



# Technical Expert to develop grid connection guidelines and standards for the Kingdom of Bahrain

## *Fire Safety Recommendations for Distributed Solar PV Systems*

Draft 1.0

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## 1 SCOPE

This section contains special considerations and prescriptions against fire hazard to be used when PV plants are to be mounted on buildings.

Fire hazard prevention is considered under the following points of view:

- PV plants and their components shall not be a source of fire.
- Should a fire originate from a PV plant it shall not propagate into the building.
- The PV plant shall not interfere with the fire safety system of the building and with the firefighters whatever the origin of the fire.

Different types of buildings are considered as regards the fire hazard and PV plants are basically divided into externally-mounted (BAPV) and building-integrated (BIPV).

In this section, the prescriptions adopted in countries with a high PV penetration have been taken into account. Particularly useful were the following: VDE-AR-E 2100-712 (Germany), Guida CEI 82-25 (Italy), UL 1699B (US).

Further than the prescriptions listed in this document, depending on the results of the risk assessment, technical, installation, and maintenance measures can be selected to reach the intended safety level of the PV system and building. Due to the fact that installation faults can increase the generally low risk for a fire in PV system, this document is recommended for each building related PV system. It may be used when there is a need from the building owner, PV system owner, insurance company, financial institution or other party.

Finally, the report addresses the stakeholders with recommendations on specific issues that should be taken into account during the lifetime of a PV plant: these recommendations are reported in Annex A.

### 1.1 Definitions

The most relevant definitions for the present document are listed below.

**AFCIs** – Arc Fault Circuit Interrupters: devices that protect specifically against arc faults. They automatically trip a circuit when they detect dangerous electric arcs. These devices are also known as Arc Fault Detection Devices (AFDDs).

**Application for Connection** – It is filled by an Applicant for a new Solar PV Connection. This application shall be made in a format prescribed and shall contain the required information.

**BIPV** – Building integrated photovoltaics – photovoltaic materials that are used to replace conventional building materials in parts of the building envelope such as the roof, skylights, or facades.

**BAPV** – Building applied photovoltaics – photovoltaic materials that are used to substitute conventional building materials in parts of the building envelope such as the roof, skylights, or facades.

**ELV** – Extra Low Voltage – Voltage less than 50 V AC or 120 DC. ELV supply systems may fall into one of the following categories: SELV (Safety Extra Low Voltage), PELV (Protection Extra Low Voltage, or FELV (Functional Extra Low Voltage).

**Inverter** – device which converts the direct current produced by the photovoltaic modules to alternating current in order to deliver the output power to the grid. The inverter is also capable of controlling the quality of this output power.

**Low Voltage (LV)** – according to international standards, a voltage below 1kV AC or 1.5kV DC. The actual range of the LV distribution system depends on the country. The Bahraini LV distribution system is operated at 400/230V AC.

**Photovoltaic (PV) Modules** – also called Photovoltaic (or PV) panels. Set of elementary photovoltaic cells for the conversion of the solar radiation into electric current.

**Photovoltaic Array** – A frame containing different Photovoltaic Panels usually grouped in a “String” for the conversion of the solar radiation into electric current.

**PV Plant** or PV System – A plant or system that produces power from the conversion of the solar radiation into energy.

## 1.2 Reference documents

The following documents are here quoted as a reference:

- [1] IEC 61730-2, Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing
- [2] ENV 1187, Test Methods for External Fire Exposure to Roofs
- [3] ANSI/UL 1703, Flat-Plate Photovoltaic Modules and Panels
- [4] MST 23 / MST 24 (information in reference [1])
- [5] NFPA, “Fire Fighter Safety and Emergency Response for Solar Power Systems”, Quincy, May 2010.
- [6] OSFM, “Fire Operations for Photovoltaic Emergencies”, Sacramento, November 2010



## 2 IGNITION HAZARDS

There are many causes of possibly ignition in a PV system; in most cases they are not associated with the PV modules directly, but are actually linked to fault problems in the wiring and in the construction and maintenance. Mainly it has to be take care of:

- The presence of debris under the panels or a surface of the roof with high index of flammability can cause ignition as long as the temperature under the panel can be around 90°C or more depending on environmental conditions;
- Short circuit current or improper mounting of electricity boxes can cause ignition;
- Joule effect in the connection cables because improperly sized at design stage or in construction phase;
- Possible damages to cables caused by rodents, that can be avoided by adopting the cable protections suited to the purpose;

Although the fire tests and classification of PV modules according to IEC 61730-2 (MST 23 and MST 24) is undoubtedly important, there are several further aspects to consider when PV modules are used in buildings. Characteristics as thermal behaviour, noise isolation and overall transparency may play a fundamental role under both a functional and a safety point of view.

Furthermore, the same PV module might be classified differently as regards the set of standards adopted (e.g. ANSI/UL or CEN). If one considers that, each building component usually must comply with several standards in order to be eligible for a given application the proper use of PV modules in buildings may become a real concern.

The standards on fire prevention must be taken into account at design level and during construction; it is also recommended that both the installer and the Owner check at every stage the correctness of the installation.

Control checks shall involve:

- Check the readiness of the wiring connections and the general cleanliness and order;
- Check the presence of any debris accumulation under the panels and check the fire ignition risks of the mounting surface. Dust and sand on the panels only cause a decrease in performance of the PV system. Electrical hazards are associated with Fire Fighters Operations.

The PV modules add to the complexity of the traditional firefighter tactics for suppression, ventilation and overhaul more complex. However, the electrical and fire hazards associated with electrical generation and distribution systems are well known, PV systems present unique safety considerations.

The increased operating temperatures allowed by newest panels mean that PV modules are not placed flush against a roof, but may now be placed four to seven inches above a roof deck. This air gap can cause any fire between the PV panel and the roof to be much more intense than a traditional roof fire.

The 2014 edition of NEC (NFPA 70) code states in 690.13(A) “Location. The PV disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors.”

It applies also to O&M operations when disconnection is requested:

- Readily accessible - Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, and so forth.
- Readily accessible provision is primarily for emergency operation. If the disconnect is not mounted in close proximity of the service entrance disconnect (usually within 1 m. of the



- meter location or service disconnect switch), then a diagram or directory must be provided to clearly identify where the disconnect device is located.
- iii. A rooftop disconnect on a residential roof will normally not qualify as a readily accessible disconnect.

### 3 FIRE RESISTANT PV MODULES

The standard IEC 61730-2:2016 includes the fire test (MST 23) and the ignitability test (MST24) for PV modules. The requirements assessed in the fire test establish the fundamental fire resistance of PV modules serving either as roof covering materials or mounted onto a building over an existing roof. These modules may be exposed to fire conditions, and therefore need to indicate their fire-resistance characteristics, both as regards fire reaction and fire ignitability, when exposed to a fire source originating from outside the building on which they are installed.

#### 3.1 Fire test MST 23

PV modules may be exposed to external fire conditions, and therefore should be tested for their fire-resistance characteristics when exposed to a fire source originating from outside the PV module, which may include the building on which they are installed or into which they are integrated, or from an adjacent building. Fire resistance requirements for a PV module intended for building applications are defined in local or national building codes.

PV modules as building product – i.e. serving as roof covering materials, elements for building integration or that are mounted on buildings – are subject to specific safety requirements originating from national building codes.

However, the fundamental requirements for fire safety are not internationally harmonised. Consequently, the IEC 61730-2 recognizes that it is not possible to define general requirements for fire safety of PV modules as recognition of test results is commonly not practiced. In the Annex B (informative) of the standard two test methods are mentioned:

- Fire test for PV modules based on ENV 1187
- Fire test for PV modules based on ANSI/UL 1703

The criteria illustrated in the Annex B of the IEC 61730-2 shall be referred in order to determine the eligibility of PV modules as regards their installation on buildings. However, where possible, it is recommended that the criteria used for fire tests are in accordance with the standards adopted in the building design, especially as regards the classes of fire reaction and fire ignitability of the building elements and materials.

##### 3.1.1 Fire test for PV modules based on ENV 1187

The ENV 1187 fire test methods, parts 1 to 4, differ in terms of radiant heat, the used brands, additional air flow (wind simulation), tilt angles, amount and size of the demanded test specimen. The pass criteria for each test method are described in ISO 13501-5.

In general building integrated PV systems shall be tested in conjunction with a defined mounting system following the installation instruction of the PV module manufacturer. When testing PV modules, the mounting material and the joints between PV modules as well as sealing materials have to be considered and included in the test set-up.

Four different test methods, representing four different scenarios, are specified in ENV 1187. The methods assess the fire performance of roof coverings under the following conditions:

- Test 1: Method with burning brands. The test evaluates of a roof under the conditions of thermal attack with burning brands. The performance includes the fire spread across the external surface of the roof, the fire spread within the roof and the fire penetration.
- Test 2: Method with burning brands and wind. The test evaluates the performance of a roof covering under the conditions of a thermal attack with burning brands and additional wind. The performance includes damaged length both on the roof covering and in the substrate.



- Test 3: Method with burning brands, wind and supplementary radiant heat. The test evaluates the performance of a roof under the condition of thermal attack with burning brands, additional wind and radiant heat. The performance includes the external fire spread and the fire penetration.
- Test 4: Two-stage method incorporating burning brands, wind and supplementary radiant heat. The test evaluates the performance of a roof under the conditions of thermal attack with burning brands, wind and radiant heat. The performance includes the external fire spread and the penetration by fire.

The choice of the test method to be applied depends on the classification envisaged by the consultant/designer. With reference to the Table 1 there are several possibilities:

- If only a classification  $B_{ROOF}$  (t1) is envisaged, only test 1 with burning brands is carried out.
- If only a classification  $B_{ROOF}$  (t2) is envisaged, only test 2 with burning brands and wind is carried out.
- If only a classification  $B_{ROOF}$  (t3) or  $C_{ROOF}$  (t3) or  $D_{ROOF}$  (t3) is envisaged, only test 3 with burning brands, wind and supplementary radiant heat is carried out.
- If only a classification  $B_{ROOF}$  (t4) or  $C_{ROOF}$  (t4) or  $D_{ROOF}$  (t4) or  $E_{ROOF}$  (t4) is envisaged, only test 3 with burning brands, wind and supplementary radiant heat is carried out.

If more than one classification is required, all the corresponding tests are carried out, as there is no direct correlation between the test methods and hence, no generally accepted hierarchy of classification between them.

Roofs intended to be installed with pitches up to 20° in practice shall be tested at a pitch of 15°. Roofs intended to be installed with pitches greater than 20° shall be tested at a pitch of 45°.

**Table 1 – Classes of external fire performance for roof coverings**

Test method	Class	Classification criteria
ENV 1187 Test 1	$B_{ROOF}$ (t1)	All the following conditions shall be satisfied for any one test: <ul style="list-style-type: none"> <li>– external and internal fire spread upwards &lt; 0.700 m;</li> <li>– external and internal fire spread downwards &lt; 0.600 m;</li> <li>– maximum burned length external and internal &lt; 0.800 m;</li> <li>– no burning material (droplets or debris) falling from exposed side;</li> <li>– no burning/glowing particles penetrating the roof construction;</li> <li>– no single through opening &gt; 25 mm<sup>2</sup>;</li> <li>– sum of all through openings &lt; 4500 mm<sup>2</sup>;</li> <li>– lateral fire spread do not reach the edges of the measuring zone;</li> <li>– no internal glowing combustion;</li> <li>– maximum radius of fire spread on “horizontal” roofs, external and internal &lt; 0.200 m.</li> </ul>
	$F_{ROOF}$ (t1)	No performance determined
ENV 1187 Test 2	$B_{ROOF}$ (t2)	For both test series at 2 m/s and 4 m/s wind speed: <ul style="list-style-type: none"> <li>– mean damaged length of the roof covering and substrate ≤ 0.550 m;</li> <li>– max damaged length of the roof covering and substrate ≤ 0.800 m.</li> </ul>
	$F_{ROOF}$ (t2)	No performance determined
ENV 1187 Test 3	$B_{ROOF}$ (t3)	$T_E \geq 30$ min and $T_P \geq 30$ min.
	$C_{ROOF}$ (t3)	$T_E \geq 10$ min and $T_P \geq 15$ min.
	$D_{ROOF}$ (t3)	$T_P \geq 5$ min
	$F_{ROOF}$ (t3)	No performance determined
ENV 1187 Test 4	$B_{ROOF}$ (t4)	<ul style="list-style-type: none"> <li>– No penetration of roof system within 1 h.</li> <li>– In preliminary test, after withdrawal of the test flame, specimens burn for &lt;</li> </ul>



		5 min. – In preliminary test, flame spread < 0.38 m across region of burning.
	C <sub>ROOF</sub> (t4)	– No penetration of roof system within 30 min. – In preliminary test, after withdrawal of the test flame, specimens burn for < 5 min. – In preliminary test, flame spread < 0.38 m across region of burning.
	D <sub>ROOF</sub> (t4)	– Roof system is penetrated within 30 min but is not penetrated in the preliminary test. – In preliminary test, after withdrawal of the test flame, specimens burn for < 5 min. – In preliminary test, flame spread < 0.38 m across region of burning.
	E <sub>ROOF</sub> (t4)	– Roof system is penetrated within 30 min but is not penetrated in the preliminary test. – Flame spread is not controlled
	F <sub>ROOF</sub> (t4)	No performance determined

Here below the test fire requirements for the test method based on ENV 1187 for the classification B<sub>ROOF</sub> (t1) with PV modules are described. The Test 1: Methods with burning brands, without wind or supplementary radiant heat is thus adopted.

The test can be performed for either one or both roof tilt angle ranges of 0° to 45° at 15° and for roof tilt ranges of 45° to 90° at 45°.

Requirements per roof pitch:

- A realistic roof construction including cross beams and all attachment parts with the PV modules installed the same as in a final system installation shall be provided by the PV module manufacturer.
- The minimum size for a test deck is 0,8 m × 1,8 m. Since it is also necessary to test transverse and vertical joints, several samples may be required to build up the complete test deck.

The Figure 1 shows an example test set-up for the fire test following ENV 1187.

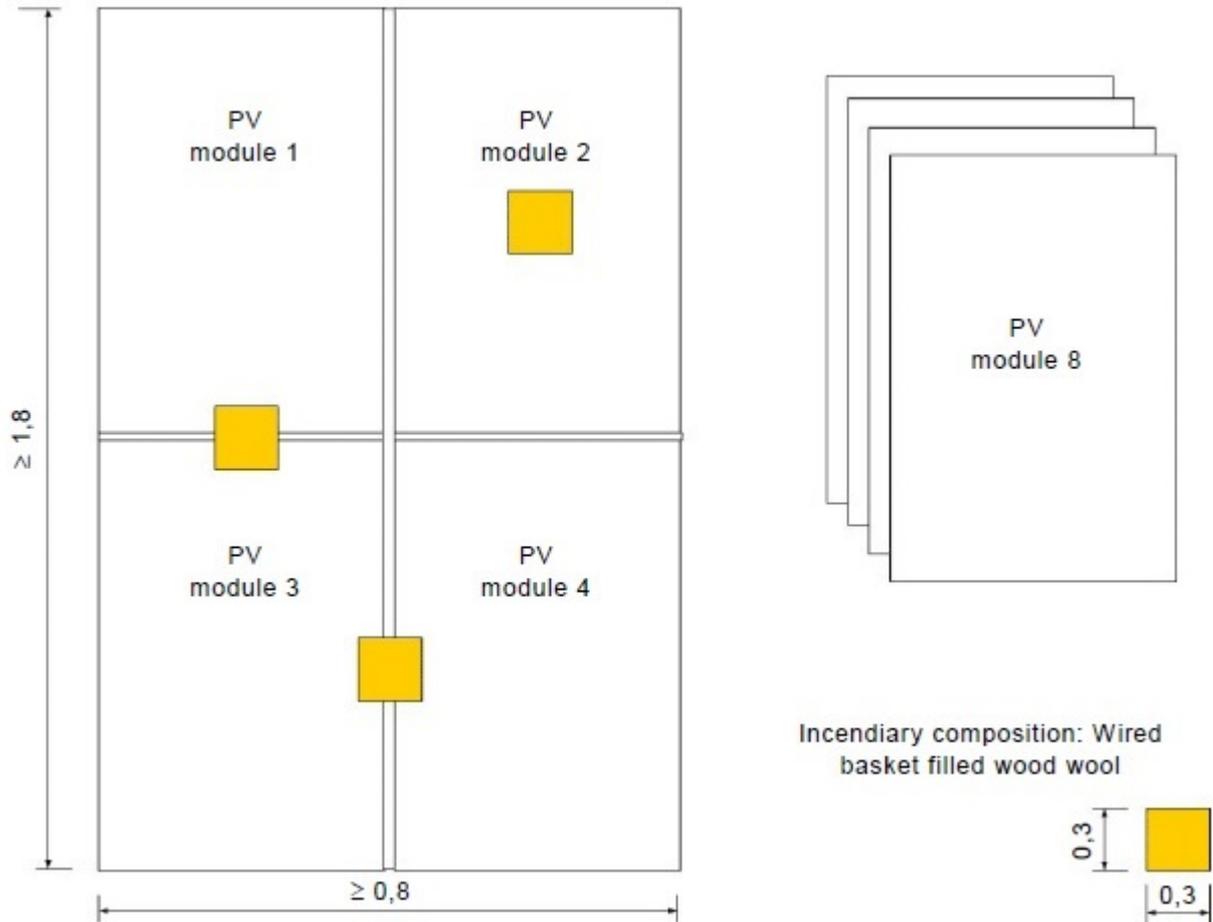


Figure 1 – Example of test set-up for fire test according to ENV 1187

- Four PV modules are required for each test (if different pitch angles have to be considered, the amount of samples increases accordingly). One vertical and one horizontal joint on top of the roof and two centric applied incendiary compositions on one PV module are tested. Thereby fire passing and the influences of a possible lower functional layer as for example thermal insulation and sealing are tested.
- For building integrated PV modules the procedure of the positioning of the incendiary compositions shall be according to the above defined instructions for all ENV 1187 test methods.
- For building added PV modules the fire test can be limited to only one PV module and a centred brand, as long as there are no polymeric material used at interconnections (joints), mounting or frame parts.

The classification is done according to ISO 13501-5 as reported in Table 1 for  $B_{ROOF}(t1)$ .

### 3.1.2 Fire test for PV modules based on ANSI/UL 1703

Fire resistance of PV modules installed on or over building rooftops has been proven to depend on more than just PV module flammability characteristics. In fact, fire resistance of PV modules is highly dependent on the combination and configuration of roofing materials, rack mounting systems, and the PV modules as a system. As a result of these findings, the PV system fire tests were developed to

establish fire resistance classifications for PV systems consistent with the fire classification of roofing materials.

To reduce the number of tests required to cover every possible combination of PV modules with PV racking systems and roofing materials two new concepts were introduced:

- a) Optional PV module typing that groups PV modules with similar constructions, flame spread characteristics and burning brand characteristics. This allows replacement of a PV module of a particular type with any PV module of the same type without affecting the PV system fire rating.
- b) Use of common roofing materials for the test that meet specific performance requirements to represent all roofing materials. One set of roofing material construction and performance requirements has been established for steep-slope roof applications and another for low-slope roof applications.

PV system fire performance construction and PV module type requirements are detailed in ANSI/UL 1703:2015, section 16. Test methods for PV system fire performance classifications are specified in ANSI/UL 1703:2015, section 31.

PV modules intended to be integrated into a building structure (BIPV modules) are evaluated for fire classifications as roofing materials under UL 790 requirements as specified in ANSI/UL 1703:2015, section 16.

To assess basic fire propagation behavior of PV modules not considering its mounting system ANSI/UL 1703:2015, section 31.1.2 and section 31.1.3 can be used. According to these sections, the fire resistance classes range from Class C (fundamental fire resistance), to Class B to Class A (highest fire resistance). A minimum fire resistance rating Class C is necessary for any building-mounted module (BAPV). Certification to a higher level may be considered in order to satisfy specific application requirements.

Depending on the building characteristics or class, design criteria and other relevant aspects, PV modules integrated in buildings (BIPV) may require specific characteristics as regards fire hazard further than those tested by means IEC 61730-2. As a rule, a minimum fire resistance rating Class A is needed.

A PV module used in place of classified roofing material or mounted to or above an existing classified roofing material needs to comply with the following:

- Spread-of-flame test
- Burning brand test

These are based on ANSI/UL 790. Sufficient samples shall be provided to create a single test assembly for a single spread of flame and a single burning brand test.

Products that comply with these tests are supposed to be not readily flammable, afford the measurable degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.

### *3.1.2.1 Spread-of-flame test*

A test sample is to be mounted, and luminous gas flame applied, as shown in Figure 2. The test is to be conducted with the module or panel oriented with respect to the test flame, so that the flame impinges only on the top surface of the module or panel.

The sample area of the test material should be not less than 1 m in width for all classes, 1.82 m minimum length for the fire safety Class A, 2.4 m minimum length for the fire safety Class B, or 3.9 m minimum length for the fire safety Class C, as measured from the leading edge of the sample.

For the safety Class A or B test, the gas flame is to be applied continuously for 10 min or until the spread flame (flaming of the material being tested) permanently recedes from a point of maximum

spread, whichever is the shorter duration. For a safety Class C test, the gas flame is to be applied for 4 min and then removed.

During and after the application of the test flame, the test sample is to be observed for the distance to which flaming of the material has spread, production of flaming or glowing brands, and displacement of portions of the test sample. The observation is to continue until the flame has permanently receded from a point of maximum spread.



**Figure 2 – Spread-of-flame test (LAPI laboratory)**

### **3.1.2.2 Burning-Brand test**

A test deck is to be mounted as described in 6.1 of ANSI/UL 790, with a few differences as specified in the standard IEC 61730-2.

As shown in Figure 3, the fire safety Class A brand is to consist of a grid, 300 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be  $2000 \pm 150$  g.

The fire safety Class B brand is to consist of a grid, 150 mm square and approximately 57 mm thick, made of kiln-dried Douglas fir pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be  $500 \pm 50$  g.

The fire safety Class C brand is to consist of a piece of kiln-dried non-resinous white pine lumber that is free of knots and pitch pockets. The dry weight of the finished brand is to be  $9.25 \pm 1.25$  g.

Before application to the test deck, the brands are to be ignited so as they burn freely in still air (times and other details depending on safety class).

Each individual tests, whether fire safety Class A, B or C, is to be continued until the brand is consumed and until all evidence of flame, glow or smoke are disappeared from both the exposed surface of the material being tested and the underside of the test deck.

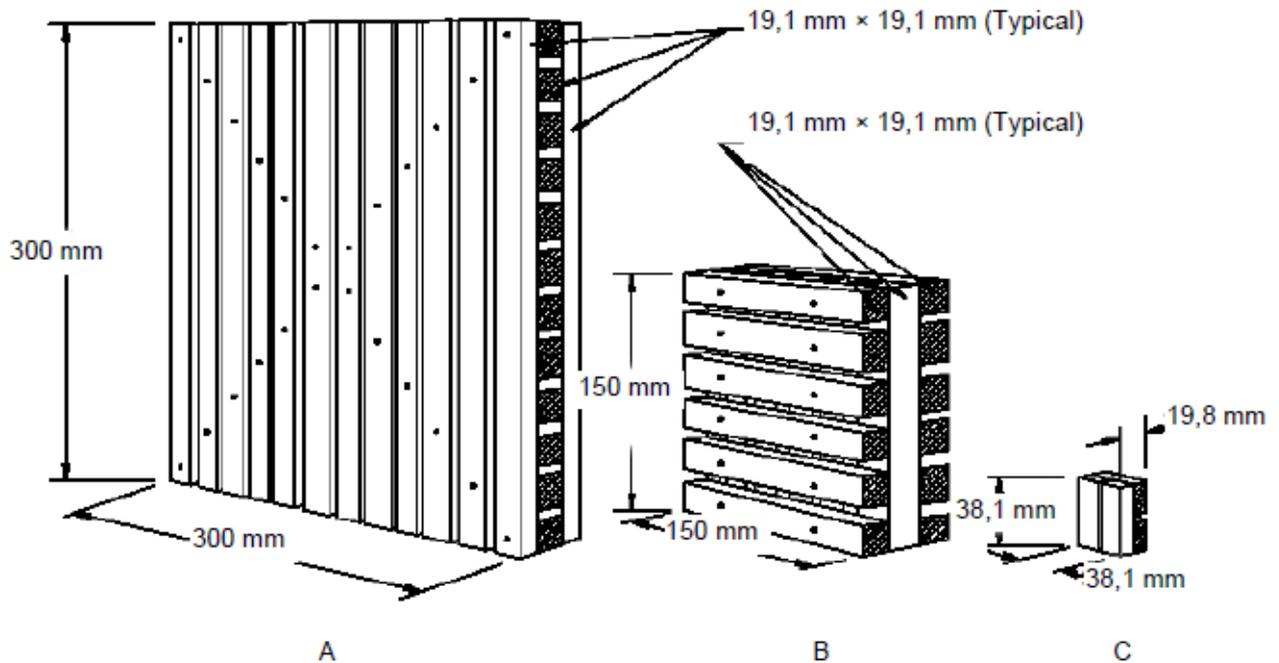


Figure 3 – Burning brand construction

As regards the conditions of acceptance, at no time during the spread-of-flame or burning-brand tests shall:

- Any portion of the module or panel be blown off or fall off the test deck in the form of flaming or glowing brands.
- Portions of the roof deck, or portions of a module or panel intended for installation integral with or forming a part of the building roof structure, fall away in the form of glowing particles.
- The flame spread beyond 1.82 m for fire safety Class A, 2.4 m for fire safety Class B, or 3.9 m for the fire safety class C rating. The flame spread is to be measured from the leading edge of the sample.
- There be significant lateral spread-of-flame from the path directly exposed to the test flame. Spread-of-flame includes flaming on both of the top surface (the surface to which the external flame is applied) and in any intermediate channel, such as the space between stand-off and integral modules and the roof.

As an example, in Figure 4 is visible the result of a Class A burning-brand test on a PV module that can be certified only for a Class C fire test. The PV module fails the test.

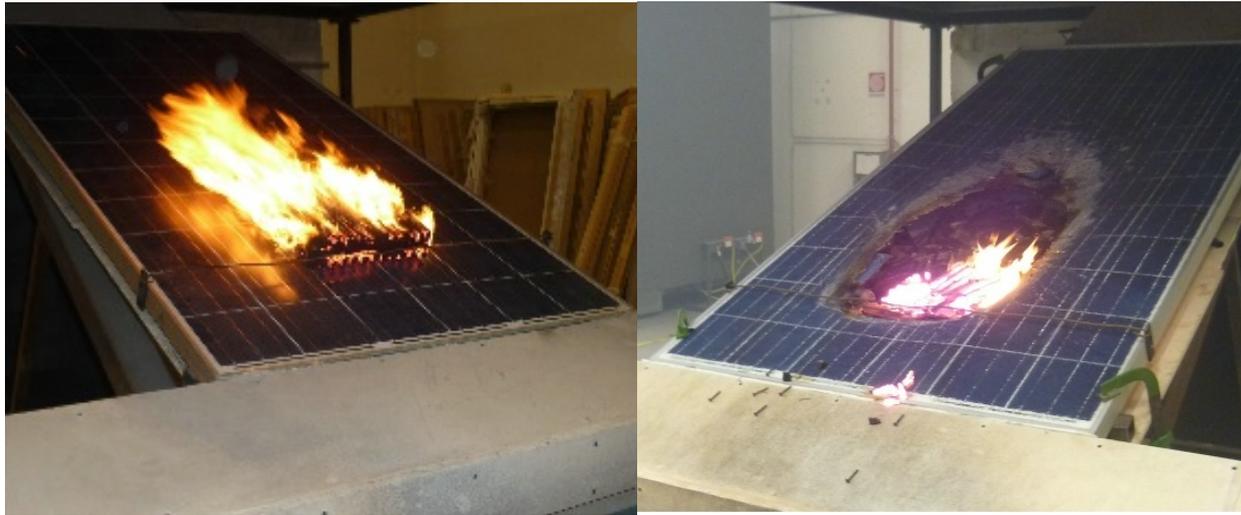


Figure 4 – Example of a Class A burning-brand test – the PV module fails the test (LAPI laboratory)

### 3.2 Ignitability test MST 24

This test determines the ignitability of PV modules by direct small flame impingement under zero impressed irradiance by external heat sources using vertically oriented test specimens. The test does not replace a fire test; it assesses ignitability, not flammability of outer surfaces of a module. The test method is based on ISO 11925-2:

- one module per type family selected (without pre-stress)
- test conditions:  $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$ ,  $50\% \pm 20\%$ , defined max. air speed 5 cm from the surface (pre-conditioning: 48 h at  $23^{\circ}\text{C} / 50\%$ )
- gas burner with specific mounting and mobility applied to defined module positions (each for 15 s)
- Polymers applied for this test; electrical components (junction box etc.), glass, metal not to be tested
- pass/fail criterions: ignitability, maximum flame height, length of destroyed area

The test can be performed on full-size PV modules, as preparation of specimens according to ISO 11925-2:2010 (Clause 5) may not always be possible. The test procedure given in ISO 11925-2:2010, Clauses 4 to 8, is therefore modified as described in IEC 61730-2 (see Figure 5).

If compliance to ISO 11925-2 can be proven by existing approvals, this test can be omitted.

If specimens can be prepared that comply with Clause 5 of ISO 11925-2:2010 and that are identical to the PV module type under test with respect to their material composition, the test procedure given in ISO 11925-2 may be used without modifications.

Characteristics of apparatus, test specimens, conditioning and procedure are described in IEC 61730-2.

The pass criteria are those here below:

No ignition or, under conditions of surface flame attack and, where required, edge flame attack, with 15 s exposure time, there shall be no flame spread in excess of 150 mm vertically from the point of application of the test flame within 20 s from the time of application.

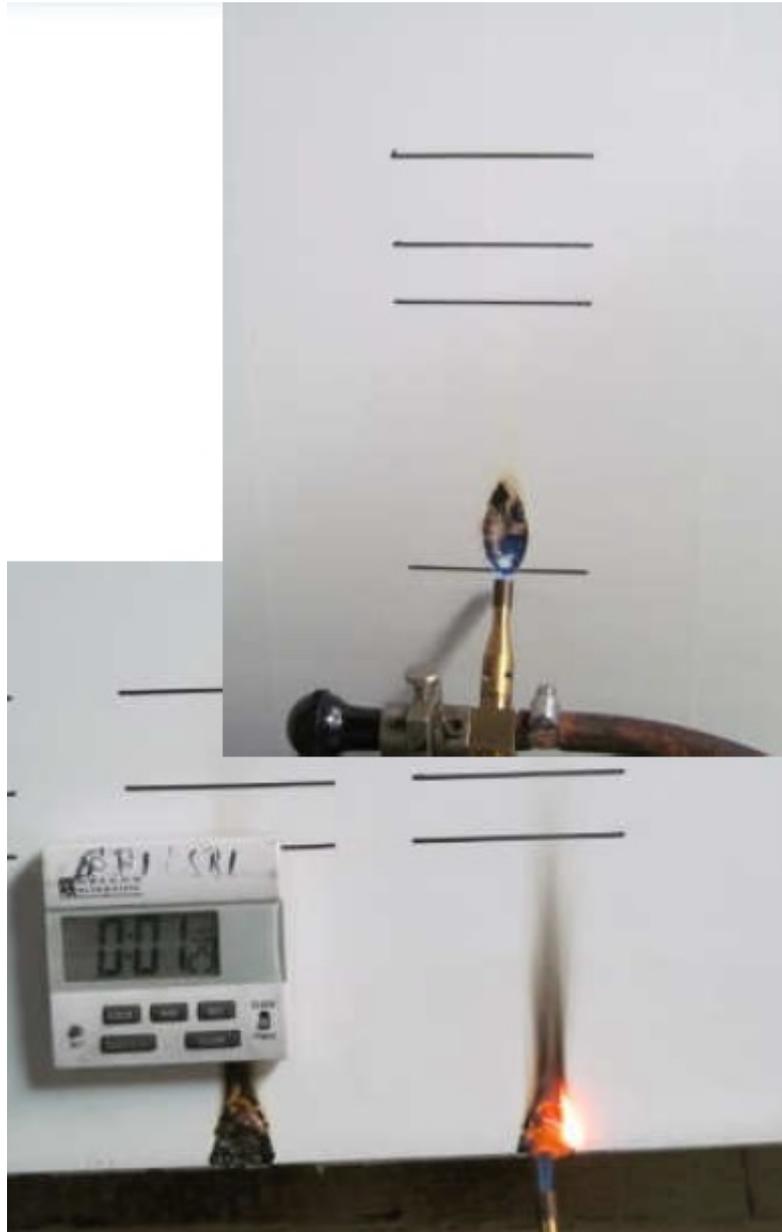


Figure 5 – Ignitability test

## 4 EQUIPMENT AND SYSTEMS

### 4.1 Fault detection

#### 4.1.1 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 North America 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 North America, 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 North American electrical codes only require arc-fault detection for dc PV system circuits operating above 80 V DC. This exempts DC circuits connected to microinverters even though it is theoretically possible, but 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. 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 in many cases results in an arc that a series arc-fault detector is incapable of stopping.

#### 4.1.2 Earth-fault detection

Earth-fault detection requirements are already very good for many types of PV systems. Some PV system designs do not have as stringent requirements for earth detectors, but those differences are being addressed currently in other IEC standards. The key issue related to earth-faults is what actions should be taken when an earth-fault is detected. Some regulatory requirements require the PV system to be shut down in the event of an earth-fault. This requirement is intended to draw attention to the problem so that maintenance crews are motivated to fix the fault and return the PV system to service.

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 another fault in the opposite pole wiring of the PV system.

## **4.2 Circuit shutdown**

### **4.2.1 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, disconnecting means on the roof would need to be opened, but coordinating those disconnects during a catastrophe is not easy to achieve.

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 fire fighters 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 must be an automatic disconnecting means on the circuit prior to entering the building, disconnecting in case of loss of mains or manual remote shutdown. Additionally, it may be necessary to add an automatic disconnecting means at the inverter to isolate any internal capacitance or the AC source from the DC conductors.

### **4.2.2 Module-level shutdown, ELV-systems**

Another, more comprehensive 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 already exist that are capable of performing this segmentation—although that may not have been the originally intended function of the products. For instance, microinverters and module-level DC-to-DC controllers are both methods that exist for many years and are capable of reducing the effective voltage of a PV array when the PV system is shut down, at the cost of lower overall system efficiency and higher risk of fire due to strongly increased component counts.

In addition to these readily available products, new products are starting to make their way into the market that simply provide an electronic switch to isolate PV modules from one another. 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 missing standard for such devices, it is recommend to apply devices, which are certified according IEC 60947-3 to fulfil functional safety requirements according 61508 or 62109-1. These components have not been evaluated for reliability after exposure to excessive heat or fire, nor will they be evaluated as such per the draft UL

1741 for Rapid Shutdown. For their own safety, firefighters will have to treat circuits with MLPE as live electric parts.

### **4.3 Further measures**

#### **4.3.1 Cable measures routing**

Fighting a fire from inside a building is more challenging for firefighters. In comparison to the roof of the building, where firefighter can see parts of the PV system and can keep a minimum distance to potential live parts, the situation inside is more difficult. Due to 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 of more than 30V outside the building can be achieved by components per string level shutdown placed outside the building. Alternatively, the inverter is installed outside the building and the DC conductors between PV array and inverter also outside the building.

#### **4.3.2 Fire resistant cable raceways**

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

#### **4.3.3 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-combustible 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-combustible 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.



## 5 MEASURES FOR SUPPORTING FIREFIGHTER AND RESCUE SERVICE OPERATIONS

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 to 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 15-20 minutes from the closest fire response may need much more significant internal fire suppression equipment to address the longer fire response time.

### 5.1 Internal fire suppression

Fire sprinklers and other internal fire suppression measures are common in larger facilities. These internal fire suppression measures have proven to dramatically reduce the risk of loss due to fire. These measures do come with a price and must be maintained or else they can become a source of water damage losses if neglected. For example, in North America building codes have acknowledged the benefit of fire sprinkler systems and have allowed some relaxation of construction requirements where sprinklers are provided. Furthermore, access pathways on rooftops may be reduced where sprinkler systems are employed. This can allow for larger PV systems to be installed on some rooftops.

### 5.2 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- and 20-minute response times 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 and particularly roof fires. Depending on the response time of fire services in general, situation on water supply and ladder trucks, where needed for access, the risk for the building may change and additional measures may be taken into account.

### 5.3 Building size and geometry

#### 5.3.1 Geometry, height, accessibility of building

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.

#### 5.3.2 Height and Width of Building

The higher the roof or the installation site of the PV system is, the higher the efforts for the firefighters are to access and to extinguish. This delay leads to a higher spread of the fire, which leads to higher damages and the risk of a building loss. Building height also impacts the need for higher water pressures to put water on interior areas 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 directly connected in interior roof sections. 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.

## 5.4 Building access

### 5.4.1 Access pathways and fire response sections

Where PV systems are mounted on rooftops, existing access pathways need to be maintained if the fire service needs to use rooftop operations for emergency responses to the building. This requires coordination with the fire service at the design stage so that pathways can be laid out specifically before construction. This may include identification of fire response roof sections planned in advance. 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. 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 uncontrolled conductors.

### 5.4.2 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 shall 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 North America the building codes require a 2m perimeter for buildings larger than 80m on a side and 1.3m for buildings smaller than 80m on a side. Bad accessibility of the PV array e.g. due to height, long distances (to walk) or restriction in using ladders increase the risks. This leads to additional measures to compensate. Additional measures may include installing fixed ladders to compensate and prevent further delays.

### 5.4.3 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 fire fighter has an alternate 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 fire fighter 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 the fact that all critical locations such as standpipes and smoke vents have pathways. 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 larger than 40 m into smaller sections to comply with this requirement.

## 5.5 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 shut down. The level of shutdown would depend on the level of risk for the building and its occupants. In a high risk building, a fire alarm system could be used to provide a proper shutdown level of PV array conductors. These precautions may be warranted as an added



safety measure in the event that the fire service does not have access to, or misses the location of shutdown switches provided for the PV array.



## 6 DESIGN AND INSTALLATION CRITERIA

Basically, the installation of a PV plant on an existing building, in consideration of the components used and their location, may increase the fire risk of that building. This may consist of:

- Interferences with smoke ventilation systems (e.g. partial or total obstruction of skylights, impediments to the opening of smoke extraction systems).
- Obstacle to cooling and fire extinguishing of combustible roofs.
- Risk of flame propagation to external or to internal of the building (presence of wiring on the rooftop of a building divided into several compartments, modification of the rapidity of fire development in a single compartment building).

Furthermore, a possible exposition of firefighters to electric-shock risk has to be considered, given the voltage present in the daylight.

### 6.1 Basic requirements

PV plants shall be designed, built and maintained in a workmanlike. Components and equipment shall be properly made, tested and certificated. For this purpose the following documents, where applicable, shall be considered:

1. IEC and CENELEC standards (in particular IEC 62548, IEC 60364-7-712, IEC 62446-1)
2. Rules, Standards and Guidelines issued by OES
3. Codes issued by the Government of Bahrain, Local Municipalities and other local competent bodies

### 6.2 Prevention of fire propagation from PV plant to inside the building

Unless differently indicated in the Risk Assessment of the given building or required by the Civil Defense Law or other Law in force, at least one of the following measures shall be adopted when installing a PV plant on a rooftop:

- PV modules and their interconnections placed on a roof made of non-combustible material according to ASTM E 136 or EN 13501-3 (class A1)
- Interposition of a non-combustible layer between PV modules with their interconnections and the roof. The non-combustible layer shall be at least one-half-hour fire-rated.
- Preparation of a new risk assessment which take into account the presence of the PV plant to be approved by a Bahrain competent body

### 6.3 Minimum distance from rooftop openings

PV modules, wirings, switchboard assemblies and other equipment shall not cover any possible ventilation systems on roof, e.g. skylights, smoke extraction systems or chimneys.

In order to allow the correct operation of the smoke extraction systems, PV components and wirings shall be placed at a minimum distance of 1 m (top view) from their perimeter and in any case their position and installation shall be in accordance with the manufacturer's prescriptions.

In order to avoid a sudden propagation of fire to external, PV components and wirings shall be placed at a minimum distance of 0.5 m (top view) from the perimeter of skylights, chimneys or other openings.

Components and equipment installed internally or externally shall not obstruct in any way the existing means of egress.

Minimum elevation of the PV modules above the roof shall be 50 mm.

## 6.4 Emergency disconnection and wiring of PV plants

### 6.4.1 Manual disconnection

A manual emergency system for the disconnection of the PV modules from the internal electric plant of the building shall be present. Electrical disconnection may be made on DC side (typically when inverters are placed inside the building) as in Figure 6 or on AC side (typically when inverters are placed outside the building or in an outer cabinet or shelter) as in Figure 7 (disconnection on DC side is possible as an alternative but it is not recommended). A proper fire-compartmented area can be used instead of an external placement of the disconnecter (DC or AC).

The Figure 8 summarizes these possible cases (the manual call point is not necessary in case of One-and-Two-Family Dwelling).

The passage of cables from PV modules inside the building before the disconnecter is allowed provided that inside the building they are placed in a channel with a fire-rated protection of at least one-half-hour.

In all above mentioned buildings, except for One-and-Two-Family Dwelling, electrical disconnection shall be operated by means of a manual call point installed at the height of 1.1 – 1.4 m above floor level and in a plain, accessible, well lit and free-hindrance place. The manual call point shall be close to an external access in order to be easily operated by personnel or firefighters.

The manual call point shall be in accordance with NFPA 72 and a proper label shall indicate that it actuates the disconnection of the PV plant.

In case of High Hazard buildings a detailed design including safety measures and new “risk assessment” shall be submitted to the Bahrain competent Body for approval.

### 6.4.2 Earth fault detection

Each PV array is equipped with an arc fault detector that preferably shut down the array in case of failure. If the PV array is not automatically shut down, it is extremely important that the action is taken in a reasonably short period of time, not longer than a week, to find and fix the fault.

### 6.4.3 Further requirements for BIPV

In case of BIPV not installed in fire compartmented areas it is necessary to adopt one of the following further measures:

- The manual call point also disconnects or short-circuits separately each module or groups of modules each of them having an open circuit voltage at STC not greater than 120 VDC.
- Installation of an Arc Fault Circuit Interrupter (AFCI) to protect the DC side from series arcs in accordance with NEC Section 690.11 and UL 1699B. When AFCI detects a failure it disconnects the DC side of the PV plant and generates an audible signal.

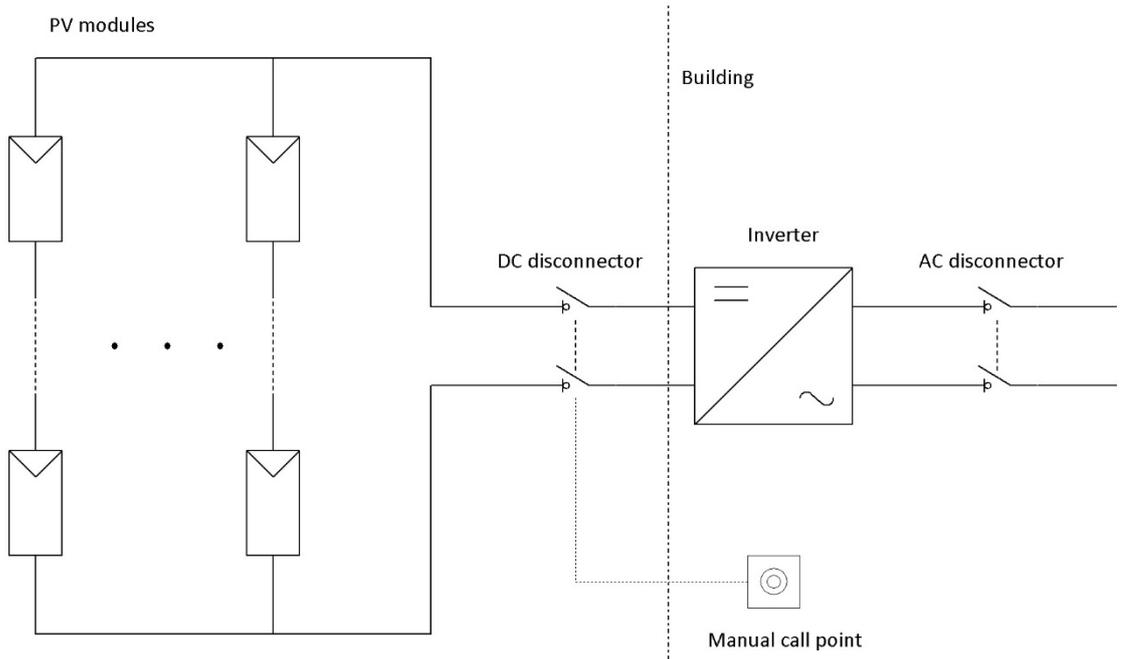


Figure 6 – Disconnection from a manual call point in case of inverter inside the building

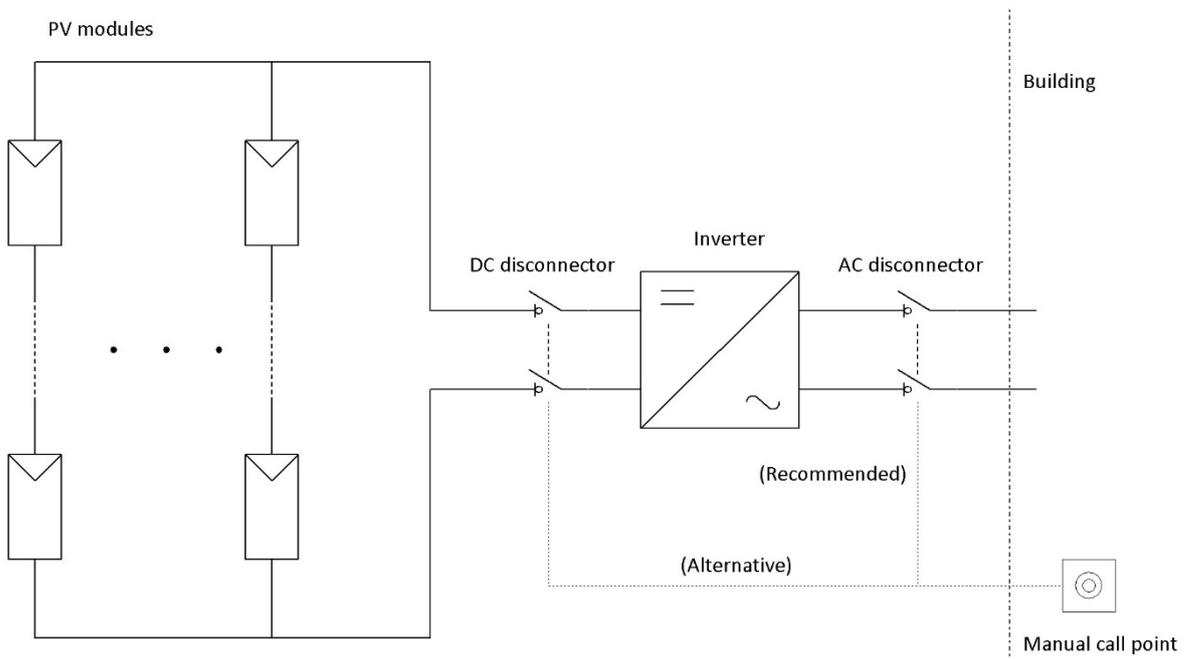
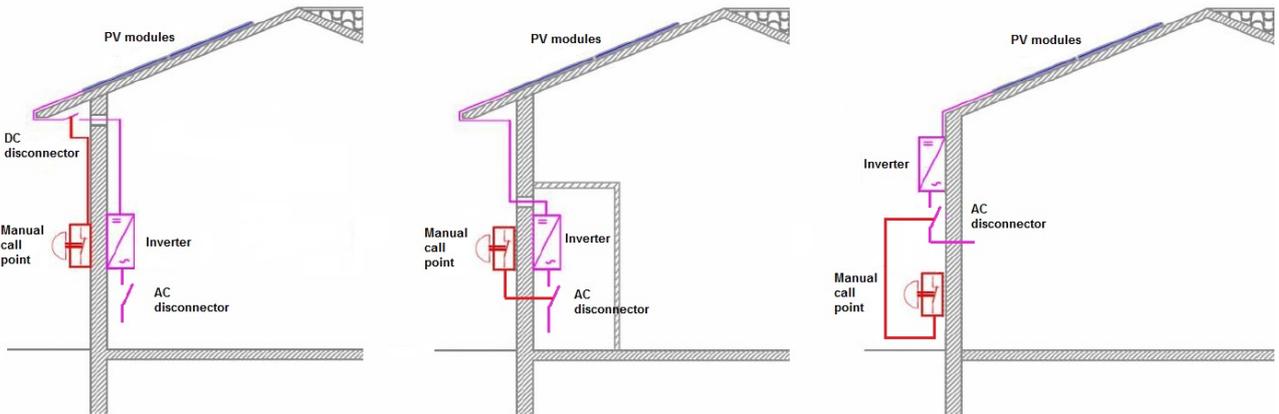


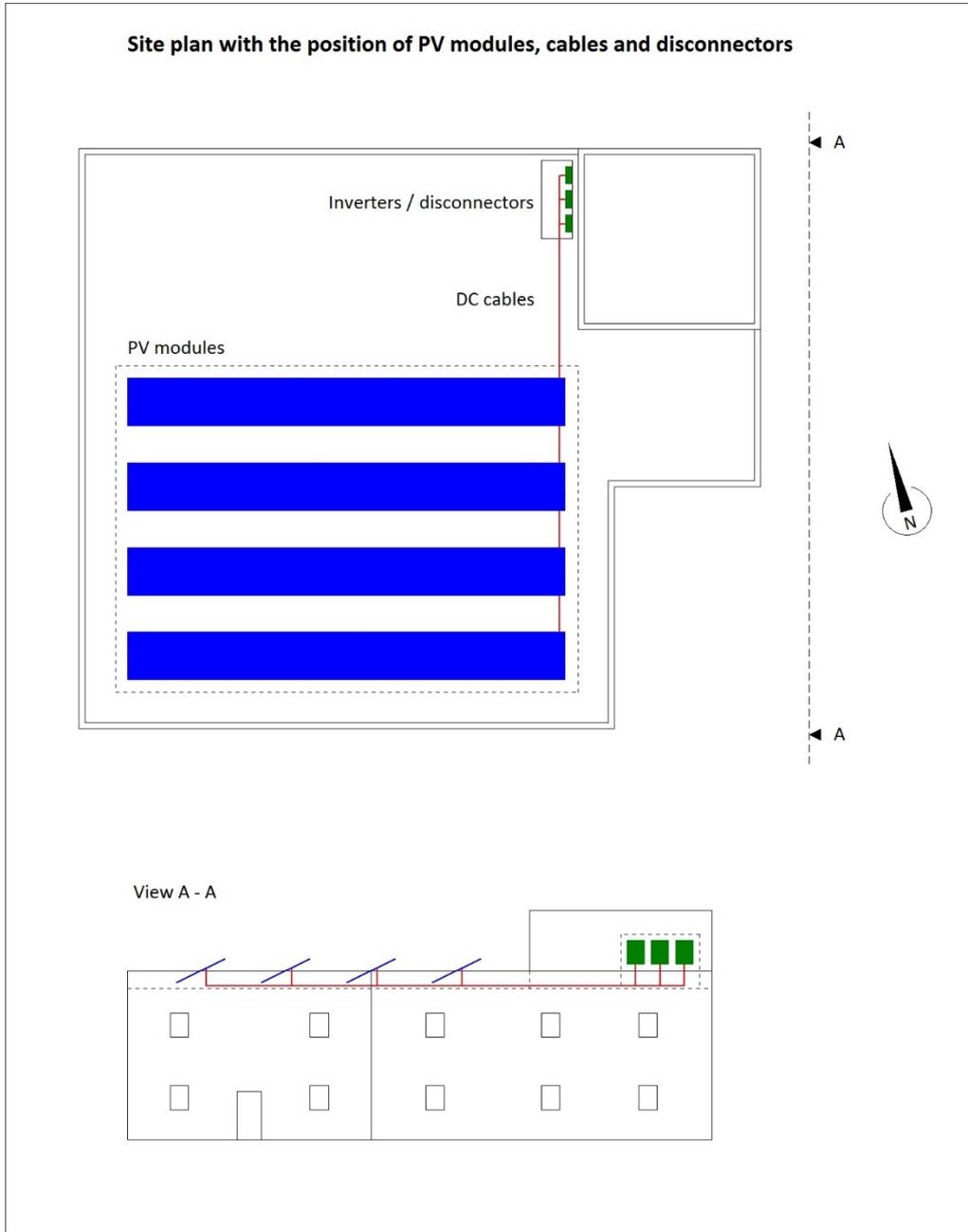
Figure 7 – Disconnection from a manual call point in case of inverter outside the building



**Figure 8 – Possible placement of the inverter and disconnector with the manual call point (when required)**

## 6.5 Labelling and marking

A simplified site plan with the position of PV modules, cables and disconnectors as in the example of Figure 9 shall be exposed close to the main energy meter. If a manual call point is present in the building a further copy of the simplified site plan shall be exposed on the side.



**Figure 9 – Example of simplified site plan to be exposed in the building**

The area where PV modules, cables and other equipment are located, if accessible, shall be marked by proper signs as that reported in Figure 10. They shall also be placed in correspondence of each access door to the PV plant. The same signs shall be used to indicate cables before disconnectors and shall be placed every 5 meters along the cable.

These signs shall be UV resistant, and shall indicate the DC voltage as the Open Circuit Voltage at STC of the PV array. Their minimum size is 200 × 200 mm (w × h).

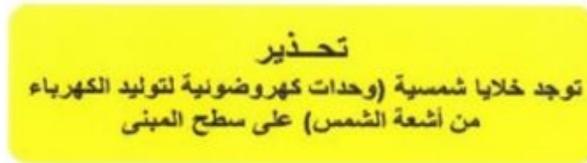
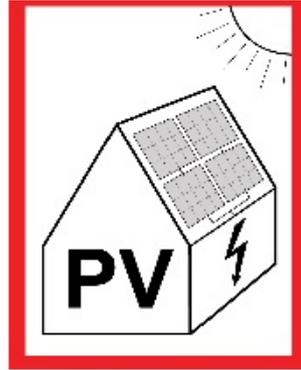


Figure 10 – Sign to be used to indicate the presence of a PV plant

## 6.6 Summary of design and installation criteria

The following Table 2 summarizes the design and installation criteria mentioned in the previous paragraphs.

Table 2 – Summary of prescriptions with reference to design and installation criteria

Criteria	Descriptions	Notes
1 Basic requirements	<p><b>A. Fulfilment of applicable standards, rules and codes:</b></p> <p>A.1. IEC 61730-2 (MST 23 and MST 24)</p> <p style="padding-left: 20px;">A.1.1. Fire test according to CEN/TS 1187 and ISO 13501-5</p> <p style="padding-left: 40px;">A.1.1.1. Fire performance according to building design</p> <p style="padding-left: 20px;">A.1.2. Fire test according to ANSI/UL 1703</p> <p style="padding-left: 40px;">A.1.2.1. IEC 61730-2 Fire Class C or greater (BAPV)</p> <p style="padding-left: 40px;">A.1.2.2. IEC 61730-2 Fire Class A (BIPV)</p> <p>A.2. Rules, Standards and Guidelines issued by Civil Defense</p> <p>A.3. Codes issued by the Bahrain Government</p> <p>A.N. Any other local competent bodies</p>	Applicable standards as specified in document "Connection Guidelines"
2 Prevention of fire propagation from PV plant to inside the building	<p><b>A. Apply one of the following:</b></p> <p>A.1. Roof made of non-combustible material according to ASTM E 136 or EN 13501-3 (class A1)</p> <p>A.2. Roof segregated from PV modules / interconnections by interposing a non-combustible layer (minimum fire-rating: 30 min)</p> <p>A.3. Submit "risk assessment" document to Civil Defence for approval</p> <p><b>B. High Hazard buildings:</b></p> <p>B.1. Submit detail design including safety measures and new "risk assessment" document to the Bahrain competent Body</p>	



Criteria	Descriptions	Notes
<b>3</b> <b>Minimum distance from smoke extraction systems and openings on rooftop</b>	<b>A. Smoke extraction systems, PV modules, components and wirings:</b> A.1. minimum 1 m (top view) from the perimeter of the systems A.2. placed and installed according to manufacturer's prescriptions <b>B. Skylights, chimneys, any openings, PV modules, components and wirings:</b> B.1. minimum 0.5 m (top view) from the perimeter of the openings <b>C. Means of egress, PV modules, components and wirings:</b> D. forbidden in obstructing positions	
<b>4</b> <b>Emergency disconnection and wiring penetrations of PV plants</b>	<b>A. Manual disconnecter on side:</b> A.1. DC when inverters are inside building A.2. AC when inverters are outside building (outdoor or in cabinet/shelter) <u>Manual call point not necessary in case of One-and-Two-Family Dwelling</u> <b>B. Cables penetration inside building without manual disconnecter:</b> provided cables inside building are in conduits with fire-rating protection of minimum 30 min <b>C. Position of the manual call point:</b> at 1.1 – 1.4 m above floor level and in plain, accessible, well lit and free-hindrance place, close to an external access for an easier emergency operation <b>D. Standard reference for manual call point:</b> in accordance with NFPA 72 and with label showing it actuates PV plant disconnection. <b>E. Earth fault detection</b> preferably with an automatic disconnection of the PV array <b>F. BIPV not installed in fire compartmented areas: adopt one of the following measures:</b> F.1. Install manual call point disconnects or short-circuits separately each module or groups of modules with $V_{oc}@STC < 120 \text{ VDC}$ F.2. Install Arc Fault Circuit Interrupter (AFCI) to protect DC side from series arcs in accordance with NEC Section 690.11 and UL 1699B	
<b>5</b> <b>Labeling and marking</b>	<b>A. Install warning signs in any area where accessible PV modules, components and wirings are located:</b> A.1. in correspondence of each access door to the PV plant A.2. to indicate cables before disconnectors every 5 m A.3. signs shall indicate DC voltage as the $V_{oc}@STC$ of PV array <b>B. Size and characteristics of warning signs:</b> B.1. signs minimum size 200 (w) x 200 (h) mm B.2. UV resistant <b>C. Site plan with the position of PV modules, cables and disconnectors to be placed near:</b> C.1. the main energy meter C.2. each manual call point, if any	

## ANNEX A: REPORT ON FIRE INCIDENTS ON PV SYSTEMS

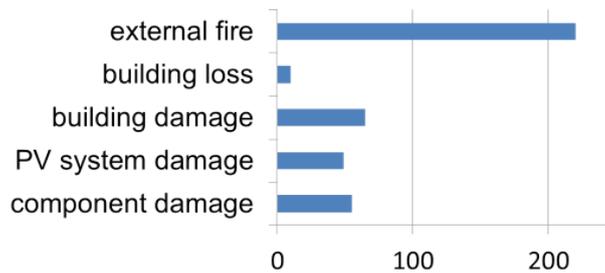
### A.1 General

According to a study made in Germany<sup>1</sup>, in total some 400 fire incident reports were found for the years 1995 – 2012. These 400 cases were reported, where a fire was at a building with a PV system. Some 180 out of these reports found that a PV system caused the fire. The findings are valid for Germany with special boundary conditions from a “boom” time period.

**Table 3 – Number of incidents with a certain damage**

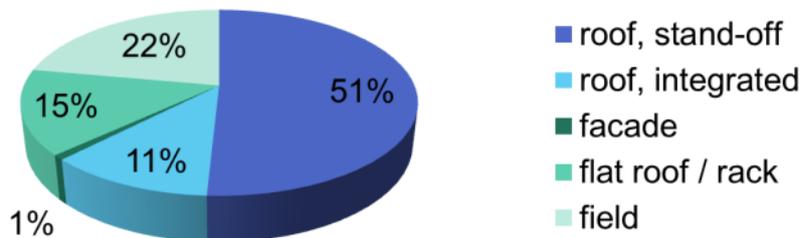
fire from outside - PV system affected	220
fire from PV - building destroyed	10
fire from PV - building damaged	65
fire from PV - PV system damaged	49
fire from PV - component damaged	55

At the time of closing the survey some 1.3 million systems with a total capacity of approx. 30 GWp were installed in Germany. Considering the number of damaged buildings in one year and relating it to the number of installed PV systems, an annual risk of approximately  $30 \times 10^{-6}$  can be estimated that a building is damaged due to a fire caused by its PV system.



**Figure 11 – Number of identified incidents and severity of effect on surrounding for a total of about 400 fire reports**

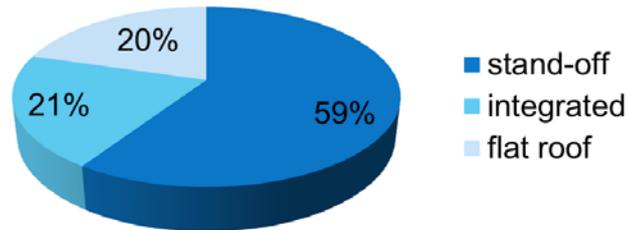
For the damaged buildings one mounting feature significantly impacts the severity of damage: roof integration. Figure 12 shows the impact of mounting type.



**Figure 12 – Distribution of fire reports depending on mounting type**

<sup>1</sup> Sepanski, A., et.al., 2015, Bewertung des Brandrisikos in Photovoltaik-Anlagen und Erstellung von Sicherheitskonzepten zur Risikominimierung. TÜV Rheinland Energie und Umwelt GmbH, Köln

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 and 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 – these are 54 cases – yields the picture in Figure 13. 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 as for regular stand-off mounted PV generators.

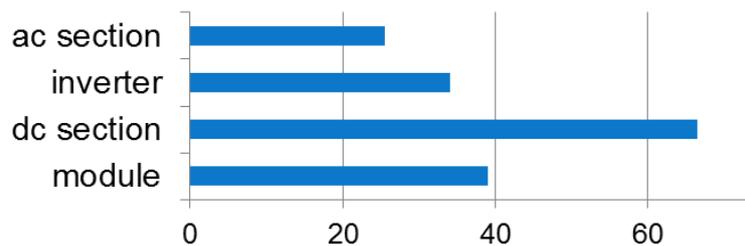


**Figure 13 – For cases of damaged buildings only: distribution of fire reports depending on mounting type**

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 14 and Figure 15 show the section and the component, respectively, where the origin of a fire could be located.

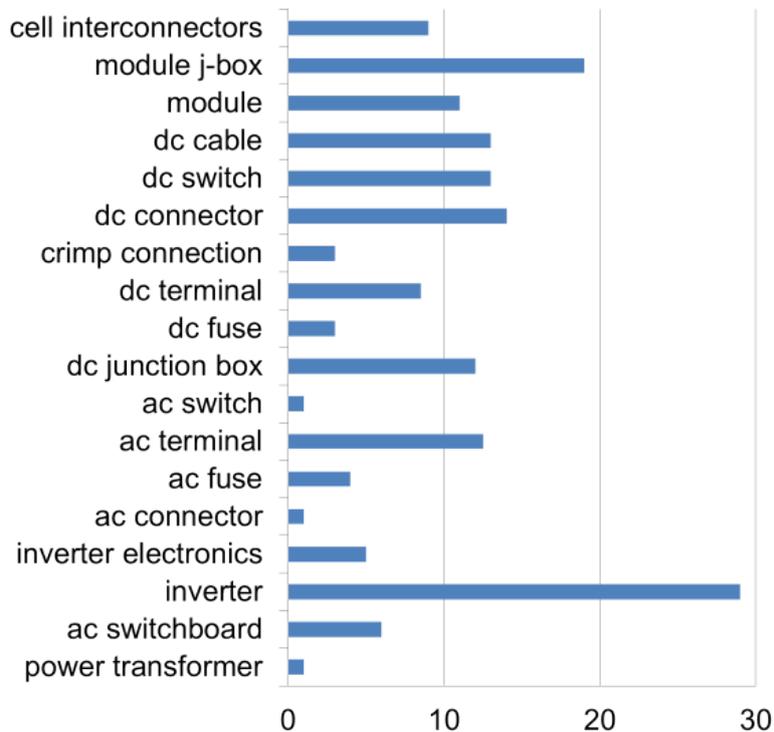


**Figure 14 – Counts of system section where fire started. AC section includes all components from inverter output terminals to the point of coupling to the grid. DC section includes all components from string connectors at modules to inverter input terminals**

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.

The next Figure 15 shows the component causing the fire with the best available resolution.



**Figure 15 – Counts of component where fire started**

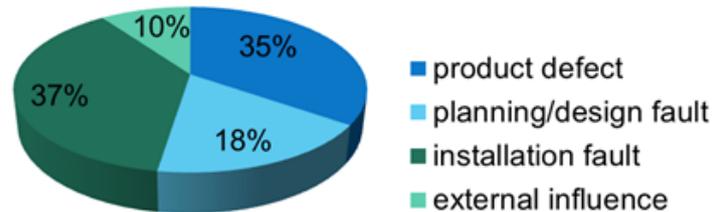
Apparently, the inverter is a “hot-spot”. Why this? Findings presented in the next sections indicate that there are two main reasons: product defects and installation errors, which cause the high rate of fires from inverters.

Another “hot-spot” is module junction boxes. Here, we assume 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 some 6 % of failures of fielded modules.

Other causal components are fairly well distributed. However, it appears that all sorts of connections are sensitive, especially those realized in the field. Furthermore, “DC switch”, “DC terminal”, “DC junction box” and “AC distribution” often mean use of screw terminals. The authors 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 equipment is rarely seen with 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 16.



**Figure 16 – Distribution of identified causes of fire incidents. Installation fault describes poor workmanship**

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

Following lists give specifically found errors and faults.

These **mechanical design errors** had been noted:

- frameless thin-film modules mounted too tight to each other → restraints occurred, mechanical tensions, glass breakage → electric arcs
- mounting rails tightly next to module junction boxes (j-box) caused shearing forces → damage to j-box → electric arc
- weather exposed array junction boxes (no rain or sun protection) developed stress on contacts due to high internal air temperatures and humidity from water vapor diffusion → increasing contact resistance → electric arc
- array junction boxes and inverters mounted on wooden panels or above combustible material → fire spread quickly and damaged building interior
- missing fire retarding seal at building entrance of rooftop PV array cabling; → electric arc penetrated from roof into building → building heavily damaged

Following a list of **design errors in electrical installations** are given with their respective result:

- multiple, bundled (=grouped) laying of cables without current derating → overheating of cables → fire in cable trunk
- underrated cables → overheating → charred contacts
- underrated DC-switch → overheating → electric arc
- neglected simultaneous maximum power dissipation from fuses (coincidence factor of 1, different from standard AC loads) → overheating of cabinet → contact degradation → fire
- AC fuse at DC circuit → fuse did not interrupt current → electric arc
- DC wiring laid over sharp metal edge → insulation damaged → short circuit → electrical arc
- unsuitable terminals used to connect aluminum conductors → increased contact resistance → fire
- cabinets for indoor use used outdoors → water penetration → contact degradation → overheating → charred terminals → loss of power
- cabinets for outdoor use, but without condensation drainage provided → water accumulation → contact corrosion → loss of power
- Inverters have been installed at unsuitable places exposed to weathering or in an unsuitable way – on or near combustible material. Damages range from defective inverters to burnt down barns.



### **Poor workmanship** and its consequences

- DC connector improperly plugged → plug molten down → string interrupted; in some case building damaged
- DC connector not at all or poorly crimped → arc and building damage
- screw terminal not fastened → arc and generator junction box destroyed; in one case building destroyed
- wire insulation partly inserted into terminal → poor contact → overheating → fire in cabinet
- fuse not latched into holder → arc → junction box damaged
- Insufficient or lacking preparation of aluminum conductors → poor contact → fire → inverter station destroyed. Several cases were reported.
- lacking strain relief of cables → is likely cause for contact failure and fire in AC distribution cabinet
- cross mating of DC connector parts of different manufacturers → overheating of hundreds of connector pairs in a large PV System → expensive repair
- module wires were used as handle for PV modules → wires slightly pulled out of j-box contacts → arc in j-box

Poor workmanship may be attributable to tough working conditions for installers, partly due to the German support scheme, which lead to high installation rates in early winter, as well as extensive employment of unskilled labor. Unskilled labor reportedly has been widely used due to lack of skilled personal during “boom” periods and to achieve low installation cost.

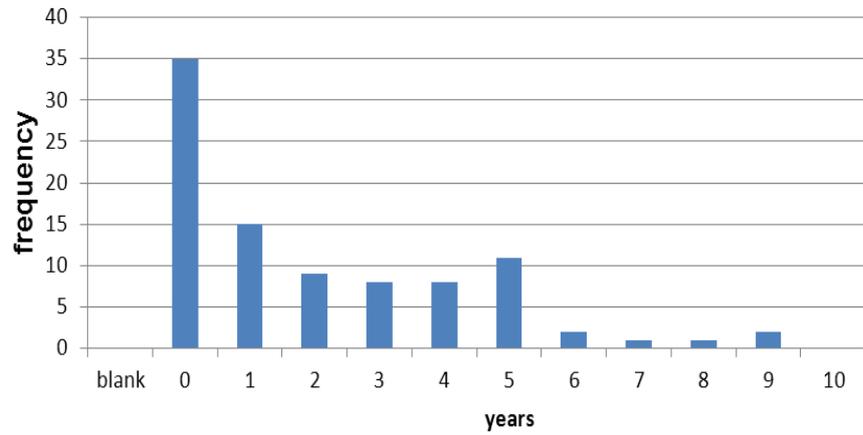
### **External influences**

- rodents and martens “eating” wire insulation → short circuit → arc
- lighting strike → damaged (i.e. shorted) bypass diodes → reverse current → damaged j-box
- craftsman working on a roof drilling long screws into invisible DC cables → short circuit → arc
- a combination of external influence, design flaw and lack of maintenance has caused several fires by DC switches. Contact degradation by growing oxide layers causes overheating. High ambient temperature e.g. in an attic or an exposed combiner box accelerates this process. Regular operation of the switch removes the oxide layers.

Besides the above mentioned errors a more subtle design flaw may also have caused fires in transformer stations of large PV systems. Transformer stations in Germany are typically designed for “utility loads”. Utility loads dwell at part load most of the time and reach nominal power for only short periods in the evening. Thus, regular transformer stations are underrated for long term continuous full power around noon as they are encountered in PV systems.

## **A.4 When did incidents occur?**

Most incidents occurred during installation or the first year of operation (see Figure 17). This fact supports the finding that most fire incidents were caused by product defects and poor workmanship.



**Figure 17 – Number of incidents over operation system age. The peak in the first year is striking**

It is assumed that the rush of clients to take advantage of the older FIT at the end of the year is partly responsible for the high rate of early failures.