

/ Perfect Welding / Solar Energy / Perfect Charging



# **FIRE SAFETY OF PV SYSTEMS**

## **INSIGHTS AND RECOMMENDATIONS**

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Business Unit Solar Energy / System Technology

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Gender-specific wording refers equally to female and male form.

# TABLE OF CONTENTS

<b>1</b>	<b>Introduction .....</b>	<b>4</b>
1.1	Objective .....	4
1.2	Risk of Fire vs. Risk for Firefighters .....	4
<b>2</b>	<b>PV Fires Statistics – Incidents and Causes .....</b>	<b>6</b>
2.1	Germany .....	6
2.2	United Kingdom .....	8
<b>3</b>	<b>DC-Connectors – Necessity and Error Source .....</b>	<b>9</b>
3.1	Installation Errors .....	9
3.2	DC-Connector Mismatching.....	10
3.3	Power Optimizers – a Dangerous Safety Measure .....	11
<b>4</b>	<b>Safety for Firefighters and the NEC 2017 .....</b>	<b>13</b>
<b>5</b>	<b>Fulfilling Rapid Shutdown in NEC 2017 .....</b>	<b>15</b>
5.1	Selection Criteria for an Optimal Shutdown Solution.....	15
5.2	Issues with Current MLPE Solutions .....	15
5.3	Rapid Shutdown Solutions with SunSpec Powerline Communication .....	16
5.4	Comparison Example between MLPE and Module-Integrated SunSpec Solutions .....	18
<b>6</b>	<b>Recommendations &amp; Conclusion .....</b>	<b>20</b>
<b>7</b>	<b>Literature .....</b>	<b>22</b>

# 1 INTRODUCTION

Recently, unsubstantiated safety concerns have been created by the media about the safety of PV systems, despite photovoltaics being an extremely safe technology. Rumours about burning houses that can't be extinguished or firefighters who do not attack a fire if PV is involved put rooftop PV systems in a light they do not deserve. In fact, PV systems are of a very high safety level concerning preventative fire protection as well as operational safety and security in case of a fire. Many recent analyses of fire incidents related to PV, like those from TÜV Rheinland and Fraunhofer ISE (Sepanski et al., 2015), BRE (2017b) and IEA PVPS (2017) show that components of PV systems are tested according to very stringent safety and reliability test protocols during the manufacturing process. This ensures they fulfil electrical safety requirements of various national and international codes and standards. Additionally, aspects like the creation of fire compartments, accessibility, functional integrity and mechanical safety have to be considered in planning, construction and operation. Modules that act as a part of a roof (building integrated PV) have to fulfil the same fire resistance tests as the roofing material.

According to the International Energy Agency Photovoltaic Power Systems Program (IEA PVPS), *"PV systems do not pose health, safety or environmental risks under normal operating conditions if properly installed and maintained by trained personnel as required by electric codes."* (IEA PVPS 2017; p. 2).

## 1.1 Objective

The aim of this paper is to evaluate and display the actual situation concerning fire incidents including a PV system in selected countries and to derive if there is a significant contribution of building related PV systems to the risk of fire. Although PV is a very safe technology and incidents are rare, this analysis should highlight the most common reasons for arc faults and therefore possible fire incidents. Based on the findings of this failure analysis in selected countries, suitable measures for reducing the already small fire risk induced by PV systems are derived.

Although low voltage electricity has been a part of almost every building for decades now, and fire fighters know how to deal with it, a certain precariousness exists in the public when it comes to the topic of extinguishing a PV-related fire. By analyzing different operation tactics and strategies as well as safety measures to reduce the risk of electrocution for firefighters, this paper provides recommendations on how to act in the event of a fire.

Furthermore, the new requirements for module-level shutdown (introduced by NEC 2017 to further increase safety for emergency responders) as well as their unintended consequences are discussed, and an overview of the options to safely fulfil such requirements is provided.

## 1.2 Risk of Fire vs. Risk for Firefighters

Before going into detail regarding the analysis of fire incidents related to PV, a distinct definition is necessary regarding the risks related to a fire.

When talking about the safety of PV systems, possible occurring risks related to a fire can be divided into two categories:

- / Risk of fire:** This risk describes the probability that a fire occurs. The higher the probability, the higher the risk that a fire occurs.
- / Risk for emergency responders:** This risk describes the probability that a firefighter or other emergency personnel is injured during a rescue or fire-fighting mission.

These two categories are both important when talking about increasing the safety of PV systems. Taking appropriate measures which reduce the risk of fire directly reduces the risk for emergency responders, as no fire means no risks for the emergency responders, and therefore this should be the top priority as far as PV fire safety is concerned.

This conclusion is not always applicable the other way around. The new requirements for module-level shutdown introduced by NEC 2017 are intended to increase the safety of emergency responders. However, significant attention should be paid with regard to the type of measure used to comply with the standard. Some measures currently available on the market, such as module-level power electronics (MLPE) devices, often do not contribute to reducing the risk of fire, but could instead lead to an even increased risk of fire, as it will be discussed in chapters 3 and 5.

Fronius sets the focus on decreasing the risk of fire as a required first step for increasing the already high level of security concerning fire protection, which directly influences the risk for emergency responders and therefore is a sustainable and more beneficial approach. When implementing an additional layer of safety for firefighters, proper measures have to be developed that are able to achieve such a higher protection without compromising the first layer of safety, which is aimed at reducing the risk of fire.

## 2 PV FIRES STATISTICS – INCIDENTS AND CAUSES

As mentioned in the introduction, this chapter should give an overview about fire incidents involving building related PV systems in selected countries.

### 2.1 Germany

Germany is one of the oldest PV markets worldwide, and the biggest in Europe. Its installed PV capacity is comparable with that of the United States, and represents therefore a good source of reference. In 2015, TÜV Rheinland in cooperation with Fraunhofer Institute for Solar Energy Systems (ISE) published a report about fire incidents involving building related PV systems until 2013 and their causes. This detailed analysis showed that 430 Fire/Heat damages were officially reported, whereof 210 were triggered by the PV system itself. Compared to a total number of installed PV systems of about 1.3 Mio. as of 2013, this equals 0.016 % of all PV systems installed in Germany (Sepanski et al. 2015). The following figures show an allocation of the fire incidents to various types of error and error sources.

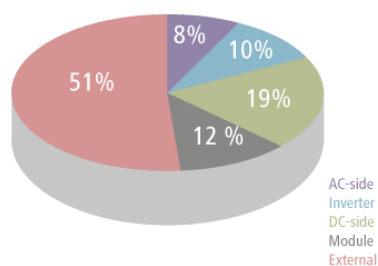


Figure 1: Error source; allocation for Germany (data from Sepanski et al. 2015)

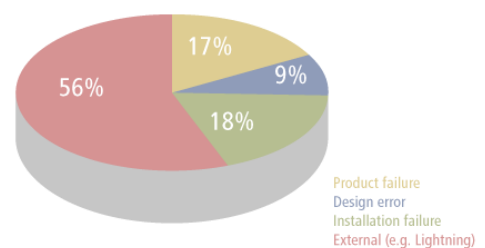


Figure 2: Type of error; allocation for Germany (data from Sepanski et al. 2015)

The analysis showed that more than 70 % of the errors are based on external influences or installation failures (see figure 2). Only about 17 % of the errors resulting in fire are based on product failure (see figure 2), and only 10 % of the errors occur in the inverter (see figure 1).

A detailed fault analysis pointed out the most common reasons for serial arc faults, which are the main causes of fire incidents involving PV systems. These reasons are listed in Table 1, and sorted according to component and likelihood of occurrence.

Table 1 Possible reasons for arc faults, sorted according to component and likelihood of occurrence (Sepanski et al. 2015)

<b>Component</b>	<b>Possible reason for arc fault</b>
<i>DC-connector</i>	connector poorly crimped on site
	mismatch of DC-connector
	connector not fully inserted
	connector mechanically damaged or corroded due to improper installation, weathering, animal bites or production failure
	connector poorly crimped in production
<i>Screw terminals in field distributor, inverter (DC-side)</i>	screwing contact tightened inadequately, inadequate insertion of cable
	undersized, arranged too close to each other
	clamped cable-insulation
<i>Solder connection (in module)</i>	bad solder connection, aging due to mechanical/thermal stress
<i>Bypass diode</i>	overvoltage due to lightning storm or switching operation in system
	long-term failure due to thermal overload
<i>Module</i>	cell damages (micro cracks, ...)
	torn-off cell connectors
	cell breakage/glass breakage
<i>DC-fuses</i>	unsuitable fuses
	incorrect installation
<i>DC-cable</i>	long-term failure due to weathering (UV-radiation, humidity, temperature change, ...)
	damage due to improper installation (kink, ...)
	animal bites
<i>DC-circuit breaker</i>	not suitable for DC
<i>Junction box</i>	bad solder connection
	aging due to mechanical/thermal stress
<i>General installation</i>	improper protection class (humidity, dust)
	top down cable insertion in PG-gland

The analysis showed that, next to external error sources, most of the errors that lead to a fire incident are due to installation failure on the DC-side of the PV system. Especially the DC-connectors, which connect the PV modules of an array, are a common error source.

## 2.2 United Kingdom

In 2017, a detailed report about fire incidents involving building related PV systems was published by the BRE National Solar Centre.

According to this report (BRE 2017a), compared to a total number of about 1 million PV systems installed in the UK, 58 fire incidents involving building related PV systems were reported since 2010. This is equivalent to a percentage of 0.0058 % of all installed PV systems in the UK. The following figures show an allocation of the fire incidents to various types of error and error sources.

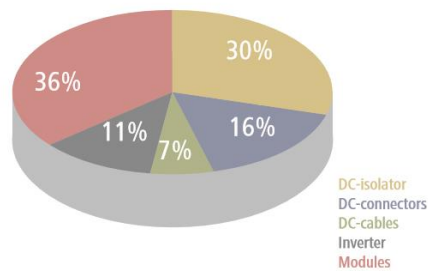


Figure 3: Error source; allocation for the UK (data from BRE 2017a)

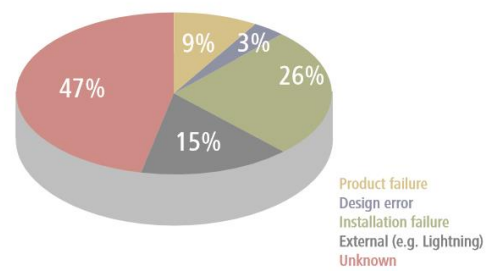


Figure 4: Type of error; allocation the UK (data from BRE 2017a)

Excluding the category “Unknown type of error”, most of the fire incidents are based on external influences and installation failures. Only about 9 % of all fire incidents were demonstrated to be caused by product failure (see figure 4).

The following list shows the main causes of arcing identified in the report (BRE 2017a), many of which are related to issues with DC connectors. Contrary to the list in table 1, this list is not sorted by likelihood of occurrence.

- / Moisture ingress causing a degradation of connections in DC connectors, junction boxes & switches
- / Incorrectly crimped connector contacts
- / Mating of incompatible connectors & sockets
- / Connectors & sockets are not fully engaged
- / Not fully tightened screws or loose screw terminals within junction boxes or isolator switches
- / Poorly soldered joints within a PV module junction box or other junction box defects
- / Damage to a component (e.g. broken busbars within a PV module)

Similar to the results of Germany (see chapter 2.1), the analysis of the fire incidents involving building related PV systems for the UK showed that, next to external error sources, most of the errors that lead to a fire incident are due to installation failure on the DC-side of the PV system. DC-connectors were found to be a highly vulnerable component subject to installation faults, and the related issues will be highlighted in the next chapter.



### 3 DC-CONNECTORS – NECESSITY AND ERROR SOURCE

Both presented studies identified that DC-connectors are one of the main causes for serial arcs in a PV-array. Other countries as well, for example the Netherlands (ECN TNO 2019) and Italy (Corpo Nazionale dei Vigili del Fuoco 2015), reported that problems with DC connectors are a major cause for failures that can lead to a fire. In recent fire events in the US, which involved rooftop PV installations on several Walmart's retail stores between 2012 and 2018, connectors were similarly considered as the most likely root cause that triggered the fires (Roselund, PV Magazine 2019, Lopez, Business Insider 2019).

The two main root causes for the occurrence of serial arcs in DC-connectors are:

- / Installation errors: Connectors not properly inserted together and poor attachment of connectors to cables.
- / Connections realized with connectors from different manufacturers (mismatching)

This chapter will further address the main problems with DC-connectors.

#### 3.1 Installation Errors

Human error is considered to be the principal cause of fires (Sepanski et al. 2015, BRE 2017c, p. 10). The most common types of installation faults include connectors which are not fully inserted, as well as poor on-site crimping of the connectors onto cables, both resulting in bad connections with higher transition resistance, which significantly increase the risk of arcing. Typical error sources include:

- / Use of incorrect crimping tools, such as combination pliers (Figure 5), or cheaper and low-quality pliers
- / Mounting of connectors without enough precision, e.g. due to time pressure or uncomfortable conditions
- / Insufficient training of installation personnel

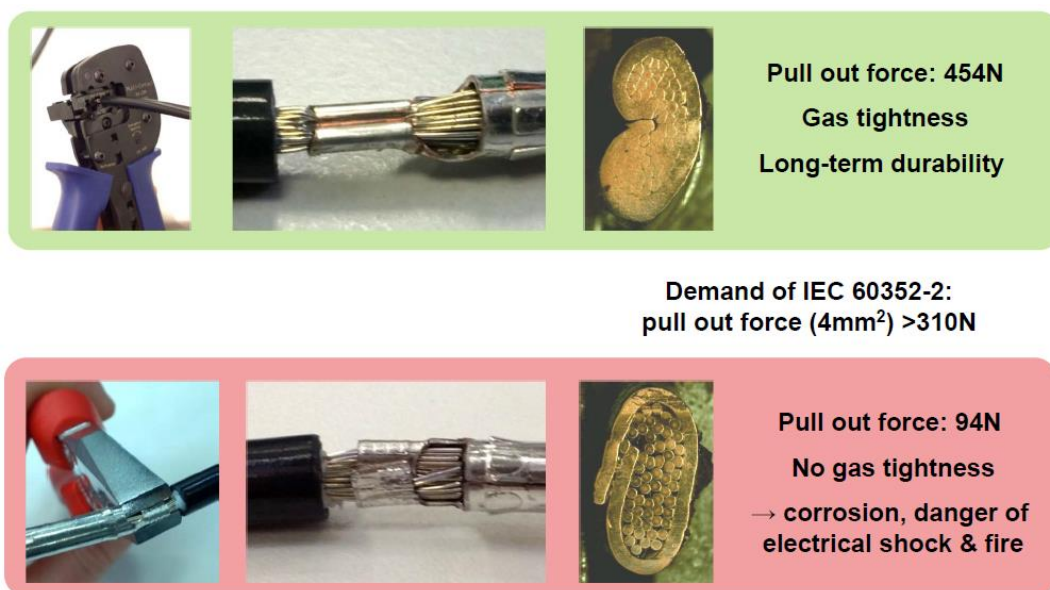


Figure 5: Comparison between connection with correct and incorrect crimping pliers (Berginski, 2013)

### 3.2 DC-Connector Mismatching

When talking about problems with DC-connectors, the term “*mismatching*” (or cross mating) often appears. Mismatching means that a connection between a male and female connector is made with DC-connectors from different manufacturers. Next to the incorrect mounting of connectors, mismatching is also regarded as one of the main error sources which makes DC-connectors more likely to ignite. But why is that such a big risk? In the past, the following reasons have been identified:

- / Different materials are used by different manufacturers. This can lead to the following:
  - / Chemical incompatibility resulting in corrosion → ingress of water
  - / Different thermal expansion behaviour resulting in arcing
- / Small differences in the design and the mechanical tolerances of the connectors, which can result in arcing

Multi-Contact (now Stäubli Electrical Connectors AG), manufacturer of the most commonly used type of DC-connector - MC4, performed lab tests on cross-mated connectors. The results have shown increased resistance, leading to temperature increases up to 97°C above ambient temperature (Figure 6), if connecting MC4 connectors to other connectors from different manufacturers.

In the NEC 2020, 690.33, it is stated that “*where mating connectors are not of the identical type and brand, they shall be listed and identified for intermateability*”. However, although many manufacturers of DC-connectors often claim their products to be “MC4 compatible”, no international or UL standards exist to test intermateability, as highlighted by UL (IAEI NEWS, 2016). Also, Stäubli itself does not recognize any third-party product to be compatible with MC4 connectors.

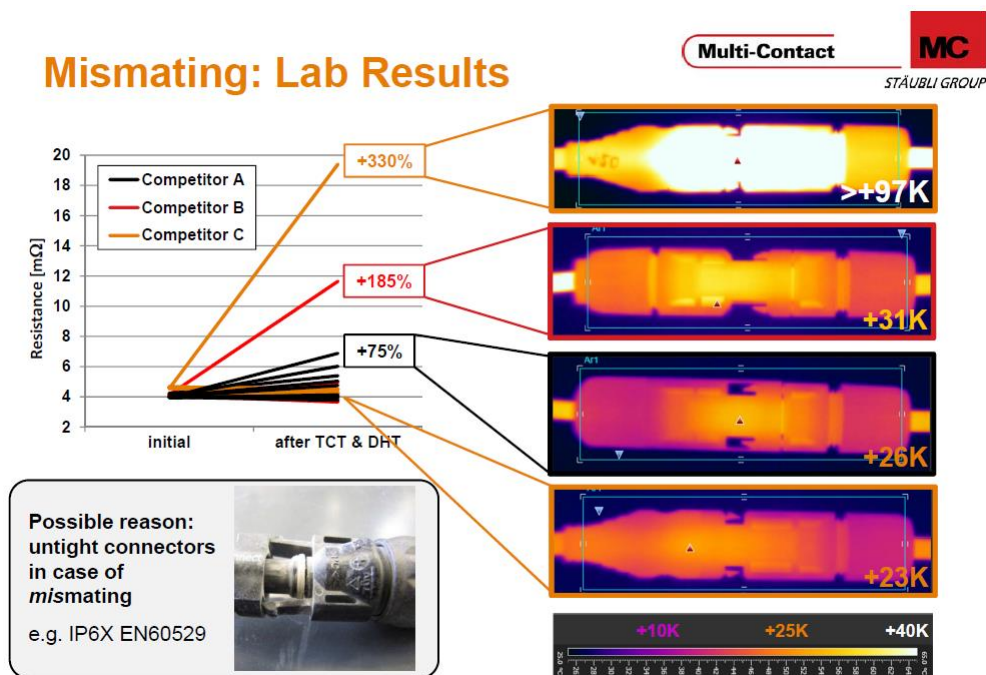


Figure 6: Accelerated degradation tests results for mismatched combinations of connectors between Stäubli MC4 and connectors from different manufacturers (Berginski, 2013)

In the IEC TR 63225: 2019, p.4, it is stated that *“this claim of compatibility is potentially misleading as it suggests a safe interoperability of DC connectors from different manufacturers”*.

The IEC 60364-7-712:2017, clause 712.526.1 - Electrical connections declares that *“Male and female connectors mated together shall be of the same type from the same manufacturer i.e. a male connector from one manufacturer and a female connector from another manufacturer or vice versa shall not be used to make a connection”*. Other important national institutes, such as VDE DKE, the German commission responsible for the development and adoption of electrotechnical standards, also agree that mismatching of DC-connectors are a major cause of fire accidents. In an announcement of VDE DKE it is clearly stated that it is not allowed to connect male and female connectors from different manufacturers (VDE DKE, 2018).

Despite the clear statements and regulations, the problem of mismatching still persists, and often connections with mismatched connectors are made at the outer connection points of the strings. This commonly happens because installers, especially when connecting the different strings together, or strings to the inverter, have to use longer cables with possibly a different connector installed. In such situations, in order not to void the module’s warranty by cutting off the DC-connector from the module cables, installers are usually forced to install DC-connectors from different manufacturers.

To address these issues, the IEC is currently discussing long-term measures, aimed to develop a common interface standard, as well as temporary ones (IEC TR 63225: 2019). The latter include the prohibition of using the term “MC4 compatible”, as well as the requirement for module manufacturers to specify the connectors or provide spare connectors of the same type and brand, or otherwise they should allow connectors to be cut without invalidating the module’s warranty.

### **3.3 Power Optimizers – a Dangerous Safety Measure**

It is obvious that DC-connectors are needed to interconnect PV-modules, as well as to connect the resulting strings to the inverter, but every additional connection on the roof increases the probability that a fire may occur. Therefore, when designing a PV-array, the minimization of the number of contact points on the roof should be an important premise in order to increase the safety of PV-systems.

As noted by TÜV Rheinland and Fraunhofer ISE (Sepanski et al. 2015, p. 204): *“Each additional component poses the risk of additional contact points and other sources of faults. A “sleek” system with as few components as possible has the advantage of having fewer points where damage could occur to the system”*.

The investigations which followed the US fires at Walmart mentioned above have revealed that, before these events occurred, the installation company owning the PV plants was replacing faulty connectors and optimizers across the country (Lopez, Business Insider 2019). It is clear that, although the connectors have been regarded as the main reason for fire, add-on MLPE (module-level power electronics) devices might still have a negative impact on safety, especially when it comes to determining the number of connectors on the roof.

Non-integrated power electronics, such as classical DC power optimizers, used to fulfil the module-level shutdown requirements (NEC 2017), imply the use of additional DC-connectors on each module.

This means that the number of connection points on the roof will be increased significantly, as shown in Figure 7, and therefore there will be far more chance for installation errors and mismatching of DC connectors to occur, with a consequent increase in the risk of fire. The latter is further increased as some optimizer manufacturers provide their products with only a few options of DC-connectors brands (ECN TNO 2019), which poses a higher risk for mismatching during installation.

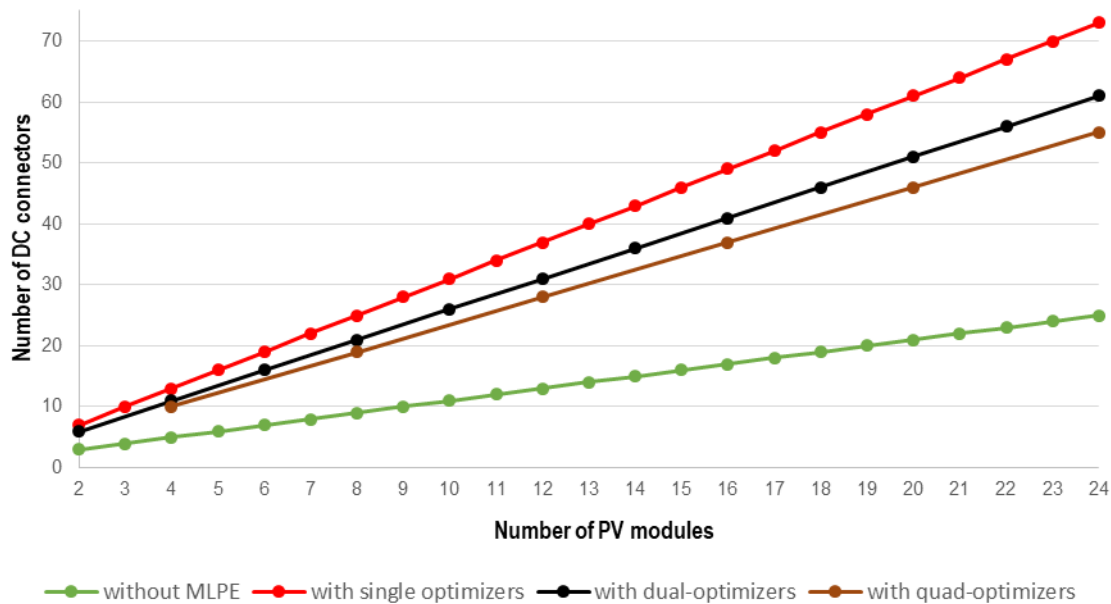


Figure 7: Comparison of the number of DC connectors, as a function of the number of PV modules, for different system configurations: without MLPE, with single optimizers, dual-optimizers and quad-optimizers. The terms “single”, “dual-” and “quad-” refer to the number of modules connected to each optimizer: 1, 2 and 4, respectively.

Furthermore, having power electronics devices for every module adds a considerable amount of components on the roof, which will increase the system complexity and the product failure rate. This means that maintenance will be required more often which results in increased costs and in higher risks for the service personnel due to the additional time spent on the roof (fall is the main cause of death in construction workplaces), as highlighted in Elsevier SciTech Connect (Plante, 2018).

## 4 SAFETY FOR FIREFIGHTERS AND THE NEC 2017

In the event (even if rare) of a PV fire, a second risk must be taken into account, that is the risk for emergency personnel during intervention operations.

PV systems can be handled in the same way as any other electrically live equipment. A joint industry study that was carried out in Germany (Fraunhofer ISE 2019) concluded that photovoltaic systems do not pose any special threat to firefighters, as long as the firefighters comply with the safety clearances.

This was also demonstrated by a test performed in Germany (Fire Retardants Online 2011 cited in BRE 2017b), which showed that if the minimum safety distances recommended in the German firefighter guidelines are fulfilled during extinguishing the fire, no unusual hazards arise.

While extinguishing a fire including a possibly damaged PV system (with a maximum voltage up to 1.5 kV on the DC side), the German Standard *VDE 0132:2008, Firefighting and assistance in or near electric installations*, recommends a minimal safety distance of 1 m if using a water spray jet and 5 m with a full water jet.

In the United States, the U.S. Department of Energy refers to experiments carried out by the UL, which showed that, for a 1000 V PV system, safe leakage currents of less than 1.5 mA can be achieved when using a solid stream with a smooth bore nozzle at a distance of 20 feet (Underwriters Laboratories, 2011).

Further guidelines by the U.S. CAL FIRE recommend (CAL FIRE, 2010):

- / at least 33 feet safety distance
- / a 30 degree fog pattern at 100 psi

The level of personal protective equipment (PPE) used by the emergency responders has also a significant impact on the current hazard, as shown in Table 2. However, not wearing any PPE represents an unlikely scenario, and even with wet gloves the measured current levels are below the electrocution limits (<150 mA according to IEC 60479-1 and <240mA according to UL, as noted by Sepanski et al. 2015). Currents regarded as safe (<2 mA for both IEC 60479-1 and UL) were observed for systems up to 600V by using dry gloves.

Table 2: Potential DC currents (mA) for ungrounded PV systems of different voltages under different PPE conditions (*Lavrova et al., 2017*).

50% Imp	Voltage Class		
PPE	600	1000	1500
Bare Hand	308	513	770
Wet Glove	41	69	103
Dry Glove	2	4	6

Table 3: Possible measures to increase safety during firefighting operations (Sepanski et al. 2015, IEA PVPS Task 12, 2017).

<b><i>Design / Installation measures</i></b>	<b><i>Organizational measures</i></b>
Provide suitable access to the rooftop perimeter	Keep the minimum safety distance
Ensure access pathways to standpipes and smoke vents	Use of the available internal fire suppression equipment
Minimize DC cables length and direct them outside of the building	Wear personal protective equipment and self-contained breathing apparatus
Protect DC cables from contact (e.g. conduits)	Coordination to ensure short response time
<i>PV labelling near distribution boxes</i>	Briefing of the local fire services
<i>Labels on DC cables</i>	PV array de-energizing procedures
<i>Maps of PV components and cable routing</i>	

Moreover, the risks for firefighters can be further reduced by adopting preventive measures at the design and installation stages of a rooftop PV system, as well as with organizational measures to assist firefighters during operation. Some common measures are reported in Table 3.

If the minimum clearance is observed, as well as proper trainings and additional measures are undertaken, there is very little risk for emergency responders when extinguishing PV-related fires. According to Fraunhofer ISE, 2019: "In Germany, no firefighter has to date been injured by PV power while putting out a fire".

Despite the safety levels are already very high, regulations are being formulated to add an extra layer of safety. The 2017 Revision to NEC 690.12 added new requirements for rapid shutdown to protect personnel interacting with a PV array. The main changes with respect to NEC 2014 are:

- / maximum voltage of 80V within 30 seconds for conductors within 1' (3 m) from the array
- / maximum voltage of 30V within 30 seconds for conductors outside of a perimeter of 1' (3 m) from the array

Since the open-circuit voltage for conventional PV modules is typically above 40 V, the new NEC 2017 implicitly requires the use of module-level shutdown devices in order to de-energize individual modules to comply with the 80V limit inside the array boundaries.

Different options to fulfil the new standard will be discussed in the next chapter.

## 5 FULFILLING RAPID SHUTDOWN IN NEC 2017

This chapter will provide an overview of the different options to comply with the NEC 2017 requirements for rapid shutdown.

### 5.1 Selection Criteria for an Optimal Shutdown Solution

Solutions used to fulfil the 2017 NEC 690.12 should be able to provide module-level shutdown (MLSD) without affecting the system safety. To evaluate the quality of a MLSD solution, the following should be considered:

- / **Number of connection points:** as discussed in chapter 3, DC connectors are the main cause of fire. Increasing the number of connectors will increase the probability that a fire will occur.
- / **Number of additional components:** any additional component increases the risk of product failure, which decreases the system reliability and increases the risks for service personnel due to the additional time spent on the roof for maintenance and replacement.
- / **Reliable shutdown:** The device needs to be able to provide shutdown even in case of product malfunction, in order not to give firefighters a false sense of security.
- / **Compliance with proper standards:** products should be tested to safely perform their required functions under the environmental conditions in which they are intended to operate.
- / **Compatibility with AFCI:** Rapid-shutdown devices should not create noise in the DC line that interferes with arc-fault circuit-interrupter (AFCI) circuits, causing unwanted tripping.

### 5.2 Issues with Current MLPE Solutions

Most of the current solutions for MLSD involve the use of retrofit module-level power electronics (MLPE) devices, such as power optimizers, micro-inverters and shutdown boxes. As with any external component, these devices can also be affected by installation faults. If not installed and maintained correctly, they might not operate in the event of a fire, which would give firefighters a false sense of security as parts of the array could still be energized.

Add-on optimizers imply the use of additional DC-connectors on each module, which means there will be far more chance for installation errors and mismatching of DC connectors to occur, with a consequent increase in the risk of fire. The risk for mismatching during installation is further increased as some optimizer manufacturers provide their products with only a few options of DC-connectors brands (ECN TNO 2019). Furthermore, having more electronic components on the roof also increases the system complexity and the likelihood of product failure. This means that maintenance will be required more often, which results in a higher risk for the service personnel due to the increased time spent on the roof (fall is the main cause of death in construction workplaces), as highlighted in Elsevier SciTech Connect (Plante, 2018).

Although micro-inverters reduce the length of DC cabling, they still increase the number of DC connectors by a factor of 2, and they increase the system complexity by introducing a high number of components on the roof, therefore reducing system reliability and safety for maintenance personnel.

Shutdown boxes performing rapid-shutdown only, might include less components, due to the absence of DC/DC or DC/AC conversion and monitoring capabilities, but they still increase the number of connection points on the roof.

Some integrated optimizers and micro-inverters are also being developed, which would reduce the number of connections with respect to their retrofit counterparts, but still the issues related to a high number of components would persist.

Regardless of the type of MLPE used, these devices need to be mounted and operate behind the PV modules, where they are subject to the harshest environmental conditions in terms of temperature and humidity, posing the electronic components under high stresses. Although the UL1741 standard provides ranges of environmental conditions (e.g. maximum ambient temperature up to 50°C and maximum air temperature behind the PV module up to 65°C) under which the equipment has to be tested, these are still subject to the manufacturer's specifications. As stated by the International Energy Agency: *"Only future experience with deployed systems will show whether these tests are sufficient over the service lifetime. Demonstrating that the new hardware is reliable, will be fail-safe under the relevant conditions, and will function as safety equipment over the life of the PV system is a challenge that will require ongoing testing and development"* (IEA PVPS, 2017). Most importantly, these **rated testing conditions** only consider **normal operation**, but are not representative of the typical environmental conditions in the event of a fire.

The **actual operating conditions** under which MLSD are intended to operate are those occurring **during a fire**. Currently, no product standards exist which define proper testing and requirements that these devices must fulfil in order to withstand the actual operating conditions, which makes it difficult to determine whether or not a product can guarantee shutdown in such an extreme situation as a fire event.

Past experiences in Australia showed that the hasty introduction of rooftop DC switches, before proper product standards could be defined, have led to a large number of fires, as reported by Fraunhofer ISE (Laukamp et al, 2018). It is therefore very important to ensure that new devices comply with safety standards, in order to avoid that an immature technology, originally intended to increase safety, could instead pose greater safety concerns.

### 5.3 Rapid Shutdown Solutions with SunSpec Powerline Communication

The SunSpec Alliance, an international consortium of more than 100 global leaders in the solar and storage industry, defined an open standard for the communication between modules, inverters and string combiners to fulfil the 2017 NEC rapid shutdown requirements.

The SunSpec communication protocol is based on powerline communication (PLC) via the existing DC cables between a transmitter, located inside or near the inverter, and receivers located at the PV modules (Figure 8). The transmitter sends a keep-alive signal to the receivers during regular operation and, once the communication signal is interrupted, the receivers initiate shutdown within the timing and output voltage requirements defined in NEC 690.12. Therefore, this rapid shutdown system does not require additional DC cabling or wireless communication (which may be subject to interference) in order to operate.



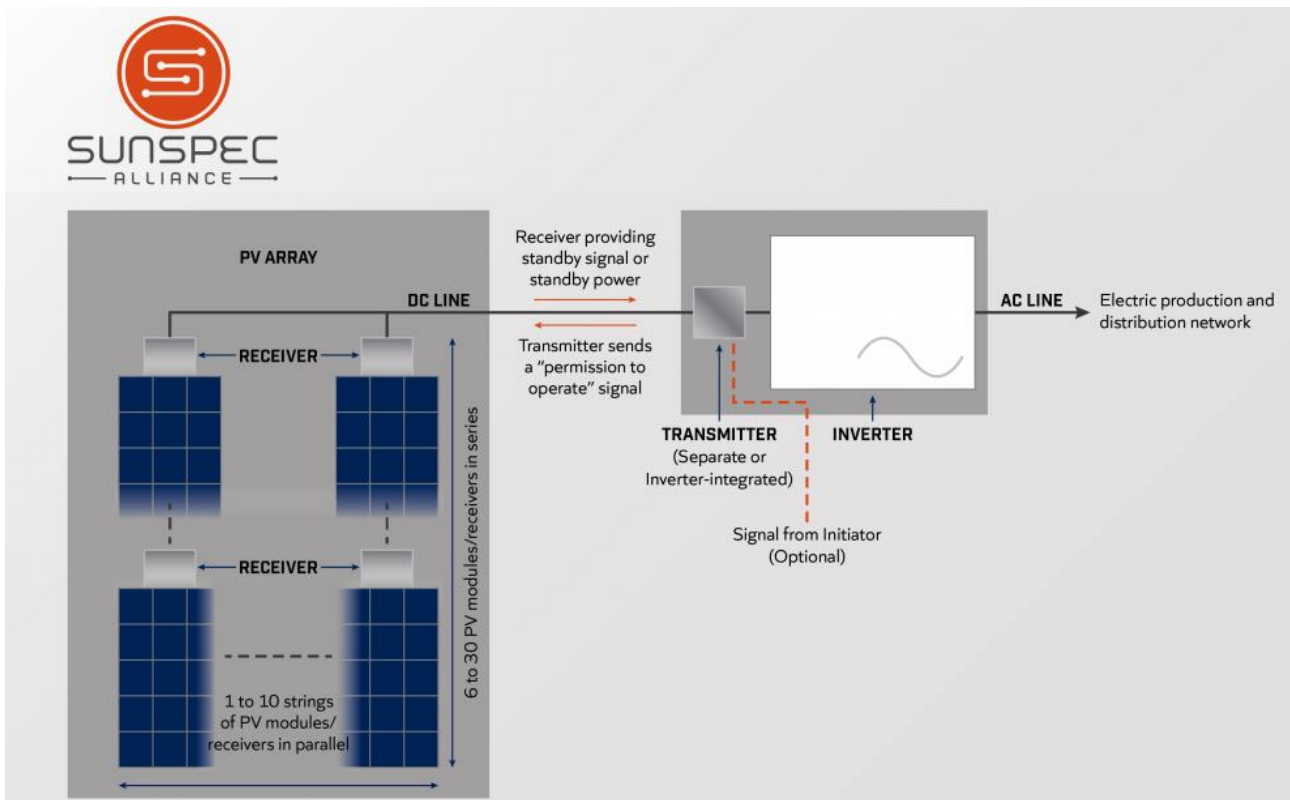


Figure 8: SunSpec Communication Signal for Module Level Rapid Shutdown (SunSpec Alliance, 2019).

The idea is to have receivers directly integrated in the module junction-boxes, and Texas Instruments, as one of the members which participated in the development of the protocol, offers design solutions for rapid shutdown as simple as a single chip. PV modules manufacturers can implement the rapid shutdown communication protocol on simple electronics embedded within their modules, which means:

- / **No additional connectors:** the installers will not have to wire exterior boxes, which would increase risks
- / **Low complexity:** no need for complex power electronics with a large number of components, therefore the probability of failure will be reduced.

Furthermore, the benefits of an open standard include (SunSpec Alliance, 2012):

- / **Products interoperability (multi-vendor):** a single communication protocol provides customers with the freedom to choose products from different manufacturers, instead of being locked into a single vendor as it is the case with proprietary solutions.
- / **Cost reduction:** the freedom of choice among different products, as well as the elimination of the need to design every new product from scratch, will result in many benefits (e.g. reduced design efforts and component parts count, reduced installation time, elimination of rip-and-replace costs, and easy access to plant information for all stakeholders) which will enable cost reduction for the entire solar industry.
- / **Risk minimization:** since a solution based on industry standards is known by the entire industry around the globe, SunSpec-based rapid shutdown systems, together with compliance with safety and installation standards (e.g. UL 1741 and NFPA 70, NEC 2017), will increase reliability and reduce risks for errors, providing a higher level of safety for emergency responders.

## 5.4 Comparison Example between MLPE and Module-Integrated SunSpec Solutions

For illustrative purposes, a 6 kW PV system was considered to compare current MLPE devices used to fulfil NEC 2017 with a rapid shutdown system solution based on SunSpec's communication protocol. Figure 9 shows two configurations of the same system: one with retrofit DC optimizers, and the other with chip-based receivers and transmitters integrated in the modules and string inverter, respectively, and using SunSpec PLC.

As it can be seen, the additional devices installed on the PV modules within the DC circuit significantly increase the number of contact points on the roof by about 3 times: 61 connectors with optimizers, compared to 21 connectors for a string inverter system. The situation would not change significantly by using one optimizer every 2 or 4 modules (51 and 46 connectors, respectively), whereas the optimization would be less effective.

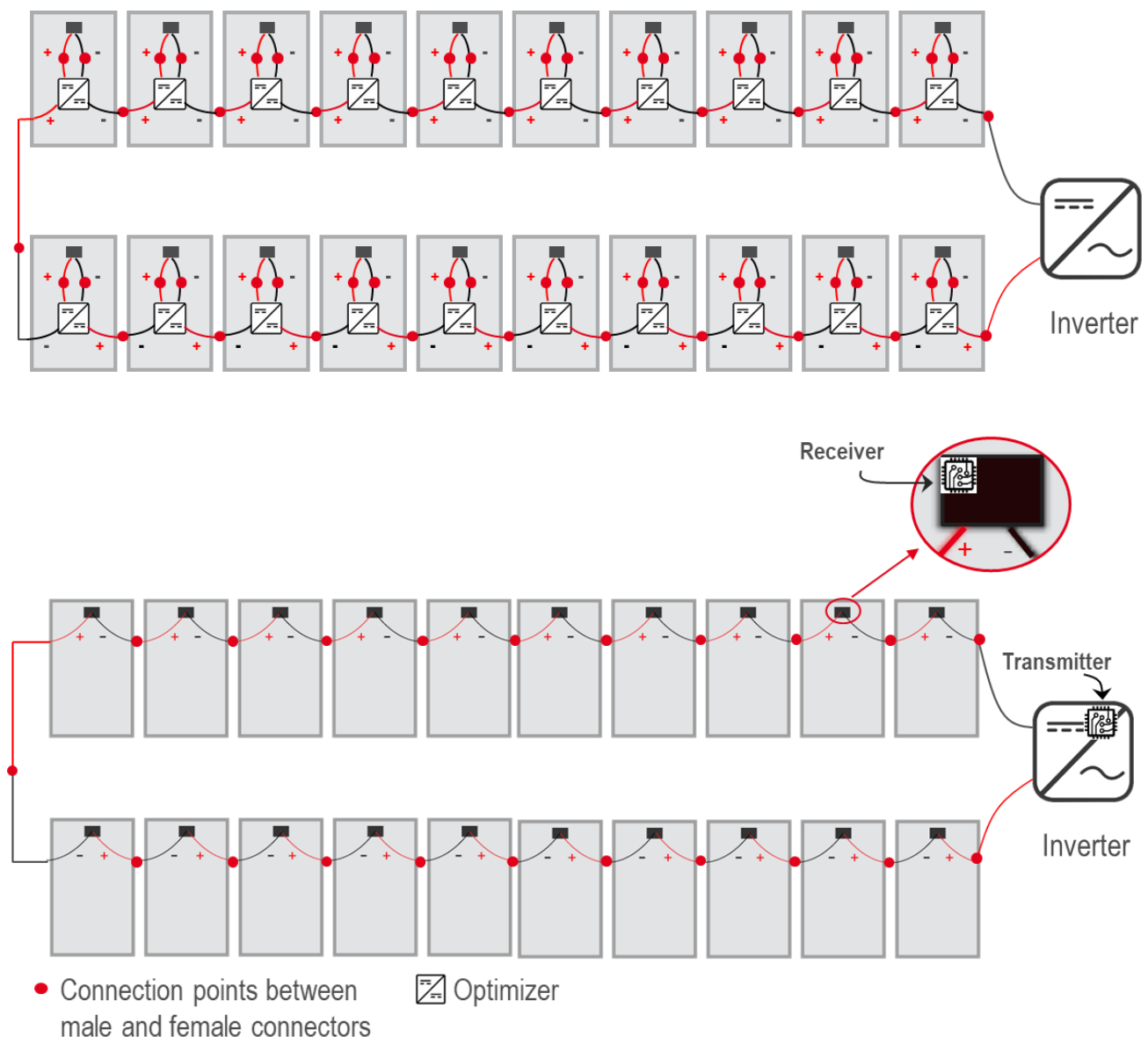


Figure 9: Comparison of two 6kW system configurations with add-on optimizers (top) and module-integrated receivers with SunSpec (bottom).

Having power electronics devices for every module also means that a considerable amount of components are added on the roof. High risks for installation errors, connector mismatching and product failure, as well as increased maintenance and system costs are therefore introduced.

A shutdown chip working under SunSpec communication to be integrated into modules' junction boxes, would instead offer a smaller number of components and higher reliability. The system complexity is minimized, and the number of connection points remains unchanged with respect to a string inverter system.

A summary of the main differences between the two solutions is also provided in Table 4 below.

Table 4: Comparison example between MLPE and SunSpec module-integrated solutions.

6kW MLPE system with 20 DC optimizers	6kW system with SunSpec based PV modules (chip-based)
<div>/ Approx. 3 times more connection points (61)</div> <div>/ Approx. 40 more MC4 mismatch possibilities</div> <div>/ Around 20 DC converters on roof</div> <div>/ Proprietary solution</div>	<div>/ 21 connection points</div> <div>/ No additional mismatch of MC4*</div> <div>/ No additional converters on roof*</div> <div>/ Based on open standard (multi-vendor)</div>

\* with respect to a PV system with a string inverter

# 6 RECOMMENDATIONS & CONCLUSION

As reported by well-known agencies and institutions, such as TÜV Rheinland and Fraunhofer ISE (Sepanski et al., 2015), BRE (2017b) and IEA PVPS (2017), PV is a very safe technology and if properly installed and maintained, PV systems do not pose safety risks under normal operating conditions (IEA PVPS 2017). Nevertheless, Fronius is taking safety very seriously, and is continuously trying to improve the already high safety level of its products.

The fire-related risks for PV systems can be divided into two categories:

- / **Risk of fire:** refers to the probability that a fire occurs
- / **Risk for firefighters:** probability that emergency responders get injured during a fire-fighting operation

The risk for emergency responders is strictly related to the risk of fire, since no fire means no risks for firefighters. Therefore, Fronius believes that, in order to protect firefighters, the priority should always be given to reducing the risk of fire, which can be minimized by:

- / **Reducing the number of connections:** As shown in chapters 2 and 3, **installation faults** are the most common reasons for fire incidents. Every additional connection point increases the possibility of installation errors (e.g. improper crimping, poor insertion and mismatching of **DC-connectors**). Although the risks of human error cannot be completely eliminated, professional trainings for installers are extremely important to ensure a high quality of installation.
- / **Reducing the number of components:** A complex system with a large number of components also involves more risks, due to the greater possibility of failure, which results in increased maintenance and time spent on the roof by service personnel.

When implementing measures aimed at reducing the risk for firefighters, such as module-level shutdown as required by NEC 2017, great care must be taken to ensure that such measures provide an additional protection without compromising and increasing the risk of fire. In Table 5 are reported the main differences between a rapid-shutdown solution based on conventional MLPE, and one based on module-integrated receivers (semiconductor chips integrated into the modules' junction boxes) communicating to transmitters at the inverter level under the SunSpec PLC protocol.

Table 5: Advantages of module-integrated SunSpec rapid shutdown compared to add-on MLPE.

Retrofit MLPE	Module-integrated solution with SunSpec PLC
<ul style="list-style-type: none"><li>/ Add-on solution (External boxes)<ul style="list-style-type: none"><li>➤ Large # of connections</li></ul></li><li>/ Greater complexity<ul style="list-style-type: none"><li>➤ Large # of components</li></ul></li><li>/ Proprietary solution</li></ul>	<ul style="list-style-type: none"><li>/ Integrated solution (chip in j-box)<ul style="list-style-type: none"><li>➤ Less # of connections</li></ul></li><li>/ Simple system<ul style="list-style-type: none"><li>➤ Less # of components</li></ul></li><li>/ Based on open standard (multi-vendor)</li></ul>

As discussed in chapter 5, currently available **MLPE** devices used to fulfil 2017 NEC 690.12 involve:

- / **Increased number of connections**, as most solutions consist of add-on boxes with MLPE installed at each module, which create more risks for mismatching and installation errors.
- / **Large number of components**, which increases the product failure rate and system reliability.
- / **Lack of proper standards** defining tests under actual operating conditions (during a fire event), which would give emergency responders a false sense of security.

Therefore, retrofit MLPE for rapid shutdown compromise the first level of safety by increasing the risk of fire, and are not a viable solution to increase the overall safety, as also illustrated in Figure 10.

A **SunSpec** rapid-shutdown solution is based on an open standard and PLC, and will enable plug-and-play interoperability between products from different manufacturers, facilitating cost-reduction and risk minimization. Furthermore, module-integrated receivers will allow:

- / **No additional connection points**, since no extra wires or connectors are introduced
- / **Low number of components**, because only a simple semiconductor chip is needed in the junction-box

and will therefore provide MLSD without compromising the risk of fire.

Many manufacturers are currently developing new technical solutions for NEC 2017 compliance, including module integrated receivers based on the SunSpec communication protocol. However, such products, which can eliminate both the number of connection points and overall component count, are not expected to be available in the short term. Until such integrated products that can effectively improve safety are available, however, the adoption and execution of NEC 2017 article 690.12 will not make solar safer.

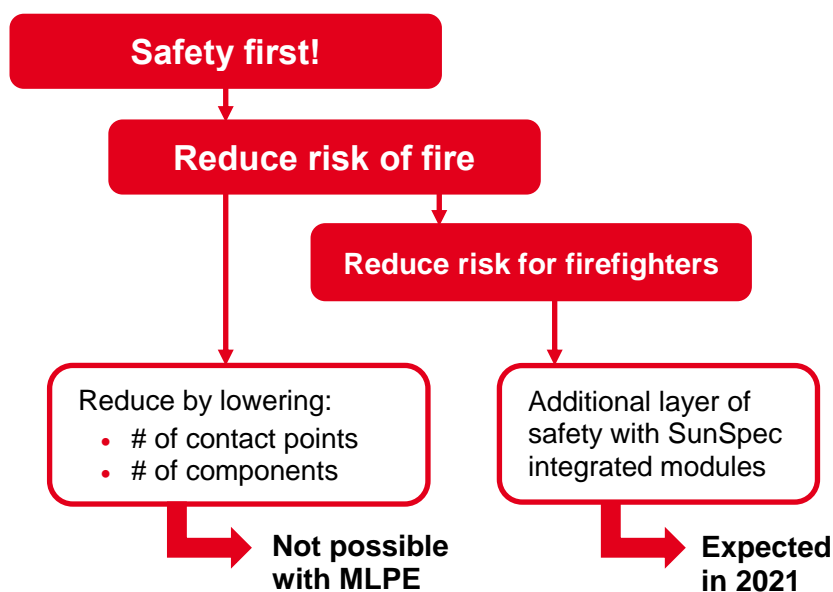


Figure 10: Overview of the fire safety layers and their relationship with MLPE and SunSpec based solutions.

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