Fire and Solar PV Systems - Literature Review

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Contents

1 Introduction

1.1 Scope

This literature review covers:

- Previous investigative work on the various factors relevant to fires involving PV systems
- A survey of relevant standards
- A survey of relevant training courses

1.2 Background

Over the last few years a number of media reports have made a link between specific fire incidents and photovoltaic (PV) power systems. With all electrical systems there is a small risk of fire. Given the prevalence of PV systems now in the UK, it is appropriate to investigate the potential for fire incidents.

In November 2016, the overall UK solar PV capacity stood at 11,429 MW across 898,029 installations (provisional figure). 48% (5,452 MW) of the total installed solar PV capacity came from large scale installations greater than 5 MW, with 21% (2,453 MW) coming from small scale 0 to 4 kW installations. The majority of the small scale installations are domestic and small commercial roof-mounted systems.

So if, for example, the long-term statistical data (once collected) were to show the risk to be 1 in 100,000, (which is about half the risk of a washing machine catching fire) we should expect an average of 9 PV-related fires per year involving currently installed roof-based systems. As the installed capacity grows, so will the number of incidents, unless the causes of fires are reduced or removed.

Whilst some incidents have been reported in the press, others are only known about through word of mouth communications, and it is suspected by some PV experts that a larger number have occurred but have gone unreported. In most cases there has been little detailed follow-up investigation to properly understand the causes of the fires or how the presence of PV on a building may have influenced firefighting operations.

Despite the significant number of PV systems installed in the UK and elsewhere, PV is still a relatively young technology and is subject to frequent changes in product design and deployment techniques. Consequently, the equipment and installation standards that control the industry are still in a process of refinement.

Understanding the cause of PV fires and how PV systems may influence firefighting operations is therefore vitally important for the ongoing development of standards. Similarly, understanding the statistical likelihood of particular faults or problems is essential for ensuring that any changes to standards are appropriate and properly justified.

This project has therefore been established in order to collate accurate information - both historical and contemporary – on fire incidents involving PV systems, and on relevant previous research.

In this first report, the findings of a literature survey are presented, along with information on current standards that are relevant to PV-related fires and on relevant training courses.

1.3 Project overview

1.3.1 Defining the problems

There are many general issues around the subject of fires involving solar panels[1]. We list here just the main areas of concern:

- Potential effects of fires caused by PV systems
  - Damage to, or loss of, PV system, and associated loss of income
  - Damage to building covering or structure
  - Complete loss of building
  - Injury or loss of life
  - Reputational damage to the industry

- Perceived additional risks faced by firefighters, whether or not the fire was caused by a PV system
  - Risk of electrocution
  - Risk of re-ignition due to arcing cables and connections
  - Falling glass
  - Tripping over cables on roofs
  - Emission of noxious gases
  - Risk of PV accelerating structural collapse
  - Impeded access to building

Where fire incidents were the result of a malfunction of a PV system, the causes can be broken down in to a few sub-categories:

- Causes of fires initiated by PV systems
  - Design errors
  - Installation errors
  - Product defects
  - Inadequate Operation and Maintenance (O&M)

Internationally, there is a body of work that has attempted to address these and other issues, and there is some (mostly anecdotal) evidence within the UK. However, a reliable body of collated data upon which to base changes to standards and practices is thus far absent, and this project aims to begin the process of collecting useful evidence.

1.3.2 Work packages

The complete three year project was originally formed from the following work packages (WP):

WP 1 & 2 (this report)	a) Literature search including both UK and overseas sources b) Survey of existing design and installation standards for PV c) Survey of training programmes for PV

[1] The PV terms 'solar panel' and 'PV module' have identical meaning and are interchangeable.

WP3	Survey of historical incidents
WP4	Site investigations, including investigator training
WP5	Compilation of database & web portal + data updates
WP6	Publishable report on improving design and maintenance standards*
WP7	Publishable report: Improving training*
WP8	Publishable report: Safety of fire-fighters*
WP9	Dissemination plan to BEIS and the solar and fire safety industries

Table 1: Project work packages, as originally designed, and status*

* **Note**: The original plan of the work packages is set out above. However, following a meeting with BEIS in November 2016, the outputs from work packages 6, 7 and 8 have been recast into the following published outputs:

[1] Fire and Solar PV Systems – *Literature review*, including standards and training (derived from WP1 & 2) - this document.

[2] Fire and Solar PV Systems – *Investigations and Evidence* (derived from WP3, 4 & 5).

[3] Fire and Solar PV Systems –

a) *Recommendations for PV Industry* (derived from WP6 & 7)

b) *Recommendations for the Fire and Rescue Services* (derived from WP7 & 8)

In this first report, the results of a literature survey are presented (WP 1), along with information on current standards that are relevant to PV-related fires and on relevant training courses (WP 2).

2 WP1 - Literature review

2.1 Scope of study

The literature search covered references published from 2009 to 2016, relevant articles cited by them and additional references already known to the project team. In some cases, older documents have been included, where they were thought to be of relevance.

The geographic coverage of the searches was international and copies of documents that appeared to have the most relevance to this study have been obtained and summarised.

2.2 Literature sources

The following sources of information were searched or consulted:

BRE, Science Direct, British Library catalogue (including conference papers, as well as journal articles and reports), BSRIA Library catalogue, Fire Prevention Association (FPA) publications, Fire Risk Management Journal and other fire-related journals and government sources, Google Scholar and Researchgate for papers in institutional repositories, Open Grey (grey literature in Europe) and BRIK (Building Research Information Knowledgebase).

2.3 About the literature listing

The list of documents identified by the literature searches is given in Appendix A. Where possible, a short summary is given below each reference. The summary has been produced by quoting or editing the document abstract or, where this is not available, from the project team's own description of the paper. Where papers are in a foreign language or could not be easily obtained, a summary may not be given.

Note that standards are referenced by their standard number.

2.4 Key themes emerging

The search revealed a very wide variety of studies that have taken place in the last 10 years or so. The general themes indicate that the UK experiences of fires involving PV are not unique. Researchers have attempted to characterise failure modes of PV modules and whole systems, suggest preventative measures, and evaluate technologies and techniques that offer the potential to enhance system or firefighter safety. Some studies are quite general, looking at statistical data, whilst others focus on specific technical aspects or product types.

The references in square brackets (e.g. [1]) below refer to the list of publications cited in Appendix A.

2.4.1 Causes and characteristics of fires in PV systems

There are many good, basic, introductions to the fire safety-related aspects of PV systems and general assessments of the risks, e.g. references [4], [12], [14], [51], [97], [118], [120], [134], [157], [173], [174].

The majority of fires involving PV systems are not caused by the PV system itself. However, where fires have originated within PV systems, substantial damage to the PV modules, other parts of the PV system and the building occurred with roughly equal likelihood [92].

Research shows that the mere presence of roof-mounted PV modules changes the dynamics of a fire involving a roof assembly [35] and there may also be interactions with building materials [45].

A good analysis of failure modes, the way in which a PV system might fail, is presented by International Energy Agency Photovoltaic Power Systems Programme, IEA PVPS Task 13 [176]. Other surveys of incidents and analyses of failure modes suggest improvements are required to design and certification processes for DC components [123].

2.4.1.1 Arc faults

One of the main causes of fires originating within PV systems emerges from the literature as electrical arcing between conductors (or conductors and earth) within defective or incorrectly installed components, or via exposed conductors. Arc faults undoubtedly represent the greatest fire hazard on PV systems and much of the investigative work has focussed on this topic in an attempt to explore the phenomenon in some detail: [6], [51], [79 - 83], [121], [122].

Three types of arcing (which tends to negatively affect the DC system) are defined:

- Series arcs
- Parallel arcs
- Arcs to ground

However, there are many potential causes of arcing, so it is necessary to dig deeper to gain a level of understanding to identify the root causes of such fires.

One component thought to be responsible for initiating series arcing in some cases is the by-pass diode, of which there are normally 3 in modern modules. Reference [79] describes the phenomenon and models the thermal behaviour of arcing within by-pass diodes, showing that corrosion in soldered joints can lead to arcing that results in the ignition of surrounding polymer materials within 0.1 seconds.

One response to the risk of arc faults has been the emergence of arc fault detection devices, designed to be permanently fitted to PV systems. These are discussed in 2.4.2.1.

2.4.1.2 Ground faults

Alongside and sometimes related to arc faults are ground faults. Ground faults can often occur as a precursor to fully developed arcs [51] and it is thus very important to detect ground faults as they arise and automatically take appropriate action. Many inverters are fitted with ground (or earth) fault detectors (see Inverters, below). However, these are not universally effective and can have ‘blind spots’, so high resolution, external ground fault detectors are sometimes recommended [18].

2.4.1.3 Components with associated fire risk

Differing approaches have been taken to research the reliability of components and associated risks, should they fail. An interesting formal statistical analysis of individual components “Failure mode and Effect Analysis” (FMEA) [28] - presents inverters as the most likely component to fail, although from a fire point-of-view, failure of other components may present a higher risk.

A few components emerge as the most common candidates within which fires originate:

- DC connectors
- DC isolators

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- PV modules
- Inverters
- Module mountings

This list does not imply that the components themselves are necessarily faulty. In fact, in many cases, it appears that installation errors are the root causes of fires.

Within this list of components, we again find that there are sub-categories of causes, ranging from poorly assembled DC connectors to faulty by-pass diodes within PV modules [14].

DC connectors

A statistical review of fire sources in 75 PV systems that caught fire, shows that the chance of the quick connector causing the fire (29%) is nearly as high as for the rest of the module (34%) or other parts of the PV system (37%) [178].

Since 2014, there has been an international standard for DC connectors: IEC 62852:2014 "Connectors for DC-application in photovoltaic systems - Safety requirements and tests". There is also a UK implementation: BS EN 50521:2008+A1:2012, “Connectors for photovoltaic systems: Safety requirements and tests”.

However, despite the safety critical nature of DC connectors there is, as yet, no standardised design that provides interchangeability of connector male and female halves. In fact there are many similar "MC4"-style[2] connectors on the market, many of which apparently fit together interchangeably. However, there is no test data to prove which combinations of connectors are safe to use together. Further information is given in 2.5.3.

DC isolators

Another known source of fires is resistance heating or arcing within the electrical switches (isolators) typically used on PV systems. This can be due to poor component design, poor specification [72] or poor installation.

Although fires in AC isolators have been known (for example if installed incorrectly or under-rated), the majority of isolator fires have initiated within DC isolators.

The design issues tend to involve the contact design. Snap-action knife contacts appear to give the cleanest make-break operation. The contacts should be designed so as to minimise the inevitable few milliseconds of arcing that occur as the contacts separate.

Specification issues tend to involve lack of understanding regarding DC rating and rating for the current and voltages involved. In particular, the isolators must be capable of breaking the maximum possible current and voltage that may be encountered, and to do this at the highest likely ambient temperature and humidity.

Installation issues tend to involve loose clamping of wires in terminal blocks or compromising weather resistance in outdoor locations. Poorly fitting or upward-facing cable glands are typical installation errors.

[2] MC4 refers to a 4mm DC connector product range from Multicontact. These have become the de-facto industry standard.

A UK guidance document has been written in order to aid the specification and installation of DC isolators [115], and the IET Code of Practice for Grid Connected Solar Photovoltaic Systems [171] also has some information.

See also Remote or automatic disconnection devices, 2.4.2.4.

PV modules

Several papers illustrate the common types of in-service defects that can occur in the panels themselves (e.g. [2]).

See also By-pass diodes.

By-pass diodes

By-pass diodes, which are normally incorporated into modules, are important in the context of reducing fire risks [41]. Their function is to eliminate the hot-spots within PV modules caused by the increased resistance of shaded cells. If a cell becomes shaded, its resistance increases, making it a ‘bottleneck’ for the series flow of current through the whole string of modules. If the string current is forced through cells of high resistance, the ohmic heating effect can be pronounced (it is proportional to the square of the current). The by-pass diodes allow the current to flow around groups of cells containing any cells of high resistance.

The design and specification of by-pass diodes is therefore critical to their function [42], [138], [168].

One issue is that lightning strikes, or electrical surges, can damage or destroy by-pass diodes. The damage is not usually obvious by visual inspection and diodes can fail either open circuit or short circuit. Open circuit diodes can give rise to overheating within partially shaded modules, potentially causing fires [168]. Shorted diodes will cause underperformance of the module, but, with correct thermal design, should be capable of dissipating the heat generated by current flowing through them.

In general, routine maintenance tests do not address the possibility of faulty diodes. Shorted diodes may be detected as a loss of string voltage, but open circuit diodes are unlikely to be detected unless there happens to be partial shading of the affected cells and an infrared imaging camera is being used to identify hot spots.

Some work has been done on understanding arc faults within by-pass diodes, and at the diode connections [79].

Inverters

Inverters are the most likely component to fail [28] and fires originating within inverters have been known to occur in the UK and elsewhere.

Modern mainstream inverters contain earth leakage and residual current detection circuits. These monitoring devices are explained in 2.4.2.3.

Microinverters (usually fitted under and connected to each module) offer the possibility of reducing fire risks [73], [102]. There are several arguments to support this view:

- The maximum DC voltage is approximately 30V for standard PV modules. Since the likelihood of electrical arcs being established reduces with voltage, this is a considerable improvement over typical system voltages of hundreds of volts.
- The overall system voltage is the same as the incoming mains voltage, and is AC, so can be handled with standard mains components and wiring.

- If the microinverter is integrated onto the back of the module, there are no external DC cables. If not integrated, the DC cabling is only the length of the module cables, thus reducing the connection risks associated with DC cables.
- Because microinverters contain active circuitry, there is the opportunity to incorporate thermal sensing and automatic disconnection – most devices on the market do incorporate this.
- Microinverters generally have communications built-in, thereby allowing remote diagnosis of any issues and remote shut-down.

DC optimisers offer many of the same advantages as microinverters, except that standard DC cabling and connections are used and the DC voltage may be high enough to produce arcing in defective components.

Module mountings

The mounting type also has a bearing on the fire risk once a fire has been initiated. One study [92] concludes that the risk of damage to roofs is 20 times higher with roof-integrated systems (i.e. systems that form part of the roof covering) than for roof-mounted systems (i.e. mounted on frames above the roof).

A chimney effect caused by systems that are mounted above roofs has been studied and demonstrated [35], [41], [149], [165]. This effect occurs where there is a gap between the roof covering and the PV array that can act as a chimney, drawing in fresh air from the lower edge of the array, which increases oxygen flow to the fire and therefore increases the intensity of the fire. The result is an enhanced heat flux through the roof, increasing the likelihood of ignition of any flammable substructure, such as wooden rafters [35]. This effect does not seem to have been addressed within the Microgeneration Certification Standard (MCS) 012 [99].

In the USA, work has been undertaken to assess and implement a fire classification rating for roof-mounted systems [132], [133]; this was implemented in 2013 and could form the basis for similar requirements in the UK.

Certain materials used for mounting systems may also exacerbate fires (see 2.4.1.4), whilst other module/material combinations claim to reduce flammability [105].

2.4.1.4 Materials

The main materials used in the construction of PV modules are glass, silicon, aluminium, copper, EVA encapsulant and a polymer backing sheet. Of these, the encapsulant and the backing sheet are normally the most flammable components and have the potential to exacerbate the spread of a building fire [24]. Studies of the flammability of PV modules in the event of internal arcs have been made [122] and alternative materials proposed. For example, fluoroplastics may prove to be a suitable encapsulant with a lower flammability than EVA [108]. Standard polysilicon PV modules become flammable at a critical heat flux of 26 kW/m^2 [165].

Environmental contamination from chemicals released by PV modules during a fire is a concern that is sometimes raised. However, toxic substances, such as cadmium, are chemically bound into PV materials and release to the environment is thought to be unlikely, even if modules are destroyed by fire [140], [141].

Some materials may exacerbate a fire incident to the extent that a building is damaged or destroyed. One such example is the use of certain types of polymer as a PV mounting system. If the polymer is flammable, given a sufficiently hot source of ignition, the mounting system can become fuel for a fire that spreads rapidly across the array and to the building itself. At present, there is no clear guidance on the use of such systems, or indeed whether they should fall under building regulations. For example, it is not clear whether the mounting system effectively covers all or part of a roof, or whether it becomes considered part of the building covering and thus subject to normal building regulations.

Some useful work has been done relating flammability to green building materials [45], [97], [152], [166], [167].

Further reading

References relevant to the causes and characteristics of PV fires are listed here; the full citations can be found in Appendix A.

[3], [4], [6], [12], [17], [24], [28], [35], [41], [45], [51], [67], [79], [80], [81], [82], [83], [84], [92], [93], [107], [114], [118], [120], [122], [123], [131], [140], [146], [160], [161], [166], [168], [173], [174], [176], [177], [178].

2.4.2 Fault detection and response (real-time monitoring)

The literature suggests that the new generation of detection devices – arc fault detection, ground fault detection, and insulation resistance breakdown detection – can provide effective protection against the kind of faults that result in fires.

However, experience from the USA suggests that some devices fitted in response to the 2011 USA National Electrical Code® (NEC) requirements have limitations (see below and Gap analysis). At least one paper suggests that these limitations can be overcome by a combination of good maintenance procedures, high-resolution ground fault detectors, and arc fault detectors [18].

2.4.2.1 Arc fault detection

The USA has led the field on the automatic detection of arc faults, including in its 2011 update of the NEC a requirement to fit arc-fault circuit interrupters (AFCI) on the DC side of new PV installations. The devices (certified to UL1699) are intended to detect DC arcs and eliminate them before they become a fire hazard, thus preventing fires, but not preventing the initial fault.

Since 2011, some arc fault detection devices have appeared on the market, in response to the changes in the NEC [169]. However, at the time of writing, BRE is not aware of any independent, credible proof that they are effective and, since UK and EU regulations do not currently require the fitting of arc fault detection systems, only a few devices are available in Europe.

The devices usually work by detecting the broad band radio frequency emissions typical of electrical arcs [63]. A survey of state-of-the-art fault detection and mitigation technologies and commercially available products is presented [3], with an assessment of their effectiveness given in [7], [13], [50], [61].

2.4.2.2 Overcurrent protection

The approach to overcurrent protection traditionally used for AC and DC power circuits (fuses or circuit breakers) is not always effective with solar PV because panels are effectively current sources operating close to their short circuit current as part of normal operation. UK guidance exists [171] on when and how to specify string fuses in PV systems, but research is currently on-going to adopt an internationally standardised approach [20].

2.4.2.3 Earth leakage and insulation resistance monitoring (ground faults)

Many modern inverters are fitted with earth leakage and insulation resistance monitoring functions, and the latest advice provided by the IET [171] mandates earthing for PV frames in order to allow these protective devices to operate correctly. The devices are designed to detect electrical faults, due to the breakdown of insulation or leakage of current, before they become more serious in the form of shock or fire hazards.

However, they are not a universal solution, as they have been shown to be insufficiently sensitive, or too sensitive causing nuisance tripping under normal conditions e.g. [11], [18]. This issue is explained further in 2.5.4.

2.4.2.4 Remote or automatic disconnection devices

There are two types of device that are designed to shut off the DC power at, or close to, the PV modules:

- Automatic disconnection devices
- Remote switches (sometimes known as “Fireman’s switches”)

Some devices are a combination of the two types.

Automatic disconnection can be achieved through dedicated devices [62], [177], or by use of microinverters or DC optimisers that have built-in temperature sensing (see Inverters).

One issue is that there are no standards relevant to the UK for the design and testing of such devices; products are appearing on the market, but how well they will function and whether they will be of any benefit in the event of a real fire is unknown.

The effectiveness of these systems depends on several factors [115]:

- The DC switch (or switches) must be positioned sufficiently close to the PV modules to disconnect the wiring inside the building.
- If there is a manual control, it must be positioned carefully – out of the reach of children - but accessible to owners and the fire services.
- The system must be fail-safe, so may require its own power supply to function if the building power is cut off.
- Any such system should be subject to regular testing and maintenance.
- The disconnection system may be required to function in the event of a fire, so high temperature cabling and fire-resistant installation techniques may be required.

In the USA, “rapid shutdown” switches were mandated in the 2011 update to the NEC. When operated, these devices are required to make safe any external wiring that is more than 3 metres from the array, and interior wiring that is more than 1.5 metres from the wiring entry point to the building [129].

The proposed 2017 update to the NEC may effectively require shutdown at the module level (i.e. at each individual module). However, this is still under discussion [90].

2.4.2.5 Thermography

A common method of assessing the health of PV modules and connections is by infrared thermography. This technique, which uses an infrared thermal imaging camera (sometimes mounted on a drone) has become very popular, especially for larger solar installations. The false colour images produced allow, by comparison with the colours of surrounding surfaces, the identification of hot spots or devices that are overheating, e.g. resistance heating in junction boxes.

For this method to be useful the operator should be trained in the use of the camera and the interpretation of the images, as they can be misleading. One issue is that the images do not provide any quantifiable data, so visual interpretation has to be relied upon. One paper provides guidance on how to perform such quantification reliably without the need of any other special device [183].

2.4.2.6 Other real-time diagnostics

If system performance is being monitored and data parsed by appropriate algorithms as it emerges, real-time statistical methods offer the possibility of detecting faults before they develop into more serious incidents [33], [34], [36], [137], [139], [170]. With these methods, where basic real-time system data is available (e.g. voltage and current, irradiance, temperature), there is often no further hardware cost involved. Sophisticated software algorithms need to be installed and tuned to the particular system, along with suitable status and alarm outputs for the system owner or maintenance team.

2.4.3 Design advice

Some key safety options available during the design phase have been explained in 2.4.2. However, as well as fitting fault detection devices, system designers are in a position to reduce fire risks and risks to firefighters, PV systems and buildings, by implementing appropriate precautions. For example, it may be possible to mount the array so as to minimise the chimney effect, should there be a fire on the roof [41]. Access can be an issue for firefighters, so due consideration should be given to being able to safely move around on roofs with PV arrays [126], [171].

2.4.4 PV Industry Codes, standards and guides

A survey of relevant standards is presented in 3.1 and Appendix B. The comments in this section relate to documents that were revealed by the literature survey and provide commentaries and guidance to standards and codes.

The number and complexity of international, European and national standards relating to renewables is growing rapidly. A 2013 report [124] identified 149 PV-specific standards (the standards shown in Appendix B are fire-related). The report provides a good overview of international standards on renewable energy technologies and states that approximately 90% of the 149 PV standards relate to the components of PV modules, either in terms of demonstrating their performance, testing and validation of claims and manufacturing validation, or component integration and safety. Therefore, if PV systems are catching fire, it seems that more PV module standards may not be the answer. Nevertheless, changes, such as requiring designs that prevent arcing, are proposed by some [162].

Since 2011, the USA NEC 690.11 has required the fitting of AFCIs on the DC side of new PV installations [6], [16]. The devices are intended to detect DC arcs and eliminate them before they become a fire hazard, thus preventing fires, but not preventing the initial fault.

Also required is an accessible switch that can be used by firefighters to shut down a PV system if required (see 2.4.2.4). The equivalent UK wiring regulations (BS 7671) require DC and AC isolators to be fitted at certain points within the circuit, but are not so specific on how much of the DC circuit must be isolated when the switch is operated.

After 2013 changes to ANSI/UL 1703, the US fire classification rating approach takes into account the PV module in combination with the mounting system and the roof covering products over which it is installed [132], [133]. This could form the basis for similar requirements in the UK.

The effects of the NEC changes are discussed in several publications, e.g. [5], as well as changes to US construction codes [19].

The changes are regarded as part of a progression as new evidence and techniques arise and proposals for 2017 NEC are also being presented [16], [19].

In the EU, directives and, in particular, CE marking is intended to provide a level of safety assurance [130]. However, CE marking is a self-certification scheme, so is reliant upon the diligence of each manufacturer. Other European guidance for the PV industry is available e.g. [25], which may translate into a standard or code in time.

National standards and guidance for the UK PV industry are evolving – the IET Code of Practice for Grid Connected Solar PV Systems [171] is the most up-to-date document and has been written to be in line with international standards. It contains good practice information for designers and installers and has a specific section on fire prevention. It is likely that this document will be adopted by MCS, which currently has its own standard [175] and guidance document [100].

MCS 012 [99] specifies test procedures for “pitched roof installation kits”, i.e. combined solar panel and mounting system sets, and forms the basis for compliance with building regulations spread of fire requirements in the UK. However, the specified fire tests apply only to in-roof systems (i.e. BIPV). Given that work has been done showing that above-roof systems can affect the spread of fire [35], it could be that the standard should be expanded to include this effect, in a similar way to that implemented in the USA [132], [133].

The function of MCS 012 is sometimes misunderstood. It is a “test and declare” standard. There is no pass or fail level, so a product that is certified to MCS 012 is not necessarily suitable for all locations or applications. It is the responsibility of the installer to assess whether the declared fire performance is adequate for the particular application.

In general, standards addressing the fire risks of PV systems have been slow to develop and the recent rapid increases in deployment now make this matter more urgent.

2.4.5 Firefighter guidance

Many documents that offer guidance to fire and rescue services (FRS) were found: see further reading below.

In the UK, an event was jointly organised by BRE Trust and the British Photovoltaic Association (BPVA) in 2011 [17], [116], [135] and another by MCS in 2013 [30] in order to start a national conversation on the subject. Also, on behalf of DCLG, BRE Fire Safety Group produced and presented a general assessment of the risks in 2013 [134], [136].

However, national guidance currently remains general [26], [27] and we are informed that FRSs have been developing their own standard operating procedures.

One of the less obvious effects of having PV modules mounted on frames on roofs is that the arrangement can create a chimney effect where a fire is present on a roof. This effect has been measured [35], [149]. In the UK, this issue is not covered by MCS 012 [99], which stipulates spread of fire testing for *building integrated* pitched roof panel and mounting combinations only i.e. MCS 012 requires pitched roof kits that replace the roof covering to be tested and for manufacturers to declare their fire performance rating [99].

MCS 012 became mandatory on the 2nd May 2016. For building-integrated systems (BIPV), existing building regulations also relate to the external spread of flame. MCS 012 requires pitched roof kits that replace the roof covering to be tested and for manufacturers to declare their fire performance rating.

2.4.5.1 Firefighter safety

Although the electrical and fire hazards associated with electrical generation and distribution systems are well known and firefighters are used to dealing with them, the DC voltages in PV systems present different risks. Firefighters’ PPE equipment (such as gloves and boots) will not provide full protection against electrical shocks, particularly in wet conditions. It may also be difficult to gain access to the roof if the panels cover the whole area, and the roof may collapse sooner than expected due to the additional weight of the PV system. PV systems also increase the slip and trip hazards when working on roofs, particularly if smoke causes problems with visibility.

Metal roofs are generally conductive and may present a shock hazard. Enclosures for electrical equipment, though rated to resist rain penetration, are not resistant to water penetration by high pressure fire hoses and could also present an electrical hazard. The Firefighter Safety and Photovoltaic Installations Research Project (Underwriters Laboratories, 2011) [9] examined in detail the various risks to firefighters, including the creation of unexpected electrical circuits from array components (module frame, mounting racks, conduits etc.) or building components (metal roofs, flashings and gutters). It also tested the risk of electrical shocks through wet or defective PPE, and methods of extinguishing PV fires. This comprehensive research has been the source for recommendations in various countries.

Various measures have been proposed in other countries to reduce the risk of PV systems to firefighters responding to fire incidents on buildings.

Already implemented in the USA (measures first introduced in California have now become nation-wide):

- Building codes to make accessing roofs with PV modules safer for firefighters (US firefighters often cut open a roof to ventilate the fire (“vertical ventilation”) and want an area they can safely saw open [19]). The 2012 and particularly the 2015 editions of the US International Fire Code (IFC) require setbacks and pathways on roofs where PV systems are installed [44], [157].
- Electrical safety codes (US National Electrical Code 2014) require an easily accessible disconnection switch for the DC current [147]. This switch needs to be placed where it can be quickly identified and accessed in an emergency, so some standardisation on where it is placed would be desirable [5].
- DC wiring inside buildings should be run in metallic conduits and preferably along the bottom of loadbearing members (US International Fire Code) [157].

Other suggestions include:

- The US Fire Fighter Safety Building Marking System (NFPA Fire Code Annex Q) specifies labelling of buildings and could be used to indicate the presence of PV systems [60]. In New Jersey, buildings larger than one or two family residential structures have an emblem placed at the front entrance to notify firefighters of the presence of a PV system [163]. Labelling the outside of buildings with special identification plates or other clear weather-resistant signage would be a next step for existing signage recommended by the IET [171], which specifies that a label is affixed at the consumer unit or main distribution board.
- Registering details of PV systems with the local fire brigade [78].

In Germany, a joint industry study concluded that PV systems do not pose any special threat to fire department personnel, provided they comply with safety clearances, and they can be dealt with in the same way as any other voltage-carrying electrical equipment [161]. The opinion is that disconnect switches are still an unproven technology which have yet to prove their reliability for the whole lifetime of the PV system, and that installing them might give firefighters a false sense of security. A damaged array could still be energised. The recommendations for German firefighters and emergency responders are to keep a safe distance from a PV system that is affected by fire, operate the main AC and DC isolators, if accessible, and request an electrician to shut down the rest of the PV system [147].

The German standard VDE 0132:2008, *Firefighting and assistance in or near electrical installations*, gives safety distances for rescue squads avoiding the risk of electrocution when being close to power carrying parts while extinguishing a possibly damaged PV system during a rescue operation. Different safety distances have been explored. The distances which have to be observed for low voltage (<1.5 kV) are 1m for a spray jet and 5m for a full water jet [119], [153].

Another practice currently used in Australia involves the use of a smartphone ‘app’ capable of providing advice to firefighters arriving at the scene of an incident involving PV [58]. However, FRSs generally operate using a set of Standard Operating Procedures (SOPs), so any such initiative would be required to integrate with SOPs.

In the UK there is little such guidance available yet, although analysis work has been done [173]. There is no database providing information for fire crews on whether a property they are attending has PV fitted. The Chief Executive and Chief Fire Officer of Merseyside Fire and Rescue Service called for action on this subject at the conference organised by BRE Trust and BPVA in 2011 “Photovoltaics and fire: separating fact from fiction" [119]. The Merseyside officer also advocated the informal approach adopted in Germany, where local installers established a dialogue with their fire service, showing them what they had installed in the area and exchanging mobile phone numbers. Creating a central database of PV systems using aerial mapping has been suggested for the Netherlands [1].

2.4.5.2 Firefighting procedures and training

As well as acquiring a basic understanding of PV systems, firefighters should be trained not just to recognise PV systems but also the electrical infrastructure associated with them; PV modules may not be easily visible from the ground, so in some cases, recognition may only come from inspection of internal equipment. Also, it may be difficult for untrained people to distinguish between solar thermal and PV modules from a distance and some buildings may have both types of panel fitted. Some hazards are common to both types of system – solar thermal, though, poses the additional risk of scalding from hot fluids [59 and 60].

The firefighting manual from the Office of the State Fire Marshal, California [21], covers these points, the possible additional hazards that may be created by a PV system such as hazardous materials and toxic gases, and how the presence of a PV system may affect firefighting tactics. One of the main risks to firefighters is likely to be electrocution during fire suppression activities [159], [181].

UL (a USA safety standards and certification agency) published a study on the safe distances from a PV-related fire for personnel using water hoses [9]. The study shows that a fog pattern was found to be safer than a solid stream. Streams or standing pools of water or foam can conduct electricity, thus creating a new hazard. The UL tests using seawater against an electrical fire had to be discontinued because of the increase in conductivity, and water from a pond or lake may also be more conductive than water taken from the mains. Further tests on safe distances, depending on the type of nozzle, on the water pressure and on the water flow rate, have been carried out using the types of nozzle commonly used in Italy [153].

Heavy, dense fabrics, such as tarpaulins, and even dark plastic films, can be used to interrupt the generation of power from a PV array, but should be used with caution, as wet materials can also become energised if in contact with live equipment and can blow off the array in windy weather [9]. Foam may be insufficiently dense to prevent light reaching the modules and energising them [148].

Kent Fire and Rescue Service‘s SOP for dealing with PV systems [12], [88], [89] includes a detailed risk assessment. Gloves with an electrical rating are used for any contact with electrical components. Inverter or isolator fires are suppressed with dry powder. It states: “Where possible the PV system isolators should be operated. Ideally the AC isolator should be operated first followed by the DC isolator.” The SOP advises that, even after a fire has been extinguished, damaged PV systems may still produce dangerous voltages, so system components should still be treated as live. Other brigades have their own SOPs [155].

Shutting down off-grid systems or systems with a battery back-up is more complicated; locating and making safe the battery banks is necessary [113]. If burning, they can produce corrosive material and toxic gases [142].

Firefighters use non-contact voltage detectors to find hot AC cables, but DC non-contact voltage detectors are not available [113]. Gloves and tools that might touch electrical equipment should be insulated [9 and 142].

A recent paper [44] from the US trade body, Solar Energy Industries Association, on rooftop PV systems and firefighter safety, appears to be one of the most up-to-date sources of information for firefighters. Included are results of in-depth interviews with firefighters discussing their rooftop operations, concerns and decision-making processes with respect to PV. However, the advice is understandably oriented towards American fire and rescue services, so not all of the information will be relevant to the UK.

2.4.5.3 Further reading (Firefighter guidance)

The following references in Appendix A provide further reading on the subject of firefighter safety when tackling fires involving PV systems:

[8], [9], [10], [12], [19], [21], [23], [26], [27], [30], [43], [44], [45], [52], [58], [59], [60], [61] , [64], [74], [75], [78], [85], [86], [88], [89], [91], [93], [95], [96], [98], [101], [110], [111], [113], [119], [126], [127], [128], [134], [135], [136], [142], [143], [147], [148], [153], [154], [155], [158], [159], [163], [167], [173], [177] and [178]

2.4.6 Insurance, risk assessment, loss adjustment

There appear to be relatively few documents specifically oriented to the insurance industry [54], [56]. Several references do address the broader subject of assessing risk, but mainly from the design or FRS points of view: [23], [25], [26], [27], [51].

2.5 Gap analysis

This section briefly lists subjects that appear to be under-represented, or not addressed at all, within the literature that was identified.

2.5.1 Health and safety

There appear to be few up-to-date UK health and safety documents that are specific to PV installations. A 2014 guide from the Electrical Safety Council addresses the electrical design aspects [47], but the only other relevant UK document appears to date back to 2000 [38]. Product designs and installation techniques have evolved significantly since that time, so there is the opportunity now for a new guide covering all health and safety aspects of installing, operating and maintaining PV systems. Useful information is available from the USA [112].

Health and safety topics for firefighters are covered in the various manuals and papers discussed in 2.4.4.

2.5.2 Operation and maintenance

With solar PV, there is a tendency, especially for building-mounted systems, to ‘fit and forget’. Systems start up, operate and shut down automatically and silently, they have no moving parts and can therefore be easily overlooked when it comes to maintenance.

It is unknown how many PV fires could have been prevented or mitigated by timely maintenance (or by performance monitoring). Some general guidance on maintenance is provided by the IET [171]. However, this appears to be an under-represented subject in the literature and standards alike. The maintenance requirements vary with the type, complexity and location of PV systems, but some guidance for owners and technicians, perhaps as a precursor to a more formal document, would be welcome.

2.5.3 DC connectors

The issue around quick-connect “MC4” type connectors has not been solved. The IET and MCS guides state that connector halves from different manufacturers should not be coupled together (MCS requires test data). However, the practical upshot is that most installers are unable to comply. This is as a result of the overwhelming majority of PV modules that are supplied with factory fitted pre-terminated flying leads. In most cases it is difficult to identify the connector type and manufacturer by visual inspection. Enquiries to product distributors are usually unfruitful, but even an enquiry direct to the product manufacturer often does not yield a clear answer as manufacturers sometimes use a range of different “MC4”-type connectors from different sources.

One response could be to introduce a mandatory standard that so closely specifies the connector design that any conforming connector half should couple safely with any other conforming half. The counter-argument is that this may stifle innovation. However, it is clear that there is a procedural gap to be addressed since some connector combinations may be dangerous. It is suggested that some work needs to be done on this subject in order to arrive at a practical solution.

2.5.4 Earth leakage and insulation resistance monitoring (ground faults)

Many modern inverters are fitted with earth leakage and insulation resistance monitoring functions, and the latest advice from the IET [171] mandates earthing for PV frames in order to allow these protective devices to operate correctly.

There appear to be two issues arising:

1) Several commentators have raised concerns over the efficacy of these safety systems under all operating modes [11], [18], [55]. The terminology being used in the industry is ‘blind spots’ in ground fault detection. The characteristics of leakage current due to insulation breakdown have been studied [67].

2) Many systems in the UK are not monitored in real time (if at all). The IET [171] requires earth fault detection alarms to be visible and unmissable. This, however, means that there is a legacy of approximately 700,000 systems that do not have an effective alarm system if an inverter detects a fault. The majority of systems installed to date are unlikely to meet these requirements.

Some clear guidelines for products sold in the UK would be useful, as well as enforcement or encouragement of implementation of the fault alarm guidance set out by the IET.

2.5.5 Battery systems

There are currently a number of energy storage technologies emerging that can complement PV systems. In particular, batteries are starting to be fitted and the market is expected to grow rapidly. Batteries can represent a significant fire hazard, if not installed and operated correctly. There are currently no UK installation standards, however, guidance documents are currently under development (IET plan to release a guide in early 2017). The risks associated with these technologies should be kept under review.

2.5.6 Spread of fire

MCS 012 [99] specifies test procedures for “pitched roof installation kits”, i.e. combined PV module and mounting sets, and forms the basis for compliance with building regulations spread of fire requirements in the UK.

However, the specified fire tests only apply to in-roof systems (i.e. BIPV). Studies have shown that above-roof systems can affect the spread of fire [35], [41], [149], therefore standards should be expanded, as in the US [132], to include this effect.

Some materials may exacerbate a fire incident to the extent that a building is damaged or destroyed. One such example is the use of certain types of polymer as a PV mounting system. If the polymer is flammable, given a sufficiently hot source of ignition, the mounting system can become fuel for a fire that spreads rapidly across the array and to the building itself. At present, there is no clear guidance on the use of such systems, or indeed whether they should fall under building regulations.

2.5.7 Insurance

We found little work to inform and address the concerns of the insurance industry, especially in the UK (see 2.4.6).

2.5.8 System Owners

The IET [171] stipulates that installers must advise their clients (new system owners) to seek professional advice on the fire protection of their building. However, many householders are unlikely to know what to do with this information and it could cause unnecessary worry. Some guidance for householders would be useful. Non-domestic building operators should already have fire protection systems in place and know how to have them reviewed.

Furthermore, a general document on operation and maintenance for system owners may prove useful.

Safety advice is provided for owners of community systems in the USA, which could be adapted for use in the UK [125].

2.6 Index of documents by category

Given the breadth of approaches and subject areas, we have placed each reference from Appendix A into a general category in Table 2, below, in order to allow easier identification of documents of interest for particular readers. Some papers fall into more than one category.

Table 2: The broad categories within which the references fall

Topic	References (see Appendix A)
Causes and characterising fires in PV systems	[3], [4], [6], [12], [17], [24], [28], [35], [41], [45], [51], [67], [79], [80], [81], [82], [83], [84], [92], [93], [107], [114], [118], [120], [122], [123], [131], [138], [140], [146], [160], [161], [166], [168], [173], [174], [177] , [178] , [179] , [182]
Failure modes of PV modules	[2], [14], [24], [138], [146], [156], [168], [176] , [177], [178] , [179]
Preventative techniques or technologies	[1], [7], [11], [18], [13], [43], [20], [41], [50], [51], [53], [54], [55], [77], [94], [97], [102], [103], [105], [108], [109], [115], [116], [118], [123], [125], [141], [145], [152], [162], [164], [169] , [181] , [183]

Fault detection and response	[33], [34], [36], [50], [62] , [63] , [80], [81], [82], [83], [90], [102], [103], [121], [137], [139], [148], [170] , [181] , [183]
Firefighter guidance	[8], [9], [10], [12], [19], [21], [23], [26], [27], [30], [43], [44], [45], [52], [58], [59], [60], [61] , [64], [74], [75], [78], [85], [86], [88], [89], [91], [93], [95], [96], [98], [101], [110], [111], [113], [119], [126], [127], [128], [134], [135], [136], [142], [143], [147], [148], [153], [154], [155], [158], [159], [163], [167], [173] , [178], [180] , [182] , [184]
PV Industry Codes, standards and guides	[5], [15], [16], [17], [21], [22], [23], [25], [31], [32], [37], [38], [40], [42], [47], [53], [54], [57], [66], [69], [70], [71], [72], [73], [74], [76], [87], [94], [99], [100], [106] , [111] , [112], [116], [117], [118[, [124], [126] , [127], [128], [129], [130], [134], [135], [147], [157], [159], [164], [169], [170], [171], [172], [175] , [184]
Product / Installation testing	[29], [39], [46], [65], [99], [119], [132], [133], [149], [151], [165], [166], [175]
Insurance, risk assessment, loss adjustment	[54], [56], [84], [118], [122], [123], [144], [173] , [182]

3 WP2: Survey of standards and training programmes for PV design and installation

3.1 Standards

The majority of significant standards covering PV industry activities originate at the International Electrotechnical Commission (IEC), as a result IEC standards make up the majority of the references listed in Appendix B.

Often European (EN) and British (BS) "localised" versions of these same standards are developed. In the listings in Appendix B, we have quoted the IET source, where possible, since localised standards tend to follow sometime after publication of IET documents.

If required, the localised version of a standard can be readily identified by searching for the base number on the relevant website. For example, the BS equivalent of IEC 61215 can be found by searching the BSI website for "61215".

There is, of course, a strong argument to say that the general wiring standards are among the most relevant standards for fire safety. In the UK this is primarily BS7671, so this, and other relevant standards, are also included.

In Appendix B, we have distinguished between published standards and those that are under development. Within these, there are sub-categories, as follows:

Published standards

- PV module standards
- Balance of System (BOS) standards
- Installation standards
- Hybrid systems & rural electrification
- General wiring / installation standards
- PV specific standards from outside IEC

Standards under development

- PV module standards
- Module material standards
- Balance of System (BOS) standards
- Installation standards
- Hybrid systems & rural electrification

It is hoped that this categorisation will aid the reader in identifying standards covering specific areas.

3.2 Training courses

To research existing training programmes, we have contacted training accreditation bodies, trade bodies, the Chief Fire Officers Association (CFOA), BRE Fire specialists and BRE National Solar Centre contacts.

The identification of training courses was found to be a difficult task. There are many training providers in the PV installer arena offering a range of different courses – many of which are likely to be the same thing but described slightly differently. Also, the dynamic nature of this market sector makes it impossible to provide an exhaustive and definitive list. Nevertheless, a 'snapshot' list of training courses has been compiled and presented in **Error! Reference source not found.**.

We have divided these into the following categories:

- **Formal (accredited) PV courses -** typically accredited by City & Guilds, Logic, BPEC, etc.
- **Unaccredited PV-specific courses -** these courses appear to have been written and run by the individual training bodies themselves
- **Other PV-related courses and potential courses -** e.g. product-related courses run by manufacturers
- **PV courses for fire-fighters -** enquiries with CFOA did not produce any information, as individual FRSs are apparently responsible for their own training. However, we are aware of a number of training documents produced by FRSs and we have been able to use some of these to infer the existence of individual FRS training.

  The majority of the PV courses for firefighters were found to be in the USA.

As a supplement to the training course listings, Appendix D provides a list of "Competency Criteria", taken from the MCS website. This list was produced by individually looking up each of the "essential" and "pre-requisite" qualifications that MCS requires for someone to be granted Nominated Technical Person status for solar PV.

4 Conclusions

A wide-ranging search exercise has been conducted in which the project team has collected references to relevant literature, technical standards and training courses.

Nearly all of the 184 literary references found and presented in this report have been supplemented with associated abstracts, either as provided by the author, or summarised by members of the team. Furthermore, the references have been categorised into 8 groups in order to aid the locating of specific types of work:

1. Causes and characterising fires in PV systems
2. Failure modes of PV modules and systems
3. Preventative techniques or technologies
4. Fault detection and response
5. Firefighter guidance
6. PV Industry Codes, standards and guides
7. Product / Installation testing
8. Insurance, risk assessment, loss adjustment

A commentary on the reviewed literature is provided, culminating in a gap analysis that briefly lists topics that appear to be under-represented in the literature and therefore point towards possible useful further work.

Where PV systems have been the cause of fires, some themes emerge. Much attention is paid to the phenomenon of electrical arcing, where a current flows across an air gap by ionising the air. High voltage arcs are extremely hot and can cause combustion of surrounding materials in less than a second. Arcing can occur where conducting parts become physically separated by mechanical movement or mis-alignment. Also, a build-up of contaminants (e.g. oxide) on electrical contacts can cause resistive heating, resulting in the breakdown of materials and subsequent arcing.

Certain components, if incorrectly specified, poorly installed or contain manufacturing faults, are typical locations of electrical arcs:

- DC connectors
- DC isolators
- Inverters
- PV modules, including by-pass diodes and junction boxes

PV module mounting systems can also be important, for example, fires starting in roof-integrated (BIPV) systems are more likely to cause structural damage to buildings. Above-roof systems may increase the heat flux through a roof in the event of a fire through a chimney effect occurring in the gap between the PV modules and the roof surface.

Certain materials can be ignited by arcing and then act as a fuel, promoting the spread of fire (e.g. certain polymers). Some work has been done on the use of low fire risk materials in PV modules.

Ground faults are sometimes a precursor to more serious issues, such as arcing, and can often be detected by insulation resistance or earth leakage tests. Many modern inverters have the capability to detect such faults and to send an alarm. However, there is evidence that they will not detect ground faults in all circumstances.

Other fault detection and response techniques include arc fault detection (now mandatory in the USA), overcurrent protection, automatic and remote disconnection devices, infrared thermography and statistical methods applied to monitoring data.

The lists of standards is thorough and has an international scope; the majority being published by IEC. These standards tend to filter down into “localised” versions, such as BS EN standards, which are readily identifiable on the websites of the relevant standards publisher (e.g. British Standards Institute).

The standards have been categorised as “Published” and “Under development”, as well as placed into sub-categories to aid identification.

In general, standards addressing the fire risks of PV systems have been slow to develop and the recent rapid increases in deployment now make this matter more urgent. However, with over 130 standards relating to PV modules, it seems that further PV module standards may not be the most effective method of preventing fires.

There appears to be no nationally accepted PV guide for UK firefighters and where information was found, it tended to be in the form of each FRS’s standard operating procedures.

Standards for battery storage in buildings are currently lacking. A guide will be published by the IET in early 2017.

The identification of training courses was found to be a difficult task with many of the PV courses duplicated under different names. Also, the dynamic nature of this market sector makes it impossible to provide an exhaustive and definitive list. Nevertheless, a ‘snapshot’ list of training courses has been compiled and presented.

The majority of PV courses for firefighters were found to be in the USA. Some training is freely available on the websites of fire departments or on YouTube, e.g. Captain Matt Paiss of the San Jose Fire Department has produced several videos explaining PV systems and describing firefighting strategies (see PV courses for fire-fighters, item 17, **Error! Reference source not found.**). UK guidance for firefighters appears to be inconsistent and localised, suggesting the need for some nationally accepted guidance.

This body of work should provide a useful point-of-reference when executing the remaining work packages in the project and addressing questions raised by our own experiences in the UK.

It will also be useful for other researchers and for identifying areas for further research.

Appendix A Literature survey listing

[1] R. Aarsen, et al. "Installed base registration of decentralised solar panels with applications in crisis management." In International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. XL-3/W3, 2015. ISPRS Geospatial Week 2015, La Grande Motte, France, 28 Sept.-3 Oct. 2015. ISPRS, 2015.

Available: http://repository.tudelft.nl/view/ir/uuid:5213b508-e930-4f26-92c9-881521dab387/ [Nov. 6, 2015]

This study suggests a new, reliable and up-to-date database of PV modules in the Netherlands, as a replacement for the current national voluntary Register of Energy Data Services Netherland (EDSN-PIR), that could provide important information in case of a calamity.

[2] A-E-S Europe GmbH. “Damages at Solar Panels.” [3]

Available: https://www.europe-solar.de/catalog/index.php?main_page=page&id=44 [Oct. 7, 2015]

This webpage illustrates some of the types of damage that can occur to PV modules during the operational lifetime. In some cases, the probable causes are also explored.

[3] M.K. Alam, et al. “A comprehensive review of catastrophic faults in PV arrays: types, detection, and mitigation techniques.” IEEE Journal of Photovoltaics, vol. 5, no. 3, pp. 982-997, 2015.

Three major catastrophic failures in photovoltaic (PV) arrays are ground faults, line-to-line faults, and arc faults. Although there have not been many such failures, two fire events in 2009 and 2011, in the USA, suggest the need for improvements in present fault detection and mitigation techniques, as well as amendments to existing codes and standards to avoid such accidents. This review investigates the effect of faults on the operation of PV arrays and identifies limitations to existing detection and mitigation methods. A survey of state-of-the-art fault detection and mitigation technologies and commercially available products is also presented. [Author abstract, abbreviated].

[4] Allianz Risk Consulting. “Understanding the fire hazards of photovoltaic systems.” Tech Talk, vol. 8, July 2012.

Available: http://www.agcs.allianz.com/assets/PDFs/ARC/Tech%20Talks/TTVol8-FireHazardsofPVSystems.pdf [Sep. 24, 2015]

This paper provides a good basic introduction to the relevant aspects of PV systems and then discusses the risks and makes recommendations for specification and installation of components, such as disconnection switches, and providing information to the local fire department.

[3] Title as quoted.

[5] F. Andorka. “How the new NEC codes will affect your installations.” Solar Power World, Sep. 2014.

Available: http://www.solarpowerworldonline.com/2014/09/new-nec-codes-will-affect-installations-2/ [Sep. 8, 2015]

New regulations in the National Electrical Code (USA) require an accessible switch that can be used by firefighters to shut down a PV system if required. Arc-fault detection equipment must also be installed. Building codes introduced in 2015 demand that PV arrays have the same fire rating as is required for the roof; tests have shown that the fire rating of PV modules does not predict accurately how the roof and PV array together will behave.

[6] K. M. Armijo, et al. “Characterizing fire danger from low-power photovoltaic arc-faults.” Proposed for presentation at the 40th IEEE Photovoltaic Specialists Conference, June 8-13, 2014 in Denver, CO.

Available: http://energy.sandia.gov/wp-content/gallery/uploads/Characterizing-Fire-Danger-From-Low-Power-PV-Arc-Faults-2014-4593C.pdf [Sep. 8, 2015]

While arc-faults are rare in photovoltaic installations, more than a dozen documented arc-faults have led to fires and resulted in significant damage to the PV system and surrounding structures. In the United States, National Electrical Code® (NEC) 690.11 requires a listed arc fault protection device on new PV systems. In order to list new arc-fault circuit interrupters (AFCIs), Underwriters Laboratories created the certification outline of investigation UL 1699B. The outline only requires AFCI devices to be tested at arc powers of 300-900 W; however, arcs of much lower power are capable of creating fires in PV systems. This work investigates the characteristics of low power (100-300 W) arc-faults to determine the potential for fires, appropriate AFCI trip times, and the characteristics of the pyrolyzation process. Overall a trip time of less than 2 seconds is recommended for the suppression of fire ignition during arc-fault events. [Author abstract, abbreviated]

[7] K. M. Armijo, et al. "Quantifying photovoltaic fire danger reduction with arc-fault circuit interrupters." Presented at the 29th EU PVSEC, Amsterdam, 2014 and published in Progress in Photovoltaics: Research and Applications, 2014.

Available: http://onlinelibrary.wiley.com/doi/10.1002/pip.2561/full [Oct. 7, 2015]

Unmitigated arc-faults present fire dangers, shock hazards, and cause system downtime in photovoltaic (PV) systems. The 2011 National Electrical Code® added section 690.11 to require a listed arc-fault protection device on new PV systems. Underwriters Laboratories created the outline of investigation for PV DC arc-fault circuit protection, UL 1699B, for certifying arc-fault circuit interrupters (AFCIs) for arc suppression. Unfortunately, little is known about appropriate trip times for arc-faults generated at different locations in the PV system, with different electrode and polymer encapsulant geometries and materials. In this investigation, a plasma model was developed, which determines fire danger with UL 1699B-listed AFCIs and consequences of arc-fault discharges sustained beyond UL 1699B trip time requirements. This model predicts temperatures for varying system configurations and was validated by 100 and 300 W arc-faults experiments where combustion times and temperatures were measured. This investigation then extrapolated burn characteristics using this model to predict polymer ignition times for exposure to arc-power levels between 100 and 1200 W. The numerical results indicate AFCI maximum trip times required by UL 1699B are sufficient to suppress 100–1200 W arc-faults prior to fire initiation. Optical emission spectroscopy and thermochemical decomposition analysis were also conducted to assess spectral and chemical degradation of the polymer sheath. [Author abstract]

[8] Australasian Fire and Emergency Service Authorities Council. Safety considerations for photovoltaic arrays. 2013.

Basic training video produced by the Australasian Fire and Emergency Service Authorities Council (AFAC) for use by AFAC member agencies. The information provided is generic by nature. Access to video is controlled by Queensland Fire and Emergency Services (QFES).

Information at: http://www.sfrst.org/training-videos/have-you-thought/safety-considerations-photovoltaic-arrays [Dec. 15, 2015. Password required]

[9] R. Backstrom and D. Dini. "Firefighter safety and photovoltaic installations research project." Underwriters Laboratories, 2011.

Available: http://www.ul.com/global/documents/offerings/industries/buildingmaterials/fireservice/PV-FF_SafetyFinalReport.pdf [Oct. 7, 2015]

Results of a research project to find safer methods of fighting fires involving PV systems.

[10] R. Backstrom and D. Dini. "Firefighter safety and photovoltaic installations research project." In SPIE Solar Energy+ Technology, Proc. SPIE 8472, Reliability of Photovoltaic Cells, Modules, Components, and Systems V, Oct. 16, 2012, pp. 84720K. International Society for Optics and Photonics.

Available: http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1379666 [Sep. 8, 2015]

Discusses the risks to firefighters from fires affecting buildings with PV modules, especially electrical shock. Enclosures for electrical equipment rated as resistant to ordinary rain can be penetrated by high pressure fire hoses.

[11] G. Ball, et al. "Inverter ground-fault detection 'blind spot' and mitigation methods." Solar American Board for Codes and Standards, 2013.

Available: http://solarabcs.org/about/publications/reports/blindspot/index.html [Sep. 8, 2015].

These Solar American Board for Codes and Standards (Solar ABCs) reports address an important safety issue in the design of many U.S. photovoltaic (PV) systems. This safety issue - undetected faults in grounded PV array conductors - came to light during investigations into two well-publicized PV system fires. The first occurred on April 5, 2008, in Bakersfield, California, and the second occurred on April 16, 2011, in Mount Holly, North Carolina. The Solar ABCs has led a broad industry- and stakeholder-based working group to research this problem and develop effective mitigation strategies. This research first focused on developing a basic explanation of the cause of the detection blind spot. It includes results of field research conducted to characterize basic array wiring impedance properties and their effects on ground fault detection, circuit modelling, and analyses of high and low impedance faults that may occur throughout the array. It also includes a technical review of the effects of different array topologies (grounded, ungrounded, and grounded through the alternating current connection) on ground fault detection blind spots. [Author abstract]

[12] P. Bennett. “Fire safety and solar PV.” Blog by Peter Bennett.

Available: http://www.solarpowerportal.co.uk/editors_blog/fire_safety_and_solar_pv 20 April 2015 [Sep. 8, 2015].

Although there is only a very small fire risk from PV installations (any fires are usually down to installer error), firefighters fighting any sort of fire at the property will be at risk from the presence of DC current, which cannot be switched off during the day. FRSs recommend that all installers should be trained to use best practice and that property owners should register details of their systems with the local FRS.

[13] S. Bieniek, et al. “Fire prevention in PV-plants using inverter integrated AFCI.”

In European Photovoltaic Solar Energy Conference; the most inspiring platform for the global PV Solar Sector, Hamburg, Germany, Sep, 2011, pp. 3199-3203. Munich: WIP-Renewable Energies, 2011.

Analysis has shown that arc fault detection offers the possibility of reducing the risk of fire in 80% of all considered failure conditions. In 2011, a listed system-integrated PV Arc Fault Circuit Interrupter (AFCI) for detecting series arc faults will be demanded by the NEC Art. 690.11 certified to UL1699. Due to these facts, a strategy for reliably detecting arc faults and simultaneously preventing the increase of Total Costs of Ownership (TCO) has to be developed. In this regard, an inverter-integrated AFCI, protecting the entire PV array, is the preferable solution in comparison to decentralized approaches. The main advantage is that existing inverter components are suitable to fulfil the specifications demanded by the standards. Furthermore, an inverter-integrated solution does not lead to additional costs for installation and maintenance. This work demonstrates that the inverter-integrated AFCI reliably detects series arc faults in the main path of the PV array as well as in parallel paths with a decreased sensitivity of measurement. [Author abstract, abbreviated]

[14] N. Bosco. “Reliability concerns associated with PV technologies.” National Renewable Energy Laboratory, Colorado, 2010.

Available: http://www.nrel.gov/pv/performance_reliability/pdfs/failure_references.pdf [Nov. 16, 2015]

A summary of known problems that affect reliability (corrosion, water ingress, delamination, hot spots, etc.), with a list of references.

[15] W. Bower, et al. “Codes and standards for PV arc-fault detection & mitigation,” presented at the Solar Power International Conference, Los Angeles, CA, Oct. 13, 2010.

Presentation explaining arc faults in PV systems, relevant NEC and UL standards, and technical developments underway at Sandia Laboratories and elsewhere.

[16] W. Bower. “National electrical code changes in 2014 for photovoltaics: processes, critical industry consensus topics and impacts”. In Proc. IEEE 40th Photovoltaic Specialist Conference (PVSC), Denver, Colorado, June 2014, pp. 3352-3355.

Most technical challenges that have emerged for safe photovoltaic (PV) systems are addressed with new installation requirements in the 2014 National Electrical Code® (NEC®). The recent cycle for updates to the NEC has been completed. Collaborative efforts among industry experts and focused groups including

the US DOE industry forum, Solar Energy Industry Association (SEIA), and Solar ABCs resulted in consensus, and extensive technically-responsible updates for the 2014 NEC for PV Systems. New firefighter safety and fault detection language was added as was updated system interconnection requirements. Details of those changes and new efforts to write proposals for 2017NEC are presented. Impacts of major changes and needs for further changes to the 2017NEC are presented. [Author abstract]

[17] British Photovoltaic Association. Photovoltaic's [sic] and fire: a guide from the BPVA. BPVA, 2011.

Available: http://www.bpva.org.uk/media/38257/fire-pv_v4_20130821105943.pdf [Sep. 29, 2015]

[18] W. Brooks. “Field guide for testing existing photovoltaic systems for ground faults and installing equipment to mitigate fire hazards: November 2012-Oct. 2013.” Golden, CO: National Renewable Energy Laboratory, 2015. NREL/SR 5D00-61018.

Available: http://www.nrel.gov/docs/fy15osti/61018.pdf [Sep. 9, 2015]

Experience suggests that ground faults and arc faults are the two most common reasons for fires in photovoltaic (PV) arrays. This report provides field procedures for testing PV arrays for ground faults, and for implementing high-resolution ground fault and arc fault detectors in existing and new PV system designs. Recent research done by the Solar America Board for Codes and Standards has shown that some PV system ground faults go undetected, which can lead to fires in PV arrays. These undetected faults have been termed blind spots in the ground fault detection circuits used in most US PV installations. These blind spots can be effectively eliminated by detection systems that monitor ground current at much higher resolution than is currently required. Arc fault detectors are now available that can detect and remove series arc faults as required by the 2011 National Electrical Code. The combination of good maintenance procedures, high-resolution ground fault detectors, and arc fault detectors effectively addresses fire hazards in existing and new PV systems. [Author abstract, abbreviated]

[19] W. Brooks. “Solar PV safety for the Fire Service.” Presentation, 2011. Solar America Board for Codes and Standards.

Available: http://www.nfpa.org/~/media/files/proceedings/photovoltaicbrooks.pdf [Oct. 6, 2015]

Brief description of the problem and of the regulatory work being carried out to refine US construction codes and standard operating procedures for firefighters.

[20] M. Calais, et al. “Over-current protection in PV array installations.” Presented at the ISES-AP-3rd International Solar Energy Society Conference-Asia Pacific Region (ISES-AP-08), Sydney, 2008.

Available: http://solar.org.au/papers/08papers/408.pdf [Sep. 29, 2015]

In photovoltaic (PV) arrays with several strings in parallel certain fault conditions may lead to potentially damaging reverse currents for PV modules. The Australian Standard AS/NZ5033 Installation of Photovoltaic (PV) Arrays recommends fuses to protect both cabling and PV modules in case of the occurrence of these fault conditions. The above standard forms the basis of the development of the international IEC draft standard on Installation and Safety Requirements for Photovoltaic (PV) Generators. This international standard development work highlighted the need for improved

understanding of the application of fuses in PV array and this paper consequently examines, in detail, requirements for fusing in PV arrays in view of various fault and environmental conditions with respect to protecting both cabling and PV modules. It reviews and discusses fusing requirements and ratings of the current PV array installation standard. Test results of typical fuse characteristics of fuses used in PV arrays are presented. This testing utilised both a laboratory power supply and a PV array. The paper also examines the relationships between acceptable reverse current levels and exposure durations of reverse currents on PV modules and compares them with trip current of fuses and typical time delays experienced with fuse tripping. [Author abstract]

[21] CAL FIRE – Office of the State Fire Marshal, California. Fire operations for photovoltaic emergencies. 2010.

Available: http://osfm.fire.ca.gov/training/pdf/Photovoltaics/Fire%20Ops%20PV%20lo%20resl.pdf [Sep. 29, 2015]

A training manual for the fire service. Includes a list of incidents and lessons learned from them.

[22] CAL FIRE – Office of the State Fire Marshal, California. Solar photovoltaic installation guideline. 2008.

Available: http://osfm.fire.ca.gov/training/pdf/photovoltaics/solarphotovoltaicguideline.pdf [Sep. 29, 2015]

The intent of this guideline is to provide the solar photovoltaic industry with information that will aid in the designing, building, and installation of solar photovoltaic systems in a manner that should meet the objectives of both the solar photovoltaic industry and the Fire Service. [From Foreword]

[23] P. Cancelliere. “Fire risk assessment and mitigation of PV electrical plants according to the Italian National Fire Brigade guidelines.” Presented at Interflam 2013 - 13th International Conference and Exhibition on Fire Science and Engineering, Royal Holloway College, Windsor, UK, 24-26 June 2013. Published in Fire and Materials, December 2014.

Photovoltaic (PV) systems design and construction are generally focused on efficiency and reliability, in order to increase the amount of solar energy that can be converted into electrical energy. Therefore, in a PV electrical generation plant, fire risk is not taken into account by technical designers and, furthermore, is not considered by constructors of PV plant installation. This paper shows a procedure to assess and mitigate the fire risk as a result of a PV plant installation located over buildings, according to the Italian National Fire Services Guidelines. Firstly, an introduction to the main faulty modes of PV arrays and modules is reported in order to highlight how the pre-existing level of fire risk is increased for a building or construction work where a PV electrical generation plant is installed. Hence, the paper explains how the guidelines point out fire risk assessment steps oriented to PV plant installation over buildings. In addition, the guidelines contain some useful fire risk mitigation technical solutions. The guidelines have been developed with safety as their main objective. The PV sector has been presented with certain limitations in roof or façade installations as a result of PV fire ignition characteristics and firefighting suppression techniques. The aim of the guidelines is to provide the solar PV industry with information and technical arrangements to aid the design, construction and installation of solar PV systems meeting the objectives of both solar PV industry and fire safety requirements. [Author abstract]

[24] P. Cancelliere and C. Liciotti. “Fire behaviour and performance of photovoltaic module backsheets”. Fire Technology, pp. 1-16, 2015.

Given that photovoltaic (PV) power plant can cause and/or contribute to fires in buildings, the fire risk resulting from a PV power plant installation on a building roof or façade should be assessed in order to meet building fire-safety requirements. In fact, PV plant installed on a roof or a façade could fail and cause a fire and/or promote or facilitate its spread. Accident analyses have shown that PV systems are often installed without due consideration of fire propagation and fire spread caused by the presence of modules, cables and electrical boards on the roof. This paper shows a proposal for a method to evaluate the reaction-to-fire characteristics of a PV module and provides experimental results that compare the behaviours and performances of four kinds of PV module backsheet. Some of the commonest type of backsheet materials available on the market have been selected in order to evaluate and compare the reaction-to-fire performances of these products: Backsheet no.1 has three layers (PET/PET/Primer), Backsheet no.2 is composed of four layers (PET/Aluminium/PET/Primer), Backsheet no.3 is a fluoro-coating/PET/EVA three-layer sheet and Backsheet no. 4 comprises an outside coating, a PET layer and an inside coating. Test results show that the choice of a single layer for Backsheet no.4 represents the best solution among the ones tested. Even though Backsheet no.2 shows the same reaction-to-fire rating as that of Backsheet no.4, the PV module production process could be critical as regards the electrical behaviour of the module itself, since aluminium foil is a material that conducts electricity. Moreover, since the fire-performance assessment of PV panels in Europe is left at a national level, the approach reported in this paper could represent a useful reference to be used as a baseline for developing a European standard or, better still, an International standard. [Author abstract]

[25] P. Cancelliere, et al. “Photovoltaic installations and fire prevention in Italy.” In: EU PVSEC 2013 - 28th European Photovoltaic Solar Energy Conference and Exhibition, Paris, Sep. 2013, pp. 4346-4350, edited by A. Mine, A. Jager-Waldau, P. Helm. Munich: WIP-Renewable Energies, 2013.

In order to identify some useful solutions able to mitigate the increase of the pre-existing level of fire risk and in general to reach the objectives of safety requirements laid down in Regulation (EU) n.30512011 of 9 March 2011, following the activities carried out by a Joint Working Group between the Italian Department of Firefighters and the Italian Electrotechnical Committee (CEI), a guide has been issued for the installation of photovoltaic systems in activities subject to fire prevention inspections. The content of the guide can be very useful for the designer or installer of PV plants not only in activities subject to fire prevention inspections and can constitute a compendium of support for the preparation of fire risk assessment. Moreover the guide could represent, at international level, an important element of comparison for the definition of both module fire test procedures and module installation. [Author abstract, edited]

[26] Chief Fire and Rescue Adviser and the Department for Communities and Local Government (DCLG). “Generic risk assessment 5.1: incidents involving electricity.” DCLG, 2013.

Available: https://www.gov.uk/government/publications/generic-risk-assessment-5-1-incidents-involving-electricity [Sep. 9, 2015]

Generic risk assessment about incidents involving electricity to help fire and rescue authorities to draw up their own risk assessments.

[27] Chief Fire and Rescue Adviser and the Department for Communities and Local Government (DCLG). “Generic risk assessment 3.1: Fighting fires in buildings.” DCLG, 2011.

Available:
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/105747/3.1_fighting_fires.pdf [Sep. 29, 2015]

Generic risk assessment for fighting fires in buildings.

[28] A. Colli. “Failure mode and effect analysis for photovoltaic systems (Review Article).”

Renewable and Sustainable Energy Reviews, vol. 50, pp. 804-809, Oct. 2015.

Failure mode and effect analysis (FMEA) is an inductive and conservative system reliability analysis approach, here applied to photovoltaic system. A system is a complex combination of components and sub-components, where technical and disciplinary interfaces apply in their mutual interactions. FMEA processes the individual analysis of each system’s sub-component with the task to identify the various failure modes affecting each part, along with causes and consequences for the part itself and the entire system. In the proposed analysis the system’s component and sub-components have been identified from the design of the Northeast Solar Energy Research Center (NSERC) photovoltaic research array located at Brookhaven National Laboratory (BNL). The complete FMEA analysis is presented, along with the applied ranking scales and final results. The approach is discussed in its benefits and limitations, the latter mainly identified in the limited amount of open source information concerning failure probabilities for the photovoltaic system parts. [Author abstract]

[29] S. Colwell S and T. Baker. External fire performance of roofs - a guide to test methods and classification. BRE Digest DG 528. Bracknell, IHS BRE Press, 2013.

Following the introduction of European fire test methods for determining the external fire performance of roof systems, and CE marking under the Construction Products Directive or the Construction Products Regulation, this Digest explains the test methods for roofs, and how the test data are used to classify the external fire performance. It discusses the limitations of the classification system, and the importance of specifiers correctly interpreting the information presented to them. It will help manufacturers to provide end-users with the information they need to specify roofing systems in relation to their fire performance. It also explains how fire performance classifications relate to the guidance in Building Regulations Approved Document B. [Author abstract, edited]

[30] M. Cotterell. “Photovoltaics and fire.” Presented at the PV Installations and Fire Safety Event, the Fire Service College, Moreton-in-Marsh, May 1st 2013.

General description of the potential fire issues with PV systems presented with firefighters in mind.

[31] M. Cotterell. “Testing PV systems: forget ‘fit and forget’.” Blog – 16th July 2014.

Available:
http://www.solarpowerportal.co.uk/martins_blog/testing_pv_systems_forget_fit_and_forget_3452 [Sep. 9, 2015]

The test and inspection of an old PV system is something many installers are called to do from time to time. It may be that it is part of a routine maintenance cycle, it could be because of a change of ownership

or it may be down to concerns in system performance. This blog looks at performing a periodic verification (condition report) on the DC side of the system. [Introduction]

[32] G. Cronshaw. “Renewable sources of electricity and the 17th edition of the IEE [IET] wiring regulations (BS 7671:2008) – a brief overview.” Wiring Matters, Winter 2008, no. 29, pp. 1-7.

Available: http://www.voltimum.co.uk/articles/renewable-sources-electricity-and-17th-edition-iee-wiring-regulations-bs-76712008-brief [Sep. 10, 2015]

Looks at the new regulations in sections 551 and 712 of BS7671 which describe additional requirements to ensure the safe connection of low-voltage generators, including PV systems. These include installing equipment that complies with the relevant British Standards, protective measures for assuring automatic disconnection of the power supply, protection against overcurrent and electromagnetic interference (including lightning), installing a means of isolating the AC and DC sides of the PV inverter, switching and earthing arrangements.

[33] M. Davarifar, et al. “New method for fault detection of PV panels in domestic applications.” In Proceedings of the 2013 3rd International Conference on Systems and Control (ICSC), pp. 727-732, Algiers, 2013. IEEE.

This research presents a new algorithm and method for fault detection of photovoltaic panels in a Residential Photovoltaic System (RPS). Our proposed PV performance diagnosis system consists of two parts, passive and active parts. In the passive diagnosis part, residue value is generated with a Model Base Fault Diagnosis (MBFD) method to observe a clear alarm signal from arbitrary data. As well, a statistical method such as the Wald test technique is used to detect primary alarm in passive part. After observing the clear alarm signal, a flash test is applied for closer scrutiny of I-V characteristics to determine different types of fault (active part). This proposed Simple Flash Test Driver (FTD) device could be integrated in the modern inverters in order to increase the efficiency and reliability of the RPS without any additional cost in commercial DC/DC inverters. [Author abstract, edited]

[34] M. Davarifar, et al. “Real-time diagnosis of PV system by using the Sequential Probability Ratio Test (SPRT).” In Proceedings of the 16th International Power Electronics and Motion Control Conference and Exposition (PEMC), pp. 508-513, Antalya, 2014. IEEE.

This paper proposes Online PV fault Diagnosis by using a Sequential Probability Ratio Test (SPRT) to improve measured signal value and anomaly detection. To identify defects characteristic of the PV system, the voltage and current of the PV system are measured online and compared with simulated values, then a residual signal is generated. SPRT allows us to detect anomaly conditions in-situ, and improve decision making for residual signal. From investigating the two residual signals of current and voltage, a fault diagnosis procedure is suggested to classify types of fault and eventually determine the probability of fault location. [Author abstract, edited]

[35] R.J. Davis. “Fire concerns with roof-mounted solar panels.” Fire Protection Engineering, Sep. 2014, Emerging Trends, issue 92.

Available: http://magazine.sfpe.org/issue-92-fire-concerns-roof-mounted-solar-panels [Sep. 10, 2015]

Regardless of the materials used in the construction of a PV module, its mere presence can change the dynamics of a roof fire. Combustible components inside the PV module and flames spreading underneath it can increase the heat flux on the roof surface. The author recommends using a complete system (PV modules, fixings and roof assembly) that has been tested to simulate actual field conditions.

[36] M.G. Deceglie, T.J. Silverman, B. Marion and S.R. Kurtz. "Real-time series resistance monitoring in PV systems." Presented at the IEEE Photovoltaic Specialists Conference, June 14-19, 2015, New Orleans, Louisiana. Publication no. NREL/PR-5J00-63998. Golden, CO: National Renewable Energy Laboratory (NREL), 2015. Published in IEEE Journal of Photovoltaics, vol.5 no. 6, pp. 1706-1709, 2015.

Available: http://www.nrel.gov/docs/fy15osti/63998.pdf [Sep. 29, 2015]

Presentation showing that real-time monitoring can provide an alert for performance problems that could become fire risks.

[37] Department of Trade and Industry; BRE; EA Technology; Halcrow Group; SunDog Energy; Energy Saving Trust. Photovoltaics in buildings - guide to the installation of PV systems. 2nd ed, 2006.

Available: http://www.bre.co.uk/filelibrary/pdf/rpts/Guide_to_the_installation_of_PV_systems_2nd_Edition.pdf [Nov. 11, 2015] Information for installers.

Second edition of the DTI guidance. This document formed the foundations for the 2013 MCS guide [100].

[38] Department of Trade and Industry; Building Services Research and Information Association (BSRIA). Photovoltaics in buildings - safety and the CDM regulations. Bracknell, BSRIA, 2000.

Provides a simple guide to the Construction (Design and Management) Regulations, 1994, (CDM Regulations) with regard to the design, installation, operation, maintenance, decommissioning and disposal of PV installations in buildings. Note that most of the safety advice is also relevant to small installations that may be exempt from the Regulations. Included here as there does not appear to be a more recent version.

[39] M.C. Despinasse and S. Krueger. "First developments of a new test to evaluate the fire behavior of photovoltaic modules on roofs." Fire Safety Journal, vol. 71, pp. 49-57, 2015.

A new test for photovoltaic (PV) modules exposed to an external fire source on roofs is proposed, and first results are presented. This is a simplification of the standards commonly in use for testing PV modules as roofing parts, roofing components or building components. Most of the tests required different fire scenarios and the use of burning brands such as wood cribs. In our study we proposed replacing wooden burning brands with a propane burner, the output of which is close to the one that can be observed in the burning of wooden cribs 500 g and 2 kg in size. The fire behaviour was assessed by measuring smoke evolution, burning drips, flaming debris, and the time to burn-through of monocrystalline, polycrystalline and amorphous silicon panels. Two different configurations of the burner were tested, with the fire source on the top of the module or under the tilted module, respectively. The fire behaviour of the modules was dependent on the burner output (16 to 46 kW), but also on the construction type of the panel (glass/glass or glass/plastic sheet) and on the position of the fire source (top or bottom).

These preliminary tests for further development of the procedure yielded encouraging results for the evaluation of PV panels on roofs. [Author abstract]

[40] Deutsche Gesellshaft fur Sonnenenergie. Planning and installing photovoltaic systems: a guide for installers, architects and engineers. Earthscan, 2007.

This is a well-known comprehensive guide to design and installation of solar systems. Section 5.8 covers fire safety and the guidance agreed by the solar industry and fire services in Germany.

[41] N.G. Dhere and N.S. Shiradkar. “Fire hazard and other safety concerns of photovoltaic systems.” Journal of Photonics for Energy, vol. 2, no. 1, 022006, 2012.

Available: http://photonicsforenergy.spiedigitallibrary.org/article.aspx?articleid=1486127 [Sep. 10, 2015]

The two main factors, i.e. open circuiting of the dc circuit and of the bypass diodes and ground faults that are responsible for fires in PV systems, are discussed in detail along with numerous real life examples. Recommendations are provided for preventing these hazards, such as designing the PV array mounting system to minimize the chimney effect, having proper bypass and blocking diodes, and interestingly, having an ungrounded PV system. [Author abstract, abbreviated]

[42] N.G. Dhere and J. Wohlgemuth. “Fire hazard and other safety concerns of PV systems.” Proceedings of SPIE (the International Society for Optical Engineering) Reliability of photovoltaic cells, modules, components, and systems, San Diego, CA, Aug, 2011. Ed. K.W. Lynn. Bellingham: SPIE, 2011, vol. 8112.

Discusses safety precautions for grid-connected PV systems, such as having PV modules fire rated to at least class C [American fire class], and using proper bypass and blocking diodes. One suggestion is to have ungrounded systems.

[43] F. Di Napoli, et al. “Single-panel voltage zeroing system for safe access on PV plants.” IEEE Journal of Photovoltaics, vol. 5, no. 5, pp. 1428-1434, 2015.

In this paper, an effective circuit for both voltage and current zeroing of single solar panels embedded in a solar field is presented. The circuit interrupts the panel current by means of a solid-state power switch and zeros the panel voltage by means of an electromechanical relay. Each solar panel can be either connected or disconnected from the string independently from each other. The circuit is connected to the existing junction box and does not require additional wiring, neither for its power supply, which is always derived from the solar panel, nor for its data transmission, which is achieved through a special suited power line communication scheme exploiting the existing dc power bus. Experiments performed on a test solar field equipped with in-house made circuit prototypes evidence the reliability of the proposed approach. [Author abstract]

[44] DNV GL. Rooftop PV systems and firefighter safety. SEIA, 2015.

Available: http://www.seia.org/research-resources/rooftop-pv-systems-firefighter-safety [Nov. 4, 2015]

This paper summarizes findings from a DNV GL study of firefighter rooftop operations, the hazards they may encounter when working around PV arrays, and means in which electrical hazards in particular can be mitigated or substantially reduced. The study included results of in-depth interviews with firefighters discussing their rooftop operations, concerns and decision making processes with respect to PV. [From summary]

[45] F. Durso. “Easy being green? An update of the fire and life safety risks associated with green buildings, from construction materials to ancillary systems like photovoltaic arrays.”, NFPA Journal: the official magazine of the National Fire Protection Association (US), vol. 106, no. 6, pp. 50-55, 2012.

Discusses recent research on the fire risks of lightweight building materials and renewable energy technologies and the NFPA Codes that address some of these issues.

[46] G. Egisto. Analisi e modellazione del test SBI di reazione al fuoco di un pannello solare fotovoltaico. Thesis, Politecnico di Milano, 2015.

Available: https://www.politesi.polimi.it/handle/10589/109062 [Sep. 29, 2015]

Reports on the fire testing of a PV module and computational fluid dynamics (CFD) modelling of the fire’s effects, including the chemical reactions of the PV components.

[47] Electrical Safety Council. Connecting a microgeneration system to a domestic or similar electrical installation (in parallel with the mains supply). Best Practice Guide 3 issue 2. London: ESC, 2014.

Available: http://www.electricalsafetyfirst.org.uk/mediafile/100117576/Best-Practice-Guide-3.pdf [Nov. 16, 2015]

[48] [Removed, not relevant]

[49] [Removed, not relevant]

[50] B. England. An investigation into arc detection and fire safety aspects of PV installations. B.Eng. thesis, Murdoch University, Perth, Australia, 2012.

Available: http://core.ac.uk/download/pdf/11245968.pdf [Sep. 29, 2015]

The number of PV systems around the world is increasing and the systems are aging with little to no inspections and maintenance. Exposed to UV, the weather and rodents, cables, connection points and other components can degrade to the point where there is a break in the circuit and over this gap the current from the PV array can continue to flow causing an arc. The heat and electrical energy from the arc can ignite nearby materials and start a fire which could cause further damage. When an arc starts there is no off switch to easily cut the power from the PV array so the arcing situation can continue. A number of systems have been developed to detect these arcs in order to identify and eliminate them early before they start a fire. One of these devices was tested to determine if it was effective in detecting arcs. The Texas Instruments SolarMagic RD-195 DC Arc Detection Evaluation Board detected all the arcs created and did not give any false positives. The devices available on the market today are effective at detecting arcs and some have been integrated into the inverters of PV systems along with devices to extinguish any arcs. The integration of these and other features into PV systems makes PV systems safer and reduces the potential for damage to people the system and surrounds. [Author abstract]

[51] M.C. Falvo and S. Capparella. “Safety issues in PV systems: design choices for a secure fault detection and for preventing fire risk.” Case Studies in Fire Safety, vol. 3, pp. 1–16, May 2015.

Available: http://www.sciencedirect.com/science/article/pii/S2214398X14000120 [Sep. 10, 2015]

Photovoltaic systems have played a key role over the last decade in the evolution of the electricity sector. In terms of safety design, it’s important to consider that a PV plant constitutes a special system of generation, where the Direct Current (DC) presence results in changes to the technical rules. Moreover, if certain electrical faults occur, the plant is a possible source of fire. Choices regarding the grounding of the generator and its protection devices are fundamental for a design that evaluates fire risk. The subject of the article is the analysis of the relation between electrical phenomena in PV systems and the fire risk related to ensuring appropriate fault detection by the electrical protection system. A description of a grid-connected PV system is followed firstly by a comparison of the design solutions provided by International Standards, and secondly by an analysis of electrical phenomena which may trigger a fire. A study of two existing PV systems, where electrical faults have resulted in fires, is then presented. The study highlights the importance of checking all possible failure modes in a PV system design phase, to assess fire risk in advance. Some guidelines for the mitigation of electrical faults that may result in a fire are finally provided. [Author abstract]

[52] Fire Department of Munich. Photovoltaic: Accident prevention during firefighting. 2005.

[53] Fire protection in photovoltaic systems – facts replace fiction – Results of Expert Workshop, January 24, 2013. Press Release February 12, 2013.

Available: http://www.ise.fraunhofer.de/en/press-and-media/press-releases/presseinformationen-2013/fire-protection-in-photovoltaic-systems [Sep. 10, 2015]

Photovoltaic systems are different, but not more dangerous, than traditional electrical installations. This is the conclusion drawn at a fire protection workshop held on January 24, 2013 by the Fraunhofer Institute for Solar Energy Systems ISE and TÜV Rheinland at the Solar Info Center in Freiburg. The workshop was attended by 120 participants, including manufacturers, researchers, representatives from the fire brigade and insurance companies. They agreed that the best fire protection is adherence to the existing regulations by qualified skilled workers. [From press release]

[54] Fire Protection Research Foundation. Property Insurance Research Group Forum on PV Panel Fire Risk, June 8, 2014, Las Vegas, USA.

Available: http://www.nfpa.org/research/fire-protection-research-foundation/projects-reports-and-proceedings/proceedings/2014-proceedings/property-insurance-research-group-forum-on-pv-panel-fire-risk [Oct. 7, 2015]

On June 8, 2014, property insurers, property owners, fire service representatives and electrical specialists met to discuss concerns and potential strategies related to fire risks associated with roof-mounted PV

panel installations. This report summarizes a roundtable discussion by participants on fire experience and mitigation strategies for installation. [From summary]

[55] J. D. Flicker and J. Johnson. Photovoltaic ground fault and blind spot electrical simulations. No. SAND2013-3459, Sandia National Laboratories (SNL-NM), Albuquerque, NM, 2013.

Available: http://www.osti.gov/scitech/biblio/1089985 [Nov. 19, 2015]

Ground faults in photovoltaic (PV) systems pose a fire and shock hazard. To mitigate these risks, AC-isolated, DC grounded PV systems in the United States use Ground Fault Protection Devices (GFPDs), e.g., fuses, to de-energize the PV system when there is a ground fault. Recently the effectiveness of these protection devices has come under question because multiple fires have started when ground faults went undetected. In order to understand the limitations of fuse-based ground fault protection in PV systems, analytical and numerical simulations of different ground faults were performed. The numerical simulations were conducted with Simulation Program with Integrated Circuit Emphasis (SPICE) using a circuit model of the PV system which included the modules, wiring, switchgear, grounded or ungrounded components, and the inverter. The derivation of the SPICE model and the results of parametric fault current studies are provided with varying array topologies, fuse sizes, and fault impedances. Closed-form analytical approximations for GFPD currents from faults to the grounded current carrying conductor - known as 'blind spot' ground faults - are derived to provide greater understanding of the influence of array impedances on fault currents. The behaviour of the array during various ground faults is studied for a range of ground fault fuse sizes to determine if reducing the size of the fuse improves ground fault detection sensitivity. The results of the simulations show that reducing the amperage rating of the protective fuse does increase fault current detection sensitivity without increasing the likelihood of nuisance trips to a degree. Unfortunately, this benefit reaches a limit as fuses become smaller and their internal resistance increases to the point of becoming a major element in the fault current circuit. [Author abstract]

[56] FM Global Property Loss Prevention Data Sheet 1-15. "Roof mounted solar photovoltaic panels." July 2014, revised October 2014.

Available: https://www.fmglobal.com/fmglobalregistration/ [Oct. 7, 2015, Registration required]

This data sheet provides guidance related to protection against fire and natural hazards for the design, installation, and maintenance of roof-mounted PV modules.

[57] German Solar Energy Association, et al. "Broschüre für Einsatzkräfte der Feuerwehr". 2010.

Available: http://www.solarwirtschaft.de/fileadmin/media/pdf/bsw_feuerwehrbroschuere_2010.pdf [Sep. 29, 2015]

Technical fire safety rules developed by an interdisciplinary working group. Useful basic design guidance (in German).

[58] Government Skills Australia. "Work safely with PV systems - GSA Mobile App."

Available: http://governmentskills.com.au/public-safety/42-projects/public-safety/384-work-safely-with-pv-systems-mobile-app February 17, 2015 [Oct. 6, 2015].

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The outcome of the project was the development of the "Work safely with PV systems" app. The app was developed for smartphones and tablets for both the Android and Apple operating systems. The development process involved operational members of the target audience (fire and SES volunteers and paid staff). Technical experts were involved in the development of content and end-users participated in a testing phase during which feedback was sought and enhancements were implemented. This app to assist firefighters built on work already undertaken by the Australian Fire and Emergency Service Authorities Council (AFAC) and a separate joint Industry Skills Council project between GSA, Construction and Property Services Industry Skills Council and E-Oz Energy Skills Australia. The app can be used as an aide memoire for an incident at which a PV system is present, or to support training for the same. In particular, support for the delivery and assessment of the nationally accredited units of competency PUAFIR302B Suppress Urban Fire and PUAOHS002A Maintain Safety at an Incident Scene. (Text from the website)

[59] C.C. Grant. “Harnessing the sun: solar power and fire protection engineering.” Fire Protection Engineering, July 2014, no.63, pp. 45-50.

Available: http://magazine.sfpe.org/content/harnessing-sun-solar-power-and-fire-protection-engineering [Sep. 28, 2015]

Discusses fire hazards from PV, problems for firefighters in accessing roof areas, and the use of PV modules to provide power for firefighting systems and buildings, particularly in remote areas, or as a back-up power supply in emergencies. The article reviews and compares the differing fire hazards of solar thermal and PV systems.

[60] C.C. Grant. Fire fighter safety and emergency response for solar power systems. Fire Protection Research Foundation, 2010.

Available: http://www.firemarshalsarchives.org/pdf/Report%20FF%20Tactics%20Solar%20Power.pdf [Sep. 29, 2015]

This study focuses on structural firefighting in buildings and structures involving solar power systems utilizing solar panels that generate thermal and/or electrical energy, with a particular focus on solar photovoltaic panels used for electric power generation. The safety of firefighters and other emergency first responder personnel depends on understanding and properly handling these hazards through adequate training and preparation. The goal of this project has been to assemble and widely disseminate core principles and best practice information for firefighters, fire ground incident commanders, and other emergency first responders to assist in their decision making process at emergencies involving solar power systems on buildings. Methods used include collecting information and data from a wide range of credible sources, along with a one-day workshop of applicable subject matter experts that have provided their review and evaluation on the topic. [From Foreword]

[61] J.A. Guerra. “Fire safety in building - mounted photovoltaic arrays.” Seguridad y Medio Ambiente, Fundación MAPFRE, vol. 34, no. 133, First quarter 2014.

Available: http://www.mapfre.com/fundacion/html/revistas/seguridad/n133/en/article4.html [Dec. 16, 2015]

This article summarises the state-of-the-art for PV array safety for building users and firefighters, reports the results of testing an arc-fault detector and draws up a firefighting guide for buildings fitted with photovoltaic arrays. [Author abstract, abbreviated]

[62] P. Guerriero, et al. (2014, June). “A wireless controlled circuit for PV panel disconnection in case of fire.” In the Proceedings of the International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), 2014, pp. 982-986. Published by the IEEE.

This paper proposes a new system to short circuit a photovoltaic panel, embedded in a photovoltaic string, with the aim to ensure safe operation of firemen in case of fire. The circuit is activated by a wireless command and doesn't require additional wiring. Moreover it is self-powered by the solar panel itself and can be either turned on or turned off in a fully reversible way. [Author abstract]

[63] H. Häberlin. “Arc detector as an external accessory device for PV inverters for remote detection of dangerous arcs on the DC Side of PV plants.” Presented at the 25th European Photovoltaic Solar Energy Conference / 5th World Conference on Photovoltaic Energy Conversion, Valencia, Spain, 2010.

Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.7714&rep=rep1&type=pdf [Oct. 7, 2015]

Despite the still relatively small number of PV plants, such arcs have already caused quite a number of fires worldwide. The best and most cost-effective solution would be the integration of such an arc detector in the inverter. Due to the high demand for PV inverters and the necessary investment in development time for integration of an AD into their devices, so far no manufacturer has decided yet to do so. Another idea to overcome this problem is presented: the development of an external AD to be positioned very close to the inverter, whose operating power (only a few 10 mW to a few 100 mW) comes directly from the inverter and which communicates with only two signal lines with the inverter over a simple interface. [Author abstract, abbreviated]

[64] H. Häberlin, L. Borgna and P. Scharf. “PV and fire brigade safety: no panic, but realistic assessment of danger and possible countermeasures”, 26th European Photovoltaic Solar Energy Conference, Hamburg, Germany, 2011. Munich: WIP-Renewables, 2011, pp. 3913-3921.

Recently it was reported in several media that some fire brigades do not dare any more to fight against fires at houses with PV, as at such PV plants even at night under faint illumination (e.g. the light of the full moon or the searchlight of the fire brigade) there would be a lethal electrical shock hazard due to high DC voltages. This is exaggerated and based on a lack of knowledge of the properties of PV plants and the hazard due to the DC currents present in such plants. In this contribution we try to supply the necessary information for a realistic assessment of the danger that actually exists in such plants. Technical solutions for a reduction of this danger and their consequences for the operation of PV plants are also discussed. By marking all houses with PV plants with a special identification plate and by special training for officers of the fire brigade, an appropriate assessment of the effective danger and an appropriate fight against the fire should be possible. [Author abstract]

[65] B.T. Hamzavy and A.Z. Bradley. “Safety and performance analysis of a commercial photovoltaic installation.” SPIE Solar Energy+ Technology, Sep. 2013, pp. 88250M-88250M. International Society for Optics and Photonics.

Available: http://proceedings.spiedigitallibrary.org/proceeding.aspx?articleid=1743204 [Dec. 16, 2015]

The electrical performance of a commercial PV array was assessed. Both non-destructive and destructive analytical methods for system, module, and subsequent material component evaluations are reviewed.

[66] J. Haney and A. Burstein. “PV system operations and maintenance fundamentals.” Solar America Board for Codes and Standards, 2013.

Available: http://www.solarabcs.org/about/publications/reports/operations-maintenance/pdfs/SolarABCs-35-2013.pdf [Sep. 29, 2015]

The intent of this report is to help qualified individuals maintain and inspect PV systems safely. It also addresses currently known major safety requirements during PV servicing and repair, including the proper use of lockout/tagout procedures, the use of personal protective equipment, procedures for safely disconnecting live circuits, and appropriate observation of and compliance with all PV-specific system signage and warnings. In addition, it includes information about routine preventive maintenance and emergency shutdown procedures. (From summary)

[67] J.C. Hernández, P.G. Vidal and A. Medina. “Characterization of the insulation and leakage currents of PV generators: relevance for human safety.” Renewable Energy, vol. 35, no. 3, pp. 593-601, March 2010.

Available: http://www.sciencedirect.com/science/article/pii/S0960148109003541 [Dec. 16, 2015]

Protection against electric shock in photovoltaic generators (PVGs) with active protective measures requires an in-depth knowledge of the electrical behaviour of PVG insulation and PVG response under operating conditions with insulation faults. On the one hand, this knowledge can be obtained with an equivalent circuit model that characterises this insulation. The model presented can be used to: (i) evaluate PVG insulation resistance and leakage current; (ii) analyse potential hazards for the general public; (iii) design the best means of protection. On the other hand, this article also describes the insulation of a functioning PVG, and its reaction to meteorological variables (MVs) in laboratory and field conditions. Test results highlight those MVs that have a greater influence on PVG insulation as well as the relation between weather and insulation. This type of characterization is crucial when it comes to testing the operating capacity of the protective devices used in active protective measures against electric shock under different meteorological conditions. [Author abstract]

[68] [Removed – not relevant]

[69] J. C. Hernández, J. De la Cruz and B. Ogayar. "Electrical protection for the grid-interconnection of photovoltaic-distributed generation." Electric Power Systems Research, vol. 89, pp. 85-99, 2012.

Available: http://books.genems.com/journals/eee/3-1/Electrical%20Machines-III/1-s2.0-S0378779612000703-main.pdf [Dec. 16, 2015]

Distribution network and transmission system operators (DNOs and TSOs) who are obliged to connect photovoltaic-distributed generation (PV-DG) to their respective distribution networks or power systems need a coherent set of electrical protection requirements for safe operation. Nonetheless, the growing importance of PV-DG has prompted continuous reformulations of these requirements. Within this context, this paper gives a detailed overview of electrical protection requirements for PV-DG grid interconnection from the LV to the HV-EHV level. For this purpose, we have analysed national and regional codes that

have been proposed and enacted in many countries where high PV penetration levels have been achieved or are expected to be achieved in the future. This survey focuses on protection relays and their settings. Also included are the ancillary services to be provided by PV-DG, specifically at the HV-EHV level. [Author abstract]

[70] J. Holden and A. Rajan. Renewable energy sources: how they work and what they deliver: photovoltaics. BRE Digest DG532 part 1. Bracknell: IHS BRE Press, 2014.

This Digest provides an introduction to different types of solar PV cells, their properties, operating characteristics, annual energy performance, standards and certification.

[71] R. Hren. (2011, Oct.-Nov.) “Understanding PV module specifications.” Home Power. [On-line].

Available: http://www.homepower.com/articles/solar-electricity/equipment-products/understanding-pv-module-specifications [Nov. 16, 2015]

Explains the technical terms used by the manufacturers of PV modules in their brochures or specification sheets.

[72] P. Hutchens. “Is solar PV a fire hazard?” (YouGen Blog).

Available: http://www.yougen.co.uk/blog-entry/2074/Is+Solar+PV+a+fire+hazard'3F/, January 7, 2013 [Oct. 7, 2015]

Briefly mentions problems due to incorrectly specified DC isolator switches and suggests the installation of a fireman’s switch.

[73] H.P. Ikkurti and S. Saha. "A comprehensive techno-economic review of microinverters for Building Integrated Photovoltaics (BIPV)." Renewable and Sustainable Energy Reviews, vol. 47, pp. 997-1006, 2015.

Available: http://www.sciencedirect.com/science/article/pii/S1364032115002348 [Dec. 16, 2015]

Advantages of microinverters over conventional inverters are detailed along with a discussion on economics of its installation in distributed solar generation systems. Different power converter topologies reported in the available literature are presented. The paper also reports the historical development of commercial microinverters and their present status in the Photovoltaic (PV) market. Survey of the available products from some of the technology leaders in the market has been done and their specifications are tabulated. The paper concludes with a discussion on the necessities of the next generation microinverters for increased penetration in the PV market. [Author abstract, abbreviated]

[74] Institute of Electrical Engineers of Japan. The Journal of The Institute of Electrical Engineers of Japan, vol. 134, no. 10, 2014. “SPECIAL ISSUE on Issues and Activities on Safety of Photovoltaic Systems”.

Available: https://www.jstage.jst.go.jp/browse/ieejjournal/134/10/_contents [Dec. 16, 2015] (articles in Japanese only) pp. 672-676. Kazuhiko Kato. “Safety issues on photovoltaic power generation systems”.

pp. 683-687. Kazuaki Ikeda. “Prevention of electrical failure in photovoltaic array-I (bypass route inspection in photovoltaic modules)”.

pp. 688-692. Takafumi Ishii. “Prevention of electrical failure in photovoltaic array-II (ground-fault protection and arc-fault protection)”.

pp. 693-695. Takashi Oozeki. “Outline of the Photovoltaic System Fire Safety Project”.

[75] International Association of Fire Chiefs and the National Fire Protection Association. Evidence-based practices for strategic and tactical firefighting. Burlington, MA, Jones and Bartlett Learning, 2015.

A synopsis of the UL/NIST research studies and experiments on fire behaviour, techniques for ventilation, fire suppression, and search and rescue as a result of the changes in modern building construction and furnishing materials. As a result of these changes, today’s fires release energy faster, reach flashover potential sooner, may reach higher temperatures, and are much more likely to become ventilation-limited than building fires of even a few years ago.

[76] International photovoltaic science and engineering - Proceedings of the PVSEC 17 Conference, Fukuoka, Japan, Dec, 2007, 6O-C10-07. Toyota Technological Institute, 2007.

Various papers (in Japanese only) cover developments in PV technology and deployment in Japan (e.g. inverter technology). Other papers include: ‘Photovoltaic module reliability, failure mechanisms and service lifetime prediction,’ by Dhere and Hadagali.

[77] S. Islam, A. Woyte, R. Belmans, P.J.M. Heskes and P.M. Rooij. “Investigating performance, reliability and safety parameters of photovoltaic module inverter: Test results and compliances with the standards.” Renewable Energy, vol. 31, no. 8, July 2006, pp. 1157-1181.

Reliability, safety and quality requirements for a new type of photovoltaic module inverter have been identified and its performance has been evaluated for prototypes. The laboratory tests have to show whether the so-called second generation photovoltaic module inverter can comply with expectations and where improvements are still necessary. Afterwards, the test results have been compared with international standards. [Author abstract, edited]

[78] G. Jakubowski. Tackling solar power challenges - tactics for fighting fires in solar-powered structures. FireRescue, May 2014.

Available: http://www.firefighternation.com/article/firefighting-operations/tackling-solar-power-challenges [Nov. 4, 2015]

Summarises the lessons of the NFPA report - “Firefighter safety and emergency response for solar power systems”.

[79] J. Johnson, W. Bower and M. Quintana. "Electrical and thermal finite element modeling of arc faults in photovoltaic bypass diodes." In World Renewable Energy Forum, May 2012. Sandia National Laboratories.

Available: http://energy.sandia.gov/wp-content//gallery/uploads/WREF_2012_Diode_Arc-Fault_Modeling_SAND2012-2024C.pdf [Oct. 7, 2015]

Arc faults in photovoltaic (PV) modules have caused multiple rooftop fires. The arc generates a high-temperature plasma that ignites surrounding materials and subsequently spreads the fire to the building structure. While there are many possible locations in PV systems and PV modules where arcs could initiate, bypass diodes have been suspected of triggering arc faults in some modules. In order to understand the electrical and thermal phenomena associated with these events, a finite element model of a busbar and diode was created. Thermoelectrical simulations found Joule and internal diode heating from normal operation would not normally cause bypass diode or solder failures. However, if corrosion increased, the contact resistance in the solder connection between the busbar and the diode leads, enough voltage potential would be established to arc across micron-scale electrode gaps. Lastly, an analytical arc radiation model based on observed data was employed to predicted polymer ignition times. The model predicted polymer materials in the adjacent area of the diode and junction box ignite in less than 0.1 seconds. [Author abstract]

[80] J. Johnson. Overview of arc-faults and detection challenges. Sandia National Laboratories, technical presentation. 2011.

Available: http://energy.sandia.gov/wp-content/gallery/uploads/SolarABCs_Arc-Fault_Challenges_Johnson_SAND2011-0704P.pdf [Sep. 29, 2015]

Gives an overview of arcing behaviour and consequences in PV systems, explaining the challenges of reliable remote arc detection.

[81] J. Johnson. "Forum - arc-fault protection in PV installations - ensuring PV safety and bankability." In Proceedings of the Solar Conference - World Renewable Energy Forum; Denver, Colorado, May 2012, pp. 2144. Boulder, Colo.: American Solar Energy Society, 2012.

[82] J. Johnson, et al. "Photovoltaic DC arc fault detector testing at Sandia National Laboratories." Presented at the 37th IEEE Photovoltaic Specialists Conference (PVSC), 2011.

[83] J. Johnson, et al. "Differentiating series and parallel photovoltaic arc-faults". Presented at the 38th IEEE Photovoltaic Specialists Conference (PVSC), Austin, TX, 2012.

[84] Z. Kadlec, et al. "Determining of damages caused by fire on photovoltaic power stations." Advanced Materials Research, vol. 1001, pp. 282-287, 2014. Trans Tech Publications Ltd, 2014.

Available: http://www.scientific.net/AMR.1001.282 [Dec. 16, 2015]

An assessment of damage to the immediate environment caused by PV fires.

[85] M. Karter. "Patterns of firefighter fireground injuries." National Fire Protection Association (NFPA), 2013.

Available: http://www.nfpa.org/~/media/files/research/nfpa-reports/fire-service-statistics/ospatterns.pdf?la=en [Nov. 4, 2015]

Tabulation of the types of injury and their causes, using 2007-2011 annual average estimates.

[86] M. Karter and J. Molis. "U.S. Firefighter Injuries 2013", NFPA Fire Analysis and Research Division, 2014.

Available: http://www.nfpa.org/research/reports-and-statistics/the-fire-service/fatalities-and-injuries/firefighter-injuries-in-the-united-states [Nov. 4, 2015]

Statistics on line-of-duty firefighter injuries in 2013 from NFPA's survey of fire departments – including non-incident-related injuries, trends, and brief narratives on selected incidents.

[87] J.R. Kaufmann, et al. "Integrating renewable energy requirements into building energy codes." Richland, WA (US), Pacific Northwest National Laboratory (PNNL), 2011. Report no. PNNL-20442.

Available: http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20442.pdf [Nov. 4, 2015]

Reviews requirements to install renewable energy technologies in US states and other countries for energy efficiency, but also mentions technical requirements for safety, etc.

[88] Kent Fire and Rescue Service. Risk assessment: electrical installations. Fires involving photovoltaic and solar thermal installations. V1.0, 14/01/2013.

[89] Kent Fire and Rescue Service. Standard operating procedure - fires involving photovoltaic & solar thermal installations. 2013.

[90] H. Knopf, et al. "Evaluating the case for module-level shutdown - an increase in safety or the creation of perceived danger?" SMA Solar Technology, August 2015.

Available: http://www.sma-america.com/partners/knowledgebase/evaluating-the-case-for-module-level-shutdown.html#sthash.mXRFghow.dpuf [Nov. 4, 2015]

The proposed 2017 NEC may effectively require shutdown at the module level, which would have a dramatic impact on how systems are designed and installed. While this change was certainly developed with first responder safety in mind, many wonder if module-level shutdown really is safer. So far there have been no PV-related fatalities of first responders in the USA or in Germany. With more than 1.4 million PV plants installed in Germany, to date no firefighter there has been injured by PV power while putting out a fire. [From text]

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[91] V. Lattanzio. “Solar panels growing hazard for firefighters.” Video at NBC10.com

Available: http://www.nbcphiladelphia.com/news/local/Solar-Panels-Growing-Hazard-for-Firefighters-222085811.html Sept. 3, 2013. [Oct. 7, 2015]

PV modules created unique challenges for firefighters who battled a massive blaze at the Dietz and Watson distribution warehouse in Delanco, Burlington County, New Jersey.

[92] H. Laukamp, et al. “PV fire hazard – analysis and assessment of fire incidents.” In Proceedings of the 28th European Photovoltaic Solar Energy Conference and Exhibition, Paris, 2013, p.4304-4311.

Available: http://wiki-cleantech.com/solar-photovoltaics/pv-fire-hazard-analysis-and-assessment-of-fire-incidents [Dec. 16, 2015]

This paper addresses an investigation of heat damages and fires of PV systems. Information on damage cases was collected by an online-questionnaire, online research, literature research, by questioning technical experts and from an insurance company´s files. Some 180 cases of fire and heat damage were found, where PV systems caused fires affecting the PV system or its surroundings. A statistical analysis of these cases is given. Main reasons for fires were component failures and installation errors. Especially in larger systems improper handling of aluminium cables caused several fires. DC-switches were found to be critical and therefore laboratory testing was conducted. This testing of aged DC switches found increased resistance and potential thermal damage. Operating the switches several times reduced the resistance markedly. Inspection of older PV systems showed that bypass-diodes are reliable and pose a low risk for reverse currents into strings. Recommendations to further improve system safety are given. [Summary]

[93] H. Laukamp, et al. “PV systems - a fire hazard? - myths and facts from German experience.” In Proceedings of the European Photovoltaic Solar Energy Conference, Frankfurt, Germany, Sep. 2012, pp.3862-3867. Munich, WIP-Renewable Energies, 2012.

Available: https://www.ise.fraunhofer.de/de/veroeffentlichungen/konferenzbeitraege/konferenzbeitraege-2013/28th-eupvsec/laukamp.pdf [Dec. 16, 2015] [same paper as previous reference]

[94] T. McCuskey and B.P. Nelson. “Managing EHS of PV-related equipment at the National Renewable Energy Laboratory: preprint.” Presented at the 2012 IEEE Photovoltaic Specialists Conference, Austin, Texas, June 3-8, 2012. Conference paper 5200-54132 - National Renewable Energy Laboratory (U.S.).

Managing environment, health, and safety (EHS) risks at a national laboratory, or university, can be intimidating to a researcher who is focused on research results. Laboratory research and development (R&D) operations are often driven by scientists with limited engineering support and lack well-refined equipment development resources. To add to the burden for a researcher, there is a plethora of codes, standards, and regulations that govern the safe installation and operation of photovoltaic-related R&D equipment -- especially those involving hazardous production materials. To help guide the researcher through the vast list of requirements, the EHS office at NREL has taken a variety of steps. Organizationally, the office has developed hazard-specific laboratory-level procedures to govern particular activities. These procedures are a distillation of appropriate international codes, fire agencies, SEMI standards, U.S. Department of Energy orders, and other industry standards to those necessary and sufficient to govern the safe operation of a given activity. The EHS office works proactively with researchers after a concept for a new R&D capability is conceived to help guide the safe design,

acquisition, installation, and operation of the equipment. It starts with a safety assessment at the early stages such that requirements are implemented to determine the level of risk and degree of complexity presented by the activity so appropriate controls can be put in place to manage the risk. As the equipment requirements and design are refined, appropriate equipment standards are applied. [Summary]

[95] L. Mathe, et al. “Firefighter safety for PV systems: a solution for the protection of emergency responders from hazardous dc voltage.” Industry Applications Magazine, IEEE, vol. 21, no. 3, pp. 75-84, 2015.

Available: http://vbn.aau.dk/en/publications/firefighter-safety-for-pv-systems-a-solution-for-the-protection-of-emergency-responders-from-hazardous-dc-voltage(ecc0766e-eb14-487c-ad9e-46711600c5c2)/export.html [Dec. 16, 2015]

An important and highly discussed safety issue for photovoltaic (PV) systems is that as long as the PV panels are illuminated, a high voltage is present at the PV string terminals and cables between the string and inverters that is independent of the state of the inverter's dc disconnection switch. The presence of these energized conductors on the dc side of the PV system can pose a danger to anyone performing maintenance or firefighting. [Abstract]

[96] S. Matsushima, et al. “Electric shock with photovoltaic modules on the firefighting” [in Japanese]. Report of National Research Institute of Fire and Disaster, no. 116, 2014.

The research measured the electrical resistance of gloves, shoes and destruction implements for firefighters, to take into account the risk of electric shock when fighting a fire involving a PV system.

[97] B. Meacham, B. Poole, J. Echeverria and R. Cheng. “Fire safety challenges of green buildings”. In: Fire Safety Design and Sustainable Buildings: Challenges and Opportunities, Report of a National Symposium - Technical Report, November 2012, National Fire Protection Association, Fire Protection Research Foundation. Published separately by Springer, 2012.

Available: http://www.springer.com/us/book/9781461481416 [Dec. 16, 2015]

Fire safety objectives are not explicitly considered in most green rating schemes, and green design features have been associated with photovoltaic panels and roof materials, lightweight timber frame buildings, and combustible insulation materials. Fire Safety Challenges of Green Buildings is the result of an extensive global literature review that sought to identify issues related to green building elements or features and ways to ensure those issues are tracked for future improvement. The book identifies actual incidents of fires in green buildings or involving green building elements, points out issues with green building elements that would increase fire risk, clarifies reports and studies that address ways to reduce fire risk in green design elements, and compares research studies that explicitly incorporate fire safety into green building design. The authors also pinpoint gaps and specific research needs associated with understanding and addressing fire risk and hazards with green building design. Using their data, the authors developed a set of matrices relating these green attributes and potential fire hazards. With these comprehensive tools, potential mitigation strategies for addressing the relative increase in fire risk or hazard associated with the green building elements and features have been identified. [From author abstract]

[98] Merseyside Fire and Rescue Service. Service Instruction 0764 - Photovoltaic (solar) panels. 2012, amended 2013.

[99] Microgeneration Certification Scheme. Briefing: MCS 012 and the fire performance of pitched roof mounted solar systems. 2015.

Available: http://www.microgenerationcertification.org/images/MCS_012-Fire_Performance_of_Pitched_Roof_Mounted_Solar.pdf [Nov.4, 2015]

A new version of MCS 012 (Product Certification Scheme Requirements - Pitched Roof Installation Kits - Issue 2.0) has now been published and will become mandatory from 2nd May 2016. Building regulations relating to the external spread of flame are relevant when installing PV modules that replace part of the roof covering. This document explains the requirements for resistance to the spread of fire.

[100] Microgeneration Certification Scheme. Guide to the installation of photovoltaic systems. 2012.

Available: http://www.microgenerationcertification.org/images/PV%20Book%20ELECTRONIC.pdf [Sep. 29, 2015]. Hard copy distributed by the Electrical Contractors Association ('ECA'), London.

The main technical PV resource for MCS. The installation standard (MIS 3002) calls up this guide for technical content.

[101] Microgeneration Certification Scheme. PV Installations and Fire Safety Event, 1st May 2013, Fire Service College, London Road, Moreton-in-Marsh.

This was a meeting called by MCS, primarily to disseminate information to the fire services.

[102] A. Mohd. Reducing solar PV fire risks in rooftop installations. May 2015.

Available: http://www.researchgate.net/publication/277474832 [Dec. 16, 2015]

Paper from manufacturer explains how micro inverters improve fire safety and why other solar PV solutions potentially cause greater fire risk and deadly harm to firefighters.

[103] A. Molina-García, et al. "A decentralized wireless solution to monitor and diagnose PV solar module performance based on symmetrized-shifted Gompertz functions." Sensors, vol. 15 no. 8, pp. 18459-18479, 2015.

[104] [Removed: *outside of search timeframe]*

[105] K. Murata, et al. "New type of photovoltaic module integrated with roofing material (highly fire-resistant PV tile)". PVSEC 12 Conference, Jeju, Korea, 21–24 Oct. 2001. Published in Solar Energy Materials and Solar Cells, vol. 75, no.3-4, pp. 647-653, 2003.

Available: http://www.sciencedirect.com/science/article/pii/S0927024802001502 [Dec. 16, 2015]

A new type of photovoltaic (PV) module integrated with roofing material (a highly fire-resistant PV tile) has been developed. It offers many attractive features, such as a lower cost, simpler construction, better design, and greater fire resistance than previous modules, and it promises to help accelerate the use of PV modules in residential applications. [Author abstract]

[106] National Fire Protection Association. National Electrical Code (NEC) and Handbook. Quincy: NFPA, 2014.

This edition of the NEC includes new rules that make it safer for firefighters to access roofs with PV modules – the installation of a 'rapid shut-down' device is now required.

[107] T. Nordmann and L. Clavadetscher, et al. "Analysis of long-term performance of PV systems - different data resolution for different purposes." International Energy Agency Photovoltaic Power Systems Programme, IEA PVPS Task 13, Subtask 1 Report IEA-PVPS T13-05: 2014.

Available: http://iea-pvps.org/index.php?id=305&eID=dam_frontend_push&docID=2307 [Oct. 7, 2015]

This report collects and studies the data supplied from installed operating PV plants from different countries in order to understand better the efficiency and reliability of the current state of the art. [From summary]

[108] T. Ohuchi, N. Ishikawa, Y. Kozawa. "Improvement of the fire-proofing and fire-resistance properties of PV modules for building's exterior walls." In Proceedings of the IEEE photovoltaic specialists conference, Anchorage, AK, Sep. 2000, pp.1533-1538.

Research was conducted to investigate the fire-proofing and fire-resistance properties of a curtain-wall-type PV module for a building's exterior walls. Several types of fluoroplastics were found to have a potential for application as fire-proofing cell encapsulation materials that can replace EVA. By using a cone calorimeter, decreases in total heat evolved and delays in ignition time were seen as the limiting oxygen index of cell encapsulation materials increased in the order of EVA, and fluoroplastics-A and B. From the test results of fire resistance tests using actual PV modules, the flames were found to be weaker with fluoroplastics compared with the case of EVA. Those also corresponded with the result of a cone calorimeter. Fluoroplastics were found to be more advantageous as fire-proofing cell encapsulation materials. [Author abstract]

[109] P. Old. "PV system safety is a burning issue". Blog on Solar Power Portal, 25th April 2012.

Available: http://www.solarpowerportal.co.uk/guest_blog/pv_system_safety_is_a_burning_issue_5478 [Oct. 8, 2015]

A PV applications engineer at Seaward Solar, looks at the fire safety implications of rooftop solar PV systems and compliance testing to IEC 62446.

[110] Ontario Association of Fire Chiefs (OAFC) and the Canadian Solar Industries Association (CanSIA). Solar electricity safety handbook for firefighters. 2015.

Available: http://www.cansia.ca/sites/default/files/solar_electricity_safety_handbook_for_firefighters_-_march_25_2015.pdf [Nov. 16, 2015]

Training manual for firefighters: how to identify PV systems and their components, the risk of electric shock, normal personal protective equipment may not give protection against electric shocks, systems may still be hazardous after a fire has been extinguished.

[111] Orange County Fire Chiefs' Association (OCFA). Guideline for fire safety elements of solar photovoltaic systems. Orange, California, 2008.

Available: http://www.agcs.allianz.com/assets/.../TTVol8-FireHazardsofPVSystems.pdf [Oct. 7, 2015]

The installation of solar photovoltaic (PV) systems presents additional areas of concern for firefighter safety (energized equipment, trip hazards, etc.) and firefighting operations (restricting venting locations, limiting walking surfaces on roof structures, etc.). This guideline establishes the minimum standard for the layout design, marking, and installation of solar photovoltaic systems and is intended to mitigate the fire safety issues. [Summary]

[112] Oregon Solar Energy Industries Association. Solar construction safety. 2006.

Available: http://www.coshnetwork.org/sites/default/files/OSEIA_Solar_Safety_12-06.pdf [Sep. 29, 2015]

This introduction to solar construction safety provides information to help develop safe work practices for typical solar construction projects, including both solar hot water and solar PV installations. [From introduction]

[113] M. Paiss. "PV safety and firefighting", Home Power Magazine, no.131, June / July 2009.

Available: http://www.homepower.com/articles/solar-electricity/equipment-products/pv-safety-and-firefighting [Oct. 6, 2015].

An industry journal provides guidance for tackling PV fires.

[114] H. Passey. "Panel debate, (May 2014)." Fire Risk Management, May 2014, pp.22-26.

Available: http://www.frmjournal.com/frm-issues/frm-issues_listing.frm-may-2014.html [Dec. 16, 2015]

Modern technology has resulted in PV modules becoming affordable and easy to obtain, but the author explains how this could lead to an increase in fire and electrical hazards.

[115] S. Pester. "DC isolators for photovoltaic systems". BRE Report FB 68. Bracknell, IHS BRE Press, 2014.

Available: http://www.bre.co.uk/nsc/page.jsp?id=3435 [Dec. 16, 2015]

PV power systems are now commonplace. In most cases the PV systems are safe and reliable, but incorrectly specified or installed isolators can cause fires, damage the reputation of the solar power industry, or worse, cause loss of life. This guide provides the key points to take into account when specifying DC isolators, including standards and certifications required. It describes the purpose, functions and features of isolators on PV systems and some of the available products, highlights some of the real issues occurring in the field (with a rogues' gallery of examples), reviews the relevant standards and guidance that are currently available, and summarises the key recommendations. [Author abstract]

[116] S. Pester. "Installer requirements". Presented at Photovoltaics and Fire: Separating Fact from Fiction, 12th July 2011, BRE, Watford

Available: http://www.bre.co.uk/nsc/page.jsp?id=3435 [Dec. 16, 2015]

A short summary of some MCS requirements having a bearing on fire prevention for PV installers.

[117] S. Pester and F. Crick. Performance of photovoltaic systems on non-domestic buildings. BRE Report FB 60. Bracknell, IHS BRE Press, 2013.

This report provides information on the design and operational factors affecting the performance of photovoltaic (PV) systems on non-domestic buildings. It uses monitoring data from real buildings and recent research. It focuses on commercial systems but also draws on experience in the domestic sector. It reviews the background to PV systems, performance measurement, their use in buildings, including building integration methods, performance design choices and operational issues affecting performance as well as system costs and carbon savings. [Author abstract]

[118] S. Pester. "PV & fire – is it safe?" Presented at the BIPV Conference 2012, Third Building-Integrated Photovoltaics Conference, London.

Available: http://www.bre.co.uk/filelibrary/nsc/Documents%20Library/Presentations/Steve-Pester_PV--Fire-Safety_2012.pdf [Sep. 29, 2015]

A brief assessment for a non-technical audience of the fire risks associated with PV installations. A summary of relevant standards and some statistics for perspective.

[119] "Photovoltaic array fire test (Germany)". Fire Retardants Online, July 2011. Proceedings of Photovoltaics and Fire: Separating Fact from Fiction, 12th July 2011, BRE, Watford.

Available: http://www.flameretardants-online.com/web/en/news/newsarchiv.htm?showid=290 [Dec. 16, 2015]

(Various presentations from this conference are available on NSC website www.bre.co.uk/nsc).

A PV array was set on fire to discover what happens when the flames impinge on the PV modules. During the test, electric tension, power, peak output power, temperature, irradiation intensity and insulation resistance were monitored. The modules were designed to national and international standards for preventing electrical shock in case of contact; as long as they are not damaged by the fire, they are safe. Results show that, when complying with the fire brigade guidelines for minimum firefighting distances, no unusual hazards arise from PV arrays in case of fire. [From text]

[120] A. Ramirez. "In the line of fire." RICS Building Control Journal, Feb/March 2015, pp. 16-17.

Available: http://www.rics.org/uk/news/journals/building-control-journal/building-control-journal-february-march-20141 [Dec. 16, 2015]

A review of fire safety research and development within the solar energy sector, specifically regarding the safety of PV Modules in the USA.

[121] M.G. Real and H. Häberlin. “Improved safety of PV against fire using a novel arc detector.” In the Proceedings of the 13th European Photovoltaic Solar Energy Conference, Nice, Oct. 1995, pp. 1858-1859. Published by H.S. Stephens & Associates, 1995.

Describes an arc detector invented by Alpha Real.

[122] F. Reil, et al. “Determination of arcing risks in PV modules with derivation of risk minimization measures,” in Proc. 39th IEEE Photovoltaic Specialists Conference, PVSC 2013, Tampa, Florida, USA, 16.06.2013-21.06.2013. Piscataway, NJ: IEEE, 2013.

On the basis of recent research which was carried out within a 3 year R&D project, around 75 cases were found where a PV system caused a fire through arc faults or hot spots. Out of these known incidents, 65 cases caused major damage, whereas 10 faults led to total loss of the system and building. These numbers display that fire incidents caused by e.g. arc faults are a minority, but every case reveals that latent risks exist when defective installation or products are applied. This work will focus on individual test series and according evaluation at different contacts, contact materials with the surrounding materials in a PV module. The purpose is to enable a mutual understanding between the possibility of an arc occurrence, the fire propagation through materials and the extinction. [Author abstract, edited]

[123] F. Reil, et al. “Determination of fire safety risks at PV systems and development of risk minimization measures.” In the Proceedings of the 26th European Photovoltaic Solar Energy Conference, Hamburg, Germany, Sep. 2011, pp.553-3555. Published by WIP-Renewables, 2011.

Available: http://www.pv-brandsicherheit.de/fileadmin/downloads_fe/4AV.2.23_Final.pdf [Oct. 7, 2015]

Since different discussions and research work in the recent past have contributed significantly to the entire aspect of fire risk and safety issues in photovoltaic systems, new challenges for the PV industry have evolved from these findings. With respect to other projects and joint working groups, a German 3-year research project, co-funded by the Federal Environment Ministry, started early 2011 to examine a wide range of fire-related issues on photovoltaic products in order to support standardization groups, firefighters, building authorities and component as well as module manufacturers regarding fire risks at PV systems. A broad view of the individual working packages, approaches and main goals will be given as very promising first results. [Author abstract]

[124] G. Richards and Kyung-Jin Boo. “International standardisation in the field of renewable energy.” Bonn: International Renewable Energy Agency (IRENA), 2013.

Available:
https://irena.org/DocumentDownloads/Publications/International_Standardisation_%20in_the_Field_of_Renewable_Energy.pdf [Oct. 7, 2015]

Review of international standards and harmonisation. The objective of the report is to improve understanding of the status of standards, test procedures and good practices for renewable energy equipment and operational practices, and to assess the needs and gaps for standardisation of renewable energy technologies.

[125] E. Romich and K. McGuire. “On-farm solar electric system safety.” Community Development Fact Sheet. Ohio State University, 2015.

Available: http://ohioline.osu.edu/fe-fact/pdf/CDFS_4105_15.pdf [Sep. 29, 2015]

This publication briefly covers safety considerations for solar systems and urges the owners of these systems to liaise with their local fire department and develop a site-specific emergency plan.

[126] San Francisco Department of Building Inspection. “San Francisco solar photovoltaic permitting guide.” 2010.

Available: http://sfenvironment.org/sites/default/files/fliers/files/sfe_re_sf_solar_pv_permitting_guide.pdf [Nov. 11, 2015]

All solar PV systems in San Francisco require an electrical permit from the Department of Building Inspection. There must be a 3 ft. setback from all roof edges that face the street for firefighter access. If the roof is over 5,000 sq. ft. and the system covers more than 80% of the roof, then the plans must be reviewed by the Fire Department. [From text]

[127] San Francisco Fire Department. “Solar photovoltaic permitting procedures and installation guidelines.” 2010.

Available: http://sf-fire.org/sites/default/files/FileCenter/Documents/1562-AB%205.11%20Solar%20-%20Proposed.pdf [Nov. 11, 2015]

Guidance requires access pathways, clear space for cutting holes in roofs, appropriate markings and a main system disconnect. DC wiring inside buildings should be run in metallic conduits and preferably along the bottom of load-bearing members.

[128] San Francisco Fire Department. Solar photovoltaic (PV) system safety and fire ground procedures. San Francisco, 2012.

Available: http://ufsw.org/pdfs/photovoltaic_systems.pdf [Nov. 11, 2015].

Training manual for firefighters.

[129] J. Sargent. “Shut it down”. NFPA Journal, Jan-Feb 2015, NFPA 70

Available: http://www.nfpa.org/newsandpublications/nfpa-journal/2015/january-february-2015/in-compliance/nfpa-70, Dec. 29, 2014. [Nov. 4, 2015]

Discusses methods of implementing the ‘rapid shut-down’ control for PV systems required by the NEC 2014 in the USA.

[130] J. Schonau and M. Nass. “Safety requirements on photovoltaic-modules.” In Proceedings of the Internationales wissenschaftliches colloquium - Information technology and electrical engineering - devices and systems, materials and technologies for the future. Technische Universitat, Ilmenau, Germany, 7-10 Sep. 2009, pp.291-292. Ilmenau; ISLE, Betriebsstatte des ISLE e. V., 2009.

Available: http://www.db-thueringen.de/servlets/DerivateServlet/Derivate-19450/54_IWK_2009_6_1_11.pdf [Oct. 7, 2015]

The consideration of requirements from all relevant directives given by the European Community is a necessary condition for the selling or operating of electrical equipment in the European Single Market. The manufacturer or seller documents compliance with the normative specifications by use of the CE mark. This paper describes the electrical safety requirements for photovoltaic modules and comments on the evaluation of these properties by means of laboratory measurements on the basis of current standards. [Author abstract, edited]

[131] F.R. Shapiro. "Fire at a PV installation." In Proc. 40th Photovoltaic Specialist Conference (PVSC), Denver CO, 8-13 June, 2014, pp. 2757-2758. IEEE, 2014.

A large food storage facility with a 1.6MW rooftop PV array was destroyed by a fire that began on the roof. During the early part of the fire the inverters were collecting data from the rooftop array, and two of the three inverters were still outputting AC power. Interesting features in the collected data correspond to the progress of the fire. The experience suggests measures that would have been valuable to firefighters once the fire started. [Author abstract]

[132] L. Sherwood, et al. Fire classification rating testing of stand-off mounted photovoltaic modules and systems. Solar America Board for Codes and Standards, 2013.

Available: http://www.solarabcs.org/about/publications/reports/flammability-testing/pdfs/SolarABCs-36-2013-1.pdf [Sep. 29, 2015]

The year 2013 marks a significant change for the fire classification rating approach for roof mounted stand-off photovoltaic (PV) modules and panels evaluated in accordance with American National Standards Institute/Underwriters Laboratories, Inc. (ANSI/UL) 1703, Standard for Safety for Flat-Plate Photovoltaic Modules and Panels. Prior to 2013, a PV module manufacturer could receive a fire classification rating based on tests of the module or panel alone. After the 2013 changes to ANSI/UL 1703, the fire classification rating approach takes into account the module or panel in combination with the mounting system and the roof covering products over which it is installed. The proposals that led to these changes were an outgrowth of research tests conducted and broad stakeholder forums held through a partnership between UL and the Solar America Board for Codes and Standards (Solar ABCs). These tests had shown that the fire class rating of the PV module alone may not predict the fire performance of the PV module, mounting system, and roof assembly as a system. [From summary]

[133] L. Sherwood. “PV and roof fire classification research project.” Presented at: Solar Power International 11, Dallas, Texas, Oct. 17-20, 2011.

The Solar ABCs and UL have an ongoing research program for photovoltaics (PV) and buildings. This work, funded by the U.S. Department of Energy, has the goal of developing effective codes and

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standards that ensure safety for buildings with roof-mounted PV systems. Work continues related to basic fire research, development of new test standards, and outreach of practical information to PV manufacturers, installers, professionals in the building codes enforcement and firefighting communities. The multi-phase project addresses the impact of PV installations on the fire classification rating of roofs. Findings indicate that the fire classification rating of the PV module is not a good indicator of the impact a rack-mounted PV system may have on the fire classification rating of the roof. The research found examples where both Class A and Class C rated PV modules can cause the fire classification rating of the roof to degrade. At the same time, installation of Class A/Class C rated PV modules in other configurations do not cause the fire class rating of the roof to degrade. Concurrent with the research, changes have been made to the International Building Code (IBC) and the International Residential Code (IRC) 2012 editions that impact photovoltaic installations. These codes include requirements for building-integrated photovoltaic (BIPV) products and for rack-mounted photovoltaic products. These codes include requirements for fire classification, wind resistance, installation and materials. Until a new system PV fire classification test is finalized, the fire classification requirements may not be easily applied. As a result of the research and in consideration of current requirements of IBC Section 1509.7.2, the Solar ABCs/UL are working with the ANSI/UL 1703 Standards Technical Panel (STP) to develop a new system test methodology, in close association with PV industry, roofing industry, standards development, building and fire enforcement community and government laboratory experts. [Author abstract]

[134] M. Shipp, C. Holland, D. Crowder, S. Pester and J. Holden. “Fire safety and solar electric/photovoltaic systems.” International Fire Professional, Issue no. 6, pp.12-17, Oct. 2013.

Available: http://www.bre.co.uk/page.jsp?id=3211 [Sep. 29, 2015]

Martin Shipp and colleagues report on BRE Global's research into safety hazards presented by PV systems.

[135] M. Shipp. “A fire safety overview.” Presented at BRE Trust/BPVA Workshop: Photovoltaics and fire: separating fact from fiction, 12th July 2011, BRE, Watford.

Available: http://www.bre.co.uk/nsc [Research and Development, Dec. 16, 2015]

[136] M. Shipp and S. Manchester “The fire risks of renewable energy technologies”, presented at The Institution of Fire Engineers 2012 AGM and International Conference "New Technologies in the Fire World", Stratford on Avon, July 4-5th 2012.

[137] S. Silvestre, et al. “Analysis of current and voltage indicators in grid connected PV (photovoltaic) systems working in faulty and partial shading conditions.” Energy, vol. 86, pp.42–50, 15 June 2015.

Available: http://www.sciencedirect.com/science/article/pii/S0360544215004727 [Dec. 16, 2015]

To ensure the optimization of the energy generated by grid connected PV (photovoltaic) systems is necessary to plan a strategy of automatic fault detection. The analysis of current and voltage indicators have demonstrated effectiveness in the detection of permanent faults in the PV array in real time as short-circuits or open circuits present in the system. In this paper, the analysis of the evolution of these indicators is focused on the detection of temporary faults due to partial shade on the PV array or disconnection of the inverter in case of grid fluctuations of voltage or frequency to prevent islanding.

These situations can be identified by observation of the evolution of both indicators and power losses due to these effects can be evaluated from them. The analysis and experimental validation were carried out in two grid connected PV systems in Spain and Algeria. [Author abstract]

[138] S. Silvestre, et al. “Study of bypass diodes configuration on PV modules.” Applied Energy, vol. 86, no. 9, pp. 1632-1640, 2009.

A procedure of simulation and modelling solar cells and PV modules, working partially shadowed in a Pspice environment, is presented. Simulation results have been contrasted with real measured data from a commercial PV module of 209 Wp from Siliken. Some cases are presented as application examples of this simulation methodology, showing its potential for the design of bypass diodes configuration to include in a PV module and also for the study of PV generators working in partial shading conditions. [Author abstract, edited]

[139] S. Silvestre, et al. “New procedure for fault detection in grid connected PV systems based on the evaluation of current and voltage indicators.” Energy Conversion and Management, vol. 86, pp. 241–249, Oct. 2014.

In this work we present a new procedure for automatic fault detection in grid connected photovoltaic (PV) systems. This method is based on the evaluation of new current and voltage indicators. Thresholds for these indicators are defined taking into account the PV system configuration: number of PV modules included and series and parallel interconnection to form the array. The procedure to calculate the thresholds that allow the identification of the faults is described. A simulation study was carried out to verify the evaluation of current and voltage indicators and their corresponding thresholds for a set of PV systems with different sizes and different configurations of interconnection of PV modules. The developed method was experimentally validated and has demonstrated its effectiveness in the detection of main faults present in grid connected applications. The computational analysis has been reduced and the number of monitoring sensors minimized. The fault detection procedure can be integrated into the inverter without using simulation software or additional external hardware. [Author abstract]

[140] P. Sinha, R. Balas, L. Krueger. “Fate and transport evaluation of potential leaching and fire risks from CdTe PV.” Presented at the 37th IEEE Photovoltaic Specialists Conference, Seattle, WA, 2011.

Fate and transport analysis has been performed to evaluate potential exposures to cadmium (Cd) from cadmium telluride (CdTe) photovoltaics (PV) for non-routine circumstances (rainwater leaching from broken modules and emissions from fire). The analysis considers Cd transport from ground mount and roof mount systems via leaching, and from roof mount systems via fire and subsequent leaching. It is concluded that potential exposures to Cd from rainwater leaching of broken modules and emissions from a fire are highly unlikely to pose a potential health risk to residents, workers, consumers, or emergency responders. [Author abstract, abbreviated]

[141] P. Sinha, et al. “Regulatory policy governing cadmium-telluride photovoltaics: a case study contrasting life cycle management with the precautionary principle.”

Energy Policy, vol. 36, no. 1, pp. 381-387, January 2008.

Market projections for cadmium-telluride (CdTe) thin-film photovoltaics (PV) are tempered by global environmental policies based on the precautionary principle which restrict electronic products containing cadmium, a known human carcinogen. An alternative to the precautionary principle is life cycle management, which involves manufacturers assuming product stewardship from beginning to end of product life. Both approaches have the aim of minimizing environmental contamination, but attempt to do so in different ways. Restrictions on electronic products containing cadmium by the precautionary principle-based restriction of hazardous substances (RoHS) directive in the European Union and a similar policy in China are presented, relative to their potential impact on CdTe PV. Life cycle environmental risks with respect to potential release of cadmium to the environment are also presented for routine operation of CdTe PV panels, potential catastrophic release of cadmium from a residential fire, and at the end of the product life. There is negligible risk of environmental cadmium contamination during routine operation and insignificant risk during catastrophic exposure events such as fire. At the end of the product life, risks of contamination are minimized by take-back programs that may be paid for by insurance premiums incorporated into the cost of the product. Therefore, policies based on the precautionary principle that could potentially ban the product based on its cadmium content may not be warranted. [Author abstract]

[142] R. Slaughter. Fundamental of photovoltaics for the fire service. Corning, CA: Dragonfly

Communications Network, for the Office of the State Fire Marshal, California, 2006.

Available: http://osfm.fire.ca.gov/training/pdf/photovoltaics/pvstudentmanual.pdf [Sep. 29, 2015]

A training manual for the fire service.

[143] S. Smith. “PV panels: fire investigation and firefighting – Kent incident case studies.” Presented at the PV Installations and Fire Safety Event, the Fire Service College, Moreton-in-Marsh, May 1st 2013.

[144] S. Smith. “Solar panels fire risk.” International Fire Professional, Issue 4, April 2013.

[145] J. Smyth. “Safety considerations for static grid-tied photovoltaic inverters.” In Proc. Existing and future rules and safety guidelines for grid interconnection of photovoltaic systems; IEA - PVPS - Task V grid interconnection of photovoltaic systems; Zurich, Switzerland, Sep. 1997, pp.109-116. Published by Enecolo AG, 1997.

[146] Solaredge. “Technical Note – Bypass diode effects in shaded conditions” – 8/2010.

Available: http://www.solaredge.com/files/pdfs/se_technical_bypass_diode_effect_in_shading.pdf, Oct. 2010 [Sept. 28, 2015].

Many people believe that bypass diodes are effective in reducing power loss due to shading in PV installations. This is far from the truth. This paper analyses several everyday scenarios and shows how the bypass diodes can actually cause great power loss. [From introduction]

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[147] S. Spataru, et al. “Firefighter safety for PV systems: Overview of future requirements and protection systems.” In Energy Conversion Congress and Exposition (ECCE), 2013, pp. 4468-4475. Published by the IEEE.

This paper gives an overview of the most recent fire and firefighter safety requirements for PV systems, with a focus on system and module shutdown systems. Several solutions are presented, analysed and compared by considering a number of essential characteristics, including their transient behaviour, components' voltage stress and conduction losses. [Author abstract, edited]

[148] D. Starling, et al. “Testing a method for de-energizing solar panels for firefighting,” presented at Solar 2014.

Available: http://www.personal.psu.edu/faculty/k/e/ked2/Foam_finalVer_PSU_Hazleton.pdf [Nov. 4, 2015]

A procedure was developed to test the ability of a common foam agent (fluoro-protein foam) to de-energize a 2.8 kW solar array under sunny conditions. While the foam did create a dramatic reduction in power, it appears that the reduction was insufficient to eliminate the electrical hazard in the DC lines. Ongoing efforts include testing of the optical properties of the foam to determine whether possible improvements could be made, and testing of other foam agents and foaming strategies. [From author abstract]

[149] M. Tabaddor and R. Backstrom. “Fire performance of rack mounted PV modules on roofing assemblies”. Proc. 26th European Photovoltaic Solar Energy Conference, Hamburg, Germany, Sep. 2011, pp. 3757-3761. Published: Munich, WIP-Renewable Energies, 2011.

In current fire safety standards, the fire performance ratings of photovoltaic (PV) modules installed on roofs are based upon separate testing of the PV module and the roofing materials. This research was carried out to determine if this component level assessment would be representative of a PV module installed on a roof, specifically a rack mounted PV module. The tests in the fire safety standards (UL 790/1703) that were part of this research were the Spread of Flame test and the Burning Brand test. In addition to testing, results from the fire modelling of the Spread of Flame test are presented. The research strongly suggests that the presence of a rack mounted PV module on a roof could adversely affect the fire performance of the roofing system. The extent of the performance degradation depends upon the PV/roof installation parameters. [Author abstract]

[150] [Removed, not relevant]

[151] B. Teichmann, S. Krüger. “Systematical fire tests of PV modules – research on fire resistance, toxicology and burning behaviour.” In Proc. Interflam 2013, 13th International Conference and Exhibition on Fire Science and Engineering, Royal Holloway College, Windsor, 24-26 June 2013, vol. 1, pp. 105-114. Published: London, Interscience Communications, 2013.

[152] J. Tidwell and J.J. Murphy. Bridging the gap – fire safety and green buildings. National Association of State Fire Marshals, 2010.

Available: http://www.scfirechiefs.com/NASFM_greenfire_guide.pdf [Sep. 29, 2015]

This guide covers the aspects of renewable energy systems and sustainable building materials/elements that affect fire safety and fire suppression. It includes checklists that identify green building components and relate each component to potential concerns.

[153] R. Tommasini, et al. "Risk of electrocution during fire suppression activities involving photovoltaic systems." Fire Safety Journal, 67, pp. 35-41, 2014.

Available: http://www.sciencedirect.com/science/article/pii/S0379711214000630 [Dec. 16, 2015]

Firefighting activities regarding buildings normally require electric power to be disconnected before a water jet is used, in order to minimize the risk of electrocution. As far as concerns Photovoltaic Systems, during a fire event it is not possible to turn off the whole power system in order to guarantee that all the components are de-energized. The object of this paper is to estimate the safe distances to respect during firefighting involving PV Systems. To this end a series of experimental tests have been performed, in order to measure the current flowing through the water stream, under different conditions of nozzle design, jet shape, water pressure and stream length. Experimental results have been compared with data in literature. Moreover, the electrical conductivity of the water streams, which actually consists of water mixed with air, has been evaluated. [Author abstract]

[154] T. Tsukame. "Degradation gas at the time of combustion of a photovoltaic generation module constituent material" [in Japanese]. Report of National Research Institute of Fire and Disaster, no. 116, 2014.

Thermal degradation products from the component polymers of a PV module were identified by thermogravimetric analysis/infrared spectrometry (TG-IR).

[155] Tyne and Wear Fire and Rescue Service. Standard Operating Procedure. 05.01.01 Renewable energy photovoltaic cells. (undated)

[156] E. Wang, et al. "Failure modes evaluation of PV module via materials degradation approach."

Presented at the PV Asia Pacific Conference 2012 and published in Energy Procedia, vol. 33, pp. 256-264, 2013.

Available: http://www.sciencedirect.com/science/article/pii/S1876610213000763 [Dec. 16, 2015]

The primary objective of this study is to investigate and understand how polymeric materials in photovoltaic (PV) module as a function of long term aging effect on the durability, reliability and safety of PV modules. Si-based PV modules were made with EVA encapsulant and different types of backsheet and then subjected to accelerated weathering conditions in laboratory-controlled exposure chambers. The disassembly approach of the PV modules was developed to obtain the samples. All of the aged sample materials were directly obtained from the PV modules. Specific coupons of EVA/glass based on the similar module design were fabricated and applied with the same lamination process as in the manufacturing for the interfacial adhesion tests. The study covers the measurements on the samples including EVA, coupons and the modules made with different backsheets as a function of exposure time under accelerated conditions of damp heat (85 °C and 85% RH) or UV (~ 80 W/m2) chamber. The durability of materials degradation and properties was tested every 1000 hours up to 4000 hours including: (1) thermal characterisation by TGA, DSC, (2) inter layer adhesion by peeling strength, (3) chemical degradation by FTIR, (4) acetic acid content using Pyrolysis-GC/Mass, and (5) thermo-

mechanical tensile modulus by DMA. Non-intrusive measurements were also performed at every 250 hours on the modules such as I-V measurements, Fill Factor and Wet Insulation. The correlation between the materials degradation behaviour and the performance of the PV module, the impact of using different backsheets (TPT or TPE), and key failure mode(s) development related to the safety and performance of the PV module will be addressed from the study. [Author abstract]

[157] R. Wills, et al. Commercial roof-mounted photovoltaic system installation best practices review and all hazard assessment. Fire Protection Research Foundation, 2014.

Available: http://www.nfpa.org/research/fire-protection-research-foundation/projects-reports-and-proceedings/building-and-life-safety/fire-resistance/commercial-roof-mounted-photovoltaic-system-installation-best-practces-review [Sep. 29, 2015]

The purpose of this literature review is to compile information on a wide variety of hazards and damage potential created by the installation of photovoltaic (PV) systems on commercial roof structures. The hazards addressed are: structural loading; wind loads; hail; snow; debris accumulation; seismic; fire (panel flammability, impact on roof fire ratings); and electrical hazards affecting firefighting operations. [Introduction]

[158] R. Wills, et al. "Electrical hazards associated with fire fighting operations." In Best Practices for Commercial Roof-Mounted Photovoltaic System Installation, New York: Springer, 2015, pp. 47-56.

Due to the increase in popularity of PV systems, firefighters, fire ground incident commanders, and other emergency first responders are encountering PV systems more often in fire events. Though the electrical and fire hazards associated with electrical generation and distribution systems are well known, PV systems present unique safety considerations. [From text]

[159] R. Wills, et al. "Fire hazards." In Best Practices for Commercial Roof-Mounted Photovoltaic System Installation, New York: Springer, 2015, pp.37-46.

The fire resistance ratings of roofs may be altered when a PV system is introduced to the roofing assembly. The electrically charged components, including the modules and wiring, pose a fire hazard. If not handled properly, electrical charges can be discharged as sparks, which could initiate a fire. The high operating temperatures of the PV systems also could affect the fire growth rate in the event of a fire. [Author abstract]

[160] R. Wills, et al. "Hazard gap analysis." In Best Practices for Commercial Roof-Mounted Photovoltaic System Installation, New York: Springer, 2015, pp. 69-72.

Limited documentation on all incident data for snow, wind, hail, fire, etc. has inhibited quantifying the risk associated with PV systems. Proposing effective solutions to problems can only be provided with data or information about past events. Although some data is known for fire incidents, the information is incomplete. It would be useful to compile estimated property losses and loss of life for each incident involving PV systems as well as the cumulative estimated total property loss and loss of life for an entire year. [Author abstract]

[161] H. Wirth. “Recent facts about photovoltaics in Germany.” Fraunhofer Institute for Solar Energy, 2015.

Available: https://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/recent-facts-about-photovoltaics-in-germany.pdf [Nov. 5, 2015]

A brief review of the subject, including reassurance about the dangers of a fire.

[162] J.H. Wohlgemuth and S.R. Kurtz. “How can we make PV modules safer?” Presented at the 38th IEEE Photovoltaic Specialists Conference, Austin, Texas, June 3-8, 2012, pp. 003162-003165.

Safety is a prime concern for the photovoltaics (PV) industry. As a technology deployed on residential and commercial buildings, it is critical that PV not cause damage to the buildings nor harm the occupants. Many of the PV systems on buildings are of sufficiently high voltage (300 to 600 Volts dc) to present potential hazards. These PV systems must be safe in terms of mechanical damage (nothing falls on someone), shock hazard (no risk of electrical shock when touching an exposed circuit element), and fire (the modules neither cause nor promote a fire). The present safety standards (IEC 61730 and UL 1703) do a good job of providing for design rules and test requirements for mechanical, shock, and spread of flame dangers. However, neither standard addresses the issue of electrical arcing within a module that can cause a fire. PV modules must be designed, built, and installed with an emphasis on minimizing the potential for open circuits and ground faults. This paper provides recommendations on redundant connection designs, robust mounting methods, and changes to the safety standards to yield safer PV modules. [Author abstract, edited]

[163] K. Wong. “What risks do solar panels pose for firefighters?”

Available: http://solarenergy.net/News/tackling-risks-solar-panels-pose-firefighters/ February 25, 2014. [Sep. 29, 2015]

Discusses the dangers to firefighters and the need for a means to turn off panels remotely. A new solar panel sensor and fuse has been developed in Germany at the request of the Munich fire department. The TOPInno product can sense when the temperature reaches a certain threshold and break the connection; it can act as a manual off-switch as well.

[164] J-L. Wybo. “Large-scale photovoltaic systems in airports areas: safety concerns.” Renewable and Sustainable Energy Reviews, vol. 21, pp. 402-410, May 2013.

Available: http://www.sciencedirect.com/science/article/pii/S1364032113000336 [Dec. 16, 2015]

An increasing number of airport authorities are installing or planning to install large surfaces of PV panels producing 20 MW or more. This paper addresses the safety concerns related to the implementation of large-scale PV systems in airport locations, such as the risk of fire if an aircraft crashed into the installation. [Author abstract, edited]

[165] H-Y. Yang, et al. “Experimental studies on the flammability and fire hazards of photovoltaic modules.” Materials, vol. 8, no. 7, pp. 4210-4225, 2015.

Available: http://www.mdpi.com/1996-1944/8/7/4210/pdf [Sep. 29, 2015]

Many of the photovoltaic (PV) systems on buildings are of sufficiently high voltages to cause or promote fires. This paper focuses on the flammability and fire hazards of photovoltaic modules. Bench-scale experiments based on polycrystalline silicon PV modules have been conducted using a cone calorimeter. Several parameters including ignition time (tig), mass loss, heat release rate (HRR), carbon monoxide (CO) and carbon dioxide (CO2) concentration, were investigated. The fire behaviours, fire hazards and toxicity of gases released by PV modules are assessed based on experimental results. The results show that PV modules under tests are inflammable with a critical heat flux of 26 kW/m2. This work will help authorities determine the appropriate fire safety provisions for controlling photovoltaic fires. [Author abstract, edited]

[166] L. Yang. "Study on fire performance of the insulation photovoltaic building components." In Proceedings of the 2015 International Conference on Materials, Environmental and Biological Engineering, Guilin, China. Atlantis Press, 2015.

Available: http://www.atlantis-press.com/php/pub.php?publication=mebe-15&frame=http%3A//www.atlantis-press.com/php/paper-details.php%3Ffrom%3Dsession+results%26id%3D17897%26querystr%3Did%253D345 [Sep. 29, 2015]

Reports the results of fire tests for wall-installed PV modules that include insulation board, compared with those of insulation board alone, and also briefly discusses fire tests for PV modules on roofs.

[167] Y-G You, B Meacham, et al. “Quantification of green building features on firefighter safety: problem definition, data collection, preliminary analysis and experimental plan.” Presented at the SFPE 10th International Conference on Performance-Based Codes and Fire Safety Design Methods, Brisbane, Australia, 12-14 November 2014.

A three-year research effort is underway to try and quantify the impact of ‘green’ building features and elements (such as innovative building materials and renewable energy generation systems) on fire safety, with a particular focus on emergency responders, who need to access and undertake operations in these buildings during fires, with the aim to recommend mitigation measures and tactical changes to reduce the potential for firefighter injury and death. [Author abstract, abbreviated]

[168] Z. Zhang, J. Wohlgemuth and S. Kurtz. “The thermal reliability study of bypass diodes in photovoltaic modules.” Presented at the 2013 Photovoltaic Module Reliability Workshop, February 26-27, 2013, Golden, Colorado. Report no. NREL/PO-5200-58225.

Available: http://www.nrel.gov/docs/fy13osti/58225.pdf [Sep. 29, 2015]

Bypass diodes are a standard addition to PV (photovoltaic) modules. The bypass diodes’ function is to eliminate the reverse bias hot-spot phenomena which can damage PV cells and even cause fire if the light hitting the surface of the PV cells in a module is not uniform. The design and qualification of a reliable bypass diode device is of primary importance for the solar module. To study the detail of the thermal design and relative long-term reliability of the bypass diodes used to limit the detrimental effects of module hot-spot susceptibility, this paper presents the result of high temperature durability and thermal cycling testing and analysis for the selected diodes. [From introduction]

[169] T. Zgonena, L. Ji and D. Dini. "Photovoltaic DC arc-fault circuit protection and UL Subject 1699B." Presented at the Photovoltaic Module Reliability Workshop, Golden, CO, February 2011.

Available: http://www1.eere.energy.gov/solar/pdfs/pvmrw2011_p06_gen_ji.pdf [Oct. 7, 2015]

Presentation explaining arc faults and the NEC requirements for circuit protection. Arc Fault Circuit Interrupters are being developed as stand-alone components, but the functionality is also being built into inverters and other PV system components.

[170] Y. Zhao, et al. "Decision tree-based fault detection and classification in solar photovoltaic arrays." In Proc. 27th Annual Applied Power Electronics Conference and Exposition (APEC), Orlando, FL, February 2012, pp. 93-99.

Because of the non-linear output characteristics of PV arrays, a variety of faults may be difficult to detect by conventional protection devices. To detect and classify these unnoticed faults, a fault detection and classification method has been proposed based on decision trees (DT). Readily available measurements in existing PV systems, such as PV array voltage, current, operating temperature and irradiance, are used as "attributes" in the training and test set. In experimental results, the trained DT models have shown high accuracy of fault detection and fault classification on the test set. [Author abstract]

[171] IET, "Code of Practice for Grid Connected Solar PV Systems," IET Standards, London, 2015.

A 2015 code of practice for the PV installation supply chain, updated and improved over previous guidance. The first IET publication specific to PV systems, the document sets out the requirements for the design, specification, installation, commissioning, operation and maintenance of grid-connected solar PV systems installed in the UK.

The scope covers all parts of a grid-connected PV system up to, and including, the AC connection, going beyond existing guidance, covering all sizes of system (DC voltages 30V - 1,500V) and such topics as: low and high voltage connections, building & ground-mounted systems, grid-connected systems with battery storage and fire safety considerations.

[172] Microgeneration Certification Scheme, *MCS 012, Product Certification Scheme Requirements: Pitched Roof Installation Kits, Iss 2.0,* London: Microgeneration Certification Scheme, 2015.

MCS requirements for pitched roof PV mountings and modules, covering wind uplift, fire retardance and rain ingress.

[173] S. Smith, Prometheus Forensic Services (2015) "The Recognition of Fire Originating from Photovoltaic (PV) Solar Systems". Presented at the 2015 Chartered Society of Forensic Sciences Fire Investigation conference, Hilton Hotel, Leeds, 21 - 22 Sept 2015.

Conference information available: http://www.csofs.org/Events/Fire-Investigation-Conference/25734#sthash.qU3Su0Iv.dpuf [Dec. 16, 2015]

A basic introduction to solar technologies for firefighters, followed by an assessment of existing sources of data on fires related to PV.

[174] Luca Fiorentini et al. “Fires in Photovoltaic Systems: Lessons Learned from Fire Investigations in Italy.” Fire Protection Engineering, 2015, Emerging Trends, issue 99.

Available: http://magazine.sfpe.org/issue-99-fires-photovoltaic-systems-lessons-learned-fire-investigations-italy [Nov. 02, 2015]

This article assesses some of the fire risks associated with of PV system installations based on fire investigations conducted in Italy.

Over the past decade the number of new photovoltaic (PV) system installations has increased sharply throughout the world. With this growth, the associated risks have grown significantly, including an increase in the number of fire incidents involving PV systems. For example, it is estimated that in Italy alone over 700 fires involving PV systems occurred in 2012. This has drawn the attention of the fire safety community and facility managers. [Author abstract, edited].

[175] Microgeneration Certification Scheme, *Microgeneration Installation Standard: MIS 3002,* London: Department of Energy and Climate Change, 2013.

This is the overarching technical installation standard for PV installations from MCS. It calls up the MCS installation guide [100] for most of the technical requirements.

[176] M. Köntges, et al, "Review of Failures of Photovoltaic Modules." International Energy Agency Photovoltaic Power Systems Programme, IEA PVPS Task 13, Subtask 3.2 Report IEA-PVPS T13-01:2014.

In order to increase the reliability and the service life of PV modules the possible failure modes need to be understood. In this report, the IEA Task 13 expert team summarises the literature as well as their knowledge and personal experiences on actual failures of PV modules. Image-based methods and visual inspection methods are elucidated, followed by a thorough review of the failure modes in PV modules. Finally, the team proposes some new test methods for detection of PV module failures in the field.

[177] A. Caraglio. “Fire And Pv Installations”. 7th International Conference – Renexpo South-East Europe, Solar Energy in Romania, 17th June 2015.

A review of issues typically causing fires on PV systems, fire extinction tests in Italy and Germany and the presentation of an automatic disconnection device.

[178] H. Schmidt, F. Reil, Begrüßung zum 2. Workshop ”PV-Brandschutz“, Zweiter Brandschutz-Workshop, Freiburg, Germany, 24.01.2013

Available: http://www.pv-brandsicherheit.de/fileadmin/WS_24-01-13/01_Schmidt_Begr%C3%BC%C3%9Fung.pdf [Dec. 16, 2015]

Presentation of a statistical review of fire sources in 75 PV systems, an explanation of arc-fault detection and a review of fire service nozzle trials. (in German).

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[179] K.-M. Jakobi, W. Nasse, M. Paterna, F. Ansorge, C. Baar, K. Ring. “Faults of Contacts in PV Module Junction Boxes due to Fretting Corrosion”. 29th European Photovoltaic Solar Energy Conference and Exhibition. Session: 5DO.11.6, Paris, 2013.

Available: http://www.eupvsec-proceedings.com/proceedings?fulltext=Fire&paper=31421 [Dec. 16, 2015]

In 2012 an increased number of arcing faults in PV module junction boxes occurred at products manufactured by the company “Scheuten Solar Holding BV”. Beside damage to modules and yield losses, also consequential fire damages to buildings happened. The Netherlands consumer product safety authority issued a European safety alert notification (RAPEX) and claimed extended tests for repair solutions as the affected products were certified and tested according to actual standards, but still failed in practice. Additional testing procedures beyond actual standards were defined after intensive discussions in an experts group. Suncycle developed a repair method in cooperation with the Fraunhofer institute for reliability and microintegration (IZM). Extended climatic chamber tests were carried out on original junction boxes as well as on different repair solutions. Measurements and analytical methods could prove the existence of fretting corrosion at original plug connections. The experience with this failure mechanism caused discussions in standardisation committees and adaptations of applicable product certification standards can be expected. [Author abstract]

[180] A. Häring, J. Laschinski. “Firefighting at PV Plants - Different Solutions for Protection Against Electric Shock During Firefighting”. 26th European Photovoltaic Solar Energy Conference and Exhibition, Session: 5BV.2.13, Hamburg, 2011.

Because of its physical behaviour, PV systems can’t be completely switched off during daytime. In case of fire it is possible that several wires are damaged. So, there is a certain risk for an electric shock for firefighter while extinguishing a fire at a PV plant or a building with PV. In an increasing number of countries are discussions about the “firemen’s issue”. Often these discussions results in a call for so called firemen’s switches. But the real question is, what it is necessary to protect? Depending on the goals for protection, different solutions are possible. The switches are one solution, but there are some possibilities in the way of installing a plant in addition. Depending on the plant-orientated risk analysis the installer should choose a safe and cost-effective solution. [Author abstract]

[181] P. Cancelliere, et al. “Behavior of the Electrical Parameters of PV Modules Subject to a Flame Ignition.” 28th European Photovoltaic Solar Energy Conference and Exhibition, Session: 4AV.4.45, Paris, 2013.

Photovoltaic (PV) modules and any wiring connected to them will be live if they are exposed to light. Whenever sufficient voltage is developed by a number of PV modules in series, there is a risk of electric shocks. Higher direct current (DC) voltage may be used in PV systems because it can lead to reduced wiring size and higher inverter efficiency. Nowadays, PV systems are rated up to 1000V DC. Since damaged modules or installations may expose high voltage conductors or live parts, during the rescue operations of the rescue personnel or firefighter, the PV system mast be considered energized if exposed to solar or artificial light. By means of a proper experimental [set-up], the paper shows the behaviour of a burning string of 4 PV modules. During the experiments not only the fire rating characteristics are monitored (e.g. Fire reaction, Flame spread, Heat Release Rate, Temperature distribution) but also the electrical output quantities, such as the voltage and current PV output in order to assess the risk of an electric shock for the rescue personnel and the fire brigades. [Author abstract]

[182] C. Liciotti, P. Cancelliere, M. Cardinali, V. Puccia. “Analysis of the Combustion Fumes and Gases Released during the Burning of Some C-Si PV Modules”. 29th European Photovoltaic Solar Energy Conference and Exhibition, Amsterdam, 2014.

The number of fires involving PV systems has increased as a result of the strong growth of PV installations. The fire risk analysis due to PV systems has been taken into strong consideration. Three issue were considered key: 1) PV modules and components fire behavior and characterization; 2) fire ignition related to PV components; 3) risk of electrocution in firefighting activities in proximity to PV generators. To protect the firefighter and to respect the environment, consideration should be given to the type of fumes and gases that are released into the environment during a PV-related fire. This paper shows the analysis of the combustion fumes and gases released during the burning of some c-Si PV modules produced with different types of backsheets and encapsulants.

[183] L. Cerná, T. Finsterle, P. Hrzina, V. Benda. “A Simple Method of Evaluating Thermograms of Photovoltaic Modules”. 31st European Photovoltaic Solar Energy Conference and Exhibition, Session: 5AV.6.32, Hamburg, 2015.

A common problem to be solved during the operation of PV systems is early detection of faults in PV modules. Diagnostic methods were developed for this purpose which can be applied directly to the PV system without the need for disassembly. A very popular tool is the analysis of temperature distribution on the PV module - thermography, which is also useful for checking electrical connections for potential fire hazards. The problem is that there is virtually no quantification of obtained thermograms. This work provides guidance on how to reliably perform such quantification without the need of any other special devices.

[184] R. Mayfield. “Code corner: the International Fire Code and PV systems”. Home Power Magazine, no. 165, January/February 2015.

Available: http://www.homepower.com/articles/solar-electricity/design-installation/code-corner-international-fire-code-and-pv-systems [Dec. 16, 2015]

Discusses section 605.11 in the 2012 International Fire Code (IFC), which covers marking electrical assemblies containing DC conductors in both interior and exterior locations to help emergency personnel quickly identify (and shut down) energised sources, which could pose a shock hazard.

Appendix B Standards listings

Current standards

The listing below shows current PV standards that have some relevance to fire safety, mainly published by the IEC TC82 standards group

Key:

IEC 6xxxx = standard

IEC TS 6xxxx = Technical specification

Standard reference	Title	Date published
PV Module standards		
IEC 61215:2005	Crystalline silicon terrestrial photovoltaic (PV) modules - Design qualification and type approval	2005-04-27
IEC 61345:1998	UV test for photovoltaic (PV) modules	1998-02-26
IEC 61646:2008	Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval	2008-05-14
IEC 61701:2011	Salt mist corrosion testing of photovoltaic (PV) modules	2011-12-15
IEC 61730-1:2004+AMD1:2011+AMD2:2013 CSV	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	2013-03-14
IEC 61730-1:2004	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	2004-10-14
IEC 61730-1:2004/AMD1:2011	Amendment 1 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	2011-11-14
IEC 61730-1:2004/AMD2:2013	Amendment 2 - Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	2013-03-14
IEC 61730-2:2004+AMD1:2011 CSV	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	2012-11-23

IEC 61730-2:2004	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	2004-10-14
IEC 61730-2:2004/AMD1:2011	Amendment 1 - Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	2011-11-14
IEC 62108:2007	Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval	2007-12-07
IEC 62716:2013	Photovoltaic (PV) modules - Ammonia corrosion testing	2013-06-27
IEC 62716:2013/COR1:2014	Corrigendum 1 - Photovoltaic (PV) modules - Ammonia corrosion testing	2014-05-08
IEC 62759-1:2015	Photovoltaic (PV) modules - Transportation testing - Part 1: Transportation and shipping of module package units	2015-06-26
IEC 62790:2014	Junction boxes for photovoltaic modules - Safety requirements and tests	2014-11-06
IEC 62852:2014	Connectors for DC-application in photovoltaic systems - Safety requirements and tests	2014-11-06

Balance of System (BOS) standards		
IEC 62093:2005	Balance-of-system components for photovoltaic systems - Design qualification natural environments	2005-03-29
IEC 62109-1:2010	Safety of power converters for use in photovoltaic power systems - Part 1: General requirements	2010-04-28
IEC 62109-2:2011	Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters	2011-06-23
IEC 62116:2014	Utility-interconnected photovoltaic inverters - Test procedure of islanding prevention measures	2014-02-26
IEC 62817:2014	Photovoltaic systems - Design qualification of solar trackers	2014-08-25

IEC TS 62910:2015	Utility-interconnected photovoltaic inverters - Test procedure for low voltage ride-through measurements	2015-10-22

Installation standards		
BS 7671:2008+A3:2015	Requirements for Electrical Installations. IET Wiring Regulations	2015
BS EN 50438:2013	Requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks	2013
BS EN 60364-4-41 AMD1	Low voltage electrical installation. Part 4-41. Protection for safety. Protection against electric shock	2015
BS EN 60364-5-53 (13/30288754 DC)	Low-voltage electrical installations. Part 5-53. Selection and erection of electrical equipment. Switchgear and control gear	2013
BS EN 60364-7-712 (10/30231324 DC)	Low-voltage electrical installations. Part 7-712: Requirements for special installations or locations − Photovoltaic (PV) power systems	2010
BS EN 60364-9-1 (13/30289140 DC)	Low-voltage electrical installations. Part 9-1. Installation, design and safety requirements for photovoltaic systems (PV)	2013
Distributed Generation Connection Guide, Energy Networks Association	A Guide for connecting generation to the distribution network that falls under G59/3	2014
ENA Engineering Recommendation ER G83/2	Recommendations for the Connection of Small-scale Embedded Generators (Up to 16A per Phase) in Parallel with Low-Voltage Distribution Networks	2013
MCS Installer's Guide	Microgeneration Certification Scheme, Guide to the installation of photovoltaic systems, London: Electrical Contractors' Association, 2012. Commonly referred to as the 'MCS Installer's Guide'	2012
Microgeneration Installation Standard: MIS 3002	Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of solar photovoltaic (PV) microgeneration systems	2015
IET Code of Practice for Grid Connected Solar Photovoltaic Systems	Code of Practice for Grid Connected Solar Photovoltaic Systems	2015

IEC 61727:2004	Photovoltaic (PV) systems - Characteristics of the utility interface	2004-12-14
IEC PAS 62111:1999	Specifications for the use of renewable energies in rural decentralised electrification	1999-07-29
IEC 62124:2004	Photovoltaic (PV) stand alone systems - Design verification	2004-10-06
IEC 62253:2011	Photovoltaic pumping systems - Design qualification and performance measurements	2011-07-15
IEC 62446:2009	Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection	2009-05-13
IEC 62446-1:2015 PRV	Grid connected photovoltaic PV systems - Part 1: Requirements for system documentation, commissioning tests and inspection	2015-09-25
IEC TS 62548:2013	Photovoltaic (PV) arrays - Design requirements	2013-07-26
AS/NZ5033	Australian Standard AS/NZ5033 Installation of Photovoltaic (PV) Arrays	2014

Hybrid systems & rural electrification (IEC 62257 series)		
IEC TS 62257-1:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 1: General introduction to IEC 62257 series and rural electrification	2015-10-09
IEC TS 62257-2:2004	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 2: From requirements to a range of electrification systems	2004-05-27
IEC TS 62257-3:2004	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 3: Project development and management	2004-11-10
IEC TS 62257-4:2005	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 4: System selection and design	2005-07-25

IEC TS 62257-5:2005	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 5: Protection against electrical hazards	2005-07-13
IEC TS 62257-6:2005	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 6: Acceptance, operation, maintenance and replacement	2005-06-22
IEC TS 62257-7:2008	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 7: Generators	2008-04-09
IEC TS 62257-7-1:2010	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 7-1: Generators - Photovoltaic generators	2010-09-29
IEC TS 62257-7-3:2008	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 7-3: Generator set - Selection of generator sets for rural electrification systems	2008-04-09
IEC TS 62257-8-1:2007	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems - Specific case of automotive flooded lead-acid batteries available in developing countries	2007-06-21
IEC TS 62257-9-1:2008	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-1: Micropower systems	2008-09-09
IEC TS 62257-9-2:2006	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-2: Microgrids	2006-10-09
IEC TS 62257-9-3:2006	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-3: Integrated system - User interface	2006-10-09
IEC TS 62257-9-4:2006	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-4: Integrated system - User installation	2006-10-09
IEC TS 62257-9-5:2013	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-5: Integrated system - Selection of stand-alone lighting kits for rural electrification	2013-04-03

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IEC TS 62257-9-6:2008	Recommendations for small renewable energy and hybrid systems for rural electrification - Part 9-6: Integrated system - Selection of Photovoltaic Individual Electrification Systems (PV-IES)	2008-09-19
IEC TS 62257-12-1:2015	Recommendations for renewable energy and hybrid systems for rural electrification - Part 12-1: Selection of lamps and lighting appliances for off-grid electricity systems	2015-10-23

General wiring / installation standards		
IEC 60364 series	Low-voltage electrical installations	On-going
BS7671 (UK version of IEC 60364)	Wiring regulations	2015
IEC 60364-7-712	Low-voltage electrical installations - Part 712 Requirements for special installations or location – Solar photovoltaic (PV) systems. Part 712 is under review by a joint TC64 and TC82 working group. CENELEC version of 712 is also being written - this has some significant differences from the IEC version and to 60548	2002-05-22
IEC 60269-1	Low-voltage fuses – Part 1: General requirements	2006
IEC 60269-6	Low-voltage fuses – Part 6: Supplementary requirements for fuse-links for the protection of solar photovoltaic energy systems	2010

PV specific standards from outside IEC		
BS EN and EN standards		
BS EN 50618	Electric cables for photovoltaic systems	2015
BS EN 50521:2008+A1:2012	Connectors for photovoltaic systems. Safety requirements and tests	2012
prEN 50583-1:2014	Photovoltaics in buildings - Part 1: Modules	2014

prEN 50583-2:2014	Photovoltaics in buildings - Part 2: Systems	2014
UL standards		
UL 4703	Photovoltaic wire	2014
UL 1699	Arc-Fault Circuit-Interrupters (AFCIs)	2006
UL 1699B	DC AFCIs	2011
UL 1703	Standard for Flat-Plate Photovoltaic Modules and Panels	2015
UL 1741	Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resource	2010

ASTM standards		
ASTM E2908 - 12	Standard Guide for Fire Prevention for Photovoltaic Panels, Modules, and Systems	2012
E1038-15	Standard Test Method for Determining Resistance of Photovoltaic Modules to Hail by Impact with Propelled Ice Balls	2015
E1171-15	Standard Test Methods for Photovoltaic Modules in Cyclic Temperature and Humidity Environments	2015
E1462-12	Standard Test Methods for Insulation Integrity and Ground Path Continuity of Photovoltaic Modules	2012
E1597-10(2015)	Standard Test Method for Saltwater Pressure Immersion and Temperature Testing of Photovoltaic Modules for Marine Environments	2015
E1799-12	Standard Practice for Visual Inspections of Photovoltaic Modules	2012
E1802-12	Standard Test Methods for Wet Insulation Integrity Testing of Photovoltaic Modules	2012
E1830-15	Standard Test Methods for Determining Mechanical Integrity of Photovoltaic Modules (Also see WK22007 proposed revision below)	2015
E2047-10(2015)	Standard Test Method for Wet Insulation Integrity Testing of Photovoltaic Arrays	2015
E2481-12	Standard Test Method for Hot Spot Protection Testing of Photovoltaic Modules	2012
E2685-15	Standard Specification for Steel Blades Used with the Photovoltaic Module Surface Cut Test	2015

US - National electrical code		
Article 690	Solar Electric Systems	2011

Article 705	Interconnected Electrical Power Production Sources.	2011
DIN VDE		
VDE 0132:2008	*Firefighting and assistance in or near electrical installations*, gives safety distances for avoiding the risk of electrocution when being close to power carrying parts.	2008

Standards under development

Project Reference	Title	Estimated publication date
PV Module standards		
IEC 61215-1 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1: Requirements for testing	2016-04
IEC 61215-1-1 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules	2016-04
IEC 61215-1-2 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of cadmium telluride (CdTe) photovoltaic (PV) modules	2016-11
IEC 61215-1-3 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of amorphous silicon (a-Si) and microcrystalline silicon (micro c-Si) photovoltaic (PV) modules	2016-11
IEC 61215-1-4 Ed. 1.0	Terrestrial photovoltaic (PV) modules Design qualification and type approval - Part 1-4: Special requirements for testing of copper indium gallium selenide (CIGS) and copper indium selenide (CIS) photovoltaic (PV) modules	2016-11
IEC 61215-1-5 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-5: Special	2017-08

	requirements for testing of flexible (non-glass superstrate) photovoltaic (PV) modules	
IEC 61215-2 Ed. 1.0	Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures	2016-04
IEC 61730-1 Ed. 2.0	Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction	2016-05
IEC 61730-2 Ed. 2.0	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	2016-05
IEC 62925 Ed. 1.0	Thermal cycling test for CPV modules to differentiate increased thermal fatigue durability	2016-10
IEC 62938 Ed. 1.0	Non-uniform snow load testing for photovoltaic (PV) modules	2017-01
IEC 62979 Ed. 1.0	Photovoltaic module bypass diode thermal runaway test	2016-12
IEC 62108 Ed. 2.0	Concentrator photovoltaic (CPV) modules and assemblies - Design qualification and type approval	2016-06
IEC 62688 Ed. 1.0	Concentrator photovoltaic (CPV) module and assembly safety qualification	2016-10
IEC 62787 Ed. 1.0	Concentrator photovoltaic (CPV) solar cells and cell-on-carrier (COC) assemblies - Reliability qualification	2016-04
IEC/TS 60904-12 Ed. 1.0	Photovoltaic devices - Part 12: Infrared thermography of photovoltaic modules	2017-05
IEC/TS 60904-13 Ed. 1.0	Photovoltaic devices - Part 13: Electroluminescence of photovoltaic modules	2017-12
IEC 62980 Ed. 1.0	Photovoltaic modules for building curtain wall applications	2016-12
IEC/TS 62782 Ed. 1.0	Dynamic mechanical load testing for photovoltaic (PV) modules	2016-04
IEC/TS 62915 Ed. 1.0	Photovoltaic (PV) Modules - Retesting for type approval, design and safety qualification	2016-08

IEC/TS 62916 Ed. 1.0	Bypass diode electrostatic discharge susceptibility testing for photovoltaic modules	2016-06
IEC/TS 62941 Ed. 1.0	Guideline for increased confidence in PV module design qualification and type approval	2016-07
Module material standards		
IEC 62788-1-2 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-2: Encapsulants - Measurement of volume resistivity of photovoltaic encapsulation and backsheet materials	2016-04
IEC 62788-1-4 Ed. 1.0	Measurement procedures for materials used in Photovoltaic Modules - Part 1-4: Encapsulants - Measurement of optical transmittance and calculation of the solar-weighted photon transmittance, yellowness index, and UV cut-off frequency	2016-08
IEC 62788-1-5 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-5: Encapsulants - Measurement of change in linear dimensions of sheet encapsulation material resulting from applied thermal conditions	2016-08
IEC 62788-1-6 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 1-6: Encapsulants - Test methods for determining the degree of cure in Ethylene-Vinyl Acetate encapsulation for photovoltaic modules	2016-09
IEC 62788-2 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 2: Polymeric materials used for front sheets and back sheets	2016-04
IEC 62805-1 Ed. 1.0	Method for measuring photovoltaic (PV) glass - Part 1: Measurement of total haze and spectral distribution of haze	2016-10
IEC 62805-2 Ed. 1.0	Method for measuring photovoltaic (PV) glass - Part 2: Measurement of transmittance and reflectance	2016-10
IEC/TS 62788-7-2 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 7-2: Environmental exposures - Accelerated weathering tests of polymeric materials	2017-02

PNW 82-1034 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 5-2: Edge-Seal durability evaluation guideline (proposed future IEC 62788-5-2)	2017-08
PNW 82-933 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 5-1 Suggested test methods for use with edge seal materials (proposed future IEC 62788-5-1)	2017-06
PNW 82-934 Ed. 1.0	Measurement procedures for materials used in photovoltaic modules - Part 6-2: Moisture permeation testing with polymeric films (proposed future IEC 62788-6-2)	2017-06
BOS standards		
IEC 62093 Ed. 2.0	Balance-of-system components for photovoltaic systems - Design qualification natural environments	2016-12
IEC 63027 Ed. 1.0	DC arc detection and interruption in photovoltaic power systems	2017-06
IEC 62109-3 Ed. 1.0	Safety of power converters for use in photovoltaic power systems - Part 3: Particular requirements for electronic devices in combination with photovoltaic elements	2016-10
IEC 62817 am1 Ed. 1.0	Amendment 1 to IEC 62817 Ed.1: Photovoltaic systems - Design qualification of solar trackers	2016-12
IEC 62920 Ed. 1.0	EMC requirements and test methods for power conversion equipment applying to photovoltaic power generating systems	2016-04
Installation standards		
IEC 62446-1 Ed. 1.0	Grid connected photovoltaic (PV) systems - Part 1: Requirements for system documentation, commissioning tests and inspection	2016-01
IEC 62446-2 Ed. 1.0	Grid connected photovoltaic (PV) systems - Part 2: Maintenance of PV systems	2017-06
IEC 62548 Ed. 1.0	Photovoltaic (PV) arrays - Design requirements	2016-11

IEC/TS 62446-3 Ed. 1.0	Grid connected photovoltaic (PV) systems - Part 3: Outdoor infrared thermography of photovoltaic modules and plants	2016-12
IEC/TS 62738 Ed. 1.0	Design guidelines and recommendations for photovoltaic power plants	2016-04
PNW/TS 82-1035 Ed. 1.0	Terrestrial photovoltaic (PV) systems - Guideline for increased confidence in PV system installation	2017-05
Planned NWS	Preventing Fires and Building Losses Related to PV Systems Mounted on Roofs	TBA
Hybrid systems & rural electrification (IEC 62257 series)		
IEC/TS 62257-7 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 7: Generators	2016-04
IEC/TS 62257-7-1 Ed. 3.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 7-1: Generators - Photovoltaic generators	2016-04
IEC/TS 62257-7-3 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 7-3: Generator set - Selection of generators sets for rural electrification systems	2016-04
IEC/TS 62257-8-1 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 8-1: Selection of batteries and battery management systems for stand-alone electrification systems - Specific case of automotive flooded lead-acid batteries available in developing countries	2016-03
IEC/TS 62257-9-1 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-1: Micropower systems	2016-09
IEC/TS 62257-9-2 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-2: Microgrids	2016-09
IEC/TS 62257-9-3 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-3: Integrated system - User interface	2016-09

IEC/TS 62257-9-4 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-4: Integrated system - User installation	2016-09
IEC/TS 62257-9-5 Ed. 3.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-5: Integrated systems - Selection of stand-alone lighting kits for rural electrification	2016-03
IEC/TS 62257-9-6 Ed. 2.0	Recommendations for renewable energy and hybrid systems for rural electrification - Part 9-6: Integrated system - Selection of Photovoltaic Individual Electrification Systems (PV-IES)	2016-09

Appendix C Training course listings

Due to the variety of training providers and courses being offered, and the dynamic nature of this market sector, it is impossible to provide an exhaustive and definitive list. The table below shows those courses the team were able to identify in the time available.

A	**Formal (certified) courses**				
#	**Course**	**Objective**	**Duration**	**Certification**	**Example**
1	City & Guilds 2399 - Level 3 Award in the Installation of Small Scale Solar PV Systems	The course focuses upon the knowledge required to plan and prepare for, install (including testing and commissioning) and handover of grid connected solar photovoltaic systems that are within the scope of Engineering Recommendation G83/1 with an electrical output of up to 4 kWp connected to both single and three-phase installations. The unit also includes fundamental design awareness and component selection outcomes but does not include detailed design.	5 days	City & Guilds 2399 Level 3 Award in the Installation and Maintenance of Small Scale Solar Photovoltaic Systems	City & Guilds
2	Qualifications and Credit Framework (QCF) – Level 3 Award In the Installation and Maintenance of Small Scale Solar Photovoltaic Systems	On successful completion the candidate will achieve the following QCF units:	3 days	Level 3 Award In the Installation and Maintenance of Small Scale Solar Photovoltaic Systems	Ecoskies
		D/602/3086 Know the requirements to install, commission and handover small scale solar photovoltaic systems			
		K/602/3088 Install, commission and handover small scale solar photovoltaic systems			
		M/602/3089 Know the requirements to inspect, service and maintain small scale solar photovoltaic systems			
		M/602/3092 Inspect, service and maintain small scale solar photovoltaic systems			

3	Solar PV Qualification Renewal	For renewal of Solar PV Qualification, this course provides the following QCF units:	1 day	QCF Level 3 Award in the Installation of Small Scale Solar Photovoltaic Systems	Ecoskies
		D/602/3086 Know the requirements to install, commission and handover small scale solar photovoltaic systems			
		K/602/3088 Install, commission and handover small scale solar photovoltaic systems			
4	NICEIC - Solar Photovoltaic (PV)	The training and assessment have been designed to provide the necessary skills for the design, installation, testing, commissioning, handover, servicing and fault-finding of solar photovoltaic systems in accordance with the latest NOS/QCF criteria and MCS scheme requirements. - See more at: https://www.niceic.com/contractor/training-courses/renewables-courses/solar-photovoltaic-(pv)#sthash.7gVWqOvL.dpuf [Dec. 16, 2015]	4 days		NICEIC
5	NICEIC - Solar Photovoltaic (PV) Maintenance	This course is ideal for individuals looking to improve their knowledge and understanding of maintaining Solar Photovoltaic systems in accordance with the latest Regulations and requirements. - See more at: https://www.niceic.com/contractor/training-courses/renewables-courses/solar-photovoltaic-(pv)-maintenance#sthash.NVRwBqoh.dpuf [Dec. 16, 2015]	2 days		NICEIC

6	Domestic Electrical Solar PV Installer	This course is suitable for anyone (over the age of 18) who wants to become a Domestic Electrical Installer and a Solar PV Installer who has little or no electrical installation experience. This course is structured to build knowledge and skills up from basic to advanced enabling the delegate to undertake the BPEC solar PV course. Once the first 4 qualifications have been passed the delegate will have gained the necessary knowledge and qualifications to complete the BPEC Solar PV qualification. Week 1 Practical Skills in Domestic Installation - C&G 4141-01 Week 2 Installation Theory and Part P Building Regulations - C&G 2393-10 Week 3 - Inspection & Testing Skills - C&G 2392 Week 4 (3 Days) - Wiring and Building Regulations - C&G 2382-12 Week 5 - BPEC Solar Panel Installation Course	23 days	City & Guilds	Tradeskills4U
7	BPEC Solar PV Installers Course	This course is ideal for electricians and domestic installers looking to up skill and provide services to the growing renewable energy sector. This 5 day solar PV installation and maintenance course offers more hands on training of actual installation in a realistic setting than most other BPEC courses. The candidate will leave the course confident in his/her ability to design and install solar PV.	5 days	BPEC	Tradeskills4U

8	City & Guilds 2399 Solar PV Course	The course has recently been updated. It is ideal for experienced electricians looking to carry out both domestic and commercial solar PV projects. This qualification will give the candidate the technical and hands on experience to carry out real life installations. It will also provide the candidate with a qualification that can be used to gain MCS accreditation. This full course covers the 2399-13 and 2399-14 elements of the City & Guilds qualification.	8 days	City & Guilds	Tradeskill s4U
9	Level 3 Award in the Installation of Small Scale Solar Photovoltaic Systems (2399-13)	The course is the main qualification needed to achieve in order to become a qualified and MCS accredited Solar PV installer. Following this course the candidate can also qualify in maintenance of Solar PV equipment.	5 days	City & Guilds	Tradeskill s4U
10	Level 3 Award in the Installation and Maintenance of Small Scale Solar Photovoltaic Systems (2399-14)	This City & Guilds qualification can only be taken as an extension to the current City & Guilds 2399-13 Courses in installing solar PV equipment. This 3 day course will show the candidate how to maintain and service solar PV equipment allowing him/her to provide a valuable added service to their customers.	3 days	City & Guilds	Tradeskill s4U
11	BPEC G59 Course - Commercial PV Installation	This 1 day G59 training course is designed to give existing Solar PV installers the knowledge and ability to design and install commercial small sized systems.	1 day	BPEC	Tradeskill s4U

12	2 Day Solar PV Course for Roofers (inc H&S)	Once the course has been completed, the candidate will have knowledge of how to fit PV modules, at height, using specialist equipment, as well gaining a health and safety certificate which will allow him/her to work on a building site. It will count towards MCS certification, should the candidate decide to pursue it.	2 days	NICEIC	Tradeskills4U
13	NICEIC Health & Safety for Solar Installation	This 1 day NICEIC Health & Safety course covers Manual Handling, Working at Heights and COSHH. This course is ideal for anyone looking to work in the Solar PV industry.	1 day	NICEIC	Tradeskills4U

B	**PV specific courses - not certified**			
#	**Course**	**Objective**	**Duration**	**Example**
1	PV for Roofers Training Course	The objectives of this course is to cross-skill roofers so that they can identify and install different types of solar PV modules using a range of mounting systems. This course will cover the installation and roof penetration in accordance with MCS standards.	2 days	Ecoskies
2	Structural Roof Calculations for PV Training Course	To impart knowledge of roof structures and coverings. The course is designed to help the installer meet the requirements of the MCS regarding the condition and structural suitability of a domestic roof and what potential problems are associated with retrofitting PV array installations. This knowledge will give the candidate the confidence to carry out an assessment of the suitability of the roof to carry the additional loads and perform the necessary structural and wind load calculations in the majority of cases.	1 day	Ecoskies
3	G59 Large Scale PV Training Course	This course provides a practical guide to designing a larger scale PV system. It includes G59 paperwork and the application process	1 day	Ecoskies

4	IET, "Code of Practice for Grid Connected Solar PV Systems"	IET, "Code of Practice for Grid Connected Solar PV Systems," IET Standards, London, 2015. BRE NSC course based on the code of practice.	Various, depending on skill level of attendees	BRE National Solar Centre

C	**Other PV-related courses and potential courses**		
#	**Course**	**Objectives**	**Duration**
1	Manufacturer courses	There are a large number of manufacturers who run training courses on their products. These are typically inverter, DC connector and mounting system manufacturers.	Typically anything from 1 - 5 days
2	MCS Certification Body - internal training	Certification bodies (CBs) provide training for their inspectors. These are critical courses - as the CBs are responsible for quality assessing projects in the field.	Typically 1-2 days
3	MCS Certification Body training - by others	An example would be the MCS training that was delivered when MCS issued the 2013 PV guide.	Typically 1 day
4	Training the trainers	It is critical that trainers have the requisite knowledge to pass on to trainees. In an unregulated market, there is scope for incompetent trainers to trade.	Unknown
6	Installation company internal training	Most companies run varying levels of training for their installers and designers of systems.	Unknown

D	**PV courses for fire-fighters** The existence of these courses has, in some cases, been inferred by the existence of a training manual or standard operating procedure held or published by individual Fire & Rescue Services.	
#	**Course**	**Objectives**

1	Kent Fire and Rescue Service. Risk assessment: electrical installations. Fires involving photovoltaic and solar thermal installations. V1.0, 14/01/2013	Operational training for FRS
2	Kent Fire and Rescue Service. Standard operating procedure - fires involving photovoltaic & solar thermal installations. 2013.	Operational training for FRS
3	Merseyside Fire and Rescue Service. Service Instruction 0764 - Photovoltaic (solar) panels. 2012, amended 2013.	Operational training for FRS
4	Tyne and Wear Fire and Rescue Service. Standard Operating Procedure. 05.01.01 Renewable energy photovoltaic cells.	Operational training for FRS
5	Government Skills Australia. “Work safely with PV systems - GSA Mobile App.”	On-line (mobile) PV safety training for firefighters. Supports for the delivery and assessment of the nationally accredited units of competency
6	Microgeneration Certification Scheme. PV Installations and Fire Safety Event, 1st May 2013, Fire Service College, London Road, Moreton-in-Marsh.	To begin a dialogue with the FRS, clarify the real and perceived risks and decide on next steps for the industry.
7	Ontario Association of Fire Chiefs (OAFC) and the Canadian Solar Industries Association (CanSIA). Solar electricity safety handbook for firefighters. 2015. http://www.cansia.ca/sites/default/files/solar_electricity_safety_handbook_for_firefighters_-_march_25_2015.pdf [Dec. 16, 2015]	Operational training for FRS
8	Orange County Fire Chiefs’ Association (OCFA). Guideline for fire safety elements of solar photovoltaic systems. Orange, California, 2008. http://www.calbo.org/uploads/Orange%20County%20PV%20Guidelines%20(Jan%202010).pdf [Dec. 16, 2015]	Operational training for FRS
9	California Department of Forestry and Fire Protection (CAL FIRE). Fundamentals of Photovoltaics for the Fire Service (Awareness Training), http://osfm.fire.ca.gov/training/photovoltaics [Dec. 16, 2015]	Basic awareness training for FRS
10	California Department of Forestry and Fire Protection (CAL FIRE). Fire Operations for Photovoltaics Emergencies (Operational Training), http://osfm.fire.ca.gov/training/photovoltaics [Dec. 16, 2015]	Operational training for FRS

11	BRE, Watford, 2011. Photovoltaics and Fire: Separating fact from fiction http://www.bre.co.uk/eventdetails.jsp?id=4968 [Dec. 16, 2015]	Basic awareness training for FRS and industry
12	San Francisco Fire Department. Solar photovoltaic (PV) system safety and fire ground procedures. San Francisco, 2012. http://ufsw.org/pdfs/photovoltaic_systems.pdf [Dec. 16, 2015]	Operational training for FRS
13	M. Shipp and S. Manchester "The fire risks of renewable energy technologies", presented at The Institution of Fire Engineers 2012 AGM and International Conference "New Technologies in the Fire World", Stratford on Avon, July 4-5th 2012.	Basic awareness training for FRS
14	R. Slaughter. Fundamental of photovoltaics for the fire service. Corning, CA: Dragonfly Communications Network, for the Office of the State Fire Marshal, California, 2006. http://osfm.fire.ca.gov/training/pdf/photovoltaics/pvstudentmanual.pdf [Dec. 16, 2015]	Operational training for FRS
15	S. Smith, Prometheus. "PV panels: fire investigation and firefighting – Kent incident case studies." Presented at the PV Installations and Fire Safety Event, the Fire Service College, Moreton-in-Marsh, May 1st 2013	Awareness training for FRS
16	Underwriters Laboratories Inc. "Firefighter safety and photovoltaic systems", 2011, on-line course for firefighters: http://content.learnshare.com/courses/73/352901/player.html [Dec. 16, 2015]	Enhancing understanding of hazards to firefighters posed by the presence of photovoltaic systems during suppression, ventilation and overhaul.
17	"Fire departments' views on solar PV" http://www.civicsolar.com/resource/fire-departments-views-solar-pv [Dec. 16, 2015] Links to videos from the San Jose Fire Department, California	How emergency personnel approach solar projects – awareness training for FRS

Appendix D MCS Scheme Competency Criteria Matrix

The following table lists - for a solar PV "Nominated Technical Person" - the knowledge outcomes that must be demonstrated to the MCS Certification Body.

The 1st column contains Ofqual reference numbers, relating to Qualification Framework units (QCF). These are used because the same competency criteria underpin both the Experienced Workers route and Qualification route. Competence may be demonstrated via either of these routes.

Taken from: MCS Scheme Criteria Matrix, Issue 2.0, Last Updated : 21st November 2014

Solar PV specific competencies		**QCF level**	**Guided learning hours**	**Unit credit value**
D/602/3086	Know the requirements to install, commission and handover small scale solar photovoltaic systems	3	35	4
K/602/3088	Install, commission and handover small scale solar photovoltaic systems	3	15	2
M/602/3089	Know the requirements to inspect, service and maintain small scale solar photovoltaic systems	3	15	2
M/602/3092	Inspect, service and maintain small scale solar photovoltaic systems	3	15	2

Prerequisite competencies		**QCF level**	**Guided learning hours**	**Unit credit value**
R/602/2596	Applying Health and Safety legislation and working practices; Installing and Maintaining Electrotechnical Systems and Equipment	3	10	3
R/602/2503	ELECTROTECHNICAL OCCUPATIONAL COMPETENCE	3	6	4
H/602/2523	Understanding Health and Safety legislation, practices and procedures; Installing and maintaining electrotechnical systems and equipment	3	54	6
M/602/2525	Understanding environmental legislation, working practices and the principles of environmental technology systems	3	36	4

J/602/2532	Understanding the practices and procedures for overseeing and organising the work environment Electrical Installation	3	56	6
T/602/2560	Understanding the practices and procedures for the preparation and installation of wiring systems and electrotechnical equipment in buildings, structures and the environment	3	96	10
A/602/2561	Understanding the principles of planning and selection for the installation of electrotechnical equipment and systems in buildings, structures and the environment	3	76	8
J/602/2563	Understanding the principles, practices and legislation for the termination and connection of conductors, cables and cords in electrical systems	3	86	9
D/602/2567	Understanding principles, practices and legislation for the inspection, testing, commissioning and certification of electrotechnical systems and equipment in buildings, structures and the environment	3	78	8
R/602/2579	Understanding the principles, practices and legislation for diagnosing and correcting electrical faults in electrotechnical systems and equipment in buildings, structures and the environment	3	58	6
A/602/2589	Understanding the electrical principles associated with the design, building, installation and maintenance of electrical equipment and systems	3	106	12
R/602/2596	Applying Health and Safety legislation and working practices; Installing and Maintaining Electrotechnical Systems and Equipment	3	10	3
H/602/2599	Applying environmental legislation, working practices and the principles of environmental technology systems	3	10	3
K/602/2605	Overseeing and organising the work environment; Electrical Installation	3	10	3
R/602/2792	Planning, preparing and installing wiring systems and associated equipment in buildings, structures and the environment	3	12	6
H/602/2828	Terminating and connecting conductors, cables and flexible cords in electrical systems	3	8	4

K/602/2703	Inspecting, testing, commissioning and certifying electrotechnical systems and equipment in buildings, structures and the environment	3	12	6
M/602/2704	Diagnosing and correcting electrical faults in electrical systems and equipment in buildings, structures and the environment	3	12	6

Report Ends