Solar Basics

Understanding the basics of solar energy technology, equipment, and terminology.
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1. Solar Basics

An introduction to the common equipment and terminology used in solar technology. Topics of discussion include solar PV systems, solar terms, system components, net metering and financial considerations with regards to solar development.

1.1 Solar PV Systems

Solar electric systems convert the energy in sunlight into electrical current, which can power electric loads, be fed back to the electric grid, or be stored in batteries. All solar electric systems consist of the same basic components but vary widely in terms of size and complexity. This tool focuses on utility grid-tied residential solar PV systems under 25 kW in size. Solar electric systems should not be confused with solar thermal systems, which are a separate technology that captures the sun’s thermal energy to heat water and air.

When sunlight strikes a solar electric array, electrons in the array are agitated into motion, creating direct current (DC). The electrical current flows along conductors from the array to an inverter. The inverter transforms the DC into alternating current (AC), which powers most common electrical appliances. The AC flows through conductors to the site’s electric service panel, and then to individual branch circuits and loads. If the solar PV system is grid-tied (connected to the electric grid) and produces more electricity than is used at the site, the excess current is pushed back into the utility grid. This basic description of a solar electric system applies to most installations.

Most of New York’s solar PV installations are residential, utility grid-tied, and do not include battery storage. They are typically roof-mounted and range from 4 to 10 kW. New York State’s Standardized Interconnection Requirements (SIR; www3.dps.ny.gov/W/PSCWeb.nsf/All/DCF68EFCA391AD6085257687006F396B) allow residential solar PV systems up to 25 kW.

1.2 Solar Terms

The following terms are frequently used when discussing solar energy and associated technologies.

**Alternating current:** AC describes one type of electric charge flow. The AC stream of charges periodically reverses itself, whereas direct current (DC) describes a stream of electrons that moves in one direction only. AC is the standard electric current for power grids worldwide. Solar electric cells capture particles of light and convert them into DC electricity. An inverter translates DC into AC for consumers to use in their homes and businesses.

**Ampere:** Abbreviated as amp, this unit is used to measure electric current.

**Balance-of-system:** BOS costs refer to the costs of all aspects of a solar PV installation, except the cost of the modules and inverters. BOS costs include all wiring and miscellaneous materials, along with soft costs, such as time and administrative costs associated with selling and signing a contract, system design and permitting, installation labor costs, inspections, travel to and from the installation site, and other costs of doing business. These costs account for as much as 50 percent of the total solar PV system installation. New York State has focused on reducing BOS costs to reach its goal of producing 3 gigawatts of solar energy by 2023.
**Direct current:** DC describes the direct, constant flow of electricity. Unlike AC, DC does not periodically reverse direction. A solar PV system comes equipped with an inverter that converts DC into AC, the standard electric current for power grids in the United States.

**Energy payback:** Gauges how long it will take to recover the energy originally required to manufacture a solar PV system. Because most solar PV systems last 20 – 25 years, there is a pronounced net environmental benefit over the system’s life span. The U.S. Department of Energy estimates an energy payback of 1-4 years for rooftop solar PV systems. The original energy used is often referred to as embedded energy.

**Feed-in tariff:** FITs are long-term generation contracts that have favorable terms designed to encourage the production of renewable energy by individuals and businesses. FITs are typically offered for long periods of time, such as 10, 15, or 20 years.

**Inverter:** A key component of any solar PV system that converts direct current (DC) electricity into alternating current (AC) electricity, which is the standard current in the United States.

**Kilowatt:** kW is a unit of measure that equals 1,000 Watts and is the main mechanism for measuring the size or capacity of a solar PV system. The Watt is named after Scottish inventor and mechanical engineer James Watt (1736 – 1819).

**Kilowatt-hour:** 1 kWh is equivalent to the electricity generated or consumed at a rate of 1,000 Watts over the period of one hour.

**Net metering:** A common feature of grid-connected solar PV systems whereby excess electricity produced by a solar array is fed back into the utility grid. System owners can earn credits on future energy bills for the excess electricity their systems generate. The credits can then be used later when homeowners need power from the local utility, such as at night or on cloudy days.

**Power purchase agreement:** PPAs are becoming a popular way for homeowners to take advantage of solar power without the financial responsibility associated with installation costs. Under the agreement, a third party installs the solar PV system and the homeowner agrees to buy the electricity (kWh) it generates, typically at a rate lower than what the utility offers.

**Photovoltaic:** PV technology converts solar energy into direct current electricity. The technology uses semiconducting materials that exhibit the photovoltaic effect, a naturally occurring phenomenon in which photons of light emitted from the sun knock electrons off their valence shell into a higher state of energy, creating electricity. A solar PV system uses solar panels, which are composed of a number of solar (PV) cells, to convert sunlight directly into electricity.

**Photovoltaic cells:** PV cells are thin layers of semiconducting material that are usually made of silicon. When the silicon is exposed to light, an electrical charge is generated. Solar (PV) cells form the basis of a solar PV panel, which together make up a solar PV system.

**Remote net metering:** A variation on net metering whereby a solar PV system’s production is credited to an electricity consumer(s) located at a different physical site.

**Solar photovoltaic (PV) systems:** A technology that converts sunlight directly into electricity. A PV system is made up of solar modules (panels), which are made up of solar cells.

**Solar thermal systems:** A technology that uses sunlight to heat water or air. In contrast to a solar PV system, a solar thermal system uses mirrors to concentrate sunlight to produce heat.
1.3 System Components

1.3.1 Modules

A solar PV module or “solar panel” is an electrical generation device that produces DC current when exposed to sunlight. Most modules consist of 60-72 small, conjoined solar cells, an aluminum frame, and a tempered glass front piece. Modules are roughly three feet by five feet and are mounted in either a portrait (a vertical rectangle) or landscape orientation (a horizontal rectangle). In monocrystalline modules, individual cells are made from single pieces of silicon. Polycrystalline modules feature cells made from multiple pieces of silicon.

Installers wire together multiple modules to combine their voltage. Multiple strings of modules can be combined to add their current (amperage).

The size of solar PV systems is typically given in rated DC capacity at standard test conditions (STC). For example, a system with 10 modules rated at 300 Watts each is a 3,000-Watt (3 kilowatt) system. Most solar PV modules come with a manufacturer’s production warranty of 25 years and are expected to have a useful life of approximately 30 years.

A SolarWorld Polycrystalline module (left) and a SunPower Monocrystalline module (right)
Source: SolarWorld and SunPower

1.3.2 Inverter

All utility grid-tied solar PV systems have at least one inverter, which converts DC to AC. Most residential solar PV systems have one or two string inverters, which are connected to one or more strings of modules. Inverters are generally mounted vertically on basement, garage, or exterior walls, and can be located indoors or outdoors.

Microinverters are a special type of inverter that are mounted on the underside of individual solar PV modules. Unlike string inverters, each microinverter services only 1-2 modules, which permits greater flexibility in system design.

Most solar PV professionals describe system size in terms of module capacity (kilowatts DC), whereas most electric utilities refer to system size by inverter capacity (kilowatts AC).

A Fronius String Inverter (left) and an Enphase Microinverter (right)
Source: Fronius and Enphase
1.3.3 Balance of System Components

“Balance of system” (BOS) generally refers to all equipment in a solar PV installation except the modules and inverter. (Occasionally, inverters are included in the term.) BOS components include racking, conductors, conduit, disconnects, fuses, mounting hardware, combiner boxes, and occasionally batteries.

BOS Components: A Square D Fusible AC Disconnect (left) and a MidNite Solar Rapid Shutdown Device (right)
Source: Square D and MidNite Solar

1.3.4 Racking

Most solar PV arrays are mounted to roofs using specially-designed aluminum racking systems. Typically, L-shaped brackets are connected to the roofing members of a house with lag bolts. Long aluminum rails are bolted onto the L-feet, and individual modules are attached to the rails with clamps. All roof penetrations must be flashed to prevent leaks and roof damage, and the system designer must ensure that the roof is structurally strong enough for the additional load of a PV system. Any necessary replacement or repair work on a roof must be done prior to the installation of the solar PV system.

A Solar Electric Racking System
Detail of an L-Foot with a SnapNrack Flashing

System designers may choose to use a ballast mounting system on flat roofs. Instead of using lag bolts to anchor the racking to the building’s structural members, heavy concrete blocks weigh down the array. Ballasted systems are less likely to create leaks in the roof membrane but add substantial weight and may be too heavy for some roofs.

Solar electric arrays are also commonly ground-mounted. Arrays can be mounted on racking directly on the ground, or atop a metal pole. As with roof mounts, metallic racking must be bonded (made electrically continuous to provide a path for fault currents). When designing a ground-mounted system, the designer must account for soil conditions. Voltage drop is a concern for ground mounted systems, which often have long conductor runs.

Ground-mounted solar PV arrays sometimes include tracking equipment, which rotates the array throughout the day to follow the sun’s trajectory. Tracking may occur along one or two axes. The additional energy produced by these systems must be weighed against their additional cost, complexity, and maintenance.

1 Section 1503.2 of the International Building Code, Section 903.2 of the International Residential Code.
1.3.5 Conductors
Conductors (wire) coming from the modules are typically factory-assembled “PV Wire” with a factory-formed termination (see NEC 690.31). These factory leads are labeled “PV Wire” or “Type USE-2” and are rated to withstand all weather conditions. They are then spliced with standard building wire, using appropriate connectors and enclosures. The standard building wire is installed in raceway (conduit) to its next point of connection. Under certain conditions, conductors may be direct burial or part of a cable assembly. NEC 690.32 and NEC 310 provide guidance on allowable conductor types and methods.

The maximum allowable voltage for residential solar PV systems is 600 volts DC, but nonresidential systems may run up to 1,000 volts DC (NEC690.7(C)). Conductors must be protected from accidental contact. When exposed, they must be installed in raceway (such as conduit), or otherwise rendered inaccessible. For example, the exposed conductors on the back side of a ground-mounted array must be guarded or located at least eight feet above ground.

1.3.6 Raceway (Conduit)
Raceway includes conduit, boxes, fittings, and enclosures that provide a pathway and protection for individual conductors. All raceway systems must be suitable for the environment in which they are installed. All metal raceways must be bonded to form part of the equipment grounding conductor.

All DC conductors that enter a structure must be installed in a metal raceway NEC 690.31(G) or MC cable that meets NEC 250.118(10). Flexible and nonmetallic conduits may be permitted under certain conditions. In addition to NEC 690, refer to Chapter 3 of the NEC for types of permitted conduits and uses.

1.3.7 Battery Backup
Most residential solar PV systems are utility grid-tied, but do not include a battery backup system. In the event of a blackout or grid failure, such solar PV systems de-energize and do not function until grid power is restored, as required by NYS’ Standardized Interconnection Requirements (SIR; www3.dps.ny.gov/W/PSCWeb.nsf/All/DCF68EFCA391AD6085257687006F396B).

Off-grid (“stand-alone”) solar PV systems are not connected to the grid. Solar PV output is stored in a battery bank, which provides power to the site’s electric loads. In addition to a battery bank, these systems include one or more charge controllers, which determine the amount and rate of power that can be stored and drawn from the battery bank.

Battery-backup solar PV systems are utility grid-tied and include a battery system that is used in the event of grid failure. Due to the high cost and additional complexity, battery backup on solar PV systems is currently rare. Section 690.71 of the NEC contains additional requirements for solar PV systems with batteries.

1.4 Net Metering
Solar electric systems are a distributed generation (DG) technology that currently qualifies for net metering in New York State. Any power produced by a solar PV system that isn’t consumed on-site is pushed into the utility grid. The solar PV system owner receives a credit for this production on their monthly utility bill. Utilities typically install a meter at solar PV sites, which tracks the amount of electricity taken from and fed into the grid. The site owner is billed for only the net electricity consumed. Nonresidential solar PV systems can credit their production to off-site electric accounts through remote net metering, but this type of arrangement is outside the scope of this document.
1.5  Financial Considerations

Most homeowners view the installation of a solar PV system as a financial investment. Over time, the power it produces generates savings on their electric bills.

1.5.1  Incentives

Although the costs of residential solar PV systems have fallen significantly in recent years, they still typically cost tens of thousands of dollars. The project cost includes the modules, inverters, balance of system components, and “soft costs,” such as installation and administrative labor, customer acquisition, and engineering.

Several incentives make projects more affordable for homeowners. NYSERDA’s NY-Sun Incentive Program administers a step-down megawatt block incentive program. Visit the NY-Sun Program Site for the most up-to-date information regarding available incentives. For information regarding tax credits, we encourage you to speak with a tax accountant.

Other incentives may exist at the local level, including real property tax exemptions, and a real property tax abatement program in New York City. Unlike most residential home improvements, most solar PV installations in New York State do not increase the taxable value of a home. However, local governments can opt out of this exemption. One excellent resource to navigate incentives is www.dsireusa.org. Customers should consult a tax advisor to determine their eligibility for tax credits.

1.5.2  Purchase Types

Many homeowners choose to buy a solar PV system with cash, or by taking out a loan. As the system owners, they can apply for all applicable tax credits. Installation companies typically offer a 5 to 10-year warranty, and some manufacturers offer extended warranties. An increasing variety of loans are available to help customers finance the purchase of solar PV systems.

Leasing a solar PV system is another common option. With this model, a third-party company (often the installation contractor) is responsible for installing, operating and maintaining a solar PV system at the customer’s site. Customers sign long-term leases (typically 20 years) and make monthly payments to the company that owns the solar PV system. In return, customers receive all electricity produced by the system. At the end of the lease term, the homeowner typically has the option of renewing the lease, purchasing the equipment at fair market value, or having the system owner remove the equipment. The company that owns the solar PV system receives most of the tax benefits.

A third option is a power purchase agreement (PPA). It is similar to a lease, but instead of paying a flat monthly fee, customers pay for the amount of electricity actually produced by the solar PV system.

Questions?

If you have any questions regarding solar basics, please email questions to cleanenergyhelp@nyserda.ny.gov or request free technical assistance at nyserda.ny.gov/SolarGuidebook. The NYSERDA team looks forward to partnering with communities across the state to help them meet their solar energy goals.

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2 http://www.nyserda.ny.gov/All-Programs/Programs/NY-Sun