

FIRE HAZARDS OF PHOTOVOLTAIC (PV) SYSTEMS

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This Tech Talk discusses the fire hazards associated with PV systems installed on industrial and commercial buildings.

AT-A-GLANCE

- Photovoltaic (PV) panels can be retrofitted on buildings after construction or can be used to replace conventional building materials used for roofs, walls or facades.
- Fire safety concerns include electrical ignition sources, combustible loading, and challenges for manual firefighting.
- Numerous fire incidents have occurred involving industrial and commercial building rooftop PV systems.
- The key to preventing fires is high quality design, installation and testing in accordance with applicable electrical codes and minimizing the combustible loading.

INTRODUCTION

"Living on Earth is expensive, but it does include a free trip around the sun each year." – Unknown

As energy costs rise, solar power is becoming a fast growing energy source. Rooftops of industrial and commercial buildings are an ideal location to convert abundant sunshine into electricity and thus recover some of the money spent on this trip around the sun. However, it is not only for economic reasons that companies want to use their buildings for photovoltaic (PV) power generation, or rent their roofs to investors. Solar panel systems on a building are also a way of demonstrating commitment to improving the environment.

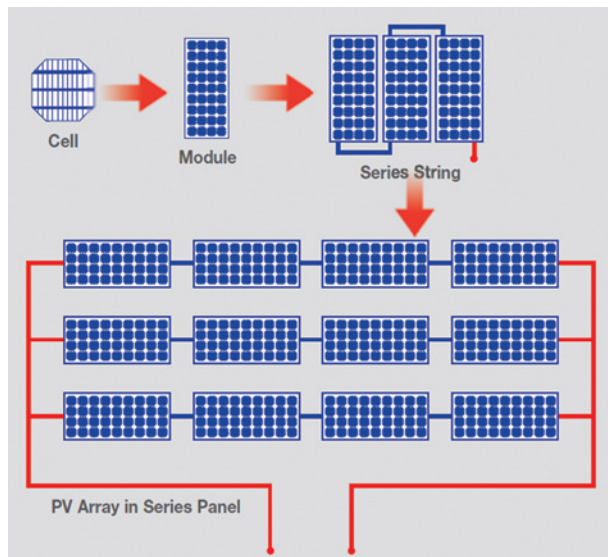
Adding photovoltaic systems to roofs (or walls) is a relatively new approach and some of these systems have been involved in fires. The extensive media coverage of these fires has increased the awareness and the industry is actively working on solutions to prevent and mitigate fire hazards. From a property insurer's perspective, two questions need to be answered:

1. What is the impact of a rooftop or wall mounted PV system in a fire scenario?
2. How can the risk of loss be reduced for a given building with a PV system?

PV systems are also subject to natural hazards (e.g., windstorms, lightning, hailstorms, etc.), overvoltage, power surges, theft, etc., however, protection for these hazards is not covered in this document.

PHOTOVOLTAIC SYSTEMS ON INDUSTRIAL AND COMMERCIAL BUILDINGS

PV systems on industrial and commercial buildings do not differ from installations on residential buildings other than in size and the fact that most are tied into the utility grid without onsite consumption and storage capacity (batteries). Currently, most installations utilize rigid (crystalline silicon) PV modules mechanically fastened to the roof. These PV modules are built from cells and then arranged in strings and arrays as shown in the following figure:

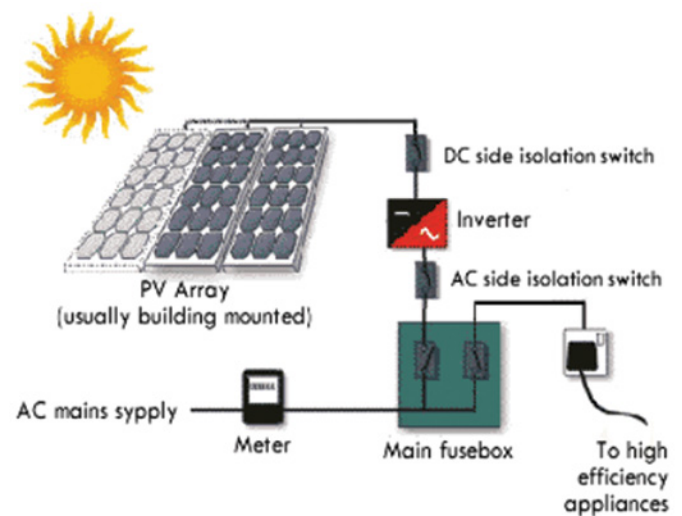


Source: Kingspan

- A PV **cell** is the smallest semiconductor element within a PV module which converts light into electrical energy.
- A PV **module** (often referred to as "photovoltaic panel") is the assembly of cells and ancillary parts, including interconnections, terminals, and protective devices, such as diodes.

- In a PV **string**, the modules are wired together in series to increase voltage. The voltage output of a PV panel/array is defined by the number of individual cells in series. The vast majority of large PV installations on buildings are currently 600 volts direct current (DC) in North America and 1000 volts DC in Europe.
- In a PV **array**, two or more strings are connected in parallel to increase amperage. These arrays are assembled on a discrete structure with common support or mounting. In smaller systems, an array can consist of a single module.

Additional components of a PV system include wiring harnesses between modules and strings/arrays and the combiner box, which connects a group of strings. From the combiner box, conductors carry the electricity to the inverter, the heart of a PV system. PV cells produce DC power, which needs to be converted into alternating current (AC) power in the inverter.



Source: electricityforum.com

INSTALLATION OF PHOTOVOLTAIC PANELS

Two methods for installing PV panels on buildings are currently used:

1. Building-applied photovoltaics (BAPV), which are a retrofit installed on the building after construction is complete. A typical example is roof-mounted PV panels.
2. Building-integrated photovoltaics (BIPV), which are PV materials that are used to replace conventional building materials in parts of the building envelope, such as the roof, walls or facades. Examples include flexible PV film attached to roof coverings, PV roof tiles, and PV facades.

BIPV systems are more common in Europe than in the United States. BIPV installations are more susceptible to water damage in buildings and thin films often use combustible foam, which may increase the fire hazard. As a result, BAPV systems are normally preferred for property insurance purposes.

FIRE SAFETY CONCERNS

MANUAL FIREFIGHTING

When firefighters arrive at a burning building, one of their first tasks is to disconnect the building utilities, including electricity. However, this is not possible with PV systems since the inverter can hold a charge and send electricity back to the PV panels. The panels themselves will continue to produce power as long as the sun is shining and possibly even at night when bright lights are present. Thus, the conduit leading from the PV panels to an inverter remains live with direct current even after the main service panel has been shut-off. The fire service can be subject to electric shock when fighting a fire due to the presence of high voltage and current. During the course of fire on a building with a PV system, DC cable insulation can melt and cause a DC arc flash. The same may occur if a PV system is disconnected incorrectly. DC arcs are not only an additional life safety threat to firefighters, but also an ignition source, which will be discussed later in more detail.

Other possible risks of PV systems for manual firefighting are:

- PV panels may block key points and pathways that firefighters may need to use on a roof
- The added weight of a PV panel array may lead to early roof collapse if the integrity of the structure is already compromised by fire
- Potentially toxic smoke generated from burning plastic materials (i.e. panels, cable insulation, etc.)
- Falling objects from the roof top or wall (e.g., broken glass)

PV systems were initially installed on buildings without further training or coordination with fire departments. Some fire departments would refuse to fight fires when they noticed a PV system on the roof. Since then, best practice guidelines and training courses for firefighters have been developed and there are known tactics on how to deal with this concern, such as safety distances and using fog nozzles.

Safely disconnecting a PV system in a fire situation should ideally result in DC currents and voltages reduced to levels which are no longer hazardous to firefighters. However, this would require isolation of each individual module with a micro-inverter or by DC switches controlling a limited number of modules in a string. Currently, there is no economically feasible solution for such an isolation tool.



Fireman's Switch

In some countries, a so called "fireman's switch" is required by local regulations. This switch is usually located on the DC side of the inverter. However, if the inverter is located inside the building, the DC lines still carry current and could jeopardize firefighters. As a solution, additional DC switches can be installed between strings / arrays and the inverter at rooftop level to at least de-energize the main conduit leading from the roof to the inverter. These switches can be actuated remotely from a safe location.

Other key factors in supporting manual firefighting include proper labeling of all components and live equipment, adding PV system information to the emergency response plan, and providing prompt access to qualified electricians familiar with the installation.

COMBUSTIBILITY OF PHOTOVOLTAIC SYSTEMS

All PV system components exposed to sunshine and other weather elements need to have highly durable characteristics. Plastic materials that have traditionally performed well in this regard do not necessarily have good fire-resistance characteristics. The panels themselves typically contain limited plastics, but frames, mounting systems, cables and boxes can add to the combustible loading of an installation and the combustibility of the roof.

Standards for testing the performance of PV panels have been developed at an international level. While some address electrical performance, others address safety of the modules with respect to construction and operation. These safety standards also address fire behavior. The safety standards applied are IEC 61730 in Europe / Asia and ANSI/UL 1703 in North America. Both standards are very similar and contain elements of fire testing based on ASTM E-108/UL 790, *Test for Fire Performance of Roofing Materials*.

FM Approvals has tested PV modules for combustibility in accordance with ASTM E-108 and has developed Approval Standard 4476 for flexible PV modules and Approval Standard 4478 for rigid PV modules. In Europe, fire tests for evaluating the behavior of roof assemblies from external building fires are described in the standard DD CEN/TS 1187, *Test methods for external fire exposure to roofs*. Product classifications are provided in the standard EN 13501-5, *Fire classification of construction products and building elements. Classification using data from external fire exposure to roofs tests*.

As a result, the combustibility of a planned PV installation needs to be evaluated on a case-by-case basis. Fire test results for the panels alone are not enough as an increasing number of mounting systems made from plastics are on the market. There are no harmonized standards for cables used in PV installations; however, fire test results and flame retardant characteristics of the cables need to be considered as well.

FIRES INCIDENTS INVOLVING ROOFTOP PHOTOVOLTAIC SYSTEMS

PV systems are subject to electrical faults like any other electrical installation, such as arc faults, short circuits, ground faults and reverse currents. These faults and other system failures, including cable insulation breakdowns, rupture of a module, and faulty connections, can result in hot spots that can ignite combustible material in their vicinity. Incorrectly installed or defective system components have been the cause for several PV fires as well. In addition, numerous fires have started in roof-mounted PV installations due to DC arcs caused by inadequate ground fault protection.

Several fire incidents involving rooftop PV systems are discussed below.

Bakersfield, California, US in April 2009: a fire occurred on the membrane roof of a big-box retail store. The store had 1,826 PV modules on the roof and the fire reportedly started in two locations due to causes associated with a ground fault.

Mount Holly, North Carolina, US in April 2011: a fire occurred on the roof of a drywall manufacturer. The fire cause was reportedly ground fault related.

Goch, Germany in 2012: a fire occurred at a warehouse that involved an approximate 43,000 ft² (4,000 m²) roof area. The fire cause was reportedly associated with a defect in the PV system.

La Farge, Wisconsin, US in May 2013: a fire occurred at the corporate headquarters of an agricultural cooperative for organic food. The fire started inside the building and spread to a concealed attic space. The building's sprinkler system was not effective at controlling the fire. At some point in the fire development, the metal roof became energized by the PV system, which inhibited suppression activity by the fire department.



Organic Valley in La Farge, WI (Source: XWOW.com)

Delanco, New Jersey, US in September 2013: a fire occurred at a cold-storage food warehouse that was approximately 300,000 ft² (28,000 m²) in size with more than 7,000 PV modules covering most of the roof. Reportedly, combustible roofing insulation was ignited and allowed the fire to spread. The large PV module array inhibited the ability of firefighters to control the fire. The fire took more than 24 hours to suppress and the building and contents were completely destroyed.



Dietz & Watson in Delanco, NJ (Source: FOX)

Florence Township, New Jersey, US in November 2013: a fire occurred on the roof of a retail store distribution warehouse. The warehouse was approximately 700,000 ft² (65,000 m²) in size with more than 8,000 PV modules installed on the roof. The fire damaged more than 300 of the PV modules. An early notification from an eyewitness allowed for a rapid response and the fire did not enter the building.

ARC RECOMMENDATIONS

PV systems on industrial and commercial buildings are a relatively new fire risk that is not controlled by conventional fire protection systems. The key is preventing fires from occurring in the first place through high quality design, installation and testing in accordance with applicable electrical codes and minimizing the combustible loading. Before installing PV systems, a hazard and risk analysis should be conducted by ARC in order to determine if the fire risk can be minimized or if there is a potential for a catastrophic loss.

The following recommendations are intended to reduce the potential for property damage and business interruption caused by PV system fires. Most items refer to rigid PV modules (BAPV) since there is limited experience to date with BIPV and flexible PV modules.

GENERAL INSTALLATION

1. If possible, ground-mounted PV systems are preferred over roof-mounted installations.
2. ARC strongly discourages the installation of PV systems on industrial and commercial buildings with combustible roofs (entirely combustible or with combustible insulation).
3. The installation should be in accordance with applicable electrical codes, such as NFPA 70, *National Electrical Code*, or equivalent international codes or standards, including proper ground fault protection.

PHOTOVOLTAIC PANELS

4. Only PV modules which comply with international standards for electrical performance and safety should be used. The safety standards, such as IEC 61730 and ANSI/UL 1703 address the combustibility of the modules. There are no uniform standards for evaluating the combustibility of the modules as roof assemblies.
5. Modules should have the approval / listing of an internationally recognized testing laboratory, such as TÜV Rhineland, Underwriters Laboratories (UL), FM Approvals or CSTB (France).
6. When evaluating the combustibility of the modules, the mounting system and the module frames need to be considered as well. Mounting systems and frames should be non-combustible.
7. In order to provide adequate firefighter access to the building, the size of the arrays should be limited to 150 ft. x 150 ft. (45 m x 45 m). The roof should have minimum 4 ft. (1.2 m) wide pathways and perimeter space around PV arrays to allow firefighters to traverse the roof safely. The required separation distance of the modules from fire walls and heat and smoke vents should be in accordance with applicable fire protection standards.

CABLES

8. Only PV cables suitable for outdoor applications (moisture and UV resistant) should be used. Protecting cables from severe weather conditions and sunlight helps to slow down the aging process and thus minimizes the risk of hot spots and arcing. In the US, UL 4703, *Standard for Photovoltaic Wire*, is applied. In Europe, individual specifications per country are currently in use.
9. Cables should be flame resistant.
10. Cables should be fixed and routed in closed metal conduit; loose cables should not be allowed. Another means of minimizing the risk of arcing is routing positive and negative wires in separate conduit. Also, cables should not be routed over sharp edges to avoid mechanical damage.
11. Routing of cables should not compromise fire compartments of the building (e.g., by penetrating fire wall parapets). If this cannot be avoided, the openings need to be protected in accordance with applicable fire wall standards.
12. Direct contact between cables or connectors and combustible roofing material, such as roof membranes, should be avoided. Cable conduits can be mounted on a steel supporting structure and the area below the cables can be covered with a non-combustible material. Gravel has been used in some instances, however this additional weight should be evaluated to ensure the roof's design load is not exceeded.
13. The main DC cables from the PV panel to the inverter should not be routed through the interior of a building; instead they should be routed along the exterior. If for any reason the cable needs to be routed through the interior of a building, it should be protected in a fire resistant enclosure.

INVERTERS

14. The inverter(s) should be easily accessible and protected from severe weather conditions. The preferred location is inside a separate non-combustible structure supervised by a fire detection system.
15. Inverter(s) should not be mounted on combustible walls, such as wood panels or combustible sandwich panels.

BATTERIES

16. If batteries are installed to store energy, they should be located in a cutoff room equipped with a fire detection system. For more information on battery energy storage systems using lithium-ion batteries, see ARC Tech Talk Volume 26.

DISCONNECT REQUIREMENTS

17. A DC disconnect switch between the PV modules and the inverter should be provided, even if not required by local electrical codes. This allows safe disconnection of a defective inverter or modules for maintenance purposes and may also be used in a fire situation.
18. Additional DC disconnect switches closer to the modules (fireman's switch) should be considered to support manual firefighting and de-energize major DC conduits with live currents and voltages. The switches should have remote actuators.

DC ARC DETECTION AND ELIMINATION

19. The risk of DC arcs can be greatly minimized in a high quality installation, however they cannot be eliminated. The use of DC arc detection and interruption devices for PV systems should be considered once approved and reliable devices are available.

EMERGENCY RESPONSE

20. The local fire department should be informed of and familiarized with the PV installation. Plans may be provided for reference in case of emergency.
21. PV systems should be labeled in a clear and systematic manner to ensure that technicians and firefighters can quickly and easily identify key elements of the system. Standards for labeling are available in some countries.
22. Pre-emergency plans and drawings for the fire department should include the fire hazard of the PV system and the disconnection means. The plan should also include contact details of reliable (24 hr. availability) and qualified electricians familiar with the installation who are able to safely disconnect the system. Disconnecting PV systems should normally not be left to the fire department.

INSTALLATION, MAINTENANCE AND INSPECTION

23. PV systems should only be installed and commissioned by qualified contractors. Training courses and certification processes are available.
24. PV systems should be inspected regularly by qualified professionals, including looking for potential damage from rodents and other pests, which could compromise the wiring or insulation.
25. Infrared thermographic inspections should be conducted at least annually to look for "hot spots."

OTHER

26. Although not covered in this document, proper grounding of the PV installation along with overcurrent protection and possibly lightning protection are of paramount importance to avoid any electrical fault that could lead to hot spots or arcing.

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QUESTIONS OR COMMENTS?

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