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White Paper

SolarEdge Safety Solution

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SolarEdge Technologies, Inc.

SolarEdge

In 2006, SolarEdge revolutionized the solar industry by inventing a better way to collect and manage energy in PV systems. Today, we are a global leader in smart energy technology. With a relentless focus on innovation and ongoing deployment of world-class engineering capabilities, we continue to create smart energy products and solutions that power our lives and drive future progress.

SolarEdge developed a DC optimized inverter solution that changed the way power is harvested and managed in PV systems. It both maximizes power generation and lowers the cost of energy produced by the PV system to yield an improved return on investment (ROI). Additional benefits include comprehensive and advanced safety features, improved design flexibility, and improved operation and maintenance (O&M), with module-level and remote monitoring.

A typical SolarEdge DC optimized inverter system consists of inverters, SolarEdge Power Optimizers, and a communication device that enables access to the SolarEdge Monitoring Platform. Smart Energy Management software and hardware that can be added to the SolarEdge solution include a battery pack for energy storage and the SolarEdge Home Smart Energy Management system, which enable greater savings for the system owner.

SolarEdge solutions address a broad range of solar market segments, from residential to commercial and small utility-scale solar installations.

Key advantages of the SolarEdge solution include:

- Enhanced safety
- High reliability
- Maximized PV module power output
- Optimized architecture with economies of scale
- Advanced system design flexibility
- Continuous monitoring and control to reduce operation and maintenance costs
- Efficient energy storage and backup

Safety Considerations and Measures in PV Systems

More and more companies are choosing to deploy PV solar systems. The main reasons for this decision are the relatively low cost of PV energy, even without subsidies, regional and national government incentives, increased awareness of solar energy as a viable alternative to legacy grid power, and lastly, an increase in the cost of fossil-based fuel.

Having multiple types of integrated safety mechanisms in a PV system make it safer. When faults are detected, these mechanisms work together to contribute to the personal safety of employees, system owners, and first responders, such as technicians and firefighters, by protecting them from physical harm and hazards.

Commercial buildings and infrastructures are high-value assets. Mechanisms that safeguard against fire help avoid property loss and interruption of business operations that can present a significant cost. If property damage does occur, some insurance companies provide compensation for buildings on which the rooftop PV installations include adequate safety detection and protection measures. Additionally, some insurance companies refuse to insure properties with solar installations that do not employ adequate safety measures.

Operation of a Typical PV System

PV systems are mainly composed of PV modules and inverters.

- PV modules generate clean electrical power by converting sunlight into DC power.
- Inverters then convert DC power into grid-compliant AC power used to power homes, buildings, and businesses.
- Power is provided for utilities when needed.

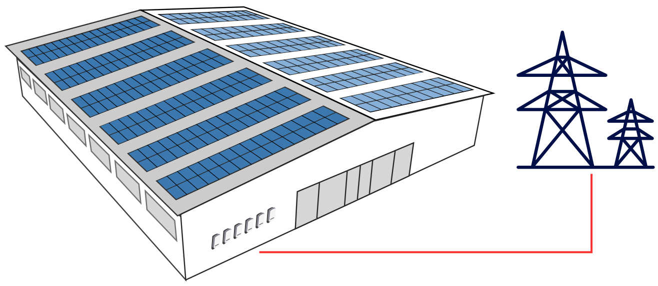


Figure 1: Typical PV system components

The Need for Safety Measures

Given that traditional PV installations can reach voltages as high as 1,500 VDC, precautions must be taken to ensure the safety of people and assets. SolarEdge architecture maintains safe energy production at the inverter level and allows the shutdown/bypass only of the relevant modules/strings. When shutdown is necessary, SolarEdge inverters either automatically shut down, as defined by set of events, or shutdown can be initiated manually.

Enhanced Safety – Holistic Approach

The SolarEdge PV system adopts a holistic approach in reducing the risks associated with electrocution and fire by providing an integrated safety solution that combines enhanced protection and detection mechanisms.

These mechanisms comply with stringent safety requirements by:

- Ensuring that a PV system's DC voltage is reduced to a safe level when the system is shut down.
- Providing early fault detection.
- Applying active and continuous protection mechanisms.
- Supporting module-level monitoring with actionable fault alerts.
- Allowing conductors to rapidly discharge their electric load down to safe voltage levels.

Arc Fault Circuit Interrupter (AFCI)

In compliance with the UL 1699B arc detection standard, SolarEdge inverters have built-in protection designed to protect against the effects of arcing faults that pose a risk of fire. In addition, SolarEdge is a member of the IEC 63027 working group, collaborating with other PV system vendors, grid operators and stakeholders. Even though the IEC 63027 standard is still in draft stage, the SolarEdge system is poised to comply with the latest draft specifications.

Risk Management - SafeDC™

SafeDC™ is a built-in module-level safety feature that minimizes the risk of electrocution from high DC voltage. The default voltage of the Power Optimizer is 1Vdc. This ensures touch-safe voltage levels, maintaining the string voltage at below 30 VDC or 50 VDC, according to the different industry standards. Only when the inverter is in production mode and all parameters are verified will the Power Optimizer voltage be increased to its optimal operating level.

Figure 2: Touch-safe voltage levels with SafeDC™

Power Optimizers will automatically revert to its natural default touch-safe voltage of only 1Vdc when AC is turned off or during safety-related events. SafeDC™ will be activated in these cases:

- During installation, when strings are disconnected from the inverter, or the inverter is turned off.
- When the inverter is locked or disabled.
- When the inverter or AC connection is shut down.

The SolarEdge SafeDC™ feature is certified in Europe as a DC disconnect according to IEC/EN 60947-1 and IEC/ EN 60947-3 and to the safety standards VDE AR 2100-712 and OVE R-11-1.

Early Detection and Prevention

SolarEdge equips its next generation S-Series Power Optimizers with the latest SolarEdge Sense Connect* technology, which is designed to proactively detect abnormal PV connector behavior and possibly prevent events that result from bad craftsmanship, wiring or connectors. Temperature sensing in SolarEdge inverters enables monitoring the AC and DC side interface installation as well as aids in detecting bad connections before they turn into an arc. When abnormal temperatures are detected, the system will even shut down the inverter.

Rapid Shutdown (RSD)

Rapid Shutdown (RSD) is a safety mechanism that refers to the fast discharge of conductors to a safe voltage level. In North America, the National Electrical Code (NEC), section 690.12 requires that, in rooftop PV systems, controlled conductors located outside the boundary or more than 1m (3 ft) from the point of entry inside a building shall be limited to not more than 30 volts within 30 seconds of rapid shutdown initiation. Controlled conductors located inside the boundary or not more than 1m (3 ft) from the point of penetration of the surface of the building shall be limited to not more than 80 volts within 30 seconds of rapid shutdown initiation. SolarEdge is among very few solar equipment manufacturers that provide integrated rapid shutdown functionality in compliance with NEC regulations. Other manufacturers offer this capability via external components such as contactors, shunt trip breakers, or other remotely controlled switches, which may add complexity and increase costs.

System Monitoring and Management

SolarEdge provides real-time remote monitoring at the module, string, and system level, allowing for greater visibility of system performance.

- The SolarEdge Monitoring Platform conducts detailed analytics tracking and provides reports on energy yield, performance ratio, and financial performance.
- Automatic alerts support accurate and immediate fault detection, remote maintenance, and rapid response that helps to minimize and shorten onsite visits.
- Hardwired Ethernet, Wi-Fi, or cellular connections are the supported communication options that connect SolarEdge inverters to the Monitoring Platform. The Monitoring Platform is easily accessed from your computer and mobile device, anytime, anywhere.

Figure 3: PV module layout and monitoring system

Keep Your System Updated with the Latest Capabilities

We constantly collect data from our two million plus installations worldwide in an ongoing initiative to keep our systems working at state-of-the-art performance levels. Customers can benefit from our insights and improvements by adopting easy to run software updates that ensure their installations are equipped with the newest safety features and functionality.

* Pending firmware version update

Arc Overview

What is an Arc?

An arc is an unintended, self-sustaining plasma discharge initiated across a small air gap. Arcs are physical phenomena which can be characterized by various properties such as: heat generation, light emission (visible, UV, IR), RF radiation, magnetic field, acoustic and chemical reactions (ionization, recombination).

An electric arc is hot enough to melt glass, copper, and aluminum, and it can initiate the combustion of surrounding materials. Since photovoltaic systems have many connection points, arc faults can occur.

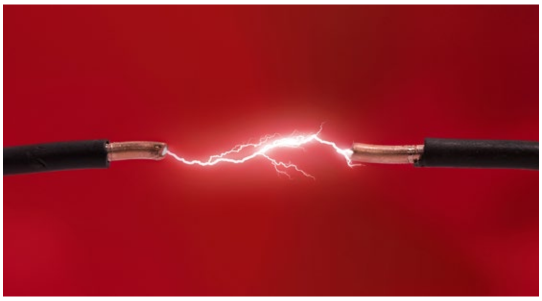


Figure 4: Electric arc

The subsequent damage caused by such faults can result in real danger to the photovoltaic systems, homes, and facilities on which they are installed. Even worse, they can endanger the lives of people occupying those properties.

Figure 5: Firefighters responding to a fire on a PV installation

The PV industry has grown rapidly in recent years, and the number of fires caused by arc faults has increased accordingly. This justifies the need for smart systems that can protect homeowners and facility owners from potential hazards.

DC Arcs in Photovoltaic Systems

Arcs can occur in small gaps between two connecting terminals, such as module connectors in PV modules and connections in the combiner box. This usually results from using bad connectors or from installation errors such as improper wiring and crimping that can cause poorly formed connections. Other conditions that can lead to arcs are aging, weathering, mechanical damage, and physical damage by animals. Bad joints decrease the cross-section area, effectively increasing the connection resistance, and significantly increasing heat. This increases thermal stress, due to the higher operating temperatures, which eventually produces loose connections. Then, a small gap can develop between two connecting terminals while interrupting the flow of current.

Figure 6: MC4 connector after arc fault

When the electric field across the gap exceeds approximately 3V/µm (the actual value of breakdown strength depends on the surrounding environment), the air in the gap starts to ionize and arc plasma develops. When left undetected, an arc will form.

The Challenges in Detecting Arc Faults

There are two main challenges in detecting arcs:

- Every arc has a different characteristic - as described above, arc faults can occur in various locations in the PV system with different electrical characteristics such as current, voltage, energy levels and duration.
- Noise levels - the photovoltaic system environment is exposed to several types of background noise.

General Approaches for Identifying Arcs

Arc faults occur in different frequency bands and amplitudes. As shown in Figure 7, there is a spectrum difference between an arcing and a non-arcing system, showing that an arc model is a time-varying non-linear model, which can be detected by monitoring the spectrum changes.

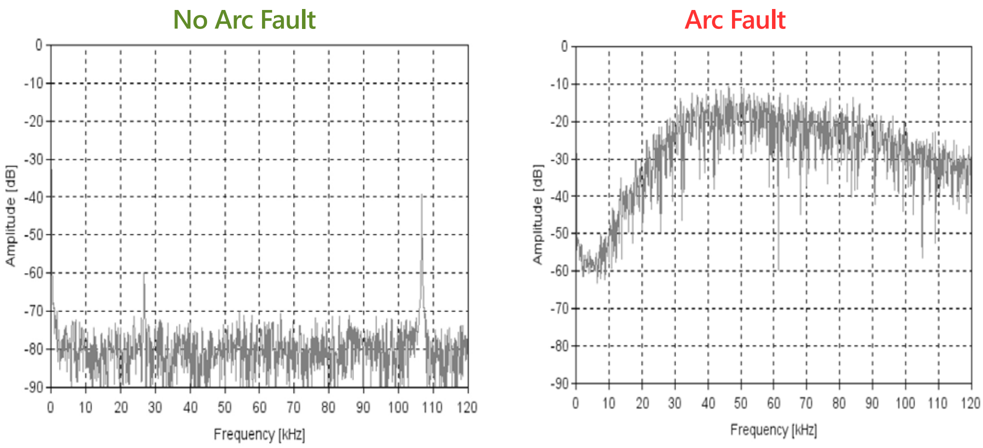


Figure 7: Amplitude of frequencies with and without arc faults

As shown in Figure 8, arcs can be monitored in the current spectrum where the spikes of the arcs can reach up to 1A.

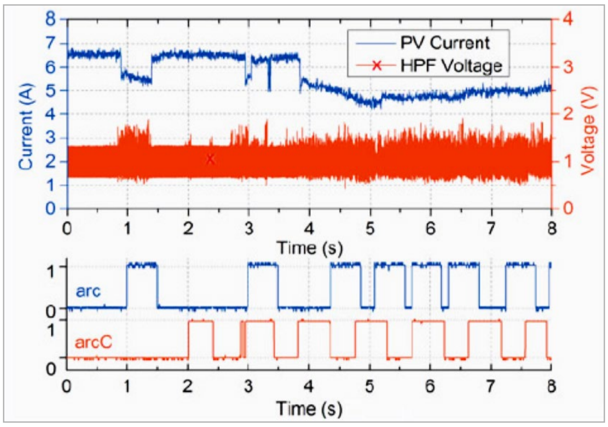


Figure 8: Current as a function of time in an arc scenario

Artificial Intelligence (AI) Based Methods

Some systems use a “black box” approach for DC arc fault detection. This approach uses AI-based methods such as Deep Neural Network (DNN) and Support Vector Machine (SVM) to infer a potential arc condition **without** specifically detecting an underlying electrical condition. However, with this method, false positive rates vary according to environmental conditions.

As opposed to other vendors, SolarEdge implements “white box” algorithms that are based on data from millions of installed systems. See the section below for more details.

SolarEdge Arc Fault Circuit Interrupter (AFCI)

A Big-Data Driven Hybrid AFCI Algorithm Solution

SolarEdge has invested extensive research to better understand and characterize arcs in PV systems. Based on data obtained from our install base of over two million sites, SolarEdge has developed state-of-the-art arc fault detection algorithms and AFCI mechanisms. These algorithms were implemented on over 2.5 million inverters and tested by certification entities and third-party companies to ensure that they pass the set requirements and provide the expected performance.

The SolarEdge AFCI solution reflects the company's experience, extensive deployment, and collection of big data from all sites. As a result, the AFCI mechanism is potentially effective under a full range of electrical conditions and types of installations.

The SolarEdge arc detection algorithm provides a comprehensive and holistic approach to arc detection and prevention that addresses all aspects of an arc fault event:

- Arc Fault Detection (AFD) – the capability to detect an arc event.
- Arc Fault Prevention (AFP) – provides a module-level arc fault prevention mechanism.

Arc Fault Detection (AFD)

SolarEdge inverters include DSPs that run the AFCI algorithms locally. For accurate and effective arc detection, the SolarEdge solution is based on data collection and analysis performed at the module level (Power Optimizer) and at the string level (inverter).

The active Arc Fault Prevention mechanism is based on insights provided by the SolarEdge Power Optimizer. The next generation S-Series Power Optimizers extend this AFP mechanism with SolarEdge Sense Connect, which detects abnormal events and proactively prevents arc faults.

How does this work (refer to figure 9)?

Each SolarEdge S Series Power Optimizer continuously "senses" the connector's temperature, proactively detecting abnormal connector behaviour and providing continuous health check of connectors and wiring. When the temperature crosses a certain threshold, the Power Optimizer triggers an event. In parallel, the SolarEdge inverter will stop production and then resume production according to standard safety guidelines. The inverter sends a system event to the SolarEdge Monitoring Platform, which processes the event, alerts the installer including location identification. The information can be viewed also during installation via the SetApp mobile app to identify possible problems while still on site to reduce truck rolls.

Finally, some SolarEdge inverters are equipped with a built-in sensor on the DC/AC terminal blocks, which detects bad connections by identifying abnormal temperatures. When abnormal temperatures are detected, the system automatically alerts the installer and shuts down the inverter if required.

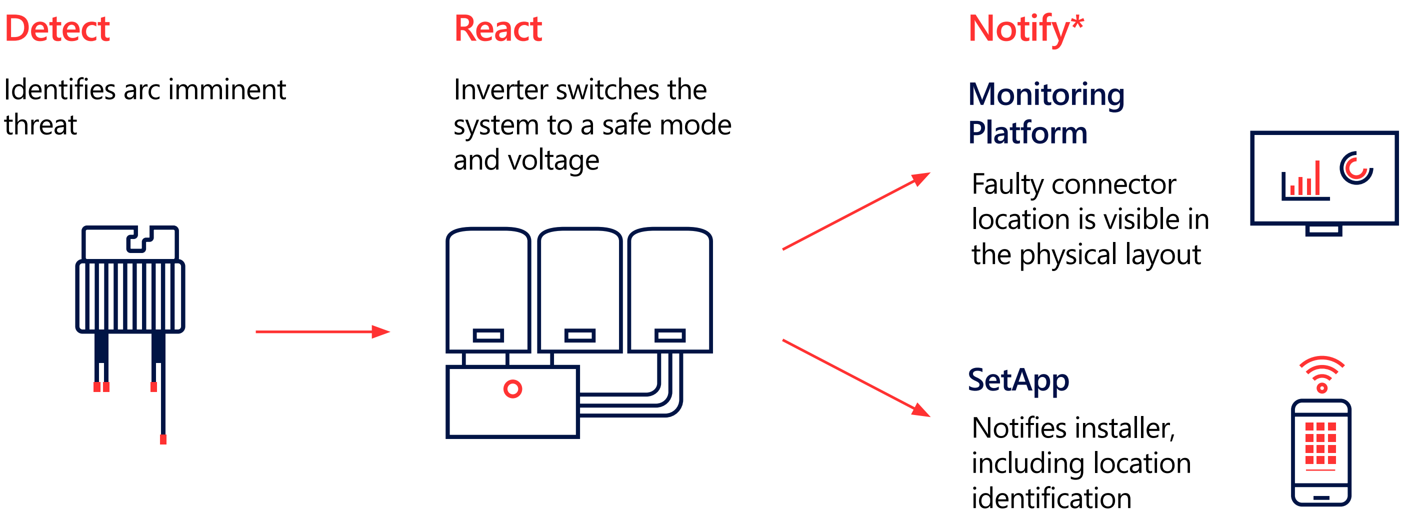


Figure 9: SolarEdge Sense Connect Operation

* Pending firmware version update

Testing and Verification – Standards Requirements

There are two main standards that must be considered in the discovery and treatment of arcs:

- UL 1699B: adopted by the US and Canada, was written in 2011 and then upgraded in 2018 after field experience.
- IEC 63027: the European standard still in draft state. SolarEdge is an active member and co-author of this standard.

Table 1: Summary of the main differences between arc discovery treatment strategies

Topic	UL 1699B (2018)	IEC 63027
Type of arc fault	Series	Series
Location of arc fault	Input and string cables	Input and string cables
The full string impedance	50 µH + 0.7 µH/meter beyond 80 meters	50 µH
Arc duration and energy thresholds	Disrupt arcing event in less than 2.5 seconds, and limit energy not to exceed 750 J	Disrupt arcing event in less than 2.5 seconds, and limit energy not to exceed 750 J
Resuming operation	After each arc is extinguished, the system shall delay no less than five minutes before resuming operation. The five-minute delay is not required after a manual reset. After five arc events in a 24-hour period, the system shall open the circuit and shall require a manual reset before returning to operation.	No manual procedure is required, if a minimum interruption time of five minutes is ensured before continuing operation of the array. When interrupting the fifth time within a 24-hour period, the reset must be performed manually.

The network requirements for AFCI Function Detection can be found in the UL 1699B (2018) standard document, figure 29.15.

In addition to SolarEdge meeting the above-mentioned standards, our testing and capabilities exceed the minimum market requirements. This ensures maximum safety, as follows:

False alarm rate

The SolarEdge inverter can be locked in response to each alarm event and stop production. Given this, it is important to measure the capability of the system to handle false alarms.

Considering this need, SolarEdge's solution ensures the number of false alarms is kept to a minimum.

Speed of electrode separation rate

One of the methods for simulating DC arcs is based on simulating electrode separation. An arc occurs when electrodes are separated during load current flows.

The standard for Separate Rate as defined in UL 1699B is 2.5-5 mm/s.

SolarEdge AFCI - Performance Test Verification Results

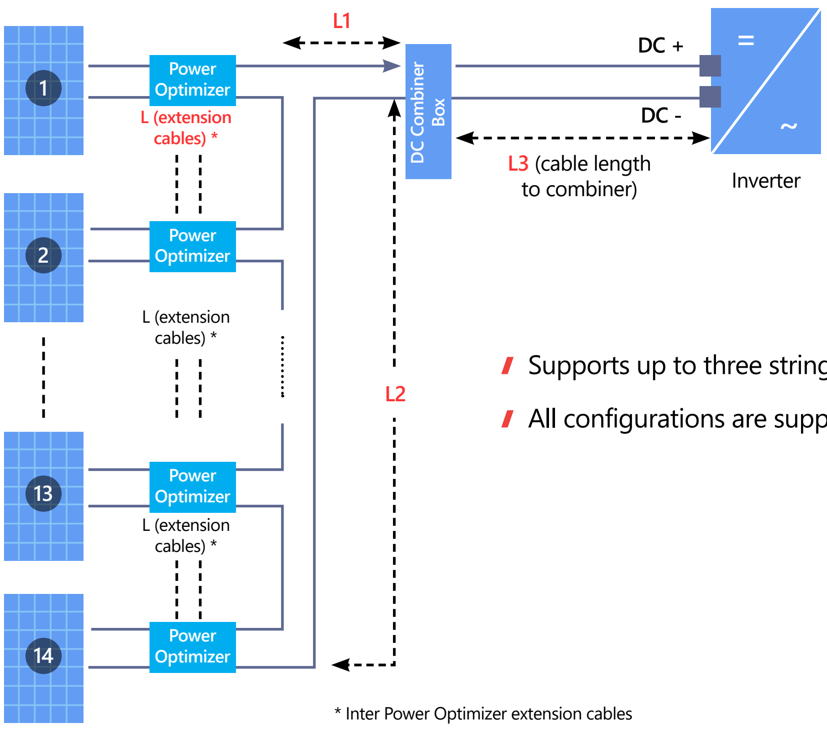
The SolarEdge safety solution employs a variety of active safety mechanisms that are designed to ensure continuous protection of the SolarEdge PV system.

This includes rapid reduction of DC voltage to touch-safe levels upon system shutdown, early fault detection and possible prevention, and real-time, actionable module-level alerts.

In doing so, the SolarEdge safety solution is compliant with US UL 1699B 2018 and European IEC 63027 safety standards as indicated in Table 2 and Figure 10 below.

Table 2: SolarEdge Performance Compliance Standards (refer to figure 10)

Types of arcs that can be detected	Defined by UL 1699B 2018
Maximum length (L1 + L2 + L-ext-cable + L3), for single string (round trip)	Up to 400m
Total string length (L1 + L2 + L-ext-cable + L3), total for all connected strings to inv/unit (round trip)	Up to 700m
Arc detection accuracy	99%
Additional technical requirements	None



- Supports up to three strings per inverter/unit
- All configurations are supported as long as long as the rules in table 2 apply

Figure 10: SolarEdge Cabling Standards