

AN INTRODUCTION TO

Photovoltaic Systems

BY HUSNU KALKANOGLU AND CHRIS FISHER

Solar photovoltaic (PV) systems are widely known for their ability to generate electric power for homes and commercial buildings through the absorption of energy from the sun's rays. In the movement toward increased sustainability, cleaner energy, and lower utility bills, they are becoming a more common sight, especially in regions of the country where sunlight is the strongest. However, there are still misunderstandings among building and design professionals—not to mention their customers—about the finer details of a PV system.

Before specifying or installing a PV system, building and design professionals should have a solid understanding of these systems and how they function. This article will go over the anatomy of PV systems and how they operate, factors that influence their performance, and how they contribute to LEED certification.

ANATOMY OF A PV SYSTEM

The most basic part of a PV system is the cell. Groups of cells are assembled in a series to form a module, which is enclosed between sheets of tempered glass or plastic to protect the cells. A group of modules wired together in one line is called a string, and a set of module strings installed together is called a PV array. The array may consist of one or more strings. An array may be designed to generate a specif-

ic amount of energy or to maximize the available roof area.

The most common type of PV cell is crystalline silicon (c-Si). These can be fabricated from either a single silicon crystal (monocrystalline) or multiple silicon crystals cast in a single block (multicrystalline or polycrystalline). Thin-film PV cells, however, use alloys, such as amorphous silicon (a-Si), copper indium gallium diselenide (CIGS), and cadmium telluride (CdTe).

Thin-film modules are made by depositing a very thin layer of semiconductor onto a substrate—usually glass, metal foil, or plastic. Flexible, thin-film modules are deposited onto flexible substrates (metal foil or plastic) and encapsulated in plastics to

retain flexibility. Currently, these modules are less efficient than mono- or multicrystalline-based modules, but also generally cost less.

BASIC COMPONENTS OF A COMPLETE SYSTEM

Along with the PV array, the PV system is completed with equipment collectively called the Balance of System (BOS). The overall task of the BOS is to convert the electricity generated by the PV array into a form identical to the electricity provided by the building owner's utility company and safely route it to the building's existing electrical system for distribution. Additional functions involve maximizing energy harvested by the PV array, safety, mainte-



Photo 1 – A California home with an EnerGen™ PV solar power roofing system from CertainTeed. The EnerGen™ system features integrated UNI-SOLAR® thin-film laminates that integrate with traditional asphalt roofing shingles. Photo by C. Scott Widdes.

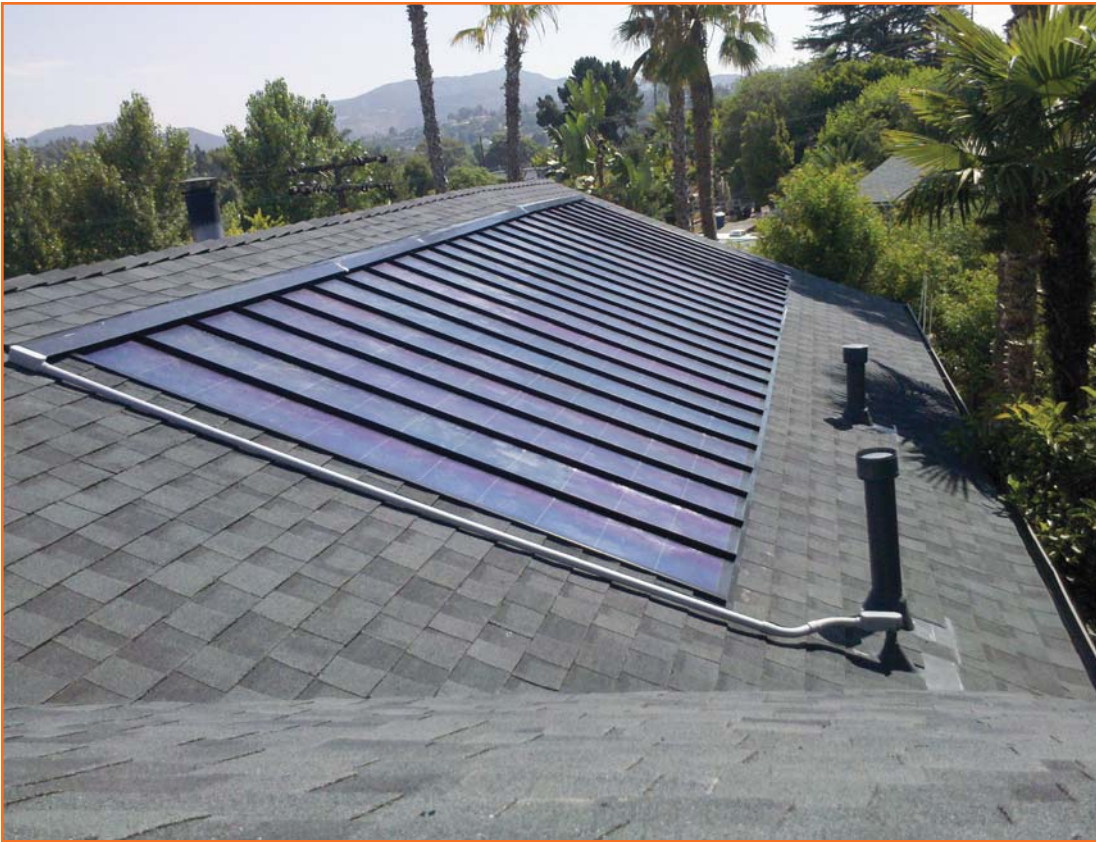


Photo 2 – EnerGen™ system installed on the Michigan governor’s mansion. Photo compliments of the Michigan governor’s mansion.

nance, and monitoring of the array. In this article, we are focusing only on buildings that are grid-connected.

The major components of the BOS include an inverter; conduit and wiring; disconnects; and fuses, if needed. The BOS connects and interacts with a building’s existing electrical system to distribute power to loads in the building or to backfeed the grid.

PV System Inverters

The primary job of a grid-tied inverter is to convert the initial direct current (DC) electricity generated by the PV array to alternating current (AC) electricity, allowing it to provide power to appliances in the building. Inverters are also responsible for conditioning the converted AC power to match that of the electrical power coming from the grid, allowing excess power to flow into the

grid. Many utilities support a policy of “net metering” so that the utility bills are credited when electricity flows into the grid via the inverter.

Grid-tie inverters are also designed to quickly disconnect from the grid if it goes down. This is a National Electrical Code (NEC) requirement that ensures that if a blackout occurs, the inverter will not be feeding any current into the grid, which could harm any linemen working on the grid. This also means that the home or building is unable to use any of the DC power being generated by the PV system while the grid is down.

Inverters typically enable the PV array to be monitored for power output, usage, and other performance characteristics. They utilize a technique called Maximum Power Point Tracking (MPPT) to get the maximum power from the PV array. The inverter constantly monitors the PV array’s electrical production and adjusts the amount of current it draws from the array to get the maximum power.

Disconnect and Overcurrent Devices

The NEC requires disconnect devices (circuit breakers or switches) between PV equipment and all sources of power. For

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example, a disconnect device is needed between the inverter and the grid. This enables service and emergency personnel to ensure that no power is flowing in the system if they have to access it or if it is damaged. Overcurrent devices, such as fuses or circuit breakers, may also be required by the NEC to protect conductors in a PV system. These devices protect the wire from excessive electrical current that may flow if there is a fault in the system, either on the DC or the AC side. A DC disconnect is required by the NEC between the PV array and inverter. An AC disconnect between the inverter and main breaker panel may be required by code or by a utility provider. At times, a circuit breaker may be sufficiently used as an AC disconnect. Many inverters have integrated DC or AC/DC disconnects that fulfill NEC requirements. PV system installers should contact their local jurisdictions to clarify PV system code requirements before beginning a project.

The Building's Electrical System

PV systems are designed to integrate with existing electrical equipment in the building. The main breaker panel is responsible for receiving and distributing power from the inverter or grid to electrical loads in the building. The utility meter records incoming and outgoing energy for the utility company for billing purposes; the excess electricity flows to the grid, generating an offset to grid use. The public utility grid provides electricity at night and whenever power demand exceeds solar production.

BASIC TYPES OF PV ROOFING SYSTEMS

As touched on earlier, there are, in general, two basic types of PV system: rigid and flexible. Both types may also be building-integrated photovoltaic (BIPV).

Rigid PV Roofing Systems

Rigid PV systems, which use rigid modules that are fixed onto the surface of the roof by a combination of rails, hooks, clamps, and/or dedicated fixings, are the most common and traditional examples of PV roofing. Though they are currently the most efficient at generating power, they are also large, heavy, and difficult to install. In addition, installers have to drill several holes through the roof deck and into the rafters of a building to provide a stronger attachment for rigid PV modules, creating potential for roof leakage. Rigid PV systems are also often considered cumbersome and unattractive from an aesthetic perspective.

BIPV Roofing Systems

BIPV roofing systems have been developed by manufacturers in recent years to answer the need for more aesthetically pleasing PV roof options that are also easier for the average roofing contractor to install. BIPV refers to PV technology that forms part of the structure to which it is affixed. Typically integrated into a more standard roofing system such as shingles, BIPV products like EnerGen™ Photovoltaic Roofing System by CertainTeed can add architectural interest to the roof. The modules sit flush with surrounding roofing

shingles or tiles, which allows them to somewhat blend into the design.

With a lighter weight than rigid PV modules, BIPV roofing systems are easier for roofing contractors to work with and are easier to install. Any roofer who has mastered the installation of a skylight will likely be able to install BIPV roofing systems. And, since the modules are attached to the roof deck instead of the rafters, installation is less intrusive to both the structure and the roofing system.

Now that we've covered the components and different types of PV roofing systems,

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let's take a look at the other essential ingredient needed to produce solar energy: solar radiation.

GENERATING ELECTRICITY FROM SUNLIGHT

There are two types of solar radiation: direct and diffuse. Diffuse solar radiation results from sunlight being absorbed, reflected, and scattered as light passes through the atmosphere. Air molecules, water vapor, clouds, dust, pollutants, fires, and volcanoes all contribute to this phenomenon. Solar energy that reaches the earth without being diffused is called direct solar radiation. The amount of direct solar radiation that reaches the earth varies between zero and 90%, based on complete cloud cover or during a clear, dry day. The sum of the diffuse and direct solar radiation is called global solar radiation.

Direct and diffuse solar radiation are collected and converted to electricity in PV roof systems through a process known as the photoelectric effect, which begins when the sun's rays connect with PV roof panels. Sunlight is composed of particles of solar energy known as photons, which contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons strike a PV roof panel, they may be reflected, pass through, or be absorbed. Only the absorbed photons can go on to generate an electrical current, as long as they are above a threshold frequency.

When enough solar energy above the threshold is absorbed by the semiconductor, electrons are released from the material's atoms. These electrons produce a voltage difference that generates DC electricity. The magnitude of the current is proportional to the intensity of the sunlight, so the more intense the sunlight, the stronger the current.

FACTORS AFFECTING THE AVAILABILITY OF SOLAR RADIATION

Performance of a PV system depends on the amount of sunlight striking it, which means that climate conditions have a significant impact on the amount of solar energy the system receives. Most modern PV modules are 14% to 16% efficient in converting sunlight to electricity, though the goal of current engineering research by PV manufacturers is to reach 20% efficiency soon.

Every surface on our planet receives sunlight, but the specific amount varies by


geographic location in relation to the equator, time of day, season of the year, the roof's position in the local landscape, and weather. The angle of the sun in the east-west direction, or the azimuth, is the largest factor in determining the total amount of sunlight exposure a PV system will receive. For locations in the northern hemisphere, an azimuth angle closest to due south provides the best sun exposure for maximum overall PV system performance. Peak solar intensity hours are between approximately 10 a.m. and 4 p.m. during daylight saving time.

Shading of the PV array may also have a significant impact on energy production. Proposed roof surfaces should always be evaluated for shading before designing a PV system. Solar azimuth and roof shading analysis software tools, such as Solar Pathfinder™ and Solometric Suneye™, have been developed to quantify the PV potential for specific locations. These tools analyze solar radiation data and calculate the effect of shading on PV system efficiency to help increase the installed capacity of solar roofing systems. It is also important to consider potential sources of shading, such as tree growth or new structures that may arise in the future.

LEED CREDIT INFORMATION

PV roofing systems qualify for LEED credits in the area of "Energy and Atmosphere 2 (EA 2) – On-Site Renewable Energy." The intent is to increase the generation of renewable energy on the building site. Under EA, two points are provided, based on the percentage of energy use that is provided from on-site renewable sources. In addition, a maximum of seven points can be earned for providing 13% of energy from on-site renewable sources. There are also exemplary credits available for exceeding the normal percentages.

CONCLUSION

Across the nation, PV systems are proving themselves as an excellent method of increasing the overall energy efficiency of homes and buildings and producing clean energy. The growth of clean energy helps decrease our dependence on traditional power sources such as coal, which have a more negative impact on the environment. As new technology develops that makes PV systems more efficient and easier to install, we can expect an increased presence on homes and buildings, helping us move toward a more sustainable future. 

Husnu Kalkanoglu

Husnu Kalkanoglu is the vice president of research and development at CertainTeed Roofing. He joined the company in 1982 as a research chemist after receiving his master of science degree in polymer science and chemical engineering from the University of Cincinnati. Kalkanoglu also holds a bachelor of science degree in chemical engineering from Robert College, Istanbul, Turkey. He is an active member of ASTM, RCI, the Asphalt Roofing Manufacturers Association, the American Society of Chemical Engineers, and the Society of Rheology. He holds more than 30 U.S. patents and is proud of his team's dedication to innovating in the area of environmental sustainability and protection.



Chris Fisher

Chris Fisher is a senior project development engineer at CertainTeed, responsible for bringing roofing-integrated PV products from conception to market. Chris joined the photovoltaic industry in 2006 after receiving a bachelor of applied science from the University of Pennsylvania's School of Engineering and Applied Science. Prior to employment at CertainTeed, he was the manufacturing manager for an amorphous silicon (a-Si) pilot line at a photovoltaic module manufacturer. Additionally, he was responsible for the process optimization of turnkey a-Si manufacturing lines sold to customers in China and Taiwan.

