PHOTOVOLTAICS FOR THE SOUTHEAST HOME

INTRODUCTION

Making electricity without creating greenhouse gases and other pollution may seem like a far off reality. However, through the use of photovoltaics (PV), sunlight can be converted directly into electricity. No fluids or moving parts are involved. As the world's desire for electricity and the comforts it can provide grows, so does the need for a clean way to produce power. Fossil fuel based electricity produces large amounts of carbon dioxide and other pollutants. Additionally, the cost of fossil fuels are expected to continue rising as the easiest to access resources become scarcer while the demand for energy rises.

The bulk of current photovoltaics are made of silicon based semiconductor materials that produce electricity when exposed to sunlight. These semiconductor materials are made into PV cells. The electricity generated by PV cells is direct current (DC) like the energy produced by batteries. As more light falls on a PV cell, more electricity is generated. Several other technologies have proven successful in the lab and some are in production. In the future, solar electric panels may look very different from those of today.

Conservation First!

A penny saved is a penny earned. The same principle is true for home electricity use. Energy not used due to energy conservation saves a homeowner just as much on their electric utility bill as the same amount of clean electricity produced by a PV (also known as solar electric) system. In most homes significant energy savings can be made through conservation practices and home improvements at a much lower cost than installing a PV system. **Economically it does not make sense to install a PV system until after the home has been made very energy efficient.** Otherwise, the homeowner is spending money to produce electricity that is being used wastefully.

Conservation practices include turning off lights and setting back the thermostat when no one is home; these efforts are very effective at reducing energy costs without adding cost. Many conservation measures can pay for themselves many times over in energy savings. Homeowners can reduce their energy bills by as much or more than the savings provided by a typical residential PV system, and spend less money in the process. By combining energy efficiency and a PV system, a house can produce all of the electricity it needs in a year. This is often known as a zero energy house (ZEH). Here are a few important energy efficient improvements for both new and existing homes.

- changing from incandescent to flourescent or lighting
- upgrading to Energy Star or better appliances
- sealing duct work and balancing air flow
- sealing the home to eliminate unknown air infiltration
- adding shading devices where appropriate
- upgrading windows and wall/attic/crawlspace insulation

For more information on energy efficiency see the NC Solar Center fact sheet ***Build a High Performance House, Earn Tax Credits*** for additional information on this topic.

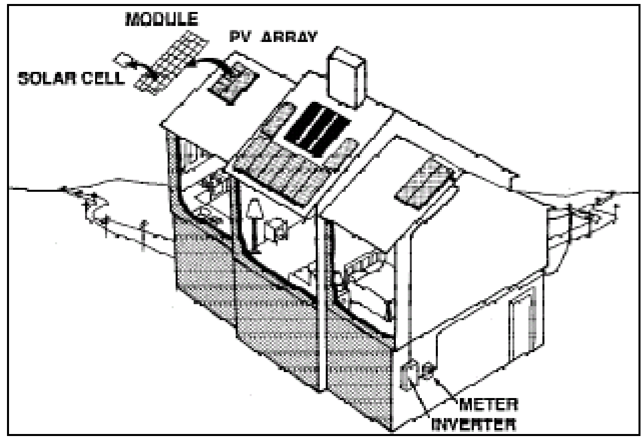

Figure 1. Residential Photovoltaic System

TYPES OF PV SYSTEMS

There are many different applications for PV systems, but this fact sheet covers only residential systems . The two basic types of residential systems are stand-alone, also known as off-grid, and utility interactive, also known as grid-tied.

Stand-Alone PV Systems

PV installations not connected to a utility power grid are referred to as "stand-alone" or "off-grid" systems. In order for a stand-alone PV system to supply all of the electricity needs for a home it must have a battery bank that is large enough to power the home at night and during extended cloudy periods. A battery bank of this size and the associated controls adds significant cost and maintenance to a PV system. However, an off-grid PV system is an excellent alternative to a gas or diesel generator, or to extending utility lines to remote locations. **Figure 2** shows the basic layout of a stand-alone system with battery storage and both AC and DC circuits.

Utility-Interactive Systems

Unlike stand-alone systems, utility-interactive systems are connected to the electric utility grid. These systems are traditionally located on residential or commercial buildings. The house pictured in **Figure 1** has a utility-interactive PV system. **Figure 3** shows the basic layout of a utility interactive system. These systems have a PV array that supplies power to the building through a high quality inverter. This inverter converts PV-generated DC electricity to AC electricity compatible with the utility grid. This AC electricity is supplied to the main electrical service of the building, offsetting the purchase of power from the utility grid. When the PV system is not generating as much power as the building is using, the utility grid provides the additional needed power. When the PV system is generating more power than the building is using, excess power is fed into the utility grid, and is credited by the local utility at a predetermined rate.

In much of the Southeast, selling power back to an electric utility may not be as attractive as it sounds. Some utili-

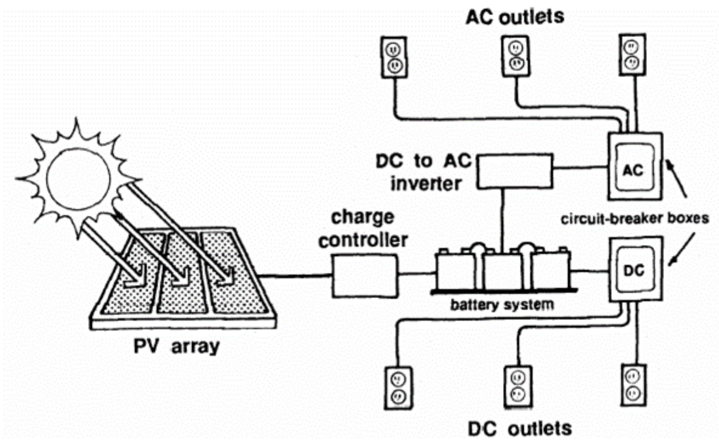

Figure 2. Stand-Alone PV System

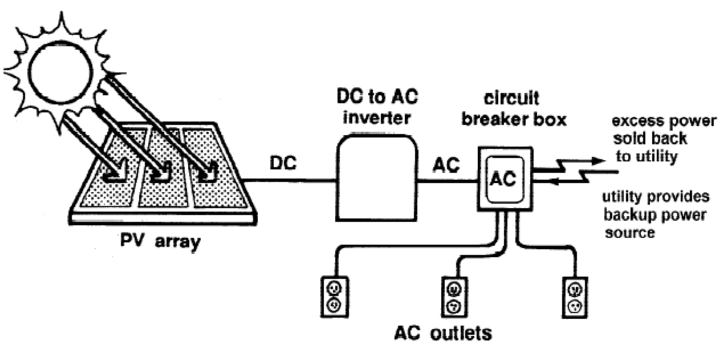

Figure 3. Utility-Interactive System

ties meter electrical energy purchased and sold separately. Customers pay a retail rate for electricity purchased from the utility but are paid a lower avoided cost (wholesale) rate for electricity sold to a utility. There is usually a significant difference between these two rates. Under these conditions, it is much more cost effective to use a PV system to displace the need for utility power than to generate revenue with it. Most southeastern states have enacted net-metering laws which require the electric utility to run the customer's meter backwards when the PV system is generating more electricity than the house is using. ***This effectively means the utility grid is acting as a battery for the PV system***. The current state and utility incentives regarding selling PV electricity to the local utility company can be found at www.dsiresusa.org.

A major benefit of utility-interactive PV is that it can be widely distributed. This asset will lead to the installation of many small scale "distributed generation" power plants located on buildings. Over time, this could reduce:

- the need for additional large centralized power plant construction, and
- costly utility grid distribution network expansion.

The nature of distributed generation can increase national energy security by increasing the number of power plants that would have to be targeted in order to shut down the national utility grid. Other examples of distributed generation technologies are wind turbines, fuel cells, and combined heat and power (CHP) systems.

Another benefit of utility-interactive PV systems is that they produce electrical power when the sun is shining strongest and the electrical utility grid needs it the most. For example, in the Summer they produce the most electrical power when the demand on the electrical utility grid is highest due to building air conditioning. This benefit is currently not well rewarded by utilities but may be in the future as the peak demand for electricity continues to rise.

Utility-interactive systems do not have to give up the benefits of back up power provided by a PV system with batteries; however, it is wise to review all utility requirements prior to purchasing any type of back up power system. Batteries can be kept charged and only used during a power outage. The inclusion of batteries does add a significant cost to the system, but it is a cost many homeowners are willing to pay.

PV CELL TECHNOLOGIES

Mono-crystalline Cells

Figure 4 shows the original PV technology and it still offers the highest efficiencies and a long expected lifespan. The cells are created by slicing a thin wafer from a solid, very pure silicon crystal. Growing these crystals and slicing them into wafers is an energy and time consuming process, resulting in expensive PV cells. A typical mono-crystalline PV cell is 12 centimeters in diameter and 0.25 millimeters thick. In full sunlight, it generates 4 amperes of direct current at 0.5 volts or 2 watts of electrical power. Currently available cells have efficiencies in the range of 13% to 19% and life spans of 35 or more years.

Figure 4. Mono-crystalline PV Cell

Multi-crystalline Cells

Polycrystalline cells are also made from wafers cut from silicon ingots, but instead of being one large crystal the ingot is made up of many smaller crystals. This process was developed because it offers a lower cost PV cell, however it also offers a lower efficiency. Multi-crystalline cells are the most common type of cell today because they offer efficiencies and life spans only slightly less than mono-crystalline cells, but at a significantly reduced cost. Multi-crystalline cells available today have efficiencies in the range of 10% to 13%.

Amorphous Silicon Cells

Amorphous silicon cells are newer forms of silicon semiconductor based materials used to produce thin film PV modules. They have no crystalline structure and cost less to produce than the other types of silicon based cells because the amount of semiconductor material used is far less than that used to produce crystalline PV. Because less material is used, thin film PV can be produced faster and cheaper than crystalline PV. Besides cost, there are other advantages to amorphous silicon cells. They can utilize diffuse sunlight better than crystalline cells and are more shade tolerant. Because these PV cells are so thin, they can be made as flexible modules that conform to curved surfaces

Figure 5. Amorphous Thin Film PV Shingle System

or be used in ways that rigid crystalline PV cells can not. They can be made into thin flexible sheets that are applied to metal roofing or used in place of asphalt shingles. Integrating PV cells into the building itself is known as building integrated PV (BIPV). Currently, thin film PV modules have much lower sunlight to energy conversion ratios (5% to 8%) than crystalline PV, but that may change as more advanced thin film PVs are developed.

Other Thin Film Technologies

The three types of PV technologies described above dominate the current PV market, however there are a number of other technologies that have proven themselves in the lab, and some are in mass production. All of these technologies involve depositing a thin film of semiconductor material in the creation of the cell. The major successful types are microcrystalline silicon, Cadmium telluride, and copper indium selenide/sulfide. Currently these technologies are not being installed in residential PV systems.

Future Technologies

There are many other technologies that work quite differently from the cells described above, which all rely on a traditional semiconductor junction to separate positive and negative charges created by the PV cell. Many of these new technologies utilize nanotechnologies or they are based on the chemical processes plants use to harness the energy in sunlight. While these technologies have proven successful in the lab, extensive applied research is necessary before they will be an option for local solar installers.

PROPER ARRAY LOCATION

Is a House Suitable for a PV System?

A solar energy system needs to be located where plenty of sunshine strikes its collection surface. Typically, the collectors are installed on the roof, but it is also possible to mount them on a pole or frame at ground level. Either way, the collectors must face an acceptable direction and must be reasonably free of shade. Some neighborhoods have ordinances against PV, solar thermal, and other types of yard and roof mounted renewable energy systems. Conversely, jurisdictions have **solar access laws** that do not allow neighborhood associations or other groups to ban solar collectors.

Below are some basic guidelines on properly locating a solar electric system. The NC Solar Center (www.ncsc.ncsu.edu) has a fact sheet on the siting of solar collectors that provides more details. A professional solar installer can do a thorough assessment of the viability of a particular home's site.

Although solar collectors perform best if they are oriented toward true South, facing collectors 45° East or 45° West of true South to accommodate roof orientation, aesthetics, and other local factors will reduce their energy output by **less than 5%**. Facing the collectors 90° off of South, toward due East or West, will reduce their annual energy output by only 10% to 20%. So, in terms of solar orientation for residential PV systems, roofs facing SE, S, SW are all quite acceptable; while roofs facing E or W may be acceptable depending largely on the homeowner's economic expectations for the system and other issues such as access to the existing utility grid.

In addition to orientation, the horizontal tilt of the collectors will also affect their performance. The optimum tilt angle for annual performance is an angle equal to several degrees lower than the local latitude. However, for simplicity and aesthetics it is best to mount collectors parallel to the roof. The exact tilt of a collector is not crucial; a 15° variation to suit a roof's pitch makes almost no difference in the output of the system.

The energy output of a PV system can be increased by having the PV modules track the sun as it moves across the sky on a daily basis instead of being fixed in one orientation. Tracking arrays work well with certain applications such as direct PV water pumping, but are not typically recommended for residential PV systems. The added complexity, maintenance, and costs of tracking arrays needs to be compared with the increased energy benefit in order to make an informed decision concerning which type of array is appropriate (fixed or tracking).

Once one or more potential locations with an appropriate orientation and tilt have been selected, determine if or when those locations are shaded. Shading can have a very large impact on the output of a PV system. Depending on the type of cells and the wiring arrangement, shading of 25% of an array could result in a drop in output of well over 50%. If your system will experience some shading the system designer should minimize the effects of this shading. Shading may be caused by other sections of roof, chimneys, other buildings, and nearby trees. To determine if or when a location will be shaded one must consider the sun's motion throughout not only each day but also throughout the year. This means that even if the location is unshaded in May it may be in full shade in January.

Many solar professionals use a tool called a Solar Pathfinder (www.solarpathfinder.com) to determine the annual shading profile of a potential collector location. Another option, which does not require any special equipment, is a sun chart for the home's latitude; this is available at no cost from http:\\solardat.uoregon.edu\SunChartProgram.html. A sun chart maps out the position of the sun throughout the year, allowing the determination of if and when a potential location is shaded. Some shading, particularly before 9AM and after 3PM, is usually acceptable. If you are unsure, it is best to consult with a solar professional.

PHOTOVOLTAIC SYSTEM SIZING AND INSTALLATION

PV Module Electrical Power

A PV module's power is rated by peak approximate DC power output at standard testing conditions (STC). STC are laboratory test conditions and are very different from the conditions that the modules will see when operating in the sun. These conditions are solar intensity of 1,000 Watts per square meter (317 BTU/hr-ft^2) and a module temperature of 25ºC (77ºF). Actual operating conditions on a sunny day may be solar intensity of 800 Watts per square meter (254 BTU/hr-ft^2) and module temperature of 50ºC (122ºF). PV module power is proportional to solar intensity so it will be less than rated at lower solar intensity levels. Also, PV module power is reduced as the operating temperature increases. Typically, PV module power is reduced by about 5% for every 10ºC (18ºF) increase in operating temperature above STC temperature. **Failure to consider this reduction could cause major system design system errors**.

Available Solar Resources

In North Carolina, for example, there are 14 hours in July between sunrise and sunset and 10 hours in December. Much of that time the sun does not shine at peak intensity (1,000 Watts/m^2) because clouds, haze, and the atmosphere reduce solar intensity. Also, the solar intensity at a PV array is reduced when the sun's rays are not perpendicular to the surface. To estimate the output of a PV system, we use "peak sun hours" which is the number of hours the sun must shine at peak intensity on a PV array to equal the amount of radiation that was actually received by the array during the day. This value is often reported as kilowatt-hours per square meter (kWh/m^2). Thus, a PV array receiving solar radiation of 7 kWh/m^2 per day has received the equivalent of 7 hours of sunshine at peak conditions (i.e., 7 peak sun hours).

PV Module Electrical Energy Generation

To estimate the energy that a PV module will produce, multiply module power and time. The power is not the STC power rating but instead is the expected power at actual operating conditions. In the summer under full sun, it is not uncommon for a PV module to operate at 55ºC (131ºF), reducing its power by 15%. There are several free software programs available to help estimate the output of a PV system. Two of the most widely recommended: RETScreen (www.retscreen.net) and PV-Watts (www.pvwatts.org)

Battery Sizing

PV systems require high quality deep-cycle batteries, such as those used in fork lift or golf cart applications, or batteries made especially for solar systems. Batteries are expensive, but are a vital part of off-grid systems. An oversized system unnecessarily increases the cost of the system, however an undersized system could leave the homeowner without power during extended periods of cloudy weather. Determining how long your batteries must be able to maintain operation of all of the home's electrical loads without input from the PV system is a key factor in sizing an off-grid battery system. This length of time required by the household will greatly effect the size of the battery bank installed. The sizing of an off-grid battery bank should be left up to professional PV system designers and installers (see below to find a qualified local installer). Depending on the goals and expectations of the system by the homeowner, sizing an on-grid battery system may be slightly simpler, but should always be done by a solar professional.

Since batteries are relatively expensive, prolonging battery life is an important aspect of PV system operation. This is best achieved by discharging the battery only partially before recharging. Good system design suggests that a battery system be sized so that the daily load does not discharge the battery more than 20%. In the event of an extended cloudy period, the battery should never be discharged more than 80%. Stand-alone systems with battery storage need a good quality **charge controller** to insure that the battery is never over-charged and a **load controller** to prevent the battery from being overly discharged. Both extremes can cause permanent damage to a battery.

Finding a Professional Installer

All PV systems should be installed by a professional photovoltaics installer with an electrical contractor's license. The PV industry is moving towards a certification for trained PV installers. It is known as the North American Board of Certified Energy Practitioners (NABCEP) (www.nabcep.org) PV installer certification. NABCEP recommends that you look for installers that have taken the time and effort to achieve this voluntary certification, which indicates that they are well trained and experienced. You can locate local PV installers through the findsolar.com website maintained by the American Solar Energy Society (ASES).

SUMMARY

The ability to generate electricity wherever the sun shines is a capability unique to photovoltaics. As the value of this capability is better understood, the market for PV will grow significantly. Over the last 25 years, the cost of PV modules has dropped from $100 to $4 per peak watt. This, combined with newer electrical technologies, has resulted in thousands of homes now being powered by PV. As developments continue, this truly unique power source is sure to play a significant role in our energy future.

This Project was Supported by:

National Association of State Universities and Land-Grant Colleges · Building America U.S. Department of Energy Research Toward Zero Energy Homes · UF University of Florida IFAS Extension · NC State University North Carolina Solar Center · LaHouse Louisiana House Home & Landscape Resource Center