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Understanding the Fire Hazards of Photovoltaic Systems

Allianz Risk Consulting

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. Roof tops 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.

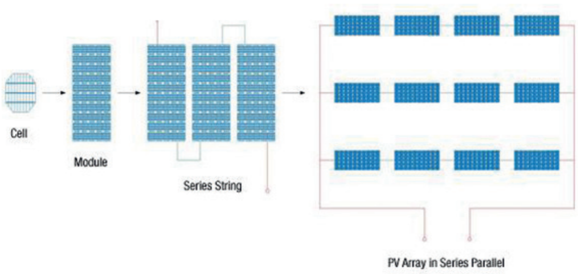
The purpose of this Tech Talk is to understand the fire hazards associated with photovoltaic systems. Adding photovoltaic systems to roofs (or walls) of commercial and industrial buildings is a relatively new approach and some of these buildings were involved in fires, which received extensive media coverage. Although many catastrophic warnings did not prove correct, the awareness has risen and the industry is actively working on technologies to prevent and mitigate fire hazards. Thus, the emphasis of this Tech Talk is on understanding the risks when there are no standard solutions available. From a property insurer's perspective, two questions are of interest:

1. What is the impact of a rooftop or wall mounted PV system in a fire situation?
2. What is the intrinsic fire hazard of the photovoltaic system itself? How can it become an ignition source and thus increase the probability of a fire for a given building?

Photovoltaic systems are not only subject to fire, but also to natural hazards (e.g. windstorms, lightning, hailstorms, etc.), overvoltage, power surges, theft, etc., and proper protection is equally important, however, is not part of this document.

Photovoltaic Systems on Commercial Buildings

Photovoltaic systems on commercial and industrial 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 solar installations are still made of rigid (crystalline silicon) photovoltaic modules, which are mechanically fastened to the roof. These solar modules are built up of cells and then arranged in strings and arrays:



Source: Kingspan Powerpanel

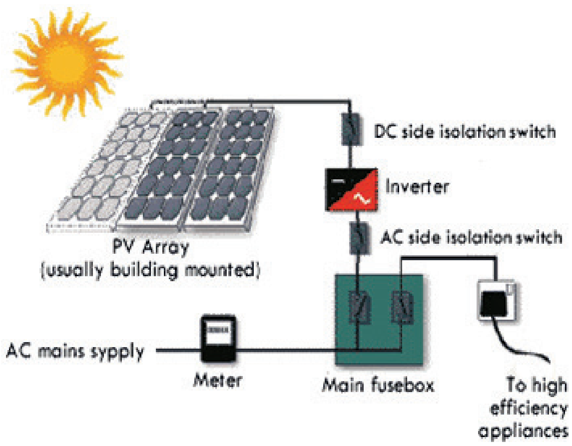
- A photovoltaic cell is the smallest semiconductor element within a PV module to perform the immediate conversion of light into electrical energy.

- A photovoltaic module (often also referred to as "photovoltaic panel") is the smallest environmentally protected, essentially planar assembly of solar cells and ancillary parts (interconnections, terminals, and protective devices, such as diodes).

- In a photovoltaic string, the modules are wired together in series to increase voltage. The voltage output of a solar panel/array is defined by the number of individual cells in series. The vast majority of large photovoltaic installations on buildings are currently 600 V DC in North America and 1000 V DC in Europe.

- In a photovoltaic array, two or more strings are connected in parallel to increase amperage. The modules of such a single energy producing unit 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 are the wiring harnesses (between modules and strings/arrays) and a group of strings are connected together at a junction called a combiner box. From the junction box(s), conductors carry the electricity to the inverter, the heart of a PV system. Photovoltaic cells produce direct current (DC) power, which needs to be converted into alternating current (AC) power in the inverter.



Source: electricityforum.com

Impact of PV Systems in a Fire Situation

Life Safety Issues for Fire Fighters

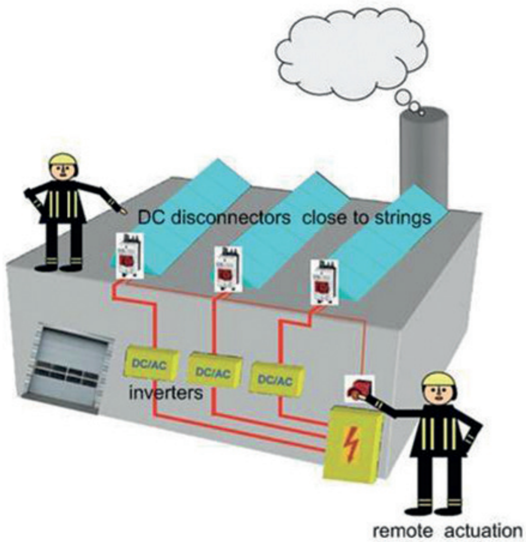
When fire fighters arrive at a burning building, one of their first tasks is to disconnect utilities to the structure. However, this is not possible with solar systems since the PV system inverter can hold a charge and send electricity back up to the solar panels. The panels themselves will continue 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 services have to fight a fire in the presence of high DC voltage and current and can be subject to electric shock. During the course of fire on a building with a photovoltaic system, DC cable insulation might melt and cause a DC flash arc. The same can happen if a photovoltaic system is disconnected incorrectly. DC arcs are not only an ignition source themselves (which will be discussed later in more detail), but an additional life safety threat to fire fighters.

Other possible risks of photovoltaic systems for manual fire fighting are:

- Solar panels may block key points and pathways that fire fighters would otherwise use on a roof
- The added weight of a solar panel array may lead to roof collapse, if the integrity of the structure is already compromised by fire
- Potentially toxic fumes from decomposed products of the panels
- Falling objects from the roof top or wall (e.g., broken glass)

Photovoltaic systems have been installed on buildings initially without further training and coordination with fire departments. Some fire departments have refused to fight fires on residential houses when they noticed a solar system on the roof. Extensive media coverage of these cases has added to the fear. Meanwhile, best practice guidelines and training courses for fire fighters have been developed. Live electrical equipment with shock potential is not a new fire hazard; however, it has not been expected on ordinary building roofs. There are known tactics on how to deal with this, such as safety distances and using fog.

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 fire fighters. However, this would require isolation of each individual module and currently, there is no economically feasible solution for such an isolation tool. The so called "fireman's switch" has been launched on the German market. Additional isolators can be installed between strings / arrays and the inverter at roof top level to at least de-energize the main conduit leading from the roof to the inverter. These switches can be remotely actuated from a safe location.



"Fireman's Switch", source: Eaton Corporation

Proper labeling of all components and live equipment, as well as adding information and documentation of the PV system to the emergency response plan and providing fast access to qualified electricians familiar with the installation, are other key factors in supporting manual fire fighting.

Combustibility of Photovoltaic Systems

All components of a photovoltaic system exposed to sunshine and other exterior elements of weather need to have highly durable characteristics, and certain materials that have traditionally performed well in this regard (i.e., certain types of plastics), do not necessarily have good fire-resistant characteristics. The solar panels themselves typically contain limited plastics, but it is the frames, mounting systems, cables and boxes that can add to the combustible loading of an installation and eventually to the combustibility of the entire roof.

Standards for testing the performance of solar 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."

Factory Mutual plans to test entire PV systems (solar panels and mounting system) in accordance with ASTM E-108 and has already released Approval Standard 4476 for flexible photovoltaic modules and Approval Standard 4478 for rigid photovoltaic modules. In Europe, fire tests for evaluating the behavior of roof assemblies from external building fires are to be described in ENV 1187 (pre-norm) and classification of the products is described in EN 13501-5. ENV 1187 is not yet a harmonized norm and national standards are still used, such as DIN 4102-7. These tests are mandatory in Europe for building integrated PV systems.

As a result, the combustibility of a planned photovoltaic installation needs to be evaluated case by case. 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 solar cables (cables used in solar installations); however, fire test results and flame retardant characteristics of the cables need to be considered too.

Fires Initiated by Photovoltaic Systems

Photovoltaic 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 failures of the system, including cable insulation breakdowns, rupture of a module, and faulty connections, can result in hot spots that can ignite combustible material in their vicinity. Wrongly installed or defect DC/AC inverters have been the reason of several photovoltaic fires as well.

In the worst case, faulty conditions on the photovoltaic system will not only result in a hot spot, but also a DC arc. Arcing has been found to be the main reason of larger rooftop fires on commercial buildings starting on PV systems and have gained a lot of attention. Popular examples are the Target store in Bakersfield, California, and the warehouse of a logistic company in Bürstadt, Germany, both of which occurred in 2009.

Bürstadt after completion of the installation in 2005 (45 000 m², 5 MW)

Bürstadt fire in 2009 (80 m² was damaged by the fire)

Any disconnection or faulty connection of current carrying wire can cause an electric arc, which is the continuation of current flow through air. An arc-flash can occur when there is sufficient amperage and voltage and a path to ground or to a lower voltage. Any electric installation is exposed to the risk of arcs, but solar installations are particularly sensitive to this exposure because of the continuous DC current and the high currents (>10 A) and voltages (300-1000 V) involved. DC arcs do not self extinguish and can reach temperatures as high as 3000°C (5400°F). Arcs at this temperature can melt metal, which can fall as slag and ignite nearby combustible materials.

There are three types of arcs:

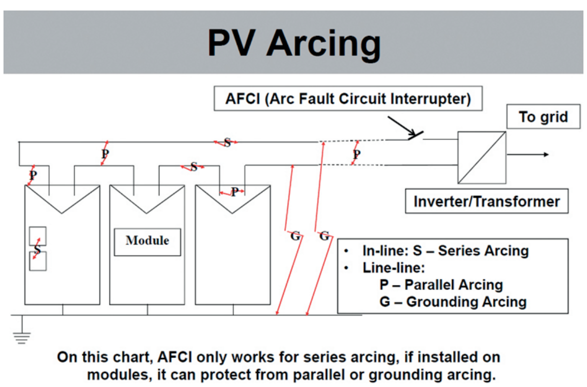
- Serial arc: Occurs when a connection is pulled apart while the PV is producing current. Typical reasons for serial arcs are loose connections or connector defects (e.g., in the soldered joints within the module). For this reason, special care also has to be taken when PV systems are isolated in a fire situation.
- Parallel arc: Occurs when an insulation system suffers break-down. Two conductors of opposite polarity in the same DC circuit are often run in close proximity to each other. The insulation between the two wires can become ineffective due to animals chewing on them, UV breakdown, embrittlement, cracking, moisture ingress and freeze / thaw circles.
- Ground arc: Arc on ground cables; requires the fault of only one insulation system.

In past fire incidents, defective soldering, loose connections, ground faults, isolation faults, aging / corrosion, and bites from rodents have resulted in arcing. Most of them (other than bites from rodents) were related to installation and material deficiencies. Considering that the operating life of a PV system is more than 20 years, the true fire incidence rate may not become apparent for another 10 to 20 years when aging of the materials will occur. Furthermore, typical PV systems on commercial buildings have hundreds and even thousands of connectors, increasing the probability of faults occurring.

Currently, there is no final solution on how to mitigate the DC arc risk. The first line of defense is the quality of the components and the installation and the presence of protective devices for the entire electrical system.

The so-called "DC arc-fault circuit interrupter (AFCI)", which is required by the 2011 Edition of NFPA 70, *National Electric Code (NEC)*, for PV rooftop systems > 80 V DC is rather a loss control than a loss prevention feature. The devices are intended to detect DC arcs and eliminate them before they become a fire hazard. However, there are no such marketable devices available currently. The purpose of the 2011 NEC requirement is to stipulate the development and there are ongoing activities being coordinated by Underwriters Laboratories.

Protecting PV systems from high voltage DC arcing faults appears to be a promising mitigation means. However, reliable detection of arc faults is a severe challenge and determination of the appropriate corrective action is difficult. Arcs must be reliably detected, without causing false alarms. Different techniques can be applied, such as voltage, current, radiated energy or a combination of these. Taking corrective actions once the arc has been detected is the second challenge. Furthermore, the correct action for serial arcs can exacerbate a parallel arc. To extinguish a serial DC arc, power production must be ceased and current flow in the DC circuit must be reduced to a very low level. Extinguishment of a parallel arc requires the opposite action: two DC conductors must be shortened to bring the DC voltage to zero. The NEC currently only requires for protection from serial arcs.



Source: Photovoltaic DC Arc-Fault Circuit Protection and UL Subject 1699B, UL, February 2011

In Germany, past PV system fire incidents resulted in the launch of a three year research project (2011-2014) carried out by TÜV Rhineland and Fraunhofer Institute ISE. This project addresses arcing, life safety of fire fighters and fire behavior of PV modules and other components.

ARC Position

Photovoltaic systems on commercial and industrial buildings are a relatively new fire risk and there are no proven, standard protection concepts currently available. "Fire" protection for photovoltaic systems is not a classical "fire extinguishing issue"; it is rather a matter of preventing fires from happening in the first place by protective devices and high installation standards, minimizing the combustible loading should they happen, and avoiding unnecessary hazards for the fire services.

Before installing photovoltaic systems on high value commercial and industrial properties, a hazard and risk analysis should be conducted in order to determine if the fire risk can be minimized or if there is a potential for a catastrophic loss. As of today, there are no reliable means to eliminate the risk of arcing on DC photovoltaic systems and Allianz Risk Consulting strongly discourages the installation of photovoltaic systems on commercial / industrial buildings with combustible roofs (entirely combustible or with combustible insulation). If only components, such as the roof membrane of built-up roofs are combustible, further means of risk mitigation can be evaluated.

The following list consists of system design elements and loss prevention programs that can be used for minimizing the fire risk of photovoltaic installations. Codes and standards are not identical in the various regions of the world and protective devices are under development. The list has been kept general, however most items refer to rigid photovoltaic modules. There is very limited experience to date with building integrated photovoltaic systems (BIPV) and flexible photovoltaic modules.

Photovoltaic Panels

1. 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.
2. Modules should have the approval / listing of an internationally recognized testing laboratory. Currently TÜV Rhineland tests the majority of panels (for compliance with international standards) and FM Approved panels are reportedly underway.
3. 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.
4. In order to provide free space for fire fighters to access the building, the size of the arrays should be limited. The roof should have sufficient pathways and perimeter space around PV modules so that fire fighters can traverse the roof safely. The required safety distance of the modules from fire walls and heat and smoke vents should be in accordance with the respective fire protection standards.

Cables

5. Only solar cables suitable for outdoor applications and severe weather conditions and UV radiation should be used. In the US, UL 4703 is applied since its release in 2005. In Europe, individual specifications per country are in use currently. The standards are not identical and when choosing solar cables, the fire performance should also be considered.
6. Protecting cables from severe weather conditions and from UV radiation helps to slow down the aging process and thus minimizes the risk of hot spots and arcing. Cables should be fixed and routed in closed metal conduits; no loose cables should be allowed. Another means of minimizing the risk of arcing is routing positive and negative wires in separate conduits. Cables should not be run over sharp edges to avoid mechanical damage.
7. Routing of solar cables should not compromise fire compartments of the building (e.g., by penetrating parapeted fire walls). If this cannot be avoided, the openings need to be enclosed and sealed in accordance with the respective standards for fire walls.
8. 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 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 may have a high impact on the roof load and lighter materials are preferred.
9. The main DC cables from the PV panel to the inverter should not be routed through the interior of a building; instead they should run along the outside. If for any reason the cable needs to be routed through the interior of a building, it should be enclosed in a fire resistant duct, chute or other enclosure.

Inverters

10. 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.
11. Inverter(s) should not be mounted on combustible walls such as wood panels or combustible sandwich panels.

Disconnect Requirements

12. A DC disconnector switch between the PV generator and the inverter should be provided, even if local electrical codes do not require this. This allows safe disconnection of a defect inverter or safe disconnection of modules for maintenance purposes. The DC disconnector can also be used in a fire situation.
13. Additional DC disconnector switch(es) closer to the modules ("rooftop shut-off valve" or "fireman's switch") should be considered to support manual fire fighting and de-energize major DC conduits with live currents and voltages. The switches should have remote actuators.

DC Arc Detection and Elimination

14. The risk of DC arcs can be minimized in a high quality installation, however cannot be excluded and the use of DC arc detection and interruption devices for photovoltaic systems should be considered once approved devices are available.

Emergency Response

15. PV systems should be labeled in a clear and systematic manner to ensure that technicians and fire fighters can quickly and easily identify key elements of the system. Standards for labeling are available in some countries.
16. Pre-emergency plans and drawings for the fire department should include the fire hazard of the photovoltaic 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 photovoltaic systems should normally not be left to the fire department.
17. The local fire department should be informed of and familiarized with the photovoltaic installation. They can be given a set of the plans to refer to in case of emergency.

Installation, Maintenance and Inspection

18. PV systems should only be installed by qualified contractors. Training courses and certification processes are available.
19. PV systems should be inspected regularly by qualified professionals.
20. PV systems should be regularly checked for damage from rodents and other pests, which could compromise wiring or insulation.

Other

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

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Questions or comments?

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