – in the proximity of the device and at a distance of 66 meters (200 feet) from the device. But also tests are included to determine whether the device is subjected to false tripping (detection when there is no arcing event). The tests consist of testing the functioning of the device when installed in combination with an inverter that can create disturbances that could mask the arcing event. But also it might occur that the device does not detect the switching of an interrupting device, for example a DC disconnecter.

### **Siemens 5SM6 094-1 arc fault detection unit**

The Siemens ADU 5SM6 094-1 has been developed and tested in compliance with the requirements of UL 1699 – Sub B. This means that the device detects series arcs. After detection of an arcing event, steps must be taken to ensure that the DC current flow from the PV panels to the PV inverter is interrupted.



# Usage

## 4.1 Intended use

The Siemens ADU is intended for use as a string level detector, but can also be used as an array and inverter level detector. Each system influences the effectiveness of the detection device. This is why various stipulations have to be observed when using the ADU in the respective system. Basically, the device can be installed in the positive conductor (recommended position) or in the negative conductor. In general, one ADU is required for each electrical circuit as the frequencies in the system travel through all connected cabling.

On the basis of measurements performed by the ADU on this conductor, the device can determine whether an arcing event is taking place. If there is an arcing event, the ADU will trip and issue an acoustic signal, an LED will flash red as a visual indication, and a relay state change (alarm output) will take place. This output can be used to initiate the correct action to be taken on detecting the arcing event.

Again please note that it is recommended to only use one ADU per MPP tracker. If there is only one MPP tracker in the inverter, all the string inputs will be connected internally, resulting in the noise signal being present in all strings as well. This is why only one detection device is recommended for this type of application.

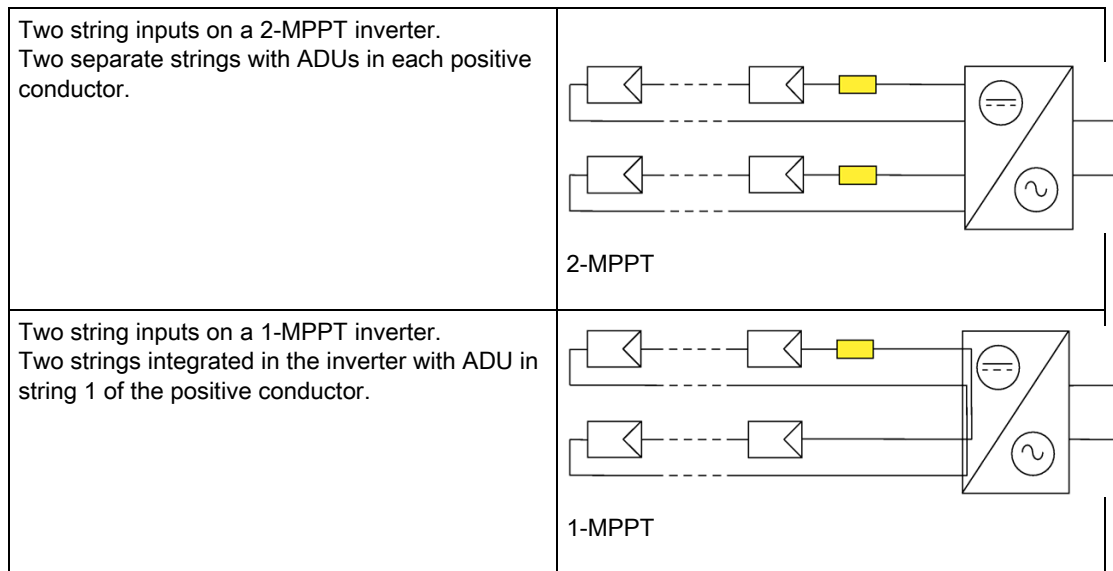
## 4.2 String level detector

### Usage

When the string level detector is used, it is advisable to install the ADU in the proximity of the PV inverter. The ADU will then be easily accessible if an arcing event should occur, in which case the relay output can also be connected easily to the inverter or a disconnecting device.

### Installation

Typical for this type of installation is a relatively low current (maximum of approx. 8 A). The figures show two possible configurations with the ADU as a string level detector.



According to the UL standard, detection must be possible within 66 meters between the ADU and the arcing event (measured upstream or downstream of the device).



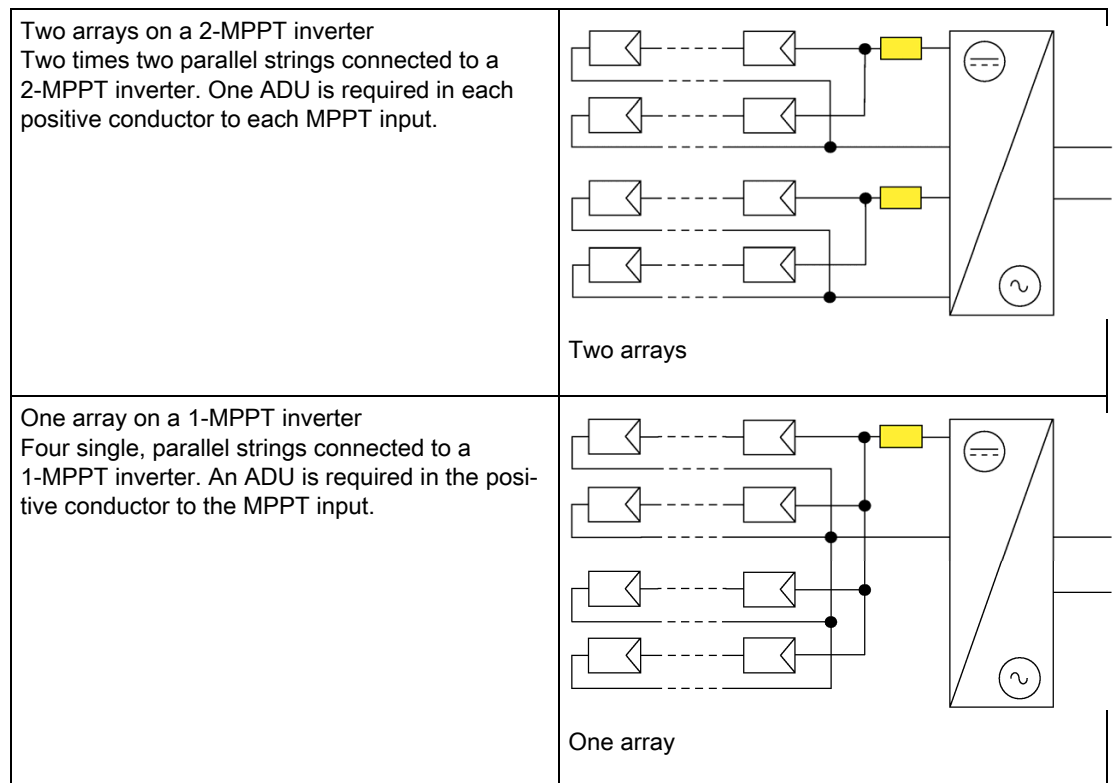
## 4.3 Array level detector

### Usage

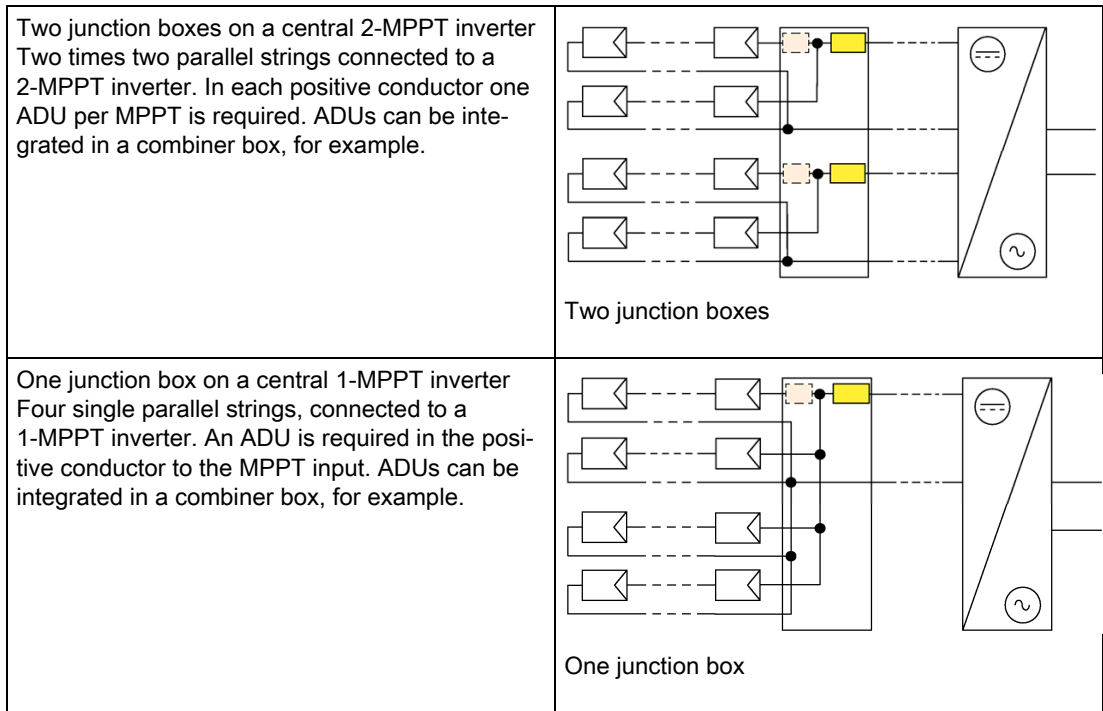
When the ADU is used as an array level detector, it is recommended to install the ADU in the proximity of the PV inverter or in the unit in which the strings are combined (junction box). In the case of an arcing event, a tripping signal is generated and can be used to operate a disconnecting device.

### Installation

Typical for this type of installation is a high current (e.g. 16 A). Possible configurations with the ADU as an array level detector are shown below.



4.3 Array level detector



As can be seen in the figure above, if the array is designed for a current higher than the 40 A admissible for the ADU, it is also admissible to install an ADU in a junction box in the incoming string before the junction. According to the UL standard, detection must be possible within 66 meters between the ADU and the arcing event (measured upstream or downstream of the device).

## 4.4 ADU operation

### Powering up

The arc fault detection unit starts after switching on the power and runs a self-test (short beep). The green LED (Power) also flashes. The green LED lights up continuously when the self-test ends.

### Normal operation

The arc fault detection unit monitors the flow of current and analyzes the signal measured to determine whether an arc fault has occurred. This takes place continuously until an arc fault occurs and/or the DC power supply is interrupted.

### Detected arcing event

If an arc fault is detected, the ADU signals this with a flashing red LED (fault). At the same time, a buzzer will start beeping for 30 seconds (after 30 seconds, the buzzer will only beep once a minute).

The status of the alarm output changes, thus ensuring that every connected disconnecting device receives the signal to interrupt the DC supply between the inverter and the solar panels.

### Resetting an arcing event

The arc fault situation can be reset by briefly pressing the Reset button with a pointed object (soft reset).



**MAKE SURE THAT THE ROOT CAUSE OF THE ARC FAULT IS RESOLVED!**

As soon as the status has been reset, the ADU returns to normal operation and the status of the alarm output switches back to normal.

### Fault state/initiating the ADU self-test

If an ADU fault occurs, the unit signals this by flashing of the green and red LEDs. Also the buzzer starts beeping and the relay output changes state.



## Validation

### 5.1 Validation of the ADU by customers

#### Testing of ADU functioning with a real arcing event (non-PV setup)

Functioning of the ADU can also be verified by connecting a DC power source (several car batteries) and a resistive load in series with the ADU. If an arc generator setup as described in Section 23 of UL 1699 – Sub B is also used (see also the following figure), an arcing event can be brought about to check the functioning of the ADU.

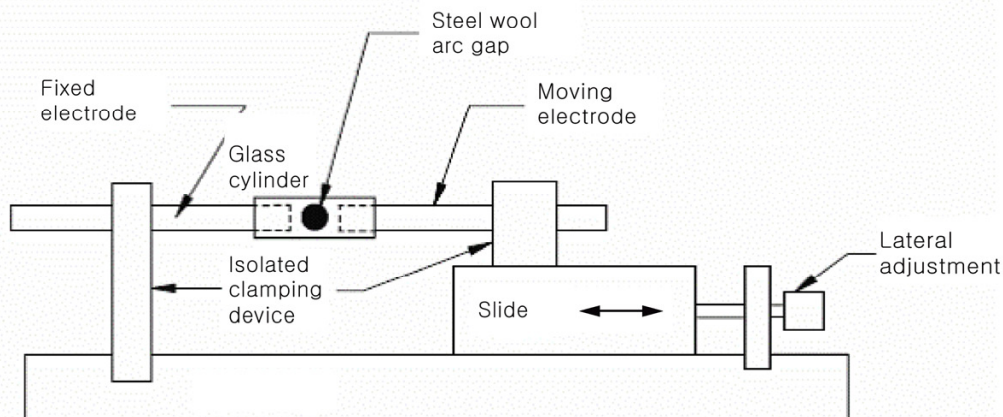


Figure 5-1 Arc generator (UL 1699)

Please note that more requirements have to be observed further to this setup in order to ensure that the ADU will detect an arc. Among other things, there needs to be adequate supply of power or current (min. voltage 100 VDC, min. current 1 A) and, moreover, the arc must be maintained for about 1 second. A resistive load must be used as the load. An inductive load does not produce the desired effect. If the ADU is operating correctly, it will detect the arcing event. The unit indicates this by means of a flashing red LED, by issuing a sound and by changing the relay status.

Note that use of DC power supplies to simulate PV panels has proven to be unreliable. Noise signals generated by the power supply disrupt arc detection, therefore leading to unwanted detections.

**Testing of ADU functioning with a real arcing event (PV setup)**

Functioning of the ADU can also be verified by connecting a PV source (multiple PV panels) to the ADU. If an arc generator setup is also used, an arcing event can be brought about to check the functioning of the ADU.

## Best practices

### 6.1 Best practices

After product launch, the ADU was installed and tested in real PV installations. The results of the tests with these installations have led to the best practices listed below.

#### Number of ADUs to be used

The number of ADUs to be used depends on the type of installation, the inverter and the prevailing distances. Siemens recommends using one ADU for every MPP tracker. This ADU enables detection at a distance of up to 66 meters from the ADU.

#### Resetting multiple ADUs

Large-scale installations with multiple ADUs can be reset in one step. Removing/interrupting the 24 V DC power supply to these ADUs for more than one second will cause the ADUs to stop operating. As soon as the 24 V DC power supply is restored, the ADUs will start again and run a self-test. After this they resume normal operation again.

#### Cabling of the installation

The cabling of the installation has a considerable influence on the signal-to-noise ratio and thus on the ADU's performance.

##### 1. Balanced positive and negative DC cabling

If there is an imbalance between positive and negative DC cabling, crosstalk may occur between the two. As crosstalk can produce a high signal-to-noise ratio in the ADU's detection range, the connected ADUs may trip falsely. You are advised to ensure balanced cabling.

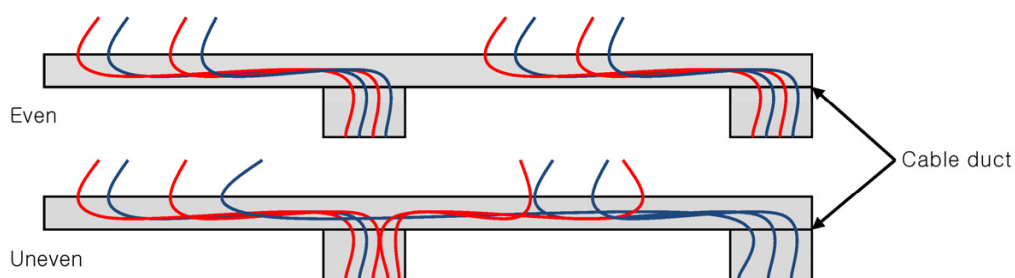


Figure 6-1 Cabling

2. AC and DC in the same cable duct

Not only crosstalk between the positive and negative DC cabling can occur, but also through the AC grid which, in turn, can lead to false tripping of the ADU. It is highly probable that the AC and the DC cabling are routed in the same cable duct. This must be prevented.

3. Excessively long cables

As the ADU works best with a high signal-to-noise ratio, it is best to minimize cable lengths. Excessive, unnecessary cable lengths will damp the noise signals and reduce the signal-to-noise ratio. This can result in failure to detect an arcing event.

**Disturbances by other equipment**

As detection of an arcing event is based on the frequencies and signal-to-noise ratio, any interference source can lead to false tripping by detection devices. For example, if the ADUs are installed in an industrial environment in which there are also frequency converters for motor drives, it is advisable to house the ADUs in metal enclosures. In this way, the ADUs are installed in Faraday cages, which minimizes the risk of false tripping.

**Parallel arcing**

Although developed and tested as a series arc detection device, in most cases the ADU is also capable of detecting parallel arcs. However, the ADU is not officially certified for detecting parallel arcing events.



## 6.2 False tripping/no detection

There are two possible problems seen in practice when implementing the ADU in a PV system, namely false tripping and failure to detect arcs. For all proposals below, proper functioning of the arc detection system needs to be verified for every PV system installed.

- **Implementing an additional filter in the event of false tripping**

If false tripping occurs in an ADU (e.g. inside the junction box), the focus must primarily be on clarifying the cause. If all attempts to rectify the fault on cabling, components, etc. do not lead to remediation of false tripping, it is highly probable that the false tripping is caused by the inverter's switching behavior during the MPP search. In this case, an additional filter on the DC lines helps to suppress the background noise in these lines. One of the ways to do this is to use a so-called common-mode choke in the junction box. Arcing events can still be detected despite using this filter because they differ from the system's background noise.



## Troubleshooting and fault rectification

### 7.1 Troubleshooting and fault rectification

#### Single string inverter setup

Q: I use my inverter for one MPPT with an ADU. The latter suffers false tripping. What is the solution?

A: *Either arcs really do occur in your system or you have an inverter in your system that generates a frequency pattern that interferes with detection. We have tested the ADU with many different makes of inverters. Not all inverter types have been tested, however. Chapter 6.2 contains a possible solution.*

#### Multiple MPPT inverters or multiple inverters next to each other

Q: My inverter has multiple MPP trackers. How should I connect the ADU?

A: *Make sure that every MPPT has its own ADU and make sure that the positive and negative poles of each group of solar panels is joined at the same MPPT input. False tripping occurs as soon as the negative and positive cables of the various groups of solar panels or inverters are mixed.*

Q: Is it allowed to join together the positive cables of two MPPTs before connecting to the inverter?

A: *No.*  
*The two MPPTs can cause mutual interference, thus generating even more noise which, in turn, generates false tripping.*

Q: My inverter has multiple MPP trackers and the ADUs are connected correctly. What can be the reason for the false tripping?

A: *There are several possible causes of false tripping:*

- *An arcing event really does occur in the system.*
- *The cables are not laid correctly. See Chapter 6.1.*
- *The positive or negative pole of one MPP tracker has been inadvertently connected to another MPP tracker.*
- *The positive or negative pole of one inverter has been inadvertently connected to another inverter.*
- *Power optimizers are in use.*
- *Somewhere in the building there are frequency converters that cause electromagnetic interference.*  
*The solution is to house the ADU in a metal enclosure.*
- *Due to its design, the inverter generates a frequency pattern within the ADU's detection range.*

#### **Integration of ADUs in junction boxes**

Q: Can (may) the ADU be used together with central inverters?

A: *No, the device can (may) only be used with string inverters.*

*When the device is used in combination with central inverters, testing must be performed in accordance with Chapter 5 to determine whether an arc can be detected in your system in compliance with the UL standard (UL 1699 – Sub B). False tripping can also occur due to different frequency patterns in comparison with string inverters.*

Q: The ADU has passed the tests detailed in Chapter 5, but false tripping nevertheless occurs. What can I do to remedy this problem?

A: *When the ADU is used in junction boxes, the inverter is usually a large string inverter or even a central inverter. These tend to have a different switching behavior. This could cause the false tripping. To solve this problem, you can use a common-mode choke in the combiner box.*

Q: What setup should I choose to protect my PV module panel? How should it be integrated in the junction boxes?

A: *We advise you to use one ADU for each junction box (up to 8 strings), in which all incoming strings are joined in two outgoing cables (positive and negative). The ADU can be positioned in one positive cable of an incoming string. The arcing signal is transmitted through all connected cables.*

*Please note that the ADU is certified up to a maximum cable length of 66 meters.*

*In the case of multiple junction boxes next to each other, a setup is required that enables simultaneous resetting because it is highly probable that two or more ADUs will simultaneously issue an alarm because arcing signals in a copper cable generally travel over large distances. During startup of the ADU, a self-test generates a frequency pattern that can also cause tripping of an ADU in the vicinity in the same electrical circuit. Make sure that the ADUs in one and the same circuit are connected to the same power supply unit.*

Q: How should I reset multiple ADUs that are installed in a solar PV park?

A: *All ADUs should be connected to one single 24 V cable that runs through the entire PV park and supplies the ADUs with 24 V. To reset the ADUs all at the same time, disconnect or interrupt the cable's 24 V supply voltage and restore the 24 V power supply after approximately one second. During startup of the ADU, a self-test generates a frequency pattern that can also cause tripping of an ADU in the vicinity in the same electrical circuit.*

### Laboratory testing

Q: I test arc detection in a laboratory with a DC power supply and observe false tripping.

A: *DC power supplies generate frequencies in the ADU's detection range. The solution is to test the system with real solar panels.*

### Technical support

[www.siemens.com/lowvoltage/support](http://www.siemens.com/lowvoltage/support)

*Please provide the following information (if known):*

- Which ADU is installed (specify the type number and production date)?
- How is the ADU used or installed? One ADU per MPPT?
- Where is the ADU installed (specify the enclosure type, the physical installation location and the surrounding equipment)?
- What are the ratings of the string/array in which the ADU is installed?
- Which inverter is connected (specify the make and type code)?
- When does the problem with the ADU arise? A few examples:
  - During ADU starting
  - During inverter starting after installation
  - Every morning during starting of the installation
  - Every evening during shutdown of the installation
  - During the day if irradiation is high



## Technical data

### 8.1 Technical data

#### 1. String specifications

|                                    |                               |
|------------------------------------|-------------------------------|
| Max. string voltage/current        | 1000 VDC/40 A                 |
| Number of poles                    | 1 pole (positive or negative) |
| Minimum cable diameter, cage clamp | 2.5 mm <sup>2</sup> /AWG14    |
| Maximum cable diameter, cage clamp | 10 mm <sup>2</sup> /AWG8      |

#### 2. Power specifications

|  |                            |
|--|----------------------------|
| Power supply                           | 24 VDC (± 10%)             |
| Current consumption (passive)          | 60 mA                      |
| Current consumption (active)           | 120 mA                     |
| Maximum cable diameter, connector (2P) | 2.5 mm <sup>2</sup> /AWG14 |

#### 3. Alarm specifications

|  |                                   |
|--|-----------------------------------|
| Alarm relay load (resistive)             | 0.3 A at 125 V AC; 1 A at 30 V DC |
| Arc detection threshold                  | 100 VDC - 1A                      |
| Maximum cable diameter, connector (3P)   | 2.5 mm <sup>2</sup> /AWG14        |
| Arc fault detection (in accordance with) | UL1699B - PV AFD Type 1           |

#### 4. Other technical data

|                             |                |
|-----------------------------|----------------|
| Degree of protection        | IP20/NEMA1     |
| Operating temperature range | -20°C to +50°C |
| Storage temperature range   | -40°C to +75°C |
| Relative humidity (RH)      | 5 to 85%       |
| Weight (approx.)            | 120 g          |





## Dimension drawings

### 9.1 Dimension drawings

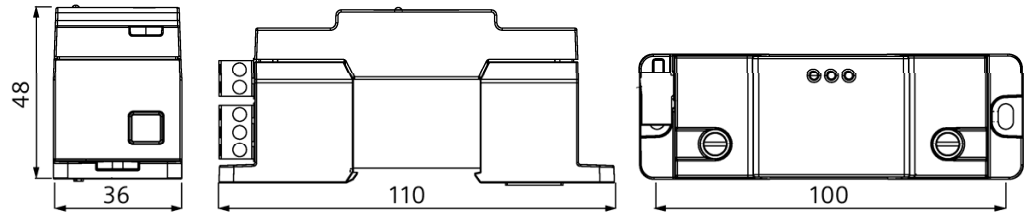


Figure 9-1 Dimension drawings



## Circuit diagrams

### 10.1 Circuit diagram

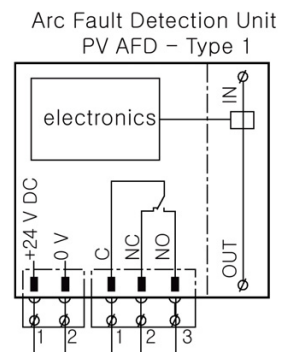


Figure 10-1 Connections

LV Explorer – Discover Low Voltage in 3D  
[www.siemens.com/lowvoltage/lv-explorer](http://www.siemens.com/lowvoltage/lv-explorer)

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