SPFA-150

Photovoltaic (PV) Systems and Spray Polyurethane Foam Roof Systems

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ABOUT SPRAY POLYURETHANE FOAM ALLIANCE (SPFA)

Founded in 1987, the Spray Polyurethane Foam Alliance (SPFA) is the voice, and educational and technical resource, for the spray polyurethane foam industry. A 501(c)6 trade association, the alliance is composed of contractors, manufacturers, and distributors of polyurethane foam, related equipment, and protective coatings; and who provide inspections, surface preparations, and other services. The organization supports the best practices and the growth of the industry through a number of core initiatives, which include educational programs and events, the SPFA Professional Installer Certification Program, technical literature and guidelines, legislative advocacy, research, and networking opportunities. For more information, please use the contact information and links provided in this document.

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This document was developed to aid building construction and design professionals in choosing spray-applied polyurethane foam systems. The information provided herein, based on current customs and practices of the trade, is offered in good faith and believed to be true to the best of SPFA's knowledge and belief.

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DOCUMENT HISTORY

Date	Sections Modified	Description of Changes
April 2017	All	New Document
October 2019	Mounting Options	Note on stand-off profiles added
January 2021	Cover and Header	New SPFA Logo

ROOFING COMMITTEE

Mission Statement

The mission of the Roofing Committee is to provide a wide range of technical service to the SPF (spray polyurethane foam) industry such as, but not limited to:

(1) Review existing documents and serve as a clearing house to ensure the "Continuity of Value" of technical information published by SPFA and others concerning roofing system products and services to the SPF industry;

(2) Review, research, develop, and issue documents concerning new products, systems and services for SPF roofing applications; and

(3) To identify, explore, develop, and communicate an understanding of roofing technical issues facing to the SPF industry.

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INTRODUCTION

More and more, roofs are being employed for purposes other than keeping rain out. As valuable real estate, many roofs are being used as platforms for PV (photovoltaic) systems for the purpose of generating electricity. SPF (spray polyurethane foam) professionals need to understand PV systems and how they interface with and affect the performance of SPF roofs.

PV systems can generally be divided into ground-mount and rooftop. Ground-mount systems can be large (utility scale), small (residential scale) and any size in between.

Rooftop PV systems can also vary significantly in size. Large footprint buildings can have PV systems rated from 50kW to 1000kW, or larger. The size of the PV system is only limited by the size of the rooftop. Residential rooftop PV systems are commonly 3kW to 5kW.

ROOFTOP PV INSTALLATION TYPES

Rooftop PV systems can be installed on racks or adhered to the roof surface. Rack types vary significantly. Racks can be placed directly on a rooftop and held in place with ballast; these are considered non-penetrating rack systems. Racks also can be installed using penetrating supports that require flashings. Each has advantages and disadvantages (ballasted racks may block water flow and affect drainage; penetrations require leak- and maintenance-prone flashings).

Note: In general, SPFA does not recommend adhering PV panels directly to SPF roof surfaces. This document includes a descriptive discussion of adhered systems for informational purposes only.

Figure 1 - Typical Penetrating Rack-Mounted PV System

Figure 2 – Typical Ballasted PV Rack System (prior to PV panel installation)

DEFINITIONS

Alternating Current (AC) – In photovoltaic applications, an electrical current that reverses direction at regular intervals or cycles.

Direct current (DC)- In photovoltaic applications, an electric current of constant direction, usually at relatively low voltage and high current.

Ground – a connection between an electrical circuit and the earth.

Grounding – connecting to ground or to a conductor that is grounded

Inverter – In a photovoltaic system, a device that converts direct current (DC) power from the PV array or battery to alternating current (AC)

Photovoltaic (PV) – able to produce electricity from light or solar energy or relating to the process of doing so.

Photovoltaic array – an assembly of photovoltaic modules or panels and their support structure and other components (if used), that forms a complete DC power producing unit.

Photovoltaic cell – a type of photocell that changes radiant energy or sunlight into electricity.

Photovoltaic module – a single package that contains two or more electrically interconnected photocells, including framing and mounting points.

Photovoltaic panel – A collection of photovoltaic modules mechanically fastened together, wired and designed to provide a field- installable unit.

Photovoltaic string – A group of photovoltaic cells or modules connect in series, commonly used to produce high voltages required in grid-tied PV systems.

Rack /racking system – The support and/or mounting system for PV panels.

Grid - An **electrical grid** is an interconnected network for delivering **electricity** from suppliers to consumers. It consists of generating stations that produce **electrical power**, high voltage transmission lines that carry **power** from distant sources to demand centers, and distribution lines that connect individual customers.

PV SYSTEMS AND COMPONENTS

PV CELLS, PANELS, STRINGS, ARRAYS

PV cells are the basic unit used to convert light to electricity. Many PV cells are bundled together to make a PV panel or module. The terms “module” and “panel” are used interchangeably. PV panels are grouped electrically to create a PV string. Depending on the size of the PV system, two or more strings are combined to create a PV array.

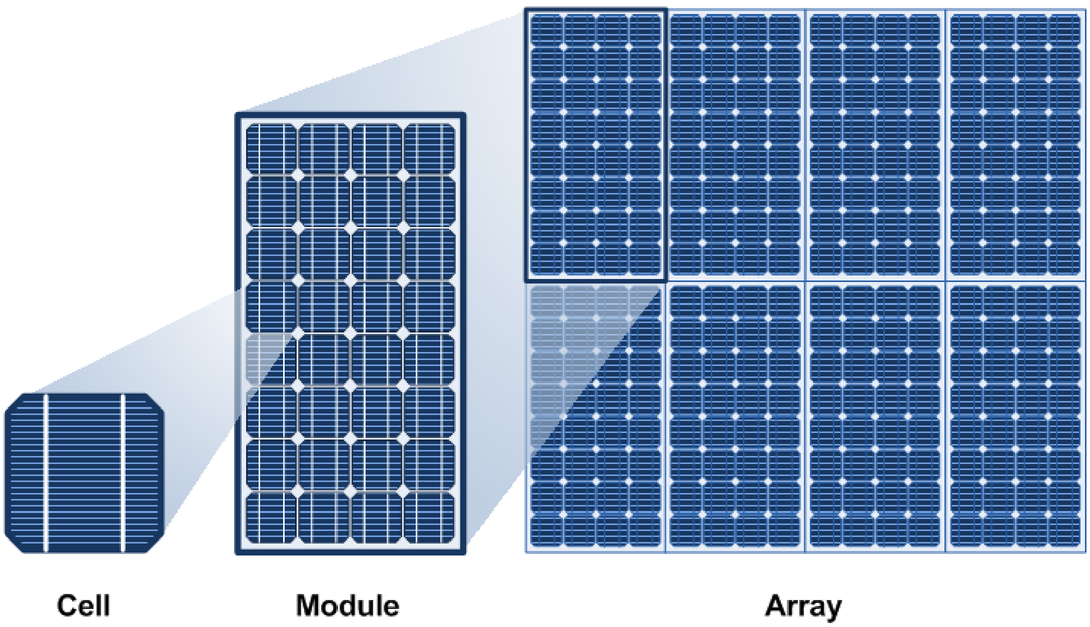

Figure 3 – PV System Components

PV TYPES: CRYSTALLINE VS. THIN-FILM

The type of semiconductor differentiates PV panels. cSi (crystalline silicon) is the dominant material used as a semiconductor. cSi panel types are typically rigid panels with a glass face and a metal frame. Visually, cSi panels have a grid of individual cells that are roughly 6” x 6” with small spaces between each cell. Cells are connected electrically, and panel-to-panel connectors are located on the underside of the PV panels.

cSi can further be subdivided into mono-crystalline and polycrystalline. Mono-crystalline cells are one consistent color, a blue-black. Polycrystalline cells are “speckled” with a variety of shades of the blue-black color. Polycrystalline cells are being manufactured in additional colors, such as yellow/gold, red and green.

Thin-film is the second predominant PV type. Thin-film is a method of production, not a PV panel type. The roofing industry initially was introduced to “thin film” PV panels as flexible, self-adhesive panels, secured directly to the roof surface. While thin-film is conducive to this type of PV panel, thin-film PV panels are often manufactured as rigid, framed panels, similar to crystalline-based panels, but they look quite different. Thin-film PV panels are not cell-based so panels do not consist of individual cells. Thin-film panels look solid; there are no spaces between cells.

Figure 4 - Glass-front, framed, rigid cSi panels on the left; glass-front, framed, thin film panels on the right.

Figure 5 - Thin film, flexible PV panels adhered to roof surface

PV COMPONENTS AND POWER CONNECTIONS

A PV system includes much more than the PV panels. The BOS (Balance of System) components include the racks, rails, rooftop attachment devices, grounding systems, wiring, wiring harnesses, combiner boxes, inverter(s), and connection to the main electrical panel. BOS components also include control modules, and batteries for PV systems that are used for off-grid installations.

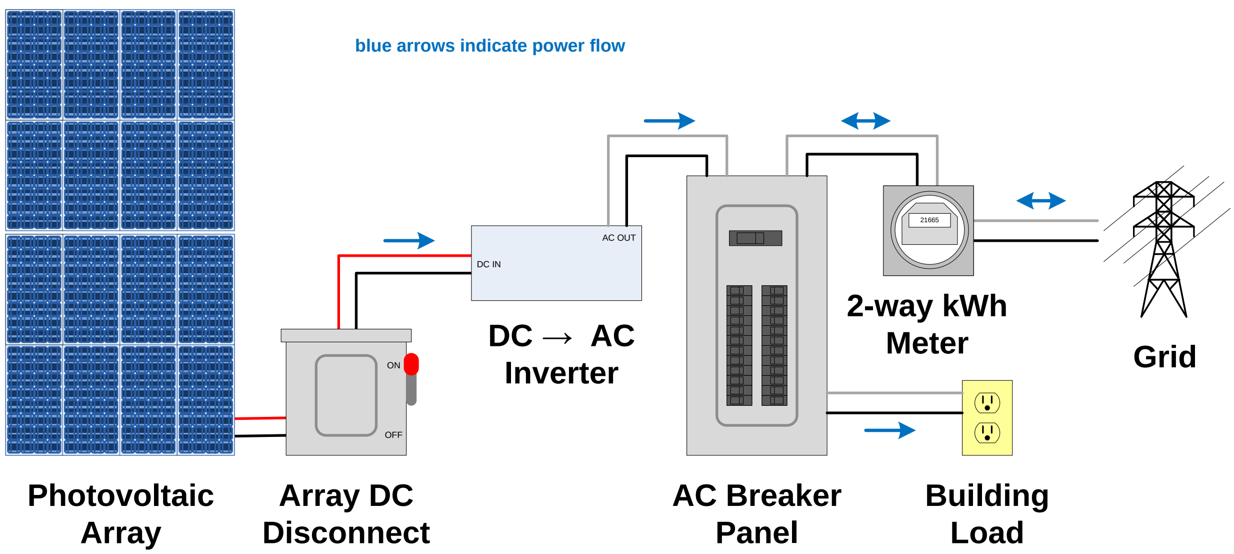

Figure 6 - PV system basic layout

PV systems are categorized as grid-tied, off-grid, or hybrid systems. Grid-tied systems do not include storage (e.g., batteries). It's very important to recognize that a grid-tied system without batteries will not send electricity to the building during a power outage. For grid-tied systems, when the power goes out, the PV system will not function as a back-up generator. A PV system needs storage (e.g., batteries) to provide power during an electrical black-out. Off-grid systems include storage and can operate electrical devices as long as there is stored energy. For off-grid systems, the PV panels send electricity to batteries that provide electrical power for use. Hybrid PV systems are grid-tied and have storage capacity. A hybrid system can be configured to operate critical components during a black out. A critical component may be a computer server or a refrigerator unit. Hybrid systems require special inverters that can switch between the batteries and the grid.

PV panels make DC (direct current) electricity. An inverter is needed to change the DC power into alternating current that most of our commercial and residential devices use.

PV systems can convert DC to AC electricity at an inverter or at the electrical panel. Most commonly, PV panels are electrically connected and DC electricity goes to a string inverter.

Separate micro-inverters can be used for each PV panel, which includes DC wiring from the PV panel to the micro-inverter. Additionally, PV panels can have micro-inverters integrated on the backside of the PV panel, which eliminates the DC wiring; these are called "AC panels."

DESIGN CONSIDERATIONS

ELECTRICAL SAFETY

PV panels produce electricity when exposed to light. Working with and around electrical generating devices can be dangerous; safety precautions are a must.

When a single PV panel is exposed to light, electricity is produced, but because an individual panel is not part of a circuit, electricity does not flow. Only when a circuit is complete, does electricity flow. Theoretically, a worker can "complete the circuit" by connecting the two wires from the backside of a PV panel.

SERVICE LIFE

Rooftop PV installations should not interfere with the main priority of any roof system, which is to provide weatherproof, long-term, reliable service. A number of factors should be considered when designing and installing rooftop PV to ensure a roof will perform as expected.

Removing a PV panel for roof system maintenance may be necessary. It is incorrect to simply unplug/disconnect an individual PV panel from a string or an array. A PV system should be properly shut down to prevent shocks to workers and arcing between electrical connections. Decommissioning a PV array typically means following a set of specific, ordered steps to reduce hazards to humans and the PV system. The owner of the PV system should have an owner's manual with a shut-down procedure to explain the shut-down/decommissioning process. The shut-down procedure is provided by the inverter manufacturer.

Caution: SPF contractors should never disconnect/decommission a PV panel or system unless they are trained and qualified to do so.

NEC® (National Electric Code, also known as NFPA 70®) includes requirements for safe electrical installation of PV systems. The NEC is published by the NFPA (National Fire Protection Association). Within the NEC, Article 690, Solar Photovoltaic Systems, includes requirements for PV systems. Article 690 includes circuit requirements, disconnects, wiring, grounding, marking (labeling), and many additional topics.

FIRE SAFETY

The fire safety of roof-mounted PV systems has not been fully investigated. PV panels may be tested in accordance with_UL 1703 *Flat-Plate Photovoltaic Modules and Panels* which incorporates UL 790 as a fire test method for the panels. This yields a PV panel fire classification similar to roofing materials (i.e., Class A, B or C). However, fire testing the PV panel itself may not provide adequate information for the design of a fire classified roof system. It is not clear what the fire resistance classification of a roof system would be where, for example, a Class A roof covering has a Class C PV panel system mounted on it.

Furthermore, fire research indicates that the installation of rack-mounted PV panels (regardless of their fire classification) increases the potential for fire spread of a roof covering system due to the panel's entrapment of flames and the resulting increase in heat flux to the covering. Thus, a Class A roof covering with a classified PV panel mounted on it may not perform as a Class A system.

Solar ABCs (Solar American Board for Codes and Standards) performed significant research on this subject for a number of years, beginning in the late 2000s. Because of the research, the existing test used to determine fire resistance classification was modified to test roof coverings and PV panels as a "system." PV panels tested to UL1703-2013 (the modified standard) are tested with a roof system, a mounting system and the PV panel. Versions of UL 1703 from 2012 and earlier do not include the modified test protocol. The SPFA recommends using PV panels that have been tested and rated according to UL 1703-2013. (See the References section for Solar ABC's report.)

An additional complication to the fire safety of roofs (and buildings) having roof-mounted PV systems is the reluctance of fire fighters to access the roof during fire events. The IFC® (International Fire Code) includes rooftop layout requirements, as well as requirements for accessing roofs and PV panels while on a roof. The IFC® requirements facilitate the safety of maintenance workers and emergency personnel who may need access to a rooftop. However, concerns over the inability to shut off the electrical potential of PV panels remain.

HEAT BUILDUP

PV panels are intended to capture light (sunlight) to create electricity. However, because PV panels only convert approximately 15-20 percent of light to electricity, there is a lot of energy that is not converted to electricity which is released as heat. A unique characteristic of PV panels is that they are more efficient as their temperature drops. Because of this, most PV panels are installed so that there is airflow under the panels; the airflow helps reduce panel temperatures and improves efficiency. PV panels that are 4 or 5 inches or more above the surface of a roof will not change the temperature of a roof surface. The PV panels actually provide to shade/block UV from the roof surface.

Although not currently common, adhered PV panels, by definition, do not have backside venting. Therefore, the underlying roof system must be capable of performing when temperatures reach 200°F or higher. SPFA does not recommend installing adhered PV panels directly to SPF roof surfaces.

LOAD

PV arrays will add weight to a rooftop. Adhered PV panels are the lightest—about 1 psf. Rack-mounted PV arrays with penetrating attachments are relatively light—about 2 to 3 psf. Ballasted arrays can be 4-6 psf. Ballast, because it is used to resist wind, may not be uniformly placed throughout a PV array. Typically, more ballast is used at perimeters and corners of a PV array; localized loading from ballast can be as high as 12-17psf.

On existing buildings, the structure should be analyzed to determine if the additional weight of the PV system is acceptable. A structural engineer should perform the analysis based on the PV racking style/type and array layout.

Roofs are required by codes to provide "live load" capacity. Live loads include people, snow, and other scenarios that temporarily add load. The weight of a PV system typically is less than the live-load capacity of a roof's structure. Without a structural analysis, the live load capacity of a roof is reduced by the addition of a PV system.

In addition to the engineering consideration of the weight added to the structure, in the case of a ballasted racking system, the load which bears upon the surface of the SPF roof should also be considered. Most ballasted racking systems employ a foot or skid which rests upon the surface of the roof. Many racking manufacturers specify a rubber pad be installed between the racking and the roof. Each racking system should be assessed to confirm that no sharp edge will contact the roof or point load an excessive amount of weight onto the SPF roof system. Many ballasted racking systems will distribute a load of approximately 5 psi onto the SPF roof though this will vary with the racking product and the amount of ballast required for the project. This load should be considered with each project to confirm that a considerable safety factor exists between the weight bearing on the roof and the compressive strength of the foam. This should also be reviewed by the SPF system manufacturer to confirm compatibility with the installed SPF roof system.

Another important loading consideration is whether a PV installation will create new locations for drifting snow. Snow can build up behind sloped PV panels and add considerable weight to the roof structure.

WIND

Wind resistance of PV systems is critical to the long-term success of a rooftop PV installation. Ballast, attachment and wind-resistant racking systems are used to resist wind loads. Like roofs, perimeters and corners of PV arrays are the critical locations. PV panels that are displaced during a wind event can abrade or puncture a roof and can damage other PV panels. It is recommended that roof-mounted PV systems have the same uplift resistance as the roof system upon which they are installed. ASCE 7 standard is the basis for determining wind loads for roofs and PV systems.

EQUIVALENT SERVICE LIFE

Ideally, a roof system and the PV system should have the same expected service life. Removal (decommissioning) and reinstallation (re-commissioning) of a PV system is costly, and the cost should be weighed relative to the cost of roof replacement at the time of PV installation. Ballasted, rack-mounted PV systems are difficult, if not impossible, to reroof (or recoat) under and around. Elevated racks with adequate space beneath may be able to be left in place when reroofing. A PV system that covers, for example, 10% of the rooftop will be easier to relocate during reroofing than a PV system that covers, for example, 75% of the rooftop. Building owners should be advised of future reroofing costs with roof-mounted PV systems.

Reroofing and maintenance should be considered when designing a rooftop PV system to account for future costs and efficiencies during reroofing and recoating.

DRAINAGE

Drainage on rooftops is important for safety of the structure and longevity of the roof system. Additionally, PV arrays and wiring supports that pond water may void the roof manufacturer warranty.

PV arrays often have many points of contact with a roof, and these are possible locations that will block or slow drainage. PV racking should be positioned to minimize ponding water, and/or include methods (notched pads) to allow drainage under points of contact.

SPF AND COATING SELECTION

Design life expectancy of the SPF roof (including foam and coating selection) should be based on the desired service life of the rooftop PV system. Toughness and durability are key characteristics for roofs used as platforms for PV systems. In general, SPF is more durable as the density increases. Three-pound density foam for roofs should be appropriate as a substrate for a rooftop PV system. An SPF roof system will be stressed during PV installation because of the quantity and repetitiveness of foot traffic. Coatings with granules will help protect a roof from damage during installation and during annual maintenance.

Coating type (e.g., silicone, polyurethane, acrylic) is less important than coating thickness, number of coats and the inclusion of granules.

A roof surface beneath PV panels is likely not to dry as quickly as non-covered portions of a roof. Coatings that stand up better to standing water and/or biological growth should be selected when drying conditions are reduced by the installation of PV panels that shade the roof surface.

The efficiency of a PV system frequently improves when it is placed above a cool roof such as an SPF system with a white top coating. Because of their lighter color, reflective coatings reflect sunlight (solar reflectance) and efficiently emit thermal radiation (thermal emittance). By cooling the roof and lessening heat transfer into the building, cool roofs reduce the cooling load of the air-conditioning system. This leads to both energy and financial savings while improving sustainability.

SERVICE AND MAINTENANCE

PV SYSTEM ACCESS AND REMOVAL

Everything requires maintenance of some kind in some amount. Roof systems should be inspected and maintained at least twice a year. PV systems, like roofs, have no moving parts, but because they are exposed to the weather, PV systems require maintenance and servicing to ensure proper operation over their life. Wiring, attachment points, and flashings should be inspected. Cleaning of the top surface of the PV panels may be required.

Caution: SPF contractors should never disconnect (decommission) a PV panel or system unless they are trained and qualified to do so.

In order to properly maintain and service a rooftop PV system, roof and PV workers must be able to access the roof and PV panels, respectively. PV systems should not block access to drains, penetrations, flashings, mechanical units, or other rooftop equipment. Similarly, PV arrays should be installed so PV maintenance workers can access the wiring, inspect panel-to-racking connections, and properly clean top surfaces without walking or stepping on PV panels. PV panels are not intended to be walked on or stepped on: point loading caused by foot traffic can result in micro cracks in the PV cells, reducing output over the life of a PV panel. Rooftop layout of a PV system will affect the overall service life of the roof and PV system. IFC® provides rooftop layout and access requirements.

OVERSPRAY PROTECTION

The cleanliness of a PV panel's top surface is critical to its performance. If the top surface becomes dirty, debris covered, or damaged in a way that does not allow sunlight to penetrate, electricity production can be reduced dramatically, or stopped completely. If SPF or coatings are sprayed in the vicinity of PV panels, it is critical to cover the top surface to ensure overspray does not adhere to the PV panel. It may be impossible to remove overspray from a PV panel; oversprayed PV panels may require replacement (an expensive remedy to a preventable problem).

ROOF AND PV SYSTEM SERVICE TRAFFIC

The presence or addition of PV arrays to a roof system will change the access and traffic patterns typically associated with maintenance activities for most roofs, roofing systems, and rooftop areas. The presence of PV arrays will increase the frequency of access to the roof for purposes of inspection, maintenance, and repair as well as focus additional traffic to areas adjacent to the PV arrays and related equipment. Designers, contractors, and building owners should consider strategies to mitigate or otherwise address potential issues that may arise from increased rooftop access and traffic.

ROOF WARRANTIES

Installation of a rooftop PV system may void an existing roof system warranty if manufacturer's requirements are not followed. A PV installation needs to comply with the roof system manufacturer's specific "PV installation" requirements. The PV system installer should contact the roof system manufacturer or warranty holder to find out the specific requirements to maintain the warranty.

New construction roofs should be designed and warranted appropriately for a rooftop PV system. PV on new construction should be coordinated with the roofing manufacturer/installer to ensure details are designed and installed for longevity and durability of the roof and PV system.

For existing roofs with labor and material warranties, the roofing contractor and roofing manufacturer should be contacted prior to design and installation of a PV system. It is likely a PV system installation will trigger requirements for construction details, abrasion resistance and traffic protection. A roofing manufacturer should inspect a rooftop/project site prior to installation to determine site-specific requirements and after a PV system is installed to ensure the warranty requirements are met. The company or entity holding a warranty has the right to a post-PV installation inspection before providing a new or continued warranty.

SPF roof system manufacturers might inspect the roof prior to PV installation and require specific repairs/upgrades so the roof is capable of being an appropriate platform for the PV system. Most roof system manufacturers will have construction detail requirements for penetrating attachments and non-penetrating supports. After installation of the PV system, the warranty holder might re-inspect the roof to ensure requirements were followed and validate the warranty.

For non-warranted SPF roof systems, PV installation should include a roofing contractor to ensure penetrations are flashed appropriately.

FINANCING AND ACQUISITION

There are numerous ways to finance or subsidize PV systems. PV system financing is a dynamic field, subject to local laws and regional incentives. Options include:

- PPA (Power Purchase Agreement): An arrangement between a solar "integrator" and a building owner. The integrator installs, maintains and owns the PV system, and the building owner receives renewable energy at a fixed rate for the length of the contract.
- PACE (Property Assessed Clean Energy) Financing: The cost of a PV system is tied to the property taxes. Essentially, a municipality loans money to a buyer for a PV system and the loan in paid back when property taxes are paid. This leaves the payments tied to the home or business owner. Specifics about PACE programs vary by location.
- Rebates and Incentives: State, federal and local governments; utility companies and others offer a variety of rebates and incentives for renewable energy investments. Details vary considerably. The US DOE (Department of Energy) and North Carolina Solar Center maintain a database at www.dsireusa.org .
- Net Metering and Feed-in Tariffs: Net metering is a way to reduce one's electricity bill. When excess electricity is produced, it is sent to the grid and "makes the meter spin backward." A PV system does not need to create more electricity than is used in a billing cycle. Electricity that is produced and not used is sent to the grid for a credit. Consider a home where no occupants are home during the day. During the sunniest part of the day, a PV system will produce electricity when the least amount of energy is being used. This is when electricity is sent to the grid. Conversely, at night, when PVs are not producing electricity, the grid supplies the energy. It is possible to produce enough electricity during peak production times to offset total use.
  Feed-in-tariffs: FITs are direct payments to the PV owner for electricity that is sent to the grid. Essentially, a PV owner is paid to produce electricity. Typically, a secondary meter is required to track the amount of electricity produced and sent to the grid.
- Leases: Building owners (most commonly residential) may lease PV systems rather than purchase outright. Typically, the building owner accrues some benefit based on energy savings, while the PV owner receives rental or other payments from the building owner as well as the rebates and incentives discussed above.

CODES AND STANDARDS

IBC® (International Building Code)

The 2012 IBC Chapter 15, Roof Assemblies and Rooftop Structures, includes rooftop PV requirements. The requirements are similar to other roof systems; included are flashing, compatibility, fire, wind, and material requirements. Rack-mounted PV system requirements are included in Section 1509, Rooftop Structures. From the building code perspective, rack-mounted PV arrays are similar to all other rooftop equipment and need to meet material, fire, wind, and labeling requirements. Section 1511, Solar Photovoltaic Panels/Modules ties rooftop PV installation to the IFC. Wind resistance requirements are included in IBC Chapter 16, Structural Design.

IRC® (International Residential Code)

The 2012 IRC Chapter 9, Roof Assemblies, includes similar requirements for roofs as the 2012 IBC. PV systems are included in the scope of Chapter 9, therefore rooftop PV needs to meet material, wind, fire and labeling requirements. However, the IRC is organized differently than the IBC. Chapter 23, Solar Systems, in the IRC includes the specific requirements for solar thermal (hot water) and photovoltaic systems. Chapter 23 ties rooftop PV to NFPA 70, the National Electric Code.

IFC® (International Fire Code)

The 2012 IFC is the first edition of the fire code that includes requirements for PV installation. The increase in rooftop and ground-mount PV installations led to the necessity for fire-safety requirements. Within in the IFC, Section 105.7.13, Solar Photovoltaic Power Systems requires a permit to install or modify a PV system. The requirements for PV systems are included in Section 605, Electrical Equipment, Wiring and Hazards. Section 605.11 includes specific requirements for rooftop PV installations. In addition to Access and Pathways requirements, 2012 IFC also includes requirements for permitting, marking, location of DC conductors (wiring), and ground-mounted photovoltaic arrays. Even if the 2012 IFC is not adopted in the location where a rooftop PV system is installed, SPFA recommends following the latest codes to ensure a rooftop and the overall building is as safe as possible.

NEC® (National Electric Code, aka NFPA 70)

NEC includes requirements for safe electrical installation of PV systems.

Others

- UL 1703 Flat-Plate Photovoltaic Modules and Panels
- UL 1741 Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources
- IEEE 1547 Standard for Interconnected Distributed Resources with Electric Power Systems
- ASTM E2766 Standard Practices for Installation of Roof Mounted Photovoltaic Arrays on Steep-Slope Roofs

MOUNTING OPTIONS

For low-slope roofs, rack-mounted PV arrays are typically installed using one or a combination of the following methods:

1. Individual stand-offs that are flashed into the roof;
2. Traditional roofing curbs with trusses spanning from curb to curb; or
3. Ballasted trays on a roof surface with occasional attachment.

Examples of these various mounting options are shown in the Figures 7-14.

> NOTE:
> Stand-offs with sharp cornered profiles, such as angles, channels, T-bars, solid bars, square/rectangular bars should be avoided. Stand-offs made from round tubes or profiles with rounded corners are preferred.
>
> The sharp corners of certain profiles may induce high stress concentrations in the coating or foam under normal array movement from wind load or thermal expansion. These stress concentrations may cause premature failure of the coating or foam near the stand-offs.

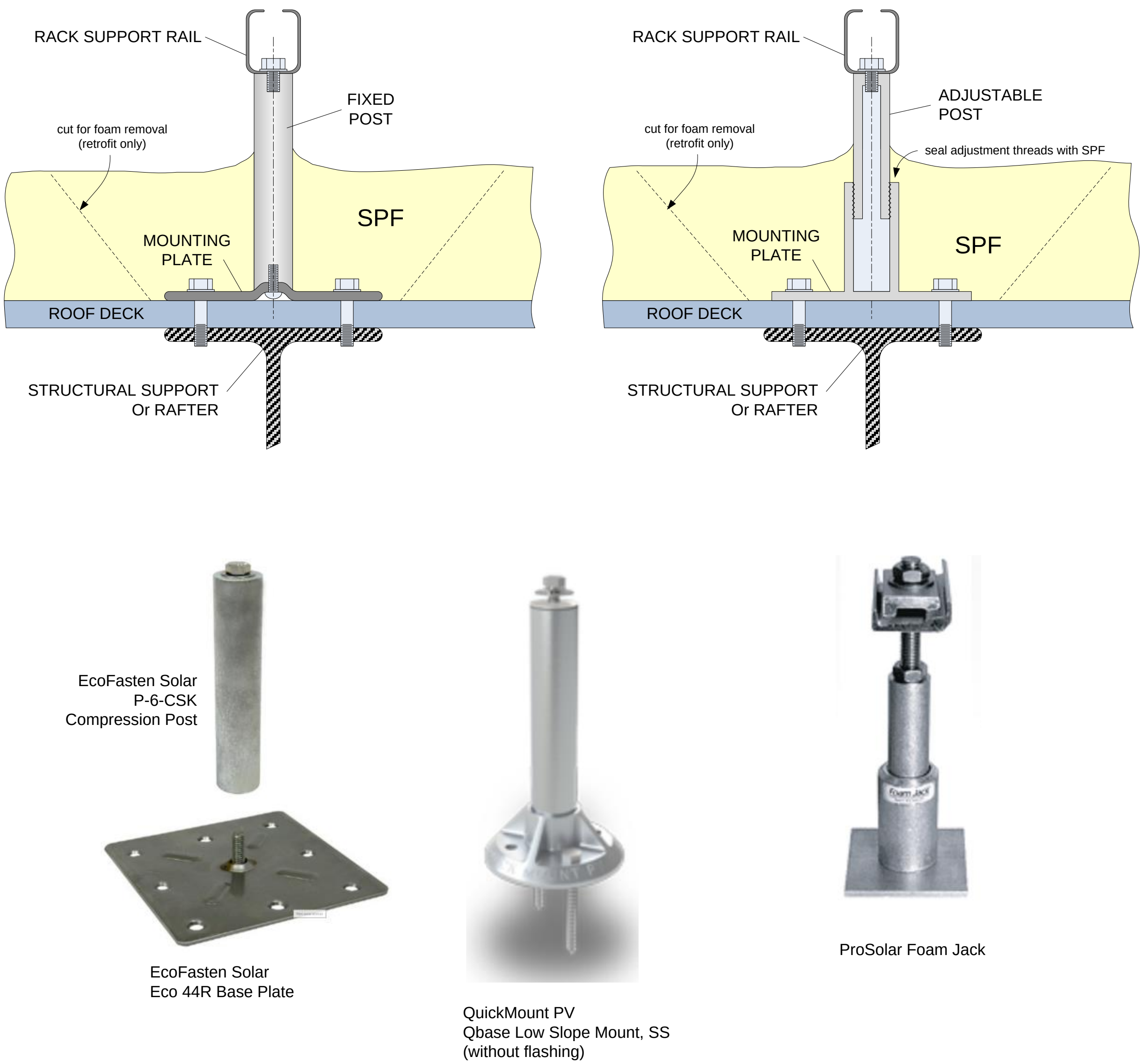

Figure 7 - Individual stand-offs

Figure 8 - Typical roof curb with truss supports.

Figure 9 - Trusses between penetrating stand-offs.

Figure 10 - Penetrating attachments with post/beam.

Figure 11 - Combination mounting using non-penetrating supports and some penetrating attachments.

Figure 12 - Non-penetrating, ballasted system

Figure 13 - Flashed stand-off attachment.

Figure 14 - Slip sheet under non-penetrating support of ballasted racking system.

RESOURCES

List of Resources

- Solar ABCs: Fire Classification Rating Testing of Stand-Off Photovoltaic Modules and Systems
- CEIR *PV Racking and Attachment Criteria for Effective Low-Slope Roof System Integration*
- NRCA *Guidelines for Roof Systems with Rooftop Photovoltaic Components*
- Solar Energy International's *Solar Electric Handbook: Photovoltaic Fundamentals and Applications*
- *Photovoltaic Systems*, James P. Dunlap and In Partnership with NJATC (National Joint Apprenticeship and Training Committee)
- *Solar Electricity Handbook - 2014 Edition: A Simple Practical Guide to Solar Energy - Designing and Installing Photovoltaic Solar Electric Systems*, Michael Boxwell
- www.energy.gov/eere/office-energy-efficiency-renewable-energy
- www.seia.org
- www.irecusa.org