Basic Technical Information on Solar PV

Welcome and introduction.
Todays agenda includes:

- Solar Thermal Systems – a quick overview
- How Does Solar PV Work?
- What are the Main Components of a PV System?
- What are the Solar PV Mounting Options?
Three main types of solar systems and the codes and components involved differ significantly.

- **Passive**
- **Solar thermal**
- **Photovoltaic**

**Passive** solar construction techniques involve no moving parts and focus on the design, materials and site of the structure – orientation, mass, daylighting, insulation, shading, fenestration – to minimize energy use and enhance comfort.

**Solar thermal** makes use of solar collectors that directly heat a fluid (like water, air or glycol) when exposed to solar radiation. Unlike PV, they do not generate electrical energy. They are used for water heating, space heating, pool heating, industrial processes and cooling.

**Photovoltaic** systems are the most common and utilize solar cells that convert solar radiation into electrical energy. The generated electricity may be used onsite with any excess stored in batteries or output to the local electrical grid.
Solar thermal Systems are a different type of system used to collect and utilize the sun's energy. Not the focus of today's presentation, but it's important to know how this differs from PV.
The difference between solar PV and solar water heating is that solar PV converts the light from the sun, or photons to electricity, while solar water heating systems preheat the water used in a home or business (such as showers, dishwashers, or sinks).
How Does Solar Water Heating Work?

Active Systems
– Use a pump and a heat exchange fluid
– Fluid may be either glycol or water

There are a variety of solar water heating configurations. This diagram represents an active closed loop system. The system includes the solar collectors, the pump, the heat exchanger, and the solar storage tank.

Here is how the system works. A heat-transfer fluid is directed through a closed loop system by a pump. The heat-transfer liquid is first directed to the solar collectors where it is heated by the sun. It is then directed to the heat exchanger in the solar storage tank. The heat-transfer liquid heats up the exchanger which, in turn, heats up a portion of the building’s water supply. The newly created hot water is then moved to the existing water heater to be stored until needed.

Most solar water heating systems use glycol as the heat-transfer agent, but water may be used as well in climates that do not drop below freezing.
Passive, open looped systems are also available for warmer climates. Passive system require no pumps since warm water rises and cold water sinks. The storage is located above the collector to capture and store the hot water.

Since the storage is housed on the roof, additional roofing supports may be needed.
Flat plate collectors are the most common collector for solar water heating systems. The heat-transfer fluid is pumped through the piping in the collector, as shown in the diagram.
Here are two other types of collectors.

The evacuated tube collectors are comprised of outer glass tube with a metal absorber inside. They are an option for active systems (no pump).

The unglazed collectors are most often used for pool heating. They are typically used in an open loop system, with the pool water running thorough the entire system.
All solar water heating systems need to have a storage component. For passive systems, the storage will be located on the roof, above the collector. For active systems the storage tank is typically located next to the existing water heater.
How Does Solar PV Work?

Link to video on youtube: [https://www.youtube.com/watch?v=0elhICVtKE](https://www.youtube.com/watch?v=0elhICVtKE)
Photovoltaic (PV) systems, also referred to as solar electric systems, convert sunlight directly into usable electricity in your home or business using semiconductor technology. Sunlight strikes the PV cells and causes the electrons to flow (shown as the + & - in the graphic), creating an electrical current. This is call the photovoltaic effect.

Photovoltaic (PV): photo = light, voltaic = produces voltage
What’s a watt?

**Watt (W)** = unit of instantaneous power

**Kilowatt (kW)** = a measure of 1,000 W

Watt = unit of (instantaneous) power

- In the solar industry, this refers to the capacity ("size") of a system.
Kilowatt-hour (kWh) = unit of energy equal to 1,000 W x 1 hour

It is the use of power over time

Kilowatt-hour is the unit of energy. This is what you are billed for, and is the use of power over time.
A kilowatt is a unit of power, whereas a kilowatt hour is a unit of energy. For example, a kilowatt is like the speedometer in your car. It shows you the rate, or the speed, that you are going at that exact moment. The odometer shows you how far you have gone.
The difference between voltage and current (amps) can be understood if we look at them like water in a pipe. Voltage is like the pressure of the water, while the current (amps) is the volume of water that flows past a fixed point in a fixed amount of time.

Power (kW) is calculated by multiplying the voltage by the current (amps).

Voltage x current = volt-amps. Wattage is slightly less than volt-amps because it also accounts for resistance (ohms).
Direct current is also used in batteries.

Alternating current alternates between positive and electric charge, in the US this is standardized at 60 hz.
What Are the Main Components of a PV System?
Individual photovoltaic (PV) cells, or modules, are embedded onto panels. Sunlight striking the panels is converted into direct current (DC) electricity.

The DC electricity goes to an inverter that transforms it into alternating current (AC) for all household electrical utilization appliances, lighting, outlets and receptacles.

The utility meter records the net amount of energy generated through the PV system. When the system creates more electricity than used, the meter will spin backward and the excess electricity is released onto the electric grid. This helps offset the cost of electricity usage at night or on cloudy days when PV systems are not producing electricity.
We are going to talk about the primary components of a solar PV array.
The most common solar technology is rigid panels with crystalline silicon modules, making up more than 93% of the market. They have the longest track record, over 50 years, and have the highest efficiency ratings. Another option is thin-film PV that comes on a flexible panel that can be applied to many different surfaces and materials. It is commonly incorporated into the construction of a building, for instance, as roofing tiles or on the building façade.

Conversion rates:
Crystalline silicon - 15-22% efficiency
Thin film - 6-10% efficiency
A Solar PV Cell is a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Crystalline PV cells are comprised of one layer of silicon, with gird lines (also known as fingers) and busbars as shown in the image above.

Solar cells are the building blocks of photovoltaic modules, often referred to as solar panels.

Typically, modules have 36-80 cells (or more).
Cells wired in series are connected to form a string by the ‘cell interconnect ribbon’. It should be noted that the cell interconnect ribbon often obscures inspection of the busbars on silicon cells because it directly overlaps them. Multiple strings are connected via the ‘string interconnect’, which is usually located near the edge of the module and may be obscured by the module frame or cover layers. The image above shows a schematic illustrating cell interconnect ribbons and a string interconnect. – International Energy Agency

Solar Photovoltaic modules (or panels) constitute the solar array of a photovoltaic system that generates and supplies solar electricity in commercial and residential applications.

A Solar Photovoltaic Array is basically the term used to describe the visible assembly of a number of PV modules and supporting structure of a photovoltaic electrical energy system that generates and supplies solar electricity in commercial and residential applications.
Electricity in nature is produced in direct current (DC). That’s why we need an inverter, to convert DC power to AC. We use AC in the built environment. AC inverters are very, very efficient now. **You lose only 1-4% at the inverter! There’s not much to be gained by going back to DC.**

The PV inverter converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into a utility frequency alternating current (AC) that can be fed into a commercial electrical grid or used by a local, off-grid electrical network.

There are basically two types of inverters: string inverters and micro-inverters. Well, actually three, there are also central inverters, however, since micro inverters and string inverters are the most commonly used on residential and commercial installations, and because central inverters are basically bigger string inverters which are used on large ground mount arrays and industrial and utility installations, we’ll just discuss string and micro inverters.

Standard efficiency of inverters: varies between micro and string.
Inverters change **DC** electricity from panels to **AC** electricity for use in your building.

- **String Inverters**
- **Micro Inverters**

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Standard efficiency of inverters: varies between micro and string.
A string inverter may be one individual inverter per array, depending on the size of the array and number of PV modules or panels. String inverters are typically the least expensive inverter option, but are best suited for the ideal solar rooftop.

This is the older, more proven technology, but has performance limitations such as: **With string inverters, overall system power generation can fall sharply if a single panel stops producing power which may occur from shading.**

String inverters are typically installed on the roof or on the side of the building next to the electric panel.

Micro inverters are better suited for roofs with multiple orientations or shading, and have the advantage of module level monitoring as well as provide a greater level of built in fire fighter safety for rapid shutdown of the PV system.

However, when paired with DC power optimizers the performance limitations of a standalone string inverter can be eliminated.
String Inverters

One individual inverter per array

**Benefits**
- Longer track record
- Established reliability
- High efficiency
- Lower cost*

**Disadvantages**
- Shading can affect power output dramatically
- Does not allow for easy system size increases

*Although adding optimizers might eliminate this benefit (likely still less expensive)*

String inverters typically come with 10 year warranty

Because the modules are wired in series, shading from one panel can affect subsequent modules in the series. When a module is partially shaded the power output drops in response. When the modules are wired in series, each module’s power output will drop to the level of the first shaded module. The power output cannot ‘jump’ over the shaded module without the addition of power optimizers. With power optimizers, the power is conditioned at the panel level (DC to DC), which allows the power output to ‘jump’ shaded modules.
Micro inverters are typically installed on the frame or racking. Micro-inverters convert the DC electricity at the module level. This maximizes the output from each module and makes the array more tolerant to shade, it also provides more flexibility in design and allows for easier future solar PV panel additions to the array(s).

The National Electrical Code requires that all solar PV conductors be capable of being rapidly shutdown within ten feet of the array for first responder safety while performing fire fighting operations on a rooftop where solar PV is present.

Micro inverter systems, as well as AC modules and systems which utilize DC power optimizers, provide built in safety features which provides for rapid shut down of PV systems to comply with the National Electrical Code sec 690.12.
Micro Inverters

One individual inverter per module

Benefits
• Makes the array more tolerant to shading
• Allows flexibility in design and for future additions
• Built-in rapid shut-down compliance

Disadvantages
• Shorter track record
• More expensive

Consider location of inverters at panels.....more subject to ambient heat, which can affect performance

Micro inverters typically have 20-25 year warranty

Recent changes to the National Electrical Code (2014 NEC) include a requirement for installers to provide “Rapid shutdown of PV systems on buildings” to give fire fighters and first responders a means to quickly disconnect and de-energize the conductors leaving the PV array in order to ensure fire fighter safety during smoke ventilation, rescue, and fire fighting operations.

Because micro-inverters and power optimizers shut down the power at the module level in the event of utility power shut down, these systems automatically provide the rapid shutdown of pv systems required by NEC section 690.12.

In contrast, typical string inverter systems will need additional external rapid shutdown equipment in order to be compliant.

As an architect, talk to your engineer about which inverter you need... there’s a trend toward DC to DC converters (or “power optimizers”).

HOW DO YOU AS A DESIGNER MAKE A DECISION ON WHICH TYPE OF
INVERTER TO USE?
WHAT’s THE COST DIFFERENCE? IT’s PROJECT-SPECIFIC. Micro inverters are usually used in the RES market. DC optimizers are used in both RES and COM markets; the largest market share is in RES. String inverters are a fairly small market (dwindling in RES), but common in COM. That’s the state of things TODAY, but it’s in flux.
DC power optimizers provide system benefits including improved performance under shading or other mismatch conditions, low-voltage safety under emergency disconnect conditions, and relaxed design constraints for the PV installer.

When paired with string inverters, power optimizers can eliminate the performance limitations of a standalone string inverter. Power optimizers can be installed on the back of each panel, or embedded into the panel itself.

Not used with micro inverters. Used with string inverters to make them function more like micro inverters.

Like micro inverters, power optimizers have a warranty period of 20-25 years.
There are many variables to choosing the right inverter for the building or site.

String inverters alone will be the lowest cost.

Micro inverters and DC power optimizers should be considered if:
- Shading on the system
- System is oriented in more than one direction (array that face more than one direction cannot be installed on the same string inverter)
- Your clients wants real-time, panel level monitoring
What are the Solar PV Mounting Options?

There are many solar PV installation options for design professionals to chose from. Site design like orientation of the building, possible shading, and available space will help dictate which installation method is appropriate.
Photovoltaic mounting systems, also called solar module racking, are used to fix solar PV modules on surfaces like roofs, building facades, or the ground. These mounting systems generally enable retrofitting of solar panels on roofs or as part of the structure of the building. Installation options include Flush mounted PV systems, Tilted rack mounted PV arrays, Ballasted PV systems, and Ground/ pole mounted PV systems.
“Flush-mounted” typically means the modules are installed parallel to, and relatively close to, the roof surface. Due to planning and zoning regulations flush mounted PV systems have been the most common mounting method for residential installations.

For fire classifications flush mounted racking systems are tested and listed as rated assemblies with specific photovoltaic modules.

Flush mounting options are typically limited to south, west and east facing roof planes.
Because a solar cell performs the best when its surface is perpendicular to the sun's rays, many photovoltaic systems are installed on tilt rack mounting systems which can help to optimize the PV module output. Tilt racking is commonly used on flat and low sloped roofs and on North and East facing roof planes. Here are a few examples of tilt rack mounted PV systems.

Tilt rack mounted system are common on both commercial roofs, as well as residential roofs.
Ballasted footing mounts, such as concrete or steel bases that use weight to secure the solar module system in position and do not require roof or ground penetration. This type of mounting system is also well suited for sites where excavation is not possible such as capped landfills and simplifies decommissioning or relocation of solar module systems.

Roofing and Insurance companies typically prefer ballasted systems on existing roofs because they require few (if any) roof penetrations.
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Ground-mounted PV systems are usually large, utility-scale photovoltaic systems.

Smaller ground mounted, or pole mounted systems are also utilized on residential and commercial properties for onsite use similar to roof mounted systems on these properties.

One of the things to consider will be the distance between the remote array and the point of service connection, because of voltage drop for conductors in longer runs, over 100 feet or so, the conductors may need to be oversized to accommodate for the voltage drop which can add significant cost to the electrical installation depending on the distance.
Solar panels can also be mounted as shade structures where the solar panels can provide shade instead of patio covers. Many schools and public facilities utilize solar shade structures in their parking lots to provide shade and offset energy costs.
A new solar technology to be aware of is “stick on solar” panels, which simplify installation, which reduces cost.

Why would they use peel and stick on this roof? Perhaps it was an existing roof and they could not add weight of crystalline silicon (especially if they could not penetrate the roof and they would have had to be ballasted.
Here is another example of peel and stick panels that are applied to a curved structure.
Quiz & Discussion
Which unit do utilities use to measure electric use for billing purposes?

a) Kilowatt-hour (kW-h)
b) Voltage (V)
c) British thermal unit (BTU)
d) Horsepower (hp)
Question 1

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What is the dominant semiconducting material used in the production of solar cells?

a) Amorphous silicon  
b) Crystalline silicon  
c) Cadmium telluride  
d) Halide perovskite
Question 2

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Question 3

What are the primary features of a microinverter?

a) Converts DC electricity to AC
b) Provides rapid shutdown capability
c) Allows flexibility in design of the array
d) All of the above
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Question 4

Which of the following is not a roof mounted PV system?

a) Tilted rack PV system
b) Pole mounted PV system
c) Ballasted PV system
d) Integrated PV system
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