IEA INTERNATIONAL ENERGY AGENCY

Photovoltaics and Firefighters' Operations:

Best Practices in Selected Countries

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

PVPS

Report IEA-PVPS T12-09:2017

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Best Practices in Selected Countries

IEA PVPS Task 12
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Executive Summary

Components of photovoltaic (PV) systems undergo rigorous safety and reliability testing protocols during manufacturing and fulfill the electrical safety requirements established by various codes and standards. These systems do not pose health, safety, or environmental risks under normal operating conditions if properly installed and maintained by trained personnel as required by electrical codes. However, with the ever-growing deployment of PV systems globally and the myriad of applications—from traditional rooftop and ground-mounted installations to more advanced building-integrated and façade systems—it is becoming increasingly important to develop practices and share knowledge on the safe management and risk mitigation of PV systems under non-routine circumstances. This focus includes conditions in which firefighters encounter a PV system that may have been installed improperly or has become damaged. This report aims to facilitate the exchange of knowledge on the best practices and standards of firefighters' operations in relation to selected countries with considerable deployment of PV systems.

Under non-routine circumstances, if a fire starts in the area of a PV system, firefighting operations may need to be adapted to account for the PV system's presence and related potential hazards. Such hazards for firefighters caused by a rooftop PV system include: electrical shock, slips and falls, electrical arcing roof collapse, and fire risks from the PV materials.

To protect firefighters and mitigate hazards, research and analyses are available to provide information on how to deal with PV components during and after firefighting. This information has been disseminated as guidelines to firefighters, PV system installers, operation and maintenance providers, and PV users in some regions of the world. This report overviews their content and approach and aims to highlight best practices.

At the same time, we also intend for this report to help people within the PV industry and other stakeholders to understand technical hazards from the viewpoint of firefighters and to promote further actions to avoid or minimize such hazards. Focus is given to rooftop PV systems, which represent the most likely scenario for firefighter interaction with PV systems.

In this report, we review guidelines related to firefighter safety from Japan, the United States, and Germany. Table ES-1 summarizes best practices to reduce potential hazards for firefighters as analyzed from guidelines.

Guidelines address the following approaches to mitigate hazards to firefighters:

1) Identify structures with PV systems installed.
2) Minimize potential hazards in firefighter operations (e.g., ensure sufficient working space and mitigate electrical shock hazards).

3) Prevent/contain fires originating from the PV system.

To implement the approaches above, the following methods have been developed. See Table ES1 for detailed methods (best practices):

1) Installation requirements that consider firefighter operations (PV installation)
2) Operational strategies for firefighters when PV is present (firefighter operations)
3) Implementing technologies to minimize potential hazards from PV systems (technology implementations).

The analysis in this report reveals the value in preparing guidelines in collaboration with those involved in developing the PV industry (technologists, installers, electricians, and inspectors) and firefighter organizations and disseminating the guidelines through the respective channels.

To improve safety, future additional hazard reduction and mitigation technologies need to be demonstrated to be effective and to perform as designed. Creating standards that demonstrate that the new hardware is reliable, fail-safe, and can function as designed over the life of the PV system is a challenge that requires ongoing testing. International cooperation between standards experts, firefighters, and technologists and other stakeholders will be crucial in successfully deploying these technologies.

Table ES–1. Summary of best practices to reduce potential hazards for firefighters

Approach	Purpose	Categories	Best practices
Identify structures with PV systems installed	Alert firefighters to the presence of PV systems	PV installation	- Mark (label) on distribution boxes or other standard location
Minimize potential hazards in firefighter operations	Ensure sufficient access and working space	PV installation	- Walkways with a certain width - Setbacks from roof boundaries
	Mitigate electrical shock hazard from PV systems	PV installation	- Label on DC cables - Map of DC cable layout affixed to distribution boards, etc. - DC cable laying outside installation / DC cable with grounded metallic conduit
		Firefighters' Operations	- PV system de-energizing procedure (outside the array boundary) - Maintain "approach boundary" of PV systems when energized - De-energize the array
		Technology implementations	- Rapid shutdown (firefighters' switch) outside the array boundary
	Mitigate electrical shock hazard from hose water streams	Firefighters' operations	- Maintain minimum distance with hose streams
	Minimize exposure to hazardous chemicals from PV modules that are on fire		- Personal protective equipment including Self-contained breathing apparatus
Prevent fires originating from the PV system	Interrupt DC fault to prevent sustained arcs and ground faults	Technology implementations	- Ground-fault circuit interrupter - Arc-fault circuit interrupter

Foreword

The IEA Photovoltaic Power Systems Programme (PVPS) is one of the collaborative research and development (R&D) agreements established within the International Energy Agency (IEA). Since 1993, participants in the programme have been conducting a variety of joint projects regarding applications of photovoltaic (PV) conversion of solar energy into electricity.

The mission of the PVPS is "…to enhance the international collaboration efforts which accelerate the development and deployment of photovoltaic solar energy as a significant and sustainable renewable energy option". The underlying assumption is that the market for PV systems is gradually expanding from the niche-markets of remote applications and consumer products to rapidly growing ones for building-integrated and centralised PV generation systems.

A PVPS Executive Committee is composed of one representative from each participating country; Stefan Nowak of Switzerland heads the overall programme. Operating Agents assume responsibility for managing individual research projects (Tasks). By the end of 2007, twelve Tasks were established within the programme.

Task 12 engages in fostering international collaboration in communicating and assessing the environmental, health, and safety (EH&S) aspects of PV technology over the life cycle of the PV systems. Task 12 also disseminates reliable and accurate information on the EH&S impacts of PV technology to policymakers, industry participants, and the public with the goal of improving consumer understanding and confidence, encouraging industry best practices, and helping policymakers to make informed decisions in the course of the energy transition. Furthermore, Task 12 brings its expertise in assessing methods and standards for evaluating the EH&S aspects of PV systems. The overall objectives of Task 12 are to:

- Quantify the environmental profile of PV electricity using a life-cycle approach to improve the sustainability of the supply chain and to compare it with the environmental profile of electricity produced with other energy technologies.
- Aim for a closed-loop supply chain by and help improve PV waste management through collection and recycling, including legislative developments as well as development of technical standards.
- Distinguish and address actual and perceived issues related to the EH&S aspects of PV technology that are important for market growth.

Further information on the activities and results of the Task can be found at www.iea-pvps.org.

1. Introduction

If properly installed and maintained by trained personnel as required by electrical codes, these systems do not pose health, safety, or environmental risks under normal operating conditions. However, with the ever-growing deployment of photovoltaic systems globally and the myriad of applications—from traditional rooftop and ground-mounted installations to more advanced building-integrated and façade systems—it is becoming increasingly important to develop practices and share knowledge on the safe management and risk mitigation of PV systems under non-routine circumstances. Under non-routine circumstances, if a fire starts in the area of a PV system, firefighting operations may need to be adapted to account for the PV system's presence and related potential hazards.

To protect firefighters and mitigate hazards, research and analyses are available to provide information about how to deal with PV components during and after firefighting. This information has been disseminated as guidelines to firefighters, PV system installers, operation and maintenance providers, and PV users in some regions of the world.

1.1. Objective

The purpose of this report is to inform firefighters, PV system installers, operation and maintenance providers, and PV users about current best practices regarding firefighters' operations and PV systems. Such a review could help jurisdictions that have not yet adopted PV-specific firefighters' safety guidelines. To that end, we have reviewed examples of firefighters' safety guidelines from Japan, the United States, and Germany. Although guidelines in other countries exist, these three countries have been chosen as representatives of the breadth of available guideline provisions.

1.2. Cases of fires involving PV systems

Although rare, there have been fire incidents involving PV systems in countries such as the U.S., Germany, and Japan. In cases where a PV system was not the source of the fire, the PV system may still have had an impact by limiting firefighter access in operations. In (relatively rare) cases where the PV system was the source of the fire, initiators of the fire typically include arc faults, undetected ground faults, and faults of the bypass diodes.

Table 1.1 provides examples of fires involving PV systems. PV may limit firefighting operations because of the heightened potential for falls, electrical shock, and collapse of roof structures. In the past, the lack of availability or operating procedures for firefighting in buildings with PV systems led to cases of uncertainty regarding how firefighters should approach fighting the fire, potentially leading to controlled burn-down scenarios occasionally reported in public media.

A 2013 survey analyzed fire incidents involving PV systems (including rooftop PV and ground-mounted PV) in Germany from 1995 to 2012[1], during which period the installed PV capacity had risen to more than 30 gigawatts. The survey found about 400 cases in which a PV system was present; in 180 of these cases, a PV component was determined to be the source of the fire. Figure 1.1 shows components where fire started in 180 fires, with inverters and power electronics, connectors and terminals, and junction boxes being are major causes of fire.

Table 1.1 Fire incidents involving a PV system referred to in related research reports and media release

Location	Structural conditions	Damage	Obstacles to operations
Bakersfield, CA, United States Apr. 2009[2]	Large retail store, 380 kW array on roof	Fire did not penetrate metal roof decking	- Two separate fires were started by a "blind spot" ground fault - Absence of DC disconnect switches at combiner boxes necessitated dispatch of an electrical worker to pull 56 fuses.
Delanco, NJ, United States Sep. 2013[3]	Warehouse,1.6 MW on roof	A 30,000 m^2 structure was destroyed	- Firefighters decided not to operate on the roof because of the perceived possibility of electrical shock
La Farge WI, United States May 2013[4]	Office,70 kW on roof	A wing of the 4,000-m^2 building was destroyed	- Substantial roof coverage by the PV modules on the roof prevented ventilation efforts and accelerated a partial roof collapse
Walldorf, Germany June 2014[5]	Warehouse, PV on roof	Damage of a few thousand euros	- Synthetic resin plate was used for mounting systems - Firefighters could operate; fire stopped before extending to the building
Norderney, Germany Aug. 2013[5]	Factory, PV on roof	Damage of a few million euros	- Fire extended for a while and roof structure collapsed with PV modules on it

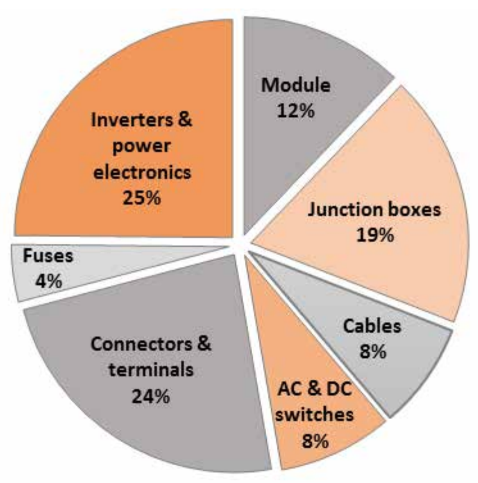


Figure 1.1 Components where fire started in 180 fires in Germany between 1995 and 2012[1]

1.3. Potential hazards in PV systems

Table 1.2 lists potential hazards for firefighters related to a PV fire. The presence of a PV system near a fire may produce hazards such as heightened potential for falls, electrical shock, and collapse of roof structures. Due to these perceived hazards, there have been cases where firefighters limited their operations and the fire was allowed to expand.

In addition to the direct fire hazard from faulty PV equipment, the presence of a PV system on a structure may complicate firefighter operations in several other ways (e.g., next paragraph)[6].

The additional weight of a PV system may lead to a more rapid collapse of a roof on a burning structure. On an inclined roof, the glass surface of a PV module presents a slip hazard that could lead to a fall. The roof area occupied by PV arrays limits the area where firefighters might walk and the area available for cutting ventilation holes (where ventilation techniques are indicated). While exposed to the sun, PV systems remain energized, even after a building's connection to the grid has been disabled. Should energized conductors become exposed due to improper installation or damage, a shock hazard may result. Figure 1.2 shows the potential for cardiac arrest triggered by contact with a potential of 230 V. In the body position shown, a body impedance of 1,150 Ω might allow the 200 mA shown to flow through the firefighter's heart to the ground.

Though a firefighter's personal protective equipment may provide some protection against shocks, even a "small" perceived shock may cause a "startle reaction" that contributes to a slip or fall. The direct current (DC) produced by PV systems is capable of producing a sustained arc that is more likely to trigger a fire than the alternating current (AC) that is obtained on the grid side of an inverter.

Table 1.2 Potential hazards for firefighters working near PV systems

Potential hazard	Description
Electrical shock	Electrical shock or burn injury by coming into contact with or spraying water on energized conductors (broken yet still energized modules or exposed wires).
Slips and falls	Space limitations reduce access and may cause slips or falls.
Collapse	PV adds to the "dead load" on a roof; the roof may collapse when support beams are weakened.
Arc or ground fault	Fire may be started by arcs, which may occur from exposed conductors in energized PV systems.
Combustion	As with other building materials, materials in the PV system may burn and release noxious gases.

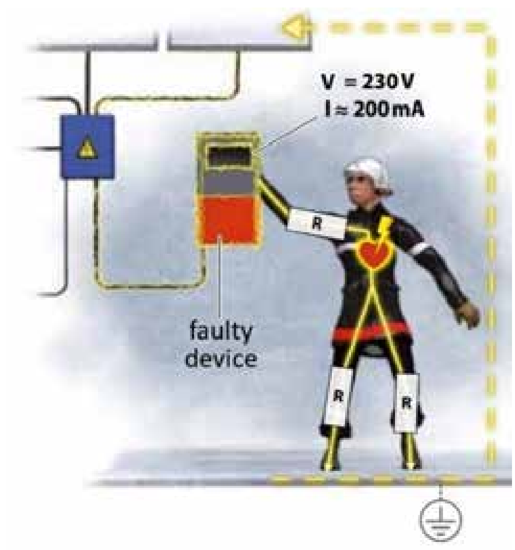


Figure 1.2. Illustration of the potential for cardiac arrest triggered by contact with a potential of 230 V[7]

1.4. Categories to mitigate hazards and components of this report

To mitigate potential technical hazards of PV systems in cases of fire, some countries have published guidelines. These guidelines for firefighters, as well as for PV installers, are relevant to the firefighter case. Also, technologies and products have been implemented to mitigate firefighter hazards.

Table 1.3 summarizes these approaches for PV fire safety. Guidelines for firefighters will be introduced in chapter 2, guidelines for installation in chapter 3, and implementation of technologies and products for fire safety in chapter 4.

Table 1.3 Categories to mitigate hazards for firefighters in PV fire

Category	User	Purpose
Guidelines for firefighters operation with PV systems present	Firefighters	- To inform on the hazards of fire in/near a PV system to firefighters - To inform on the operational procedure in a fire where PV is present
Guidelines for PV installation	PV system installers, operation and maintenance providers, and PV users	- To help ensure firefighters' safety through improved design, installation, and operation and maintenance of PV systems
Additional technologies and products for fire safety		- To help ensure firefighters' safety in their operations - To mitigate the possibility of a PV fire

2. Guidelines for firefighters

Guidelines for firefighters have been published in countries such as Japan, the United States, Germany, Australia, Austria, Canada, France, Italy, Spain, and the United Kingdom (Table 2.1). In countries where PV has become commonplace, increasing attention has been placed on mitigating firefighter hazards. As representative cases, we overviewed guidelines published in Japan, the United States, and Germany, which are leading countries in PV deployment. In the Appendix, a table of contents of each guideline is shown for reference.

Table 2.1 Guidelines for firefighters

Country	Title	Author	Publication Date
Japan	Technical information about firefighting operations in PV fire[8]	AIST (National Institute of Advanced Industrial Science and Technology)	Feb. 2014
United States	Fire Operations for Photovoltaic Emergencies[9]	CAL FIRE - Office of the State Fire Marshal	Nov. 2010
	Firefighter Safety and Emergency Response for Solar Power Systems[10]	The Fire Protection Research Foundation	May 2010
	Firefighter Safety and Photovoltaic Installation Research Project[11]	UL	Nov. 2011
Germany	Information about the use of photovoltaic systems for emergency responders, fire brigades and technical assistance services[12]	Deutscher Feuerwehr Verband	Oct. 2010
	Assessment of fire risk in photovoltaic systems and creation of security concepts to minimize the risk[5]	TÜV Rheinland Energie und Umwelt GmbH, Frauhhofer ISE	Mar. 2015
Australia	Safety Considerations for Photovoltaic Arrays[13]	Australasian Fire and Emergency Service Authorities Council	Apr. 2013
	Solar Electric Systems – Safety for Firefighters[14]	Ted Spooner (Chair of the Australian standards committee responsible for PV systems)	Sep. 2011
Austria	PV systems – Additional safety requirements[15]	The Austrian Electrotechnical Association	Mar. 2013
Canada	Solar Electricity Safety Handbook for Firefighters[16]	Ontario Association of Fire Chiefs	Mar. 2015
France	Controlling Risk Linked to Photovoltaic System Installations[7]	CEA, INES, Gimelec, ADEME	Jun. 2013
Italy	Fire Safety of Photovoltaic Systems[17]	Province of Trento	2011
Spain	Firefighter safety for PV plants[18]	Firefighters of Barcelona	Sep. 2013
United Kingdom	Photovoltaics and Fire: A guide from BPVA[19]	British PhotoVoltaic Association	2011

2.1. Japan

Technical information about firefighting operations around PV systems was developed under a research project on PV fire safety funded by the Ministry of Economy, Trade and Industry (METI) between 2012 and 2014[8]. These guidelines provide firefighters with technical information on PV systems and hazards in firefighters' operations in the case of a fire in a PV-equipped building. Included is general information about PV systems, potential hazards for firefighters, and suggested tactics on firefighter operations in houses that have solar PV systems.

In the guidelines, potential hazards for firefighters in a PV fire are shown in Table 2.2. There are hazards of an electrical shock from coming into contact with broken modules, wires, and firefighting water, falling down, combustion gas, collapse, and fire outbreak.

Table 2.2 Potential hazards for firefighters in a PV fire referred to in the Japanese guidelines for firefighters[8]

Hazards	PV systems features	Overview
Electric shock and burn	PV systems generate electricity whenever sunlight hits the panels	Electric shock and burn due to contact with broken modules, wires, and possibly conducted by water
Slips and falls	Panels on slanted rooftops are slippery	Firefighters' falling accidents due to operations on roofs (or "startle reaction" from minor electric shock)
Combustion gas	PV module materials may burn under the high heat from a structure fires	Combustion gas generation as in the case of common building fires
Collapse	Building is under the additional load of PV modules	Collapse, if building structure is weakened due to fires
Fire outbreak	Arcing may occur if insulation is insufficient	Fire propagation and burns due to arcing

Table 2.3 summarizes operations to reduce potential hazards when firefighters operate where PV systems are present. For electric shocks, it is important to be aware that a PV system is energized during daytime operation. Employing a fine spray of water (rather than a continuous stream) where energized conductors may be exposed is important in reducing the potential shock hazard to the hose operator. When cleaning up at a fire scene, attention must be paid to avoid potential electric shocks from damaged PV modules and any other exposed conductors.

2.2. United States

In the United States, California Department of Forestry and Fire Protection (CAL FIRE) published "Fire Operations for Photovoltaic Emergency" in November 2010 as a training manual for firefighters[9]. These guidelines include fire operations and tactics for firefighters working around PV systems. Comments for operations are described for each firefighter operation type as Table 2.4.

Table 2.4 Recommended operation in a PV fire referred to in the U.S. CAL FIRE guidelines for firefighters[9]

Operation	Comments
Roof Operation	- Determine if the PV system components themselves are on fire, or if the PV components are impinged by fire. - Protect from potential hazardous chemicals coming from PV modules on fire with the use of self-contained breathing apparatus (SCBA).
Interior Operation	- Water has to be directed on or near a PV system in a 30-degree fog pattern at 100 psi (~0.69 MPa) to prevent any electric current from traveling upstream toward firefighters - Firefighters must be at least 33 feet (~10 m) away from the energized source. - Firefighters must wear personal protective equipment (PPE) and SCBA when dealing with an emergency involving potential toxic gas and explosion hazards that PV system battery banks may have.
Search Operation	- The location of the PV-system-related components must be immediately relayed to the Incident Commander and all personnel working at the scene, and disconnect switches must be turned to "OFF."
Overhaul	- Whenever possible, an overhaul of the fire ground should be delayed until there is competent confirmation that the PV system has been "de-energized."

The Fire Protection Research Foundation, a research organization of the National Fire Protection Association (NFPA) released "Firefighter Safety and Emergency Response for Solar Power System" for firefighters and fire commanders in May 2010[10].

Approaches to ensure firefighters' PV safety, fireground tactics, code development, and education and training are shown in Table 2.5. An example of fireground tactics is to identify the type and extent of a solar system. Code development is indicated to provide new capabilities for electrical system isolation and to create consistent placarding and labeling for the use of emergency responders such as firefighters.

Table 2.5 Approaches for firefighter safety referred to in the U.S. Fire Protection Research Foundation report[10]

Operation	Contents
Fireground tactics	Components are always assumed to be "hot": consider that PV systems and all their components are electrically energized.
	Operate normally, but do not deliberately touch PV hardware. Fire service personnel should follow their normal tactics and strategies at structure fires involving PV systems, but do so with awareness and understanding of possible exposure to energized electrical equipment.
	Size up, identify, and validate any hazards. Identifying the type and extent of a PV system when sizing up the emergency event is critical to properly addressing the hazards they present.
	Leave the scene in a non-hazardous condition. Emergency response personnel address and mitigate hazards, and hand the area back to the owners and/or occupants after the scene is stabilized.
Code development	Provide ability for electrical system isolation for emergency responders. A key task handled by emergency response personnel at a building fire is the isolation or shutdown of the building's electrical power.
	Create consistent placarding and labeling. Standardized approaches to provide consistent identification of solar power systems and their components will assist emergency responders in safely completing their tasks.
	Ongoing operation and maintenance concerns for solar power systems must be addressed.
	Require system contact information for emergencies. Establish points of contact for emergency responders.
Education and training	PV systems are energized electrical equipment like other equipment, but with an inability to power down when illuminated.

2.3. Germany

In October 2010, Deutscher Feuerwehr Verband, the German Firefighters Association, released guidelines which refer to information for firefighter operations in PV buildings[12]. In these guidelines, hazards for firefighters in fire operations and comments are shown in Table 2.6.

Table 2.6 Potential hazards for firefighters referred to in the German Firefighters Association guidelines[12]

Hazard	Description
Toxic gas	- Flammable toxic gases may be released from fire where PV is present. - Wear protective masks regardless of ventilation conditions in building. - Turn off ventilation systems.
Collapse or falling objects	- Rooftop PV systems may fall inward after the roof under the systems is damaged. - Steer around dangerous areas due to falling objects and mark off the hazardous areas. - Pay attention to increased roof load when entering the building and during firefighting.
Electricity	- Electric hazard exists at contact voltages of >50 V_{AC} or > 120 V_{DC}. - Follow DIN VDE 0132[20] for firefighting. - Follow GUV- I 8677[21] "On-site electrical hazards" for firefighting near electric systems. - Be sure to keep at least 1 m away from components that may be live(energized). - Follow DIN VDE 0132 and note the rules about applying fire extinguisher agents to live components. - Handling of defective switches and isolation of PV modules may be done only by electricians. - Pay attention to the hazards of firefighting water pouring onto electric systems.
Fire propagation	- Arcing and resistive heating may cause fires. Protect the areas against arcing, and let electricians shut down the system. - Rooftop systems and façade structures can have a chimney effect, increasing the flame propagation hazard depending on the conditions. - Monitor possible flame propagation using devices such as infrared cameras.

As main activities to improve firefighters' safety, the German guidelines explain the importance of recognizing PV systems, installation methods of DC wires to lower electric shock risks for firefighters, and a specific firefighting operation flow for fires involving PV systems.

In Germany, PV system operators have to install layout diagrams showing the building premises, conductors, and other PV system components to provide information for firefighters. These diagrams have to be affixed to the connection points of the electric system such as the junction boxes and distribution boards (Figure 2.1).

Because DC conductors in a sunlit PV array remain energized after main circuits have been turned off, DC wiring requirements are prescribed more strictly. For example, DC wiring has to be within a fire control area if installed inside the building, protected by flame-retardant materials, and labeled as fire-resistant wiring. These provisions are defined in VDE-AR-E2100-712[22] (May 2013). The guidelines provide a flowchart for fire response in the presence of PV systems (Figure 2.2).

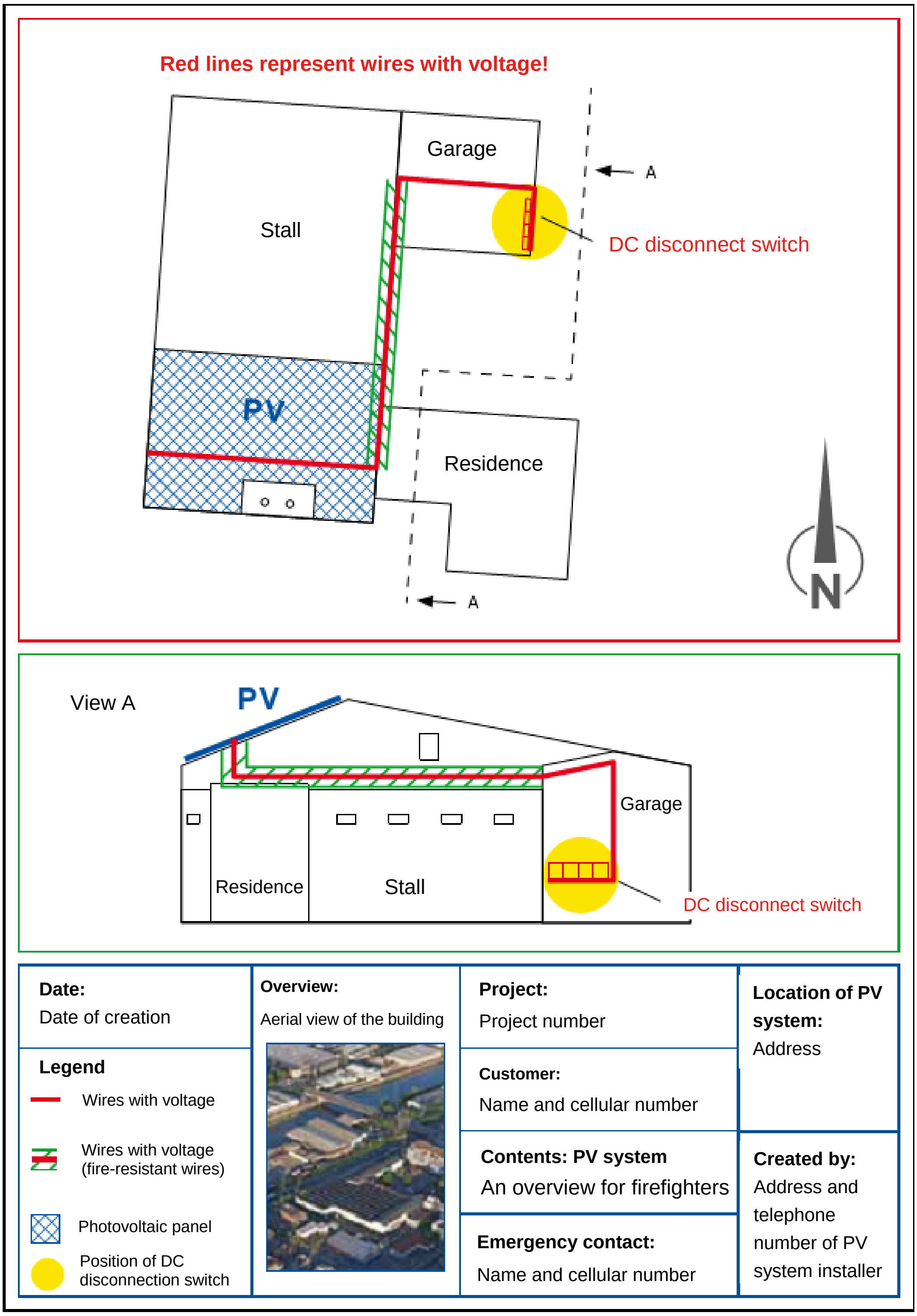


Figure 2.1 Maps for DC wire in PV system referred to in the German Firefighters Association guidelines[12(translated)]

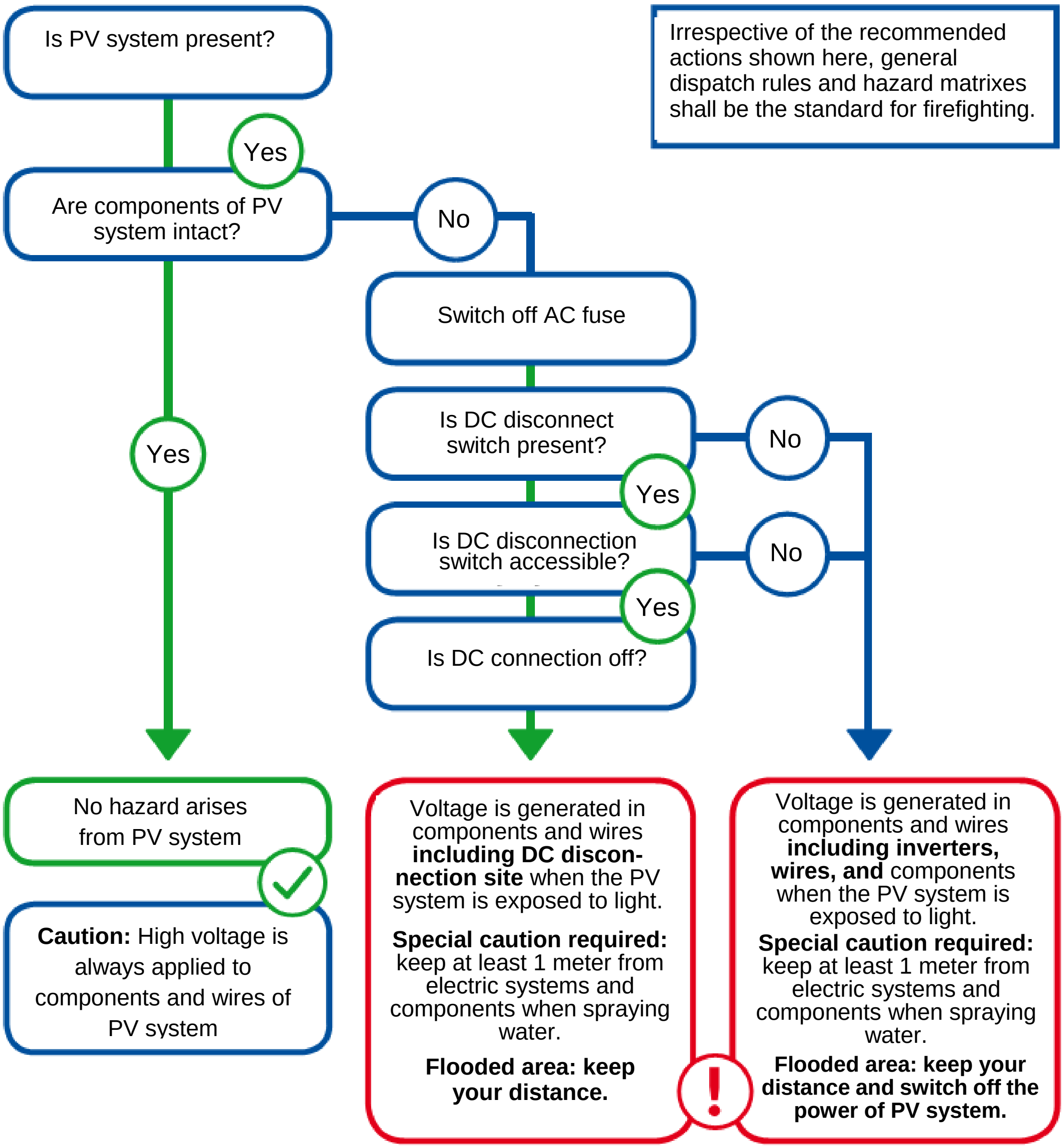


Figure 2.2 Firefighters operation flow on PV fire referred to in the German Firefighters Association guidelines[12(translated)]

3. Guidelines for installation with respect to firefighters' operations

PV installation guidelines have been published in countries such as Japan, the United States, Germany, France, Italy, Spain, Switzerland, and the United Kingdom (Table 3.1).

In some countries, guidelines have become codes with which installers must comply. As representative cases, we have reviewed guidelines below from Japan, the United States, and Germany. In the Appendix, a table of contents of each guideline is shown for reference.

Table 3.1 Guidelines for installation

Country	Title	Author	Date
Japan	Guidelines and technical information on electrical safety of photovoltaic systems[23]	AIST	Mar. 2015
	Directive standards for fire safety measurement regarding PV systems[24]	Tokyo Fire Department	July 2014
United States	Solar Photovoltaic Installation Guidelines[25]	CAL FIRE - Office of the State Fire Marshal	Apr. 2008
Germany	Fire-protection-oriented planning, construction, and maintenance of photovoltaic systems[26]	BSW, BFSB, DGS, ZVEH, etc.	Feb. 2011
France	Guide UTE C 15-712-1,Guide UTE C 15- 712-2[27]	UTE	2013
Italy	Guidelines for PV plant Installation, 2012 Edition[28]	Dipartimento dei vigili del fuoco, Dipartimento del soccorso pubblico della difesa civile	Feb. 2012
Spain	Preventive measures for installers to install solar photovoltaic and thermo panels[29]	CEPYME, Aragón	Dec. 2013
	Prevention and action against fire in buildings with photovoltaic systems[30]	MAPFRE	2014
Switzerland	Fire Safety Data Sheet — solar systems[31]	VKF AEAI	Aug. 2012
	Technology paper for VKF fire safety leaflet — Solar systems[32]	SWISSOLAR	Sep. 2012
United Kingdom	Guide to the installation of PV systems 2^{nd} Edition[33]	BRE, EA Technology, Halcrow Group SunDog Energy	2006
	Photovoltaics in Buildings — Safety and the CDM regulations[34]	The Building Services Research and Information Association, DTI	Feb. 2000
	Guide to the Installation of Photovoltaic Systems[35]	Electrical Contractors Association	2012

3.1. Japan

The "Guidelines and technical information on electrical safety of photovoltaic systems" were developed between 2012 and 2014 under a research project on PV fire safety by METI[23].

To improve the electrical safety of PV systems, guidance is given for system design, selection of system components, and an outline of operation and maintenance procedures on a site.

The Tokyo Fire Department released "Directive standards for fire safety measurement regarding PV systems" to ensure the safety of firefighters in July 2014[24]. The scope includes buildings requiring fire prevention such as commercial buildings and public buildings in Tokyo. It went into force on October 1, 2014. This standard is referenced by the Japan Photovoltaic Energy Association and disseminated to the PV industry in Japan. The standards include installation restrictions of PV systems on a roof, and specific labeling for PV signage to enable firefighters to recognize the presence of a PV system.

This directive states the setbacks necessary for a PV module on the roof, to make space for the passage of firefighters in large-scale PV installations (over 300 m^2), and limits the distance between any passage and the center of a PV array to within 24 m, so that water being directed from the passageway can reach the fire (Figure 3.1). PV installation locations, including the DC wiring conduits, are restricted to being no more than 50 cm outside boundaries around the building areas used by firefighters. These areas include outdoor stairs, rescue entrances, and alternative openings (Figure 3.2). The standard also includes some easing of regulations, such as "Permission of installation of PV module in area limited by existing fire laws". To mitigate the hazard of an electrical shock to firefighters, the directive standards require markings (signage) for the PV system, junction box, power conditioner, and DC wiring (Figure 3.3).

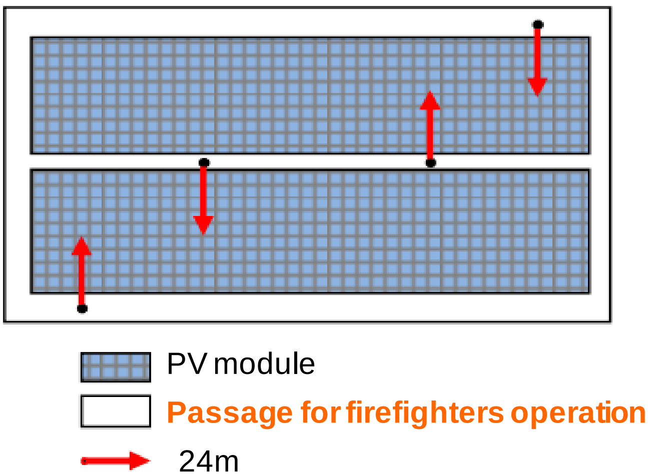


Figure 3.1 Setback rule of PV module referred to in Tokyo Fire Department directive standards[24(translated)]

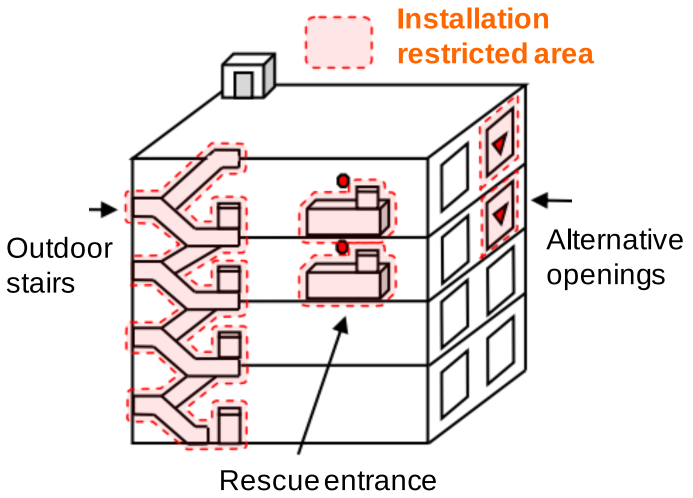


Figure 3.2 Installation restriction of PV module referred to in Tokyo Fire Department directive standards[24(translated)]

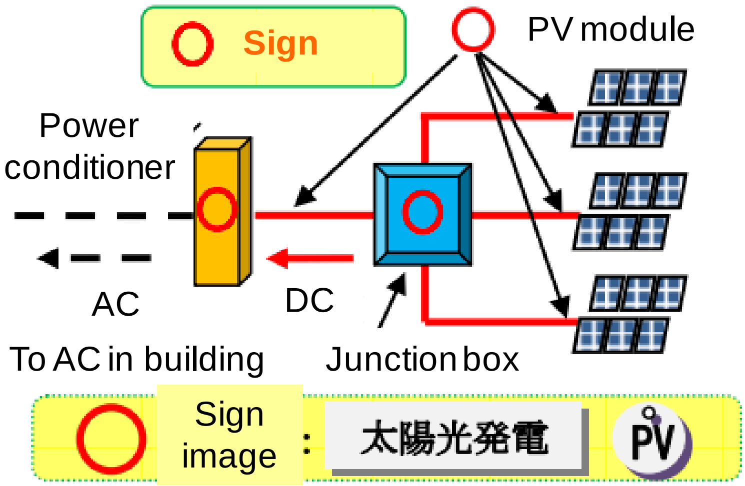


Figure 3.3 Signage rule on a PV system referred to in Tokyo Fire Department directive standards[24(Translated)]

3.2. United States

In the United States, the California Department of Forestry and Fire Protection published "Solar Photovoltaic Installation Guide" in April 2008 as guidelines for PV installers[25]. These guidelines were developed in collaboration with CAL FIRE and representatives of the PV industry, considering hazards for firefighters operating near PV systems and providing hazard mitigation measures. The guidelines show markings for PV systems, access pathways for firefighters, and locations of DC conductors relevant for firefighters.

The International Fire Code[36], in which the rules for installers to reduce hazards to firefighters are stated, has also been updated based on these guidelines. Rules include methods for recognition of PV systems and setback of PV installation. To help firefighters recognize PV systems, markings for a DC conduit and the main service disconnect are required. The location of DC conducters is designated, because DC conductors may remain energized, even if power is shut down at the disconnect breaker.

Setbacks for PV installations are required to ensure space for firefighters' access and operation on the roof. In the United States, smoke ventilation is sometimes still implemented in firefighter operations. Ventilation is usually performed at the peak of the roof, so PV module installation is prohibited within 3 feet (~0.9 m) from the ridge on each roof slope.

The National Fire Protection Association (NFPA) produces the National Electric Code (NEC), with updates published every three years. The NEC is used by various Authorities Having Jurisdiction (AHJs) as a benchmark for minimizing electrical hazards through proper design, installation, and inspection. Several sections within the NEC describe proper installation of PV systems and signage to decrease fire hazards. For a given AHJ, each new version of the NEC is evaluated and may be rejected, adopted as a whole, or adopted and modified only in parts. Compliance with respect to the NEC therefore varies across the United States.

3.3. Germany

In Germany, design and construction guidelines related to fire protection for PV installers are given in "Fire protection oriented planning, construction and maintenance of photovoltaic systems" by the German Solar Industry Association (Table 3.2). German guidelines are a set of recommendations that include certain provisions that are included in code, and therefore, are required.

Table 3.2 Fire protection outline referred to in the German Solar Industry Association guidelines[26]

Item	Contents
Markings (signage)	- Sign indicating a PV system is affixed to the main power box and main distribution panels of the building - Schematic diagram for firefighters - Supplement to existing diagrams for firefighters
Architectural fire prevention	- Installation of fireproof DC wiring outside the buildings - AC wiring only is allowed inside the building; the inverter is installed outside
Technical fire prevention	- Installation of a remote DC switch for firefighters in the main fuse box of the building that isolates the DC wiring

When firefighters start operations, it is important that they are able to recognize PV systems because the operational approach may change as a result of the presence of the PV system. Recognition of a PV system may be a straightforward matter of visual observation, but any delay to emergency operations must be minimized. Low visibility due to darkness or smoke may obscure the PV arrays, and a building-integrated PV array may be almost indistinguishable from other common roofing materials. Therefore, PV signage is needed. In Germany, PV signage (Figure 3.4) is required at the connection points of a PV system (e.g., connection box, main distribution board). This is stated in VDE-AR-E2100-712, released in May 2013. PV system operators must install layout diagrams showing the locations of PV system components with respect to the structural layout (Figure 2.1). These diagrams have to be affixed to the connection points of the electric system such as the junction boxes and distribution panels.

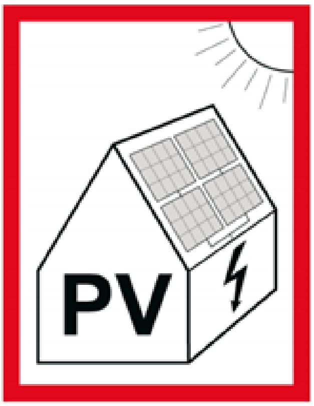
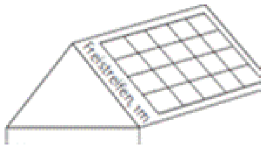
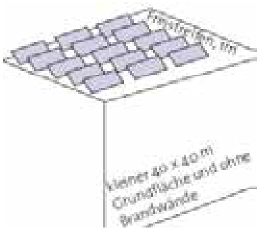
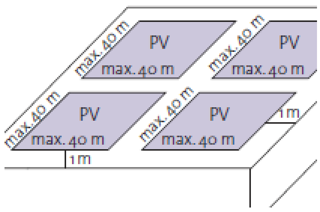


Figure 3.4 Example markings (signs) in Germany to identify the presence of PV systems [26]

To ensure a safe space for firefighters' operations, PV installation methods are given for each roof type shown in Table 3.3.

If disconnecting devices for strings or shutdown devices for PV modules are not used in the system, DC cable management options stated in VDE-AR-E2100-712 have to be applied. If installed inside the building, DC wiring protected by flame-retardant materials and labeled as fire-resistant wiring is one of the measures according to VDE-AR-E2100-712.

Table 3.3 Rules for PV system installation setback referred to in the German Solar Industry Association guidelines[26]

Roof type	Installation example	Contents
Inclined roof without any special access route		Personnel can access the ridge via open setback routes.
Flat roof without any ingress route such as windows or skylights		For a small flat roof without any other ingress route, personnel can access the roof via the open routes of the long side of the building.
Large flat roof		The roof has to be equipped with access routes for each fire compartment (40 m × 40 m in general) around the PV systems. The route width must be 1 m or wider.

4. Implementation of technologies and products for fire safety

Technologies (hardware and software) can provide firefighters with better control over the hazards associated with PV arrays. Ground-fault circuit interrupters (GFCIs) and arc-fault circuit interrupters (AFCIs) may reduce the incidence of fires and shocks, respectively, from energized conductors. Disconnect switches can reduce the number of conductors that remain energized with an illuminated PV system. These technologies are summarized in sub-sections below.

4.1. Ground-fault circuit interrupter

Ground faults, in which current flows (and power is dissipated) in the grounded conductors, create both fire and shock hazards. Continuous flow of current causes resistive heating (and possible arcing), leading to fires near the grounded components. Because grounded components can include uninsulated conductors (such as the module frames), contact with these conductors in a ground-fault condition can cause an electric shock. As a result, ground-fault protections for PV systems have been in widespread use since the 1990s. For example, in the United States, the 1993 version of the National Electric Code (article 690.5) stipulated that grounded, roof-mounted arrays would require a "ground-fault protection circuit" capable of detecting the fault, interrupting the current flow, and disabling the affected solar array. More recently, a requirement for a ground-fault indicator (such as a red indicator light) has been added. When excessive current flow to the ground is detected, a GFCI puts the conductor into an open circuit and prevents continuation of the ground faults.

As with any technology, the addition of GFCIs can have unintended consequences: the "Bakersfield Fire," a notable entry in Table 1.1, is thought to have started when a PV system developed two ground faults. The first ground fault went undetected; when the second ground fault occurred, it triggered a GFCI that, in turn, increased the current flowing through the initial ground fault, which eventually resulted in an arc fire.

4.2. Arc-fault circuit interrupter

Arcing happens when electrical energy flows through resistive media such as air. The high resistance of air leads to heating, which may trigger a fire. Whereas the oscillating nature of an AC current renders AC arcs self-extinguishing, DC circuitry is capable of generating sustained arcs that can ignite nearby fuels. The hardware to address this issue includes AFCIs, arc-fault detectors, and interrupting devices. Compared to ground-fault detection, arc-fault detection can be more challenging. The use of grounded conductors can make an arc fault more difficult to detect; the ungrounded PV systems that are more common in Europe and elsewhere are more robust against arc-fault hazards.

Because grounded PV systems remain common in the United States, arc-fault detection and interruption has grown in importance there. The presence of an arc in a grounded circuit can be intermittent and particularly difficult to distinguish from normal operation. Various arc-fault detection devices monitor voltage, current, or emitted radiation. An arc-fault detector must be sensitive to small differences in the circuit condition and can be triggered by conditions other than arcing ("false" or "nuisance" tripping). Since 2011 (NFPA 70, article 690.11), AFCI, which detects and interrupts arc faults, is required to be included in PV systems in the United States. Certification and testing methods for AFCI are given in UL 1699B[37].

4.3. De-energizing conductors ("firefighters' switch" and "rapid shutdown")

In several countries, including Australia, Germany, and the United States, the rise in the number of PV installations that remain energized (under sunlight) has led to calls for a "firefighters' switch" that can reduce the shock hazard from any exposed, energized conductors in the PV system (Figure 4.1).

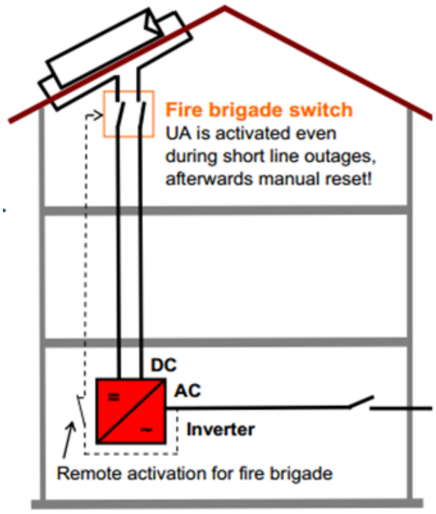


Figure 4.1. Firefighters' switch[38]

In the United States, this has taken the form of "rapid shutdown" equipment. The ability to carry out a "rapid shutdown" is now required for PV systems to be compliant with the 2014 National Electric Code[40] ("NEC", NFPA 70, article 690.12). The rapid shutdown switch makes it possible to disconnect circuits remotely for use in fire emergencies and maintenance.

The 2014 version of article 690.12 specifies that the controlled conductors (outside the array boundary) be brought below 30 V (and 240 V-A) within 10 seconds of the initiation of "rapid shutdown". Hardware that might comply with the 2014 NEC article 690.12 includes disconnect switches, which effectively de-energize the controlled conductors outside the defined array boundary.

A 2017 version of 690.12 (2)[39] adds provisions within the array boundary, where conductors remain energized while the array is sunlit. These provisions go into effect in 2019. An 80 V limit was included as option 2 in article 690.12 (2) for a "rapid shutdown" within an array boundary. The 80 V limit is not harmonized with respect to existing approach limits for energized equipment[40]. Rather, it matches the system voltage (per article 690.11, 2011 NEC) below which no AFCI is required. Because conventional PV modules typically obtain over 40 V in open-circuit conditions, the new 80 V limit implicitly requires additional electronics for each module. For arrays consisting of more than two rows of modules, this may render inspection or replacement of the rapid shutdown equipment particularly challenging. The implicit requirement for "module-level shutdown" that results from the 80 V limit has proven to be contentious[41]. There are two other options for compliance: arrays with no conductive components; and "listed" equipment that, as of 2017, has not yet been defined. A concern with using the "rapid shutdown" designation for both the de-energized conductors outside the array and energized conductors within the boundary of an array has been how to avoid giving firefighters a false sense of security. For example, the marking shown in Figure 4.2 (b) should not be construed to suggest that the equipment is "off" inside the array boundary, because sunlit modules and their conductors will remain energized after "shutdown".

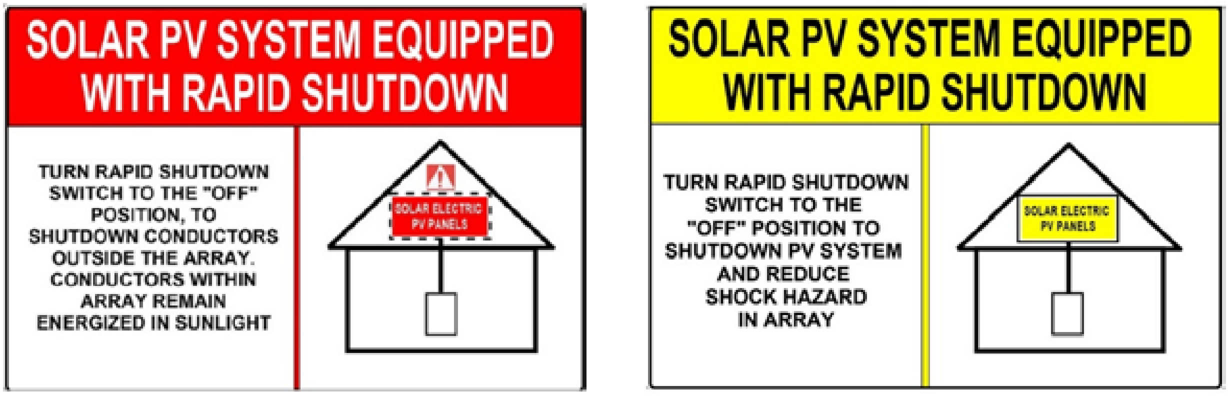


Figure 4.2. Proposed marking for PV systems equipped with rapid shutdown equipment (a) outside the array boundary and (b) within the array boundary[42], per NFPA 70, the 2017 NEC, article 690.56(c)(1).

4.4. Issues regarding fail-safe operation of novel equipment

Properly installed and undamaged PV arrays are not hazardous. The relative simplicity of PV systems makes hazards easier to predict and avoid. New technologies need to be demonstrated to be effective under the conditions in which the PV system is improperly installed or damaged. The damage that makes a PV array potentially hazardous to a firefighter might also render any new technologies inoperative. To avoid giving firefighters a false sense of security, new technologies must be fail-safe, inspectable for failures, and replaceable in the event of failure.

Generally speaking, listed electro-mechanical devices such as disconnect switches and circuit breakers can meet these criteria. With electronic hardware solutions, it can be more difficult to verify the performance under operating conditions. Under the UL1741[43] standard for inverters, converters, and controllers, it is up to the manufacturer to provide the "worst-case conditions" under which the equipment must be tested. Only future experience with deployed systems will show whether these tests are sufficient over the service lifetime. Demonstrating that the new hardware is reliable, will be fail-safe under the relevant conditions, and will function as safety equipment over the life of the PV system is a challenge that will require ongoing testing and development.

5. Conclusion

As PV deployments have become commonplace around the world, codes and standards bodies have worked with the fire services and the PV industry to develop guidelines to address the potential hazards to firefighters working near energized PV systems. As of 2016, a substantial body of best practices has been established for PV system design, installation, and firefighter operations.

Installation practices, firefighter procedures, and hardware that can reduce the fire and/or shock hazards of PV arrays are now deployed in multiple countries. The variation in implementations over time and around the world provides a means to determine best practices for minimizing the hazards in firefighter operations worldwide, which have been summarized here. International cooperation between standards experts, firefighters, and technologists will be crucial to future success.

Appendix

Related guideline table of contents are shown for reference.

Tables of Contents from Guidelines for Firefighters

Table A.1 Table of contents: Japanese guidelines for firefighters[8]

Table of contents	
I. Main chapter	
1. General information about solar photovoltaic systems	1.1 What are solar photovoltaic systems?
	1.2 Nature of solar photovoltaic power plants
	1.3 Composition of solar photovoltaic systems
	1.4 Examples of fire and electric shock injury due to solar photovoltaic systems
2. Hazards for firefighters in extinguishing fires in buildings with solar photovoltaic systems	2.1 Hazards intrinsic to solar photovoltaic systems
	2.2 How to recognize solar photovoltaic systems
	2.3 Electric shock and burn hazards
	2.4 Fall hazards
	2.5 Generation of combustion gas
	2.6 Collapsing
	2.7 Outbreak of fire
	2.8 Others (batteries)
3. Consideration points for firefighter operation in houses which have solar photovoltaic systems	
II. Appendix	
1. Signs on electric poles and wires representing solar photovoltaic system installed in house	
2. Isolating DC circuit	2.1 Isolating circuits at junction boxes
	2.2 Isolating circuits at solar photovoltaic modules (insulating connecters)
III. References	

Table A.2 Table of contents: United States CAL FIRE guidelines for firefighters[9]

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	1.2 What are photovoltaics?
	1.3 State safety regulations
	1.4 Number of photovoltaic systems in California
	1.5 Incident summary
Section 2: Photovoltaic cells and components	2.1 Introduction
	2.2 Anatomy of a solar cell
	2.3 Photovoltaic modules
	2.4 Photovoltaic array
	2.4 Photovoltaic tiles and shingles
	2.5 Rack mounted photovoltaic modules
	2.6 Inverters
	2.7 Batteries

Table A.2 Table of contents: United States CAL FIRE guidelines for firefighters[9] (Continued)

Table A.3 Table of contents: United States Fire Protection Foundation report[10]

Table of contents	
1. Introduction and background	
2. Overview of solar power systems	a. Evolution of technology for harnessing energy from the sun
	b. Types of solar power systems
	c. Marketplace trends
	d. Loss history and data
	e. Information resources
3. Photovoltaic solar power	a. Photovoltaic basics
	b. Solar cell technology and photovoltaic systems
	c. Background on fireground electrical hazards
4. Overview of fire service operational materials	
5. Assembly of best practice guidance for emergency response	a. Identification of common themes and principles
	b. Target applications workshops
	c. Final evaluation of best practice guidance
6. Summary observations	
7. Bibliography	
Annex A: Solar power-related definitions	
Annex B: Example of fire service training program on solar power systems	
Annex C: Overview of fire service training and education	
Annex D: Attendees at fire service Workshop on solar power systems	

Table A.4 Table of contents: German Firefighters Association guidelines[12]

Table of contents
Introduction
1. Solar energy: How it can be used
2. Ranges of application of photovoltaic system
3. Composition of photovoltaic system
4. Firefighting and technical help
5. Additional information
Appendix

Tables of Contents from Guidelines for Installation

Table A.5 Table of contents: Japanese guidelines for installation[21]

Table of contents	
Section 1: Introduction	
Section 2: Guide for system designing	2.1 General instructions for designing a system
	2.2 Documentation of systems (writing system descriptions)
	2.3 Designing DC safety of a system
	2.4 Basic strategies for isolation, earth fault protection and overcurrent protection
	2.5 Designing lightning-resistant systems
	2.6 Designing each element
	2.6.1 Installation site and installing electronic facilities
	2.6.2 Wiring method
	2.6.3 DC series/parallel arc-fault circuit protection equipment
	2.7 Plans for protecting firefighters
Section 3: Selecting system components	3.1 General instructions for selecting components
	3.2 Selecting solar photovoltaic modules
	3.3 Selecting power conditioners
	3.4 Selecting junction boxes (including cabinets and current breakers)
	3.5 Selecting cables and wiring facilities
	3.5.1 Selecting connectors
	3.5.2 Selecting cables
Section 4: Outline of operation and maintenance procedure on a site	4.1 General instructions concerning O&M of solar photovoltaic systems
	4.2 How to inspect solar photovoltaic modules
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Table A.6 Table of contents: United States CAL FIRE guidelines for installation[25]

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About the guidelines	
General information about solar photovoltaic systems	
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Adopting the guidelines	
General	
Local ordinance required by city, county, city and county, fire protection district	
Findings and filings	
Wording	
1. Marking	1.1 Main service disconnect
	1.1.1 Marking content and format
	1.2 Marking for direct current (DC) conduit, raceways, enclosures, cable assemblies, and junction boxes
	1.2.1 Marking content and format
	1.3 Inverters

Table A.6 Table of contents: United States CAL FIRE guidelines for installation[25] (Continued)

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<tr><td rowspan="7">2. Access, pathways and smoke ventilation</td><td>2.1 Residential systems—single and two-unit residential dwellings</td></tr>
<tr><td>2.1.1 Access/pathway</td></tr>
<tr><td>2.1.2 Smoke ventilation</td></tr>
<tr><td>2.2 Commercial buildings and residential housing comprised of three (3) or more units</td></tr>
<tr><td>2.2.1 Access</td></tr>
<tr><td>2.2.2 Pathways</td></tr>
<tr><td>2.2.3 Smoke ventilation</td></tr>
<tr><td colspan="2">3. Location of direct current (DC) conductors</td></tr>
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<tr><td colspan="2">5. Ground mounted photovoltaic</td></tr>
<tr><td colspan="2">Example 1 – cross gable roof</td></tr>
<tr><td colspan="2">Example 2 – cross gable with valley</td></tr>
<tr><td colspan="2">Example 3 – full gable</td></tr>
<tr><td colspan="2">Example 4 – full hip roof</td></tr>
<tr><td colspan="2">Example 5 – large commercial 8' walkways</td></tr>
<tr><td colspan="2">Example 6 – large commercial 4' walkways</td></tr>
<tr><td colspan="2">Example 7 – small commercial 4' walkways</td></tr>
<tr><td colspan="2">Example 8 – small commercial 8' walkways</td></tr>
</table>

Table A.7 Table of contents: The German Solar Industry Association guidelines[26]

<table>
<tr><th colspan="2">Table of contents</th></tr>
<tr><td colspan="2">1. Introduction</td></tr>
<tr><td rowspan="6">2. Principles for the designing, construction and maintenance</td><td>2.1 Construction and fastening to the substructure</td></tr>
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<tr><td>2.5 Handing over, admission, identification and documentation of the system</td></tr>
<tr><td>2.6 Maintenance</td></tr>
<tr><td>2.7 Responsibilities of the operator</td></tr>
<tr><td rowspan="4">3. Principles of the planning appropriate for fire prevention and establishment</td><td>3.1 General tips and concepts</td></tr>
<tr><td>3.2 Architectural fire prevention</td></tr>
<tr><td>3.3 Personal protection of emergency personnel</td></tr>
<tr><td>3.4 Defense fire protection</td></tr>
<tr><td rowspan="5">4. Installing solar photovoltaic systems appropriate fire prevention facilities</td><td>4.1 Realization of the architectural fire prevention</td></tr>
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<tr><td>4.4 Additional defense fire protection for solar photovoltaic systems</td></tr>
<tr><td>4.5 Tips for special investment types</td></tr>
</table>

Table A.7 Table of contents: The German Solar Industry Association guidelines[26] (Continued)

5. Appendix	5.1 Additional information
	5.2 General plans for emergency personnel
	5.3 Building classes based on model building regulation (MBO)—abstract
	5.4 References to product standards and requirement profiles
	5.5 Building material classes
	5.6 Maintenance and a maintenance check list
	5.7 Glossary

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