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Rooftop Solar PV & Firefighter Safety

I. Introduction

Solar photovoltaic (PV) installations have experienced significant growth in recent years. In particular, solar PV systems worldwide have increased from 1,400 MW in 2000 to 102,156 MW in 2012.[1] Due to technological innovations and cost reductions, solar energy is a viable option for an increasing number of residences and businesses across the United States. Rooftop solar is considered safe – to date there has been no documented case of death from the electric shock, chemical burn or conventional fire caused by a solar panel;[2] however, as more buildings install rooftop solar systems, the likelihood increases that fires will occur on buildings with solar, making it critical for firefighters to receive comprehensive solar education and training.

The sections below give a brief overview of typical solar PV installations, address the major hazards and risks to firefighters, discuss the case study of Germany, and suggest recommendations and resources to ensure that first responders are prepared to fight fires on homes and buildings with rooftop solar PV.

II. Overview – Types of solar systems

There are two main types of solar power: solar photovoltaics and solar thermal. Solar PV is the conversion of the sun's energy to electricity whereas solar thermal technologies convert this energy into heat for building systems.

[1] Masson, Gaetan et al., "Global Market Outlook for Photovoltaics 2013-2017" (European Photovoltaic Industry Association, 2013).
[2] Slaughter, Rodney, "Fundamentals of Photovoltaics for the Fire Service" (California Solar Energy Industries Association, September 2006).

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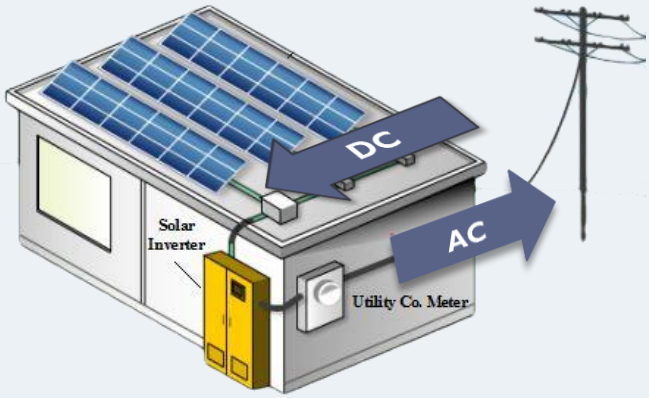
There are three main types of solar PV systems:

1. **Grid-dependent:** in a grid-connected system, any electricity not used onsite is pushed to the electric grid – there is no on-site battery. The vast majority of PV systems installed today are grid-dependent.
2. **Back-up generator:** this model uses a back-up generator to allow for on-site electricity storage that can be accessed in the event of a power outage, but the system is still connected to the electric grid.
3. **Isolated battery storage:** in this option, the system is entirely disconnected from the grid and the structure is reliant on solar PV and an on-site battery for all its electricity needs.

An important part of a solar PV system is the **inverter**, which changes the DC power that is generated by the solar modules into the AC power that is used by home appliances and the electric grid. As shown in Figure 1, the inverter is positioned between the solar modules and the utility meter.

Figure 1: Typical solar PV system configuration



Although solar thermal rooftop systems are less common in the U.S. than are rooftop solar PV systems, solar thermal has been used to heat water for centuries. In recent years, however, the prevalence of rooftop solar thermal has increased. These systems work by using sunlight to heat fluid (typically a chemical other than water to decrease the risk of freezing and increase the efficiency of the heat transfer), which is then connected to an internal storage tank.[3] There is no risk of electrical shock from a solar thermal unit, and so they are generally considered to present a smaller threat to firefighters than solar PV does; however, there is still the potential for scalding liquid to escape should the system be damaged.

[3] Grant, Casey C., "Fire Fighter Safety and Emergency Response for Solar Power Systems" (The Fire Protection Research Foundation, October 2013).

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III. Firefighter Concerns

1. Electric shock from solar panels, inverters, or wiring

The greatest hazard presented by rooftop PV is electric shock; solar arrays should be treated as *electrically charged at all times*. Even systems rated for outdoor weather exposure may not be resistant to water penetration from a fire hose, and firefighter's gloves and boots provide only limited protection against the electrical shock that could be caused by a damaged solar array.[4] There are several methods for mitigating the risk of electric shock, but it is important to remember that none of these factors eliminates the threat entirely:

a. **Never damage solar panels** – typically, firefighters break through the roof of a building to create vertical ventilation and relieve the structure of some of the heat, smoke and gases from the fire. If there is solar on the roof, though, firefighters must take care to *never damage the solar panels* in the process of creating vertical ventilation, as doing so could result in electric shock (or a burn from scalding fluids in the case of solar thermal).
b. **Make use of tarps** – Placing dense tarps over solar panels reduces the light that passes through and thus reduces the electricity the modules can generate, but it is unlikely that it will block 100% of light. Even solar panels that have been covered with a tarp should be treated as electrically charged.[5]
c. **Make use of firefighter foam** – The foam firefighters use is thick enough to reduce the light that reaches solar panels; however, like tarps, it cannot completely block the generation of electricity within the cells.
d. **Be alert even at nighttime** – While fires that occur at night greatly reduce the risk of electrical shock from a solar panel, the artificial light produced by a fire department light truck or potentially even by the fire itself may be enough to cause the solar system to begin producing electricity.[6]

It is important to remember that the panels are not the only part of a solar PV system that can cause electric shock. The wiring and inverter are both electrically charged as well, and similarly cannot be turned off when the sun is out; in addition, batteries (for systems with storage capabilities) can maintain an electrical current at night. It is therefore critical that first responders never cut or damage *any* part of the PV system.[7]

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[4] Backstrom, Robert and Dini, David A., "Firefighter Safety and Photovoltaic Installations Research Project" (Underwriters Laboratories Inc., November 29, 2011).
[5] Slaughter, Rodney, "Fundamentals of Photovoltaics for the Fire Service."
[6] Id.
[7] Grant, Casey C., "Fire Fighter Safety and Emergency Response for Solar Power Systems."

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2. Chemical burns from battery storage systems or thin-film solar cells

The batteries used for electricity storage in PV systems contain chemicals that are highly flammable and toxic. While PV systems with batteries make up less than 10% of installed PV capacity today, the use of batteries will likely increase over time. Although batteries' casings do not catch on fire easily, the electrolyte within is combustible and sometimes, if it comes in contacts with other metals, explosive.[8] First responders should only approach storage batteries with full protective gear – including respiratory protection – and should use dry chemicals, CO2 and/or foam to treat fires involving batteries, as water may not be effective on a chemical fire.[9]

Thin film Solar PV cells also contain trace amounts of toxic/hazardous chemicals. Thin film PV cells are far less common than are multi- or mono-crystalline PV panels, which contain virtually no toxic or hazardous chemicals. While there is no evidence that these substances cause a health or safety threat or that they leach from the panels under normal conditions, there is the potential for trace amounts of these chemicals to escape should the solar panel be damaged or catch fire.[10] Some of the hazardous materials in thin film solar panels can include:

a. **Cadmium Telluride –** a carcinogen that can cause coughing, chest pain, sweating, chills and – in extreme cases – pulmonary edema and death when inhaled.[11]
b. **Gallium Arsenide –** a highly toxic carcinogen.[12]
c. **Phosphorus –** phosphorus is highly toxic and extremely flammable.[13]

3. Additional hazards

a. **Rooftop load** – the weight of solar panels could threaten the structural integrity of the roof, if the roof is damaged in the fire, or as the fire progresses and compromises other sections of the structure.
b. **Hiding places for stinging/biting insects** – most solar panels are raised several inches above the surface of the roof, creating an ideal setting for stinging/biting insects to nest.
c. **Tripping/slipping** – any pitched roof inherently creates the risk of tripping/slipping, but firefighters should be especially cognizant of this risk when on a roof with solar PV, so as to avoid falling onto a panel and potentially damaging it and being electrically shocked.

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[8] Id.
[9] Id.
[10] Fthenakis, V.M. Overview of Potential Hazards, National PV EHS Assistance Center, Dept. of Environmental Sciences, Brookhaven National Laboratory, Upton, NY. Available at: http://www.bnl.gov/pv/files/pdf/art_170.pdf
[11] Slaughter, Rodney, "Fundamentals of Photovoltaics for the Fire Service."
[12] Id.
[13] Id.

d. **Solar architecture** – solar developers have created new types of PV systems such as roofing shingles and thin film PV that can be integrated into the vertical surfaces of buildings. Although these developments do not introduce unique hazards, they create additional obstacles for first responders to combat fire.
e. **Scalding fluids** – Solar thermal systems present all of the same threats as PV does, except that there is no risk of electrical shock, nor is there the potential for any battery hazards. Rather, in the event that a solar thermal cell is damaged, there is a risk of being scalded with the hot fluids inside the panel.[14]

IV. Case Study - Germany

1. Germany

With over 1.4 million solar installations, Germany has the most installed PV capacity of any country.[15] Inevitably some of these structures have caught fire; however, despite the relatively large concentration of installed PV, over the past twenty years only 350 solar systems have caught fire. To date, no firefighters have been injured by solar PV while combatting a fire, nor have there been any other documented PV-related deaths in Germany.[16] This track record can be attributed to solar PV's relative safety and to German procedures for firefighter safety. Germany is at the forefront of developing procedures for firefighter safety, and it has created handbooks on treating fires with solar that firefighters can keep with them at all times.

Similar to the US, Germany defines the main dangers to first responders as exposure to toxic gases, falling pieces, and overheated panels that could combust; and the risk of electric shock.[17] Consequently, Germany requires first responders to use respiratory protection (self-contained breathing apparatus or SCBA) and, if possible, to turn off the building's ventilation system in order to reduce the spread of any toxic airborne chemicals before entering the scene.[18] They then survey the situation to identify where the components of the solar system are, and to determine whether any of them has been compromised by the fire. A second hazard for first responders is encountering live, damaged cables within the building that are connected to the PV system. Touching or spraying these cables could result in electric shock;

[14] Grant, Casey C., "Fire Fighter Safety and Emergency Response for Solar Power Systems."
[15] Wirth, Dr. Harry, "Recent Facts about Photovoltaics in Germany" (Fraunhofer ISE, May 28, 2014), http://www.ise.fraunhofer.de/en/publications/veroeffentlichungen-pdf-dateien-en/studien-und-konzeptpapiere/recent-facts-about-photovoltaics-in-germany.pdf.
[16] Id.
[17] Berufsfeuerwehr Muenchen and Landeshauptstadt Muenchen Kreisverwaltungsreferat, "Photovoltaik: Information fuer Einsatzkraefte von Feuerwehren und Hilfeleistungsorganisationen," n.d.
[18] Id.

therefore, the German solar industry is developing emergency switches with safety relays, which can isolate the PV modules from the rest of the building's electric system.[19]

Although rooftop solar is the most common form of solar PV and thermal systems in Germany, there are also buildings with solar installed on the sides of the buildings, a factor which could potentially make it more difficult to evacuate anyone inside and/or combat the fire without damaging the modules. Consequently, firefighters are required to maintain at least one meter of clearance from any live parts of the solar system in order to reduce the risk of electric shock.[20]

In terms of disabling the solar PV modules, the Munich Fire Department recommends using chemical foam to completely cover all of the panels, and then measuring the voltage drop.[21] Foam may not completely inhibit electricity production in all cases and therefore the panels should still be treated as active; however, foam can significantly reduce the amount of sunlight that reaches the panels, thus reducing the severity of an electric shock. Even under the best conditions when foam can block close to100% of sunlight, it will last a maximum of 5 minutes before the foam starts to break down. Foam should be treated as a safety measure that can reduce risk while combating the fire, but not prevent electric shock. Once the solar system has been disabled and isolated to the extent possible, first responders can then follow their standard procedures to extinguish the fire and secure the area.

IV. Recommendations

1. Safety procedures

Although many of the above hazards cannot be eliminated, even with proper installation of rooftop solar system, there are numerous safety procedures first responders can employ to minimize risk. First and foremost, fire fighters should **take a survey of the site** and evaluate it to answer the following questions:[22]

a. **Impact of the fire –** is the entire system affected or just a section? What is damaged and where?
b. **Blueprint of the area –** where are the different components (e.g. modules, inverter, fuses, battery storage, disconnection from network)?
c. **Information retrieval –** if possible, first responders should contact the solar installers and/or operators to retrieve relevant information about the system.

[19] Wirth, Dr. Harry, "Recent Facts about Photovoltaics in Germany."
[20] Berufsfeuerwehr Muenchen and Landeshauptstadt Muenchen Kreisverwaltungsreferat, "Photovoltaik: Information fuer Einsatzkraefte von Feuerwehren und Hilfeleistungsorganisationen."
[21] Id.
[22] Id.

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Once the site has been adequately assessed, first responders should **observe the following procedures** when entering the PV fire emergency:[23]

a. **Clothing –** wear protective clothing and a SCBA; remove all jewelry. It is imperative to keep gloves and boots dry, because they provide little to no protection against electrical shock when wet.
d. **Tools –** all tools used should have insulated handles to reduce the risk of electrification.
e. **Wildlife –** look out for any insects/birds that may be living underneath the solar modules.
f. ***Never break/cut into/walk across PV-modules*** – solar PV is *always generating electricity during daylight.* All precautions should be taken not to damage the modules.
g. **Lock out/tag out main electrical panel –** this action will isolate a solar PV system from the rest of the building wiring systems.
h. **Lock out/tag out system disconnects** – at the module, controller, batteries and/or inverter to provide additional safety.
i. **Roof ventilation –** if firefighters need to break through the roof in order to ventilate the fire and prevent pressure from building up, the whole should be created at the highest possible point over the fire *without damaging the PV/thermal array.*
j. **Extinguishing a battery –** if there is on-site battery storage which has caught on fire, it should be extinguished with CO_2, foam or dry chemical extinguishers, rather than with water.
k. **Never leave until the site is secure** – especially at night when solar arrays are not generating electricity/heat, the systems may appear secure before they actually are. First responders may require approval from a specialist to approve the safety post-fire.[24]

2. Codes/standards

Given that solar is an increasingly popular technology, the National Standards and state-level building, electrical and fire codes need to be updated to incorporate safety measures for rooftop solar. California's guidelines are among the most progressive in the country; some of their requirements for solar installations include:[25]

a. **Wiring identification –** different power lines are required to be labeled so that first responders can identify which are connected to the solar PV system.
b. **Disconnection means –** must also be accessible to the fire department and must be able to disconnect all conductors of a PV power source from the other conductors in the building.
c. **Battery –** if there are more than twenty-four 2-volt cells connected in series, there must be disconnection means to isolate it from the rest of the system.

[23] Slaughter, Rodney, "Fundamentals of Photovoltaics for the Fire Service."
[24] Berufsfeuerwehr Muenchen and Landeshauptstadt Muenchen Kreisverwaltungsreferat, "Photovoltaik: Information fuer Einsatzkraefte von Feuerwehren und Hilfeleistungsorganisationen."
[25] Slaughter, Rodney, "Fundamentals of Photovoltaics for the Fire Service."

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a. **Labeling –** all parts of the solar system must be labeled so that firefighters can determine where the different components are.
b. **Pocket maps/manuals** – with technical procedures should be available for firefighters.

V. Summary

Solar is a growing technology that presents a new set of considerations for firefighters. While there have not been any documented deaths related to fires that involve solar systems to date, it is important that firefighters understand the potential risks and dangers associated with solar systems and adjust their protocols accordingly when dealing with buildings with solar systems. With appropriate training and education, firefighters will be prepared to address emergencies involving solar systems safely.

VII. Useful Links

- DOE SunShot Initiative: http://www1.eere.energy.gov/solar/sunshot/
- Solar Energy Industries Association's Fire Safety & Solar page: http://www.seia.org/policy/health-safety/fire-safety-solar
- National Fire Protection Association: http://www.nfpa.org/research/fire-protection-research-foundation/reports-and-proceedings/for-emergency-responders/fireground-operations/fire-fighter-safety-and-response-for-solar-power-systems

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