IEC TR 63226

Edition 1.0 2021-02

TECHNICAL REPORT

colour inside

Managing fire risk related to photovoltaic (PV) systems on buildings

IEC TR 63226:2021-02(en)

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Managing fire risk related to photovoltaic (PV) systems on buildings

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 27.160

ISBN 978-2-8322-9395-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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MANAGING FIRE RISK RELATED TO PHOTOVOLTAIC (PV) SYSTEMS ON BUILDINGS

FOREWORD

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IEC TR 63226, which is a Technical Report, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this Technical Report is based on the following documents:

Draft TR	Report on voting
82/1500/DTR	82/1553A/RVDTR

Full information on the voting for the approval of this Technical Report can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

PV systems provide electric energy in an environmentally beneficial way. They work silently, without pollution or other emissions and can be mounted nearly anywhere in close proximity to where people use electricity including living, working and sleeping facilities. However, since they contain electrical equipment, they share a similar risk of causing damage on both the DC side and on the AC side of an installation as any electric or electronic equipment.

This document is about fire prevention measures and additional measures for supporting firefighters. In general, PV systems are considered safe when relevant product and installation standards are applied. But even for PV systems installed according to relevant safety standards, there is a remaining risk that a fire is caused by the PV system. Additional measures are considered to further improve the situation at special locations, independent of whether the PV or an external event is the source of a fire. Also the restrictions to firefighters facing damaged PV systems in case of fire are considered in general.

At some locations or buildings there are greater needs due to higher risks. For such locations additional requirements often apply. This is why building and fire codes often vary based upon risks to safety. Also in the installation standards there are additional requirements for fire safety, for example IEC 60364-4-42 or IEC 60364-5-51. In case of higher risks regarding fire, people's safety, and financial risks, additional measures are reasonable depending on the building itself. This document is designed to assist PV designers and insurance companies to select suitable measures to address the on-site specific needs of special locations. This document contains measures for reducing risks in general and depending on the on-site conditions.

General information is provided to further reduce fire risks of PV systems. Also, information is given how to handle PV systems after a fire.

MANAGING FIRE RISK RELATED TO PHOTOVOLTAIC (PV) SYSTEMS ON BUILDINGS

1 Scope

This document, which is a Technical Report, is intended for use as guidance for reducing fire risks in general and for site-specific needs for buildings with PV systems. In addition to the general recommendations, technical, installation, and maintenance measures can be selected to reach the intended safety level of the PV system and building, depending on the results of a risk assessment. This document contains general information about building related risks and includes measures for reducing those risks. These measures are not general requirements or recommendations. They are explained as a guide for selecting suitable measures depending on the on-site needs.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

4 Risk evaluation

4.1 General

It is recommended to perform a risk evaluation, to identify, if additional measures are needed and which measures are reasonable in order to reach the intended safety level. Such a site-specific evaluation can help the needs of all stakeholders to be covered without putting unnecessary requirements on all PV systems.

4.2 Site selection

The selection of the site can have a major impact on the recommended measures. The designer should evaluate if the proposed building or part of the building is the best choice for a PV installation. Shifting to another part of the building, to another building or to a ground installation can be a reasonable step to avoid additional measures.

The fire zones and the position of fire protection walls should be evaluated. The PV array should not provide a fire path (bridge) between adjacent fire zones.

4.3 Aspects for building risk evaluation

4.3.1 Roofing materials

Roofing materials have an impact on how much damage an exterior fire will cause to a building. In some countries, for example USA, building codes require fire ratings of roofing systems based upon the occupancy of the building. Buildings, where people assemble, such as theatres and churches, require a higher level of roof fire ratings than warehouses. Both are susceptible to exterior fires, but the assembly occupancy has a higher risk to human life and is therefore required to have a more fire-resistant roof.

Roofing materials are tested for certain fire withstand capabilities. However, these product characteristics may not be sufficient to withstand the energy from an arc or fire caused by a fault. If a roofing material is capable of being ignited by an arc or fire caused by a fault, additional measures may be taken into account. Additionally, the presence of PV modules in close proximity to roofing materials may trap or radiate heat from a rooftop fire causing additional roof damage. The higher the fire resistance of the roofing system, the less likely a rooftop fire will cause widespread damage.

Depending on the occupancy of the building and the financial risk of loss for the building, it may be necessary to upgrade a roof system's fire resistance when a PV system is installed on the roof or use additional measures to reduce the fire risk. If the cost of upgrading the fire resistance of the roof or additional equipment is too high, then other installation locations should be considered that require less investment.

For buildings covered with exposed flammable roofing materials, additional safety measures should be considered to help prevent fire ignition. Flammable roofing materials include many common roofing materials such as bitumen, asphalt, tar paper, and various polystyrene and polyisocyanurate insulating materials. Higher fire-rated roofing systems that incorporate the most flammable polystyrene insulating materials normally include what is referred to as a cover board between the roof membrane and the insulation to prevent a fire on the membrane from involving the flammable polystyrene materials beneath the membrane.

All roofs in Europe – with or without PV – must comply with fire resistance classes according to CEN/TS 1187. There are four different regions with four different tests within Europe. Generally, the requirements are separated into building-integrated PV (BIPV) where PV modules need to comply with the same requirements as the roof skin and building-applied PV (BAPV) with lower requirements related to fire resistance such as ignitability.

Building products and building materials in Europe are classified according to the EN 13501 series, for example class E. Ignitability (e.g. in Germany for BAPV "normal ignitability" is required by building codes – DIBt) is tested according to ISO 11925 (all parts).

4.3.2 Building construction

Not only is the roof construction important to the fire risk of a building, the entire building construction is also important. Buildings constructed of concrete, brick, and stone are more fire resistant than steel or wood structures. The concern with building construction types may be accelerated building collapse or propagation of fire to adjacent structures.

4.3.3 Building contents

In the case of buildings that warehouse flammable materials, these contents can add significantly to the risk of loss should the fire originate inside the building or penetrate the roof and get into the building. Examples of flammable contents are polymeric materials, butter, and wood-based products. Should the fire engage these contents without adequate fire sprinkler systems to control the fire, contents fires are capable of destroying buildings, even those with good fire-resistant construction. The contents of buildings such as warehouses may change over the lifetime of the building and may require that the risk evaluation be revised based on the change of contents.

4.3.4 Use of building

4.3.4.1 General

Building use can play a major role in the risk profile of a project. The financial risk of a fire is closely related to the risk to human life and the risk to structures and building contents. A barn housing hay for livestock may be a low risk, particularly if the livestock is not housed in the structure. A warehouse storing consumer electronics may have a higher financial risk in case of fire. Thus a building full of people, such as a theatre or a shopping mall, has a much greater financial risk than either of the previous examples given the threat of loss of human life. These building types generally require more sensitive fire alarm and fire suppression equipment to help mitigate these risks. A PV system installation should take into account these varying levels of risk due to building use, especially with respect to the operation times (daylight) of the PV system, and employ the highest safety levels for buildings with the highest risks.

4.3.4.2 Building type considerations regarding risks to humans

Where risks to humans are involved, fire prevention measures and measures supporting firefighter safety are important (e.g. hospitals). Additionally, firefighters need quick access to the fire location to extinguish and avoid the spread of fire in the early stages of a fire before it becomes a problem for the people inside the building regardless of whether the PV was the cause or not. In order to access the fire, firefighters may need to open parts of the roof, depending on the location of the fire. Where this area is covered by PV modules, there is already a time delay, caused by removing modules and mounting structure.

Firefighting tactics vary from country to country. Therefore, measures for supporting firefighter activities should be chosen accordingly.

4.3.5 Building type considerations regarding financial risks

Additional safety measures may be selected according to the financial risks involved with losses at a particular building and place of business. This includes costs for any building contents and inventory as well as costs for interruption of the facility operations. For instance, a manufacturing process that is critical to the production of a particular product may require a high level of safety since the loss of facility production could interrupt the production of the final product. Facilities that have redundant manufacturing options would be a lower risk to the production. Also, the value of stored products will impact whether the facility has a higher or lower financial risk in the event of a fire. Safety measures should be selected based on the level of risk. Often the insurance company will determine the classification of risk.

In order to address financial risks, fire prevention measures are recommended as well as measures supporting firefighters. Damages and losses can be reduced when quick access to a fire location is enabled. This allows firefighters to extinguish the fire quickly and avoids the spread of fire in an early stage. In order to access the fire, firefighters often need to open parts of the roof. Where this area is covered by PV modules, there is additional time delay, caused by removing modules and mounting structure.

4.4 Measures for supporting firefighter and rescue service operations

4.4.1 General

Buildings are often constructed with a variety of measures that are intended to assist emergency responders in rescue and fire operations. The level to which these measures are employed is often correlated with the risk levels of the building, occupants and contents, and the response time available from the fire service and other emergency personnel. For example, buildings located more than 15 to 20 minutes from the closest fire response may need much more significant internal fire suppression equipment to address the longer fire response time.

4.4.2 Response times of emergency responders and available apparatus

When determining the overall risk of loss for a building, the response time of emergency personnel is an important factor. The difference between a 10-minute response time and a 20-minute response time after a fire is detected may mean the difference between a minor loss and a total loss. Also, the type of apparatus and water that is available (height of ladder trucks, water pressures, water volume, water source) can heavily impact the ability to fight a fire – particularly roof fires. Depending on the response time of fire services in general, and the location of water supply and ladder trucks, where needed for access, the risk for the building may change and additional measures may be taken into account.

4.4.3 Geometry, height, accessibility of building

4.4.3.1 General

Roof fires can be the most difficult to reach and engage for the fire service because of limited perimeter access to the building and the height and width of a building. A low-rise building with full perimeter access for large fire apparatus and limited width (under 50 m wide) may provide for the widest variety of fire-fighting apparatus to address a rooftop fire.

4.4.3.2 Height and width of building

The higher the roof with a PV system, the more difficult it is for firefighters to access and extinguish a fire. This delay leads to a higher spread of the fire, which leads to greater damage and the risk of a building loss. Building height also impacts the need for higher water pressure to get water to the middle of a roof. It is safest for the fire service if fire apparatus can fight the fire from the perimeter with minimal or no direct roof operations. For wider and higher roofs, rooftop standpipes may be necessary so that hose lines can be connected to a water source near the middle of the roof. This allows for water to be locally supplied from on-site water sources, reducing the need for off-site water sources and longer water spray distances. If this cannot be ensured, additional measures according to Clause 5 are recommended to lower risks.

4.4.3.3 Access pathways and fire response sections

Where PV systems are mounted on rooftops, access pathways need to be maintained if the fire service needs access for rooftop operations on the building. This requires coordination with the fire service at the design stage so that pathways can be laid out specifically before PV system construction. This may include identification of fire response roof sections planned in advance. Fire response sections can be established in the planning stage of a building or PV system installation so that there are adequate pathways from the roof perimeter to roof ventilation opportunities such as skylights and smoke hatches. Also, roof standpipe access should be provided from the roof perimeter so that hose lines can be quickly and easily deployed where necessary. Pathways through a PV array are important to keep firefighters away from conductors. For larger buildings and higher risk facilities, it is necessary to establish good communication with the local fire service so that valuable time is not lost at a fire scene due to poor information or communication. Access pathways should be included in the documentation (see 7.4).

4.4.3.4 Accessibility of roof

Perimeter access to a building's roof can be critical to the ability to fight a rooftop fire. Full perimeter access for large fire apparatus is ideal, but many buildings simply do not have the ability to provide for such access. For a building of any size, it is preferable to have at least two locations where ladders can access the roof from ground level. Those access points should be at locations where the fire service can deploy equipment and personnel at the roof level. Larger buildings will require wider access pathways around the perimeter. For example, in the USA the building codes require a 2 m perimeter for buildings larger than 80 m on a side and 1,3 m for buildings smaller than 80 m on a side. Bad accessibility of the PV array – for example due to height, long distances (to walk) or restriction in using ladders – increases the risks. This leads to additional measures to compensate. Additional measures may include installing fixed ladders to compensate and prevent further delays.

4.4.3.5 Need to reach critical sections of roof

A key aspect of access pathways on rooftops is providing at least two escape paths so that if one path gets cut off in the process of fighting a fire, the firefighter has an alternative route. Pathways to critical firefighting locations such as standpipes or smoke vents will typically have access from either side of the roof so that if the initial accessing pathway is cut off, the firefighter can proceed to the opposite roof edge for escape. For example, the building codes in Germany require access pathways at intervals no greater than 40 m apart. This 40 m requirement is in addition to pathways to critical locations such as standpipes and smoke vents. Essentially, the PV array roof layout starts with providing access pathways to all standpipes and smoke vents and then breaks up the remaining array sections into sections no larger than 40 m to comply with this requirement. Figure 1 illustrates typical PV array layouts with access pathways provided for emergency responder access. This can be achieved by pathways having either sufficient distance to conductors or, where conductors cross the pathways, by measures providing mechanical protection of the cables. The intention of both measures is to avoid damage to cables by people stepping on them.

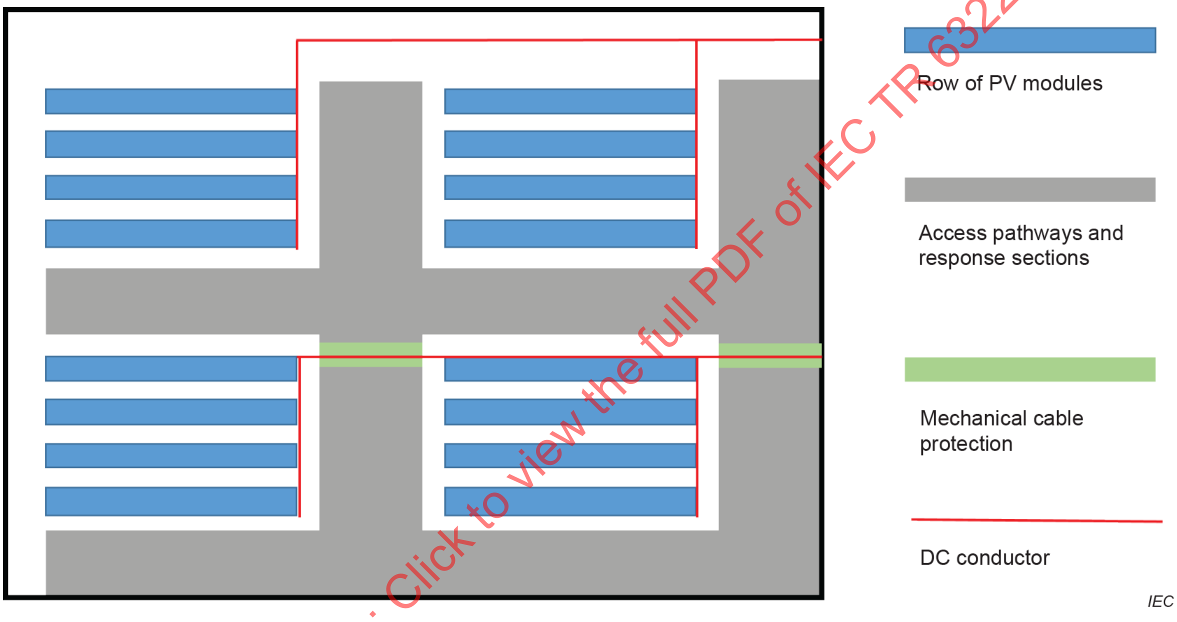


Figure 1 – Cable routing related to pathways

4.4.4 Coordination with fire alarm systems

Fire alarm systems generally do not include detection equipment on rooftops. Therefore, typical fire alarm systems cannot be relied upon to detect a rooftop fire in a timely manner. However, it may be beneficial to use a fire alarm system that has detected an internal building fire to signal the PV system to automatically take measures in accordance with 6.3 or 6.4.. These precautions may be warranted as an added safety measure in the event that the fire service does not find or have access to the location of shutdown switches provided for the PV array.

4.5 Other organizational aspects

4.5.1 Briefing fire services in on-site specific aspects

Depending on the size of the PV system and the risk situation of the building, a briefing of the local fire services is recommended. Such a briefing should include location of the array(s), cable routing, impact to pathways, and applied measures for firefighters such as the measures in 6.3. to 6.6. Suitable documentation should be provided to the fire services.

4.5.2 Harmonize measures with fire protection measures of building

During the design of the PV system, additional measures should be aligned with existing fire protection measures to ensure the PV system safeties are as effective as possible. For example, a shutdown system may be more effective if it is integrated to the building's smoke and fire alarm systems or security system. Another reasonable step is to include warning and fault indications to the building's facility management.

4.5.3 Harmonize measures with owner, user and building and inventory insurance

During the design phase, a risk evaluation and the selection of measures should be performed considering the needs of the owner of the PV system, the owner of the building, the user of the building (if it is not the owner), and the insurance for the building and the inventory. This avoids additional or other measures after installation and helps keep PV systems cost effective.

5 Technical PV system design measures for fire prevention

5.1 General

The first priority in a PV system design on a building is to consider the building risks and to design the PV system accordingly and avoiding buildings with highly combustible roofing. However, even with the best attention to these broader details, it remains important that the PV system does not become the source of a fire. Higher voltage DC circuits are inherently more capable of starting and sustaining fires than similar voltage AC circuits. This is due to the ability of a DC circuit to sustain significant arcs at lower voltage levels than is possible with AC circuits. In order to address concerns about DC arcing fires in PV systems, various technologies have been developed to make these events far less likely.

Components and measures used to minimize risks need to be qualified for their intended function, expected lifetime, climatic condition and application regarding safety and reliability. For some measures, there are existing IEC standards, for some there are IEC project teams working on new standards. Until available, it is recommended to select components with certificates from other national standards.

The initial PV system design considerations according to 5.2 should be taken into account in general. The other measures are options to reduce fire risks and may be selected according to the on-site needs.

5.2 Initial PV system design considerations to minimize risk

5.2.1 General

The measures within 5.2 are general recommendations.

5.2.2 Ventilation

When designing PV systems, it is good practice to avoid high temperature of components wherever possible. High temperature reduces the lifetime of electronics and increases failure rates. A good way to avoid extensive heating of components is to allow free airflow around the components to dissipate waste heat. This measure also reduces the risk of secondary damages through overheated defective electronic components.

Choose the position of components that produce much heat, like inverters or DC-DC-converters, in such a way that the heat sink is not likely to be blocked.

Most PV module manufacturers recommend or require a minimum clearance (e.g. 10 cm) behind their PV modules to provide adequate airflow.

5.2.3 Accumulation of flammable material

Measures should be taken to prevent accumulation of flammable material (e.g. dry leaves, birds' or other animals' nests) behind the PV modules. One way to help prevent accumulation is to install bird nets to prevent birds from accessing and to keep dry leaves from accumulating under modules. If not, cleaning according to 8.5 should be considered.

5.2.4 Cabling

A very important aspect to prevent fire is proper installation of conductors according to the applicable installation standards, as cable damage and poor connections may result in fires.

This has also to be considered for DC connectors. Especially connecting connectors from different manufacturers has a high risk for creating a fire hazard and is not allowed according to most installation standards. IEC 62548 and IEC 60364-7-712:2017 explicitly do not allow the connection of DC connectors from different manufacturers.

NOTE For further information see IEC TR 63225.

5.3 Arc-fault detection

Arc-fault detection has been around in both the AC and DC electrical worlds for several decades. There are a variety of technologies used to detect arcing events that are employed on all types of circuits from airplane circuits to home circuits. In 2011, electrical codes in the USA began requiring arc-fault detection on PV systems mounted on buildings. At the time the requirement was enforced, no commercial products were available. Now, several years after the initial requirement in the USA, most manufacturers of smaller inverters (under 100 kW) have arc-fault detection products available on the market. While these products are still early in their development, improvements are being made such that these detectors are becoming more and more reliable.

The US electrical codes only require arc-fault detection for DC PV system circuits operating above 80 V DC. This exempts DC circuits rated less than 80 V DC (1,25 × module Voc rating) connected to microinverters even though it is theoretically possible, but considered unlikely, to have an arcing event on microinverter DC circuits. For other than microinverter systems, the string inverter is typically the location where the arc-fault detector is located. Arc-fault detectors at inverters are looking for arcing evidence on the input circuits to the inverter and they operate to stop DC current flowing when an arc is detected. This method of arc interruption only addresses series arc faults. Because of the large number of series connections in PV arrays, the vast majority of arc-fault events are series arc faults.

However, in the unlikely event of a line-to-line DC fault, stopping the flow of current at the inverter will not interrupt a line-to-line fault, also known as a parallel fault. Parallel faults that occur line-to-line are far less likely because it requires both the positive and negative conductors to become damaged and connect through a conductive medium for this type of fault to occur. Isolation resistance measurement and fault current detection help to identify and remove the first fault. These well-established measures help to prevent parallel arcs even before they can occur. While these faults are unlikely, they have occurred particularly in PV arrays where cable management is poor and conductors are damaged by sharp edges of metal supports. These metal supports are typically electrically continuous so a cable fault at one location in one pole (positive for instance) and a fault in the opposite pole in another location will cause a short circuit of the PV array. This short circuit is poorly connected electrically at the cable damage locations and results in an arc that a series arc-fault detector is incapable of stopping.

IEC 63027 for arc-fault detection equipment in PV systems is in development and expected to be published in 2021.

5.4 Earth-fault detection

Inverters according to IEC 62109-2 are equipped with isolation resistance measurements and for non-isolating inverters also a residual current monitoring. Depending on the inverter-topology and the earthing concept of the PV generator, an operation of the system may be tolerable in case of the first fault.

Whether or not there is a requirement to shut down a PV system in the event of an earth fault, what is extremely important is that action is taken in a reasonably short period of time to find and fix the fault. A period of one week is a recommended maximum duration to address an earth fault in a PV system. The reason that such a short time period is recommended is that earth faults are often indicators of damage due to poor workmanship or weather-related issues. If a single fault occurs in a large PV array feeding the same inverter, all that is necessary to create a real hazard is for another fault to occur in the opposite pole wiring of the PV system. Once the short-circuit of the array occurs, the only way to stop a resulting arc or fault current is to shut off the PV modules. If no technology is deployed to shut off the PV modules, then a potential arc will continue until all flammable and conductive materials are depleted or until the sun goes down.

5.5 Automatic shutdown after first fault

As discussed in 5.4, automatic shutdown after a fault is one method of alerting PV system owners and repair technicians of a serious problem. In the case of a series arc detection, immediately interrupting the circuit is an effective means of addressing the problem. This is often done by shutting down the inverter as described in 5.4. Another possible method for both arc- and earth-fault detection is to segregate the circuit with the fault. This requires opening the connections to the problematic circuit from all sources. For many typical PV arrays, this would require isolating any conductors connected to PV modules and inverters. Once the circuit is fully disconnected from all potential sources, the circuit becomes benign.

As arc-fault and earth-fault detectors get more sophisticated, it may be possible for these circuits to perform a series of tests to confirm that a fault has occurred prior to annunciating the fault. With simpler detection systems, it is generally necessary to err on the side of safety and annunciate that a fault has occurred each time a threshold is exceeded. However, finding earth faults and arc faults can be very challenging and time consuming. There is plenty of room in these detection technologies to improve the methods to more accurately determine when and where a fault has occurred.

Earth-fault detection and alarm is provided according to IEC 62548 or IEC 60364-7-712. But after an earth fault the system needs to be repaired. If this is not done in time, a second earth fault on another location can create a short-circuit without any available method for disconnection. Systems fulfilling 6.4 can nearly eliminate this risk, either by disconnecting all PV modules from each other in case of an insulation fault or by limiting the PV array section size down to one or two PV modules. Systems according to 6.3 can eliminate this risk only for the raceways, which could be an adequate measure in case of non-critical roofing material but critical building material.

5.6 Coverboard

Where flammable insulating materials are used in a roofing assembly, it may be advisable to make the roofing assembly more fire resistant by installing a non-flammable coverboard in the assembly. Roofing assemblies with a single-ply membrane as the top layer can have their fire resistance significantly improved with the addition of a non-flammable coverboard in the assembly. The coverboard is often installed immediately below the membrane. The coverboard installation may be possible as a retrofit to an existing roofing system, or as part of the reroofing process. Since a PV array has a useful life of more than 20 years, it is often beneficial to reroof the building prior to the PV array so the roof will last as long as the PV array. If reroofing is being considered by the building owner prior to the installation of a PV array, it is important that building owner consider improving the roof fire resistance. Installation of a coverboard may be a simple and low-cost improvement for some types of flammable roofing assemblies.

6 Technical PV system design measures for supporting firefighter and rescue service operations

6.1 General

To support firefighters and rescue service operations, measures that provide access to the fire location or to critical location and/or reduce the risks of shock hazards are useful.

The initial PV system design considerations according to 6.2 should be taken into account in general. The other measures are options to reduce risks and may be selected according to the on-site needs.

6.2 Initial PV system design considerations to minimize risk

6.2.1 General

The measures within 6.2 are general recommendations.

6.2.2 DC cable lengths and routing

An easy measure to reduce risks is to keep DC circuits as short as possible and preferably outside the building.

6.2.3 DC cabling marking

Marking of the DC cables and raceways helps firefighters and rescue services to become aware of the DC cabling which may be live after AC disconnection.

6.2.4 Access pathways and escape routes

For site selection, equipment location and cable routing, access pathways and escape routes need to be taken into account. Such pathways and escape routes are typically included in building plans and documentation. They need to stay free of obstacles (e.g. inverters or combiner boxes) to allow the intended function. The designer should look for a cable route not crossing and especially not running along such pathways or escape routes.

6.2.5 Caution board

For firefighter's work or maintenance person's entrance gates of stairway to the PV system installation on the roofs, it is recommended to install a caution board that indicates a PV system is installed on the roof. The caution board should warn anyone accessing the roof that anyone interacting with the PV system needs to be skilled for the work. The indication should refer to the local codes or rules. It is recommended to provide documentation including:

- location of cabling,
- information on whether cables are energized after shutdown or not,
- location of disconnectors and distribution boards,
- location of the PV array and fire-resistant cabling inside the building.

6.3 Generator/string-level shutdown

One way to improve the safety of a PV system on a building is to provide a means to shut off the conductors leading to a PV array. This is especially important when PV array DC conductors enter a building. When PV circuits are external to a building, they are often evident visually and can be avoided in a fire or other catastrophic event. Also fire services can extinguish the fire by allowing minimum distances and visibility of parts of the PV system. When PV array DC conductors enter a building, they can take numerous paths that can be difficult or impossible to track inside the building. Energized PV array DC conductors inside a building present a hazard to emergency responders in the event of a fire or other catastrophe. In order to systematically de-energize these conductors, segmentation means on the roof would need to be opened. Coordinating those segmentations during a catastrophe is not easy to achieve.

The application of these measures should be carefully evaluated, since additional contacts from relays may increase the risk of fire as shown in Annex A.

If switches are applied, a maintenance plan is needed, to ensure that the switch is operated 10 times a year.

To address this concern of conductors entering a building, many system designers have employed methods to make sure that all conductors entering the building can be easily shut down. These shutdown methods are often located at the point where the building receives utility service so that firefighters can be sure that these circuits are off prior to entering a damaged building. This requires one of two approaches based on the type of PV system installed.

1) For PV systems where all the circuits entering the building are AC circuits, the utility-interactive inverters on the roof or exterior of the building provide the automatic shutdown when the AC PV system disconnect is opened.
2) For PV systems where the circuits entering the building are DC circuits, there needs to be an automatic segmentation means on the circuit prior to entering the building, segmenting in case of loss of mains or manual remote shutdown. Additionally, it may be necessary to add an automatic segmenting means at the inverter to isolate any internal capacitance or the AC source from the DC conductors.

6.4 Module-level control, ELV-systems, distributed array protection

Measures according to Clause 6 do one of the following.

1) Disconnect or limit the voltage in case of shutdown to the module voltage or lower (e.g. DC-DC converters, module-level switches).
2) Have a system voltage considered to be safe according to national standards, either in general or during shutdown (e.g. ELV-systems, microinverters). Examples for voltages to be considered as safe are 30 V (USA) or 35 V (ELV according to IEC 62109-1 in wet conditions).
3) Employ other PV hazard control methods as introduced in USA by creating a distributed array protection using strategically located electronic devices or electromechanical relays within PV strings to limit current flow and simultaneous access to circuits of hazardous voltage potentials. UL 3741 "PV Hazard Control" gives more information.

One method is to apply disconnecting means inside the PV array to segment the array into lower voltage, less hazardous sections. While it is possible to do this type of segmentation with electromechanical relays, it is far more likely that electronic means are used for this type of segmentation. Many products, for instance microinverters and module-level DC-to-DC controllers, already exist that are capable of performing this segmentation – although that may not have been the originally intended function of the products.

The application of these measures may increase the number of contacts from relays or connectors, which may increase the risk of fire (see also Annex A). This should be considered in fire prevention considerations (see Clause 5). In addition to these readily available products, new products that simply provide an electronic switch to isolate PV modules from one another are starting to make their way into the market. These electronic switch technologies may be as simple as a controlled transistor circuit that is activated by some type of communications system. Being able to turn on and off a PV array with a remote command may be an attractive method of providing a more comprehensive approach to PV system safety in the event of a fire or other catastrophe. Due to absence of a standard for such devices, it is recommended to apply devices which are in conformity with IEC 60947-3 or according to UL 1741 or UL 3741, and fulfil functional safety requirements according to IEC 61508 or IEC 62109-1.

6.5 Cable routing measures

Firefighting inside a building is more challenging for firefighters. In comparison with the roof of the building, where a firefighter can see parts of the PV system and can keep a minimum distance to potential live parts, the situation inside a building is more difficult. Because of space constraints and limited view due to smoke, the risk of touching damaged DC conductors is higher inside the building. An installation measure to avoid this is to keep DC conductors outside the building. This can be achieved by installing the inverter outside the building and running the DC conductors between PV array and inverter also outside the building.

6.6 Fire-resistant cable raceways

Another method to avoid touching a damaged DC conductor is to use fire-resistant cable raceways in the considered area or building section. Cables running inside stone or concrete walls provide the same protection level as fire-resistant cable raceways. In this case there is no risk of touching the DC conductors. The insulation does not get damaged by a fire.

7 Installation and commissioning

7.1 General

In general, the safety of PV systems is ensured by the product and installation standards. For PV installation, IEC 62548 and the IEC 60364 series, especially IEC 60364-7-712, give requirements for the design and installation of PV systems on buildings. These standards are applicable for all PV systems on buildings and ensure the minimum level of safety against fire and electric shock. If there are no special risks, the application of these standards is sufficient. Due to additional risks, some buildings and locations require additional measures. As with the general electrical installation rules (e.g. IEC 60364-4-42 and IEC 60364-5-51), a risk evaluation within this document follows a similar approach. Subclauses 7.2 to 7.4 cover specific installation topics that the designer and installer should be aware of to keep the fire risks as low as possible.

See also Annex A for further information regarding root cause of fire incidents in PV systems.

7.2 Important installation requirements impacting risk

While all installation requirements have some type of safety or performance benefit, several installation requirements are more directly connected to fire risks. For instance, cable management is among the most important aspects of the fire safety of a PV system. If electrical cables are exposed to damage from sharp metal edges or abrasive surfaces, it is likely that cable insulation can rapidly deteriorate, eventually causing faults to ground. While ground faults may signal an alarm or even turn off inverters, if the faults are ignored or not repaired in a reasonable time period, multiple array faults can cause circulating currents in the array. These circulating currents can be a fire hazard by creating arcing faults. Proper cable management can reduce or eliminate the possibility of cable damage and the associated fire hazards that could result. Other wiring methods such a wire ducts are used to protect conductors. Wire ducts, if improperly installed, may cause damage to conductors creating hazards that they were intended to prevent. An example of improper installation of wire ducts is improperly installing couplings and end fittings that keep the ducts intact and prevent sharp edges from contact with conductors.

In addition to taking care in the installation of conductors in a PV system, the selection of materials that can withstand decades of outdoor exposure helps reduce risk of failures over time. PV modules are manufactured with the ability to last for 25 years or more in most environments. Exposed plastic materials need to be rated for sunlight exposure when used within the PV array and other outdoor locations. The mounting system, wiring methods, and other electrical equipment should be selected to have similar longevity to the PV modules. More corrosive environments like coastal regions require closer attention to material selection such as galvanized steel, aluminium, or stainless steel for metallic structures and equipment. For PV modules, IEC 61701 and IEC 62716 can be used for verification. Also, dissimilar metals in contact with one another may not corrode in dry environments but may deteriorate rapidly in humid environments. Of particular importance are products for electrical bonding, grounding, and lightning protection. Should these materials be permitted to deteriorate, safety hazards may result. Deterioration of metal structures or equipment can increase risks of damage to buildings and PV systems.

While the materials used for mounting structures are important for the longevity of a PV array, the structural design is of similar importance. Insufficient structural integrity can cause damage to PV modules and buildings. Structural design should also factor in other conditions such as higher localized snow accumulations or wind flows due to the placement of the PV system and micro-conditions from the built environment. Proper structural design accounts for loading of the structure caused by wind, snow, and seismic events. Structural deficiencies can impact fire events. Additionally, a failed mounting structure on a building could allow loose pieces of a PV array to become projectiles that could damage buildings and put people in danger.

7.3 Commissioning procedures

Once a PV system is installed, it should be commissioned to verify that the installation is complete and is in compliance with the engineered design. If the system design is not carefully followed, it is difficult to verify that changes to the design will not negatively impact the longevity and safety of the PV system. Given the importance of commissioning the PV system, it is best to have an independent party to perform the commissioning. A person who has not been directly involved in the installation of the system can have an unbiased perspective and may be more likely to catch installation mistakes that were overlooked by the installing personnel. For commissioning and initial inspection, IEC 62446-1 applies.

7.4 Documentation – clear installation, owners, fire services and maintenance manuals for PV equipment

Documentation and a plan of the PV-installation and the pathways should be provided. PV systems require some level of operation and maintenance direction for the system owner. Documentation such as owner's manuals for key equipment like inverters and monitoring equipment is necessary for the long-term operation of PV systems. Recommended intervals for maintenance of various equipment within the PV system is necessary to assist the owner to keep the system operating properly. Too often, documentation is either insufficient or not made available, giving the owner the impression that maintenance is unnecessary. Neglect of key operational and maintenance issues will cause a PV system to deteriorate, which results in poor system performance and possibly risk of damage to the building and the PV system.

8 Operation and maintenance

8.1 General

Periodic inspections and maintenance are important for fire prevention, as given in 8.2 to 8.6. The more often such inspections are performed the smaller is the risk of fire. Requirements for inspections during a system's lifetime are given in IEC 62446-2.

8.2 Inspection of electric system

Monitoring of the PV system can detect a critical situation before a fire starts. Indications of insulation faults (as required by IEC 62548 and IEC 60364-7-712) need to be applied in such a way that needed actions are started. Depending on the risk level, important data such as insulation faults, component faults (especially components including safety functions) need to be sent to the operator and owner and, where available, facility management staff.

Physical inspections for systems health regarding electric safety should be performed according to IEC 62446-2.

8.3 Inspection of mounting structure and building influence

A failing mounting structure can turn into a fire risk due to damaged cable insulation, arcing from loose connections or broken equipment. Checking the health of the mounting structure and the influence on the building can avoid those risks. The inspection includes checking that all parts of the PV array (including the PV modules), the raceways/cabling, and the inverter are still properly fixed in place. The mounting structure should not be bent or shifted. There should be no indications of a negative impact on the building such as damaged roofing, broken tiles, or cracks in the walls.

8.4 Inspection of pathways

To avoid delay in firefighting and rescuing people, pathways need to be free of obstructions. During inspection, all pathways should be checked to ensure that there is no impact on pathway functionality.

8.5 Cleaning

Accumulation of dry leaves, vegetation, and dirt can add a fire risk by adding flammable material and reduce ventilation by blocking air flow. Cleaning should be performed according to the frequency determined by site-specific evaluation according to IEC 62446-2. Special attention should be paid at locations with additional heat such as power conversion equipment and combiner boxes. This includes also frequent cleaning of filters.

8.6 Thermography

Thermography inspections are very important to avoid fires. By a simplified inspection according to IEC TS 62446-3, module hot spots can be detected before they turn into a fire risk. The inspection may be performed from the front side of the PV modules (to detect problems in the modules, as well as the junction boxes which are observable thermally from the front), or alternatively from the back side. Inspection of the balance of system components (cables, fuses, inverters, switchgears) on the DC and AC sides following IEC TS 62446-3 is also recommended.

8.7 Recommendations for empty buildings or systems not under supervision

When a building is empty and open for sale or to let, electricity may not be supplied by the electric power grid, and control power may not be supplied to the grounding fault or arc alarming system. Since PV modules are always active in sunlight, fire risks remain. Some measure such as disconnection of each string circuit in the combiner box or special attention is recommended for such cases.

9 Corrective measures after fire

9.1 General

Clause 9 gives guidance for actions after a fire. Even if a PV system appears to be safe from the first view, hidden damages with risks may be present.

9.2 Measures to avoid safety risks or further damage

As a first step, it is recommended to establish exclusion zones around uncontrolled parts of the PV array, if there could be an impact on safety of the array. If there is a risk for creating or spreading a fire by short-circuits or arcs of an array, flammable material should be removed where possible. This system needs to be observed and potential live equipment not handled as long as no electrician with PV knowledge is available on site. Special attention needs to be paid in case of a night-time emergency. When the sun is rising, the voltage and current will increase, which may lead to critical situations. A stable situation during the night can change to a critical situation in the morning.

9.3 Safety inspection

A competent person should inspect the system regarding an impact of safety measures of the array. First a visual inspection of the array should be performed. The integrity of the insulation of cables and equipment, the fixing of PV modules and equipment and damage to any PV equipment should be evaluated. In case of an impact, see 9.4.

In case of no visual impact, an insulation check should be performed at all strings/sub-arrays. In case of insulation faults, the faulty parts (cable, modules) should be isolated.

9.4 Measures to bring PV system into a safe state

An electrician with PV knowledge should bring the system into a safe state as follows.

- Shut down the system. All available shutdown procedures should be performed and all available switch-disconnectors should be switched to the off position. Measures for avoiding reconnection, such as locking switches or using warning signs, should be applied.
- Check if there is a hazardous voltage between uninsulated parts and other uninsulated parts or earth potential.
- Isolate uninsulated conductors or parts.
- Split into the smallest available voltage parts as possible, for example by disconnecting all connectors (after checking current flow). Isolated tools and isolated personal protections (e.g. gloves) should be used. The cables and system components are considered to be energized, until they are separated and put to safe state.

Annex A
(informative)

Analysis from fire incidents in PV systems

A.1 General

The content of Annex A is based on an investigation in Germany (Assessment of fire risks in PV systems and development of safety concepts for risk mitigation; 2014). In total some 400 fire incident reports were found for the years 1995 to 2012. These 400 cases include mostly cases where a PV system on a building structure was affected. Some 180 out of these reports found that a PV system caused the fire, with 75 incidents that affected the building. Results are presented in Table A.1 and Figure A.1. The findings are valid for Germany with special boundary conditions from a "PV boom" time period, where average installation quality is assumed to be below standards. Similar sources of faults have been observed also in other countries.

Table A.1 – Number of incidents with a certain damage

fire from outside – PV system affected	220
fire from PV – building destroyed	10
fire from PV – building damaged	65
fire from PV – PV system damaged	49
fire from PV – component damaged	55

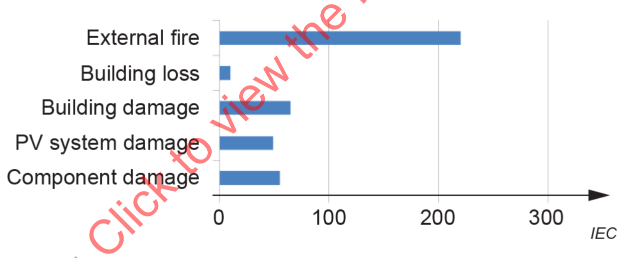


Figure A.1 – Number of identified incidents and severity of effect on surroundings for a total of about 400 fire reports

At the time of closing the survey, some 1,3 million systems with a total capacity of approximately 30 GWp were installed in Germany.

For the damaged buildings one mounting feature significantly impacts the severity of damage: roof integration. Figure A.2 shows the impact of mounting type.

NOTE Information on the mounting type was not available for all incidents.

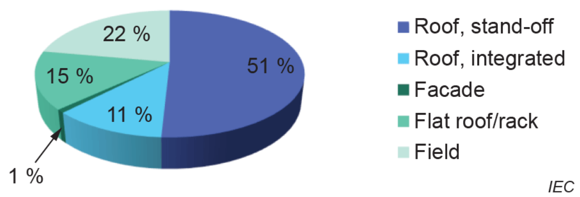


Figure A.2 – Distribution of fire reports depending on mounting type

The fraction of each mounting type roughly correlates with the market share of each market fraction as given by the German solar industry association BSW. Only roof integrated systems stand out. They, together with other BIPV systems, account for about 1 % of the whole market. Looking closer at the incidents where building damage had been reported – 54 cases – yields the picture in Figure A.3. Roof-integrated PV generators account for some 20 % of building damage. Thus, roof-integrated PV systems had a fire risk which is 20 times higher than for regular stand-off mounted PV generators.

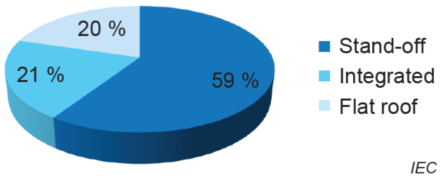


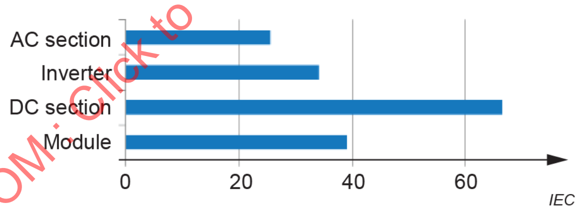
Figure A.3 – For cases of damaged buildings only: distribution of fire reports depending on mounting type

This can easily be explained by the fact that German buildings with stand-off system are typically covered by a "hard roof" (i.e. tiles), which shields the building from external fires. For BIPV systems, however, a fire within the PV system is already inside the building.

This clearly indicates that BIPV systems should receive very careful planning and thorough installation and possibly special protection for critical components.

A.2 Component where fire started

Is there a pattern in incidents which indicates options for easy improvements? Do some components stand out as frequent cause for fire? Figure A.4 and Figure A.5 show the section and the component, respectively, where the origin of a fire could be located.



AC section includes all components from inverter output terminals to the point of coupling to the grid. DC section includes all components from string connectors at modules to inverter input terminals.

Figure A.4 – Counts of system section where fire started

Dominant section in terms of fire risk is the DC section, i.e. string and array cabling and array junction boxes. The main system components, PV modules and inverters, account for roughly half the fire incidents. Surprisingly inverters have been found nearly as often as modules, which are used in far higher numbers. Aside from inverters, the AC section of systems is far more often involved in fires than expected, considering that the components used are regular AC components with a long-term evolution.

Figure A.5 shows the component causing the fire with the best available resolution.

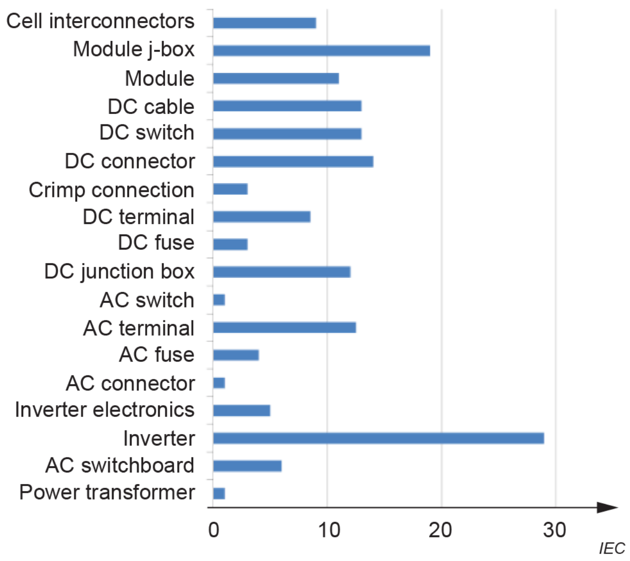


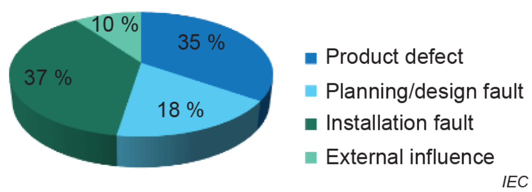
Figure A.5 – Counts of component where fire started

The data indicates that the inverter is a "hot-spot". Why is this the case? Findings presented in A.3 indicate that there are two main reasons: product defects and installation errors, which cause the high rate of fires from inverters. Another "hot-spot" is module junction boxes. Here, it is possible that product defects in combination with deficient manufacturing quality assurance are the major cause of fires. A survey of field failures of PV modules in the US found failing connectors to account for 6 % of failures of fielded modules.

Other causal components are fairly well distributed. However, the data show that all sorts of connections are potential failure points. This is especially true of connections performed in the field. Furthermore, "DC switch", "DC terminal", "DC junction box" and "AC distribution" often include the use of screw terminals. The authors of the study believe that screw terminals are a potentially weak spot in PV systems and should be replaced by other connection technologies. Tightening screws can be forgotten and good contact quality needs controlled torque according to the terminal manufacturer's specifications. Suitable tools are rarely used by some installers. DC switches showed a special failure.

A.3 Cause of incident

For some 110 incidents a likely cause could be identified. The distribution of these causes is shown in Figure A.6.



Installation fault describes poor workmanship.

Figure A.6 – Distribution of identified causes of fire incidents

Installation faults and product defects are the main reasons for damage. They account for roughly 35 % of damages, each.

The specifically found errors and faults are listed in 1) to 4).

1) Mechanical design errors: