



Types of Solar Photovoltaic Systems

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Introduction

Solar energy systems can help Arizona individuals, families, and businesses achieve energy conservation goals beyond the adoption of energy-efficient appliances, and LED bulbs. Which type of system is the best? Knowing which system to select is the first important question. This factsheet will focus on solar photovoltaic energy systems. The term photovoltaic refers to the conversion of light energy to electricity.

Solar Photovoltaic Energy Terminology

Making sense of the electrical terms commonly used in the solar energy and presented in this factsheet will help the potential solar system owner.

Watts – A unit of power found by multiplying volts and amps ($W = V \times A$). Solar modules are measured in Watts.

Voltage – The pressure from an electric circuit's source that pushes the electrical current. A car battery is often rated at 12 volts.

Current – Flow of electricity measured in amperes. Solar industry uses the letter "I" to represent current.

Direct Current (DC) – Electric current that flows in one direction only. Common to batteries, electric arc welding, and solar cells and modules.

Load – A device operating on electricity such as a fan, lamp, or pump.

Power – Rate of doing work, measured in watts.

Energy – The capacity to do work in power with the element of time. Measured in watt-hours.

Kilo-watt – A thousand watts. Energy consumed is reported in kilowatt-hours (kWh).

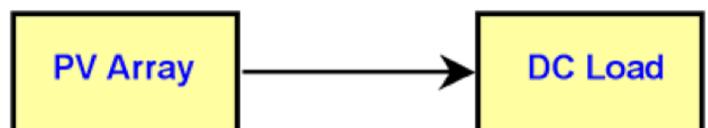
Solar photovoltaic (PV) systems vary in type and design depending on the power requirements of the particular load to be powered. Systems can be simple, using energy directly from the sun to power the DC load (such as a lamp, fan, pump or to recharge a battery), only when the sun shines, to more complex systems where energy is used to power both a load and stored for later use when the sun is not shining.

Solar energy systems can provide power that is converted and used for both direct current (DC) loads, and alternating current (AC) loads. A residential or business can produce energy that may be sent to a utility grid to offset the cost of electrical energy used by the homeowner or business. The type of system adopted depends on the needs of the energy user.

Photovoltaic (PV) Direct – A simple system, no energy storage.

The simplest system consists of a load, such as a ventilation fan or an electrical pump to move water, and a PV source as a single solar PV module. The size and number of solar PV modules in a PV-direct system is determined by the energy demand (size) of the load. Since solar PV modules produce direct current (DC) electricity, the load in a PV-direct system operates on DC electrical current. If solar energy was not available, this same load would be powered by a battery source. The PV-direct system is ideal when power for a load is needed during daylight hours only. Power for a ventilation fan mounted on the roof of a storage building or a storage container that needs to operate during the hottest part of the day can be accomplished by using a PV-direct system. A complete PV-powered ventilation fan system can be ordered and purchased from do-it-yourself centers and mounted on the structure.

A direct current (DC) submersible pump in a pond or fountain in a garden can be powered by a solar module. The power requirement of the pump (volts and amps) is matched to the power output of the solar module. A small-



Source: Florida Solar Energy Center
Figure 1. A block diagram of the simple PV system.



Figure 2. A solar module powers a DC bilge pump to move water. An example of a simple, or PV direct system.

scale complete system with a solar module and pump can be purchased on-line. The disadvantage of the PV-direct system is the energy cannot be stored so the energy flows when the sun is shining, and is subject to the quality of sunlight. When the sunlight fades at the end of the day, or is blocked by a cloud, sunlight intensity (irradiance) is reduced and the current output of the module decreases. This decreases the performance of the load to the point where the ventilation fan or water pump ceases to operate.

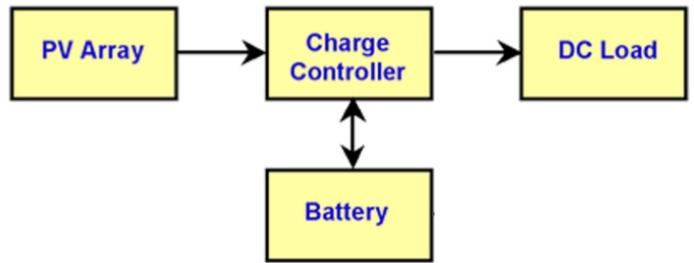
If the fountain or pond pump operates on alternating current (AC), electrical current from the solar module needs to be converted from direct current (DC) to alternating current (AC). This requires the use of an inverter. The inverter is a device that changes DC to AC. Inverters will be discussed further in another section of this fact sheet.

Battery-Based System – storing power for times when there is no sunlight

When energy is needed to power loads at times of the day when the sun is not shining, a system needs to have access to a source of constant, non-interrupted power like a utility, or a generator. An alternative is to use a stored energy source such as a battery. A battery-based, stand-alone system (also called “off-grid” system) is more complicated than a PV-direct system.

A solar module can be used to charge a battery, but there needs to be a way to monitor how much current is flowing to the battery to prevent from over-charging. A charge controller is installed in the system between the PV module and the battery. The charge controller regulates the amount of current going into the battery. The simple controller lets the user know of the level of charge of the battery. Controllers are available in multiple sizes and capacities.

More advanced controllers can be connected to a DC load and have a “low voltage disconnect (LVD)” option. The load is powered by the battery. When the voltage of the



Source: Florida Solar Energy Center

Figure 3. A block diagram showing components of the stand-alone PV system.



Figure 4. A solar module connected to a charge controller and battery. The controller monitors the “state of charge” (SOC) of the battery, preventing overcharging from the solar module.

battery reaches a low voltage point, the power to the load is disconnected until the battery is recharged by the PV module. If the size of the load requires more power, additional batteries may be connected together to form a battery bank. The design of a battery-based system takes into account the amount of time the load draws its power from the battery bank. The system design will include the amount of time the system will operate when there is no sunshine due to cloudy conditions. For example, the size of the battery bank can be designed to provide power for the load to operate autonomously for three days. Battery bank sizing includes calculating the percent draw-down of the batteries. It is not wise to allow a battery to cycle all the way down to zero percent discharge. This practice will reduce the life cycle of the battery and result in replacement.

Battery-based systems are used when it is not feasible to power an electrical system with connection to a utility and the load requires power for a period of time when there is no sunlight. Examples of battery-based systems include communication systems located in rural areas, railroad crossing signals, street lighting, and traffic control systems. The advantage of battery-based systems is there is available



Figure 5. Stand-alone battery-based system. The load (fountain) is powered by energy stored in the battery. The solar module produces electricity and stores it in the battery. The controller regulates the amount of energy in the battery.

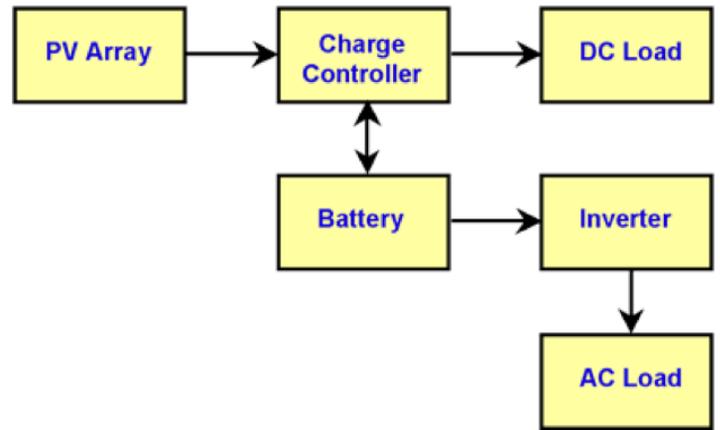


Figure 6. The battery controller has connections for the solar module, the battery, and the load. This model has a "low voltage disconnect" (LVD) option and automatically de-energizes the load until the battery is re-charged by the solar module.

power at all-hours of the day. In rural areas where critical loads must be energized at all times, the stand-alone or battery-based system is ideal. The limitation to this system is the initial cost, maintenance, load-calculations, and eventual replacement of the battery or batteries. All of the loads in the simple battery-based system run on direct current (DC). If an AC load is to be used, small inverters, such as those that can be plugged into a vehicle 12 volt DC power outlet, or connected to a battery, can be used and an AC power cord plugged into it. Inverters are available in different wattages ranging from 125 watts to 6,000 watts, or more.



Figure 7. Examples of inverters used to convert DC electricity from 12 volt battery systems to AC electricity.



Source: Florida Solar Energy Center

Figure 8. A block diagram of off-grid, battery-based system capable of operating both DC and AC loads.

Off-Grid System – living in a residence or cabin not connected to a utility

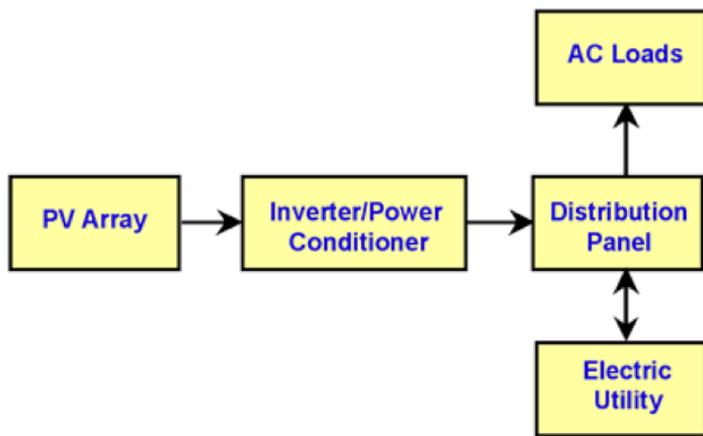
One limitation to living in a remote area is the cost to bring in utility-supplied electricity. A homeowner would need to rely on a fossil-fueled generator, propane gas, or a combination of both. Today, a battery-based solar PV system can be designed to power a home or cabin not connected to a local utility. This is an off-grid system.

Electrical loads found in a home run on alternating current (AC), but solar PV modules and batteries produce direct current (DC) electricity. An inverter is used to change the DC electrical current to AC electrical current. Inverters like controllers, are available in different sizes and capacities to match the needs of the user.

In designing a battery-based system, it is important to calculate all of the electrical loads that will be powered by the solar PV system. The calculation will take into account the number of hours per day and the days per month the loads will be used. Exceeding the capacity of the system by adding loads will result in the system not able to operate efficiently and waiting for the battery bank to be recharged by the PV array.



Figure 9. A bank of batteries connected together in series (wired positive to negative) to build voltage. The batteries are housed in a vented enclosure.



Source: Florida Solar Energy Center
 Figure 10. A block diagram showing the components of the grid-connected PV system.



Figure 11. Example of a "balance of system" (BOS) of a grid-connected system. Components include safety disconnect switch on the DC-side, the inverter, a safety disconnect switch on the AC-side of the system, a meter, and the service distribution panel.

Grid-Connect System - connecting to your local electric utility and sending power to the grid

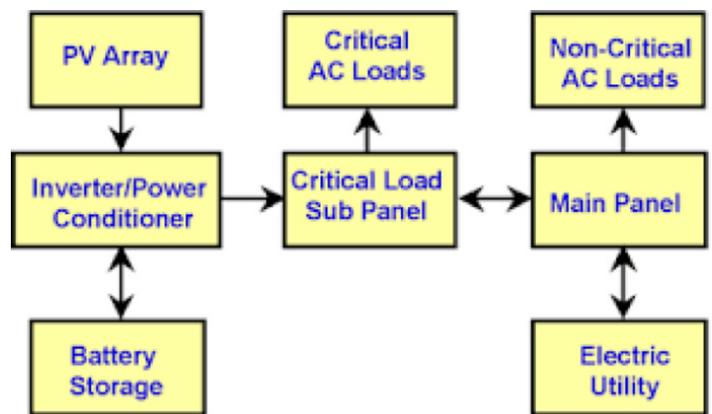
One of the fastest growing type of PV systems is the grid-connect system. Residential and commercial grid-connect systems are popular for reducing the amount of energy supplied by the local utility. The grid-connect system is made up of a solar array (PV modules wired together), and an inverter to change DC electricity into AC electricity. The system is connected to the service entrance panel (SEP) of the residence or company facility. Electrical energy produced by the solar array is sent to the utility during daylight hours. At night, the electrical needs are supplied by the utility connection.

The owner of the PV system can save money by producing and sending more electrical power to the utility than what the owner uses when the PV system is not sending power, such as at night or on cloudy days. Net-metering is the process of calculating the amount of power the owner sends to the utility and the amount of electricity the owner uses from the utility. For safety reasons, if there is a power failure from the utility-side, the inverter is designed to shut down and not send any power from the system to the utility. This is designed to protect utility workers who maybe making repairs to utility lines.

Grid-connect systems fit well in a residence where the electrical loads are small during the day when the occupants are away at work or school. During the day, the PV system is producing more power than the loads of the residence require, generating credit for the owner with the local utility. When the occupants return at the end of the day, power for the electrical loads will be supplied by the utility. State and federal subsidies and rebates help offset the initial costs of installing a system.

Grid-Connect Interactive System – adding a battery-bank or generator

A grid-connect system may be designed to include a battery-bank or a generator to provide back-up electrical power in the case there is a power outage from the utility.

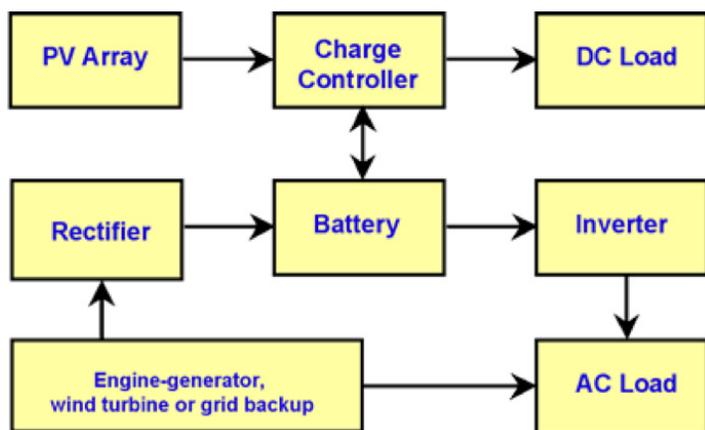


Source: Florida Solar Energy Center
 Figure 12. A block diagram showing the grid-connected PV system with battery-backup.

The solar array charges the battery-bank and provides power to the system during the day. At night or during a power outage, electrical power may be supplied by the battery-bank or by turning on the electrical generator. The generator can be connected to the system inverter to provide AC power. These are additional costs to a system design and are considered when loads must be powered at all times.

Hybrid System – adding wind or hydro energy

A hybrid system includes more than one energy-producing source. In northern Arizona where wind energy is available, including a wind turbine in a solar PV system can take advantage of blowing winds to produce DC energy. The system can be connected to an inverter or tied to a battery-based system. The advantage of the hybrid system with a wind turbine is when sustained winds blow during non-daylight hours, the battery-bank can be charged, or DC appliances can be energized. An energy storage system can be designed where the wind turbines are disengaged until the battery bank state of charge reaches a certain level. The wind turbine



Source: Florida Solar Energy Center
 Figure 13. A block diagram of an off-grid hybrid PV system with battery-backup. The rectifier changes AC current to DC current.

can be engaged to provide energy to charge the battery bank until a predetermined charging level is obtained. A location with access to year-round running water such as a stream or creek may be suitable for the installation and use of a micro-hydro system. Running water is channeled through an opening called a penstock at an upper elevation point. The water is piped downhill to a turbine. The rotating action of the turbine turns a generator to produce DC electricity. The water can be channeled back to the stream or creek. While the solar array is producing electricity during the day, the hydro can be producing electricity at all hours of the day, year-long or seasonally.

Conclusion

Solar PV systems are designed to meet the electrical power needs of the user. Systems can be simple or complex. System cost will depend on factors such as location, type and size of load, length of time of use of loads, and system maintenance. For residential systems, lifestyle of the user needs to be understood as well as the adoption and use of energy-efficient loads, such as appliances. Costs will depend on factors such as size of the system and available space for the array. Off-grid systems require a detailed estimation of the loads used by the consumer. For the agriculture producer, the value of use of solar PV energy needs to be compared to existing energy sources such as utility-supplied electricity, natural gas systems, and fossil-fueled systems. An understanding of the individual components within each system is another important part when considering the adoption of solar photovoltaic energy systems.

Resources

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