Feasibility of Photovoltaic Systems

RENEWABLE ENERGY
THE INFINITE POWER
OF TEXAS

HIGHLIGHTS

- **Off-grid photovoltaic (PV) systems can use batteries for night time energy needs**
- **Grid-connected PV systems use the utility as backup**
- **PV can be affordable compared to other power options**

INTRODUCTION

Photovoltaic (PV) energy generating systems (or PV systems) convert the sun's energy directly into electricity using state-of-the-art semiconductor materials. PV systems vary in complexity. Some are called "stand-alone" or "off-grid" systems, which means they are the sole source of power to a home, water pump or other load. Stand-alone systems can be designed to run with or without battery backup. Remote water pumps are often designed to run without battery backup, since water pumped out of the ground during daylight hours can be stored in a holding tank for use any time. In contrast, stand-alone home power systems store energy generated during the day in a battery bank for use at night. Stand-alone systems are often cost-effective when compared to alternatives, such as lengthy utility line extensions.

Other PV systems are called "grid-connected" systems. These work to supplement existing electric service from a utility company. When the amount of energy generated by a grid-connected PV system exceeds the customer's loads, excess energy is exported to the utility, turning the customer's electric meter backward. Conversely, the customer can draw needed power from the utility when energy from the PV system is insufficient to power the building's loads. Under this arrangement, the customer's monthly electric utility bill reflects only the net amount of energy received from the electric utility. However, a grid-connected PV system without battery backup will not generate power for the house when the utility grid is down.

Each type of system requires specific components besides the PV modules. Generating AC power requires a device called an inverter. Battery storage requires special batteries and a battery charge controller. The final cost of any PV system ultimately depends on the PV array size, the battery bank size, and on the other components required for the specific application.

The average Texas household uses approximately 1,100 kilowatt-hours (kWh) of electricity per month, or about 36,000 watt-hours (Wh) of electricity per day. In contrast, a home designed to be energy efficient can use as little as 6,000-10,000 Wh per day. As you might guess, a PV system designed to power an energy efficient home will cost much less.

SOURCE: ANDREW MCCALLA

GRID-CONNECTED RESIDENTIAL PV *More Austin homes are using solar electric systems tied to the utility for their power.*

TOOLS FOR WORKSHEET: ESTIMATING THE SIZE AND COST OF A PHOTOVOLTAIC SYSTEM

This worksheet will explain how to estimate the size of a PV array and battery bank and total cost of a stand-alone PV system. It can be used for grid-connected systems, too, but with several caveats that are identified in the step-by-step instructions. The worksheet is adapted from a method developed by Sandia National Laboratories, and the analysis is conducted in two sections.

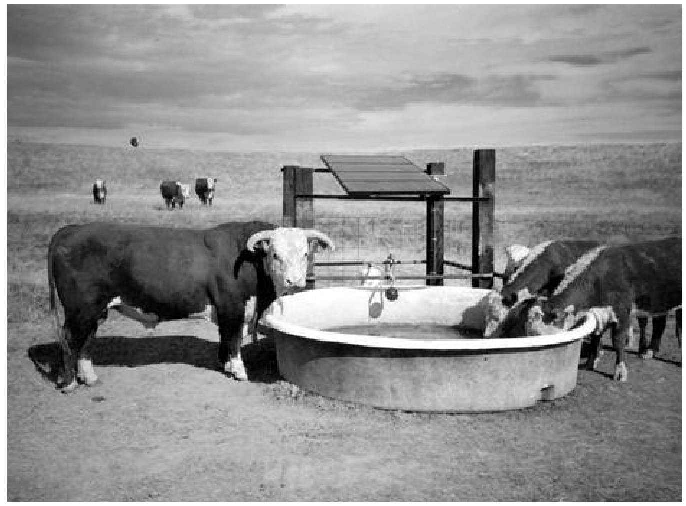
STEP 1. DETERMINE LOAD, AVAILABLE SUNLIGHT, PV ARRAY SIZE, AND BATTERY BANK SIZE

1.a. Determine Load. The preferred method for determining PV system loads is a "bottom-up" approach in which every daily load is anticipated and summed to yield an average daily total. For PV systems designed to power simple loads, such as a single water pump, electric light or other appliance, this method is easy. Simply look at the nameplate power rating on the appliance to calculate its power consumption in watts. Some labels show amperage and voltage only; to obtain watts, just multiply amps by the voltage. Then multiply by the number of hours it is expected to operate on an average day to obtain watt-hours (Wh).

For more complex loads, such as powering a whole house, you will need to estimate all the different loads in the house on a typical day and sum them. Table 1 provides an example calculation for a household using this method.

Applicance	AC or DC Watts		Housrs Used/Day		Watt Hours/Day
Ceiling Fan	100	x	8.0	=	800
Coffee Maker	600	x	0.3	=	180
Clothes Dryer	4,856	x	0.8	=	3,885
Computer	75	x	2.0	=	150
Computer Monitor	150	x	2.0	=	300
Dishwasher	1,200	x	0.5	=	600
Lights, 4 Compact Fluorescents	4 x15	x	5.0	=	300
Microwave Oven	1,300	x	0.5	=	650
Radio	80	x	4.0	=	320
Refrigerator	600	x	9.0	=	5,400
Television	300	x	8.0	=	2,400
Vacuum Cleaner	600	x	0.2	=	120
VCR	25	x	8.0	=	200
Washing Machine	375	x	0.5	=	188
TOTAL					**15,493**

TABLE 1 *Typical household electrical appliances and run times*



SOURCE: ANDERSON, JERRY – NORTHWEST RURAL PUBLIC POWER DISTRICT

RURAL PV *Remote water pumps for livestock are often economically powered by PV.*

For complex loads like households, it is sometimes difficult to anticipate every electric load. Electric clocks, TVs, stereos and other appliances sometimes draw small amounts of power even when they are turned off. For this reason, we recommend multiplying your estimated daily load by a "fudge factor" of 1.5. Some other elements accounted for by this factor are all the system efficiencies, including wiring and interconnection losses, as well as the efficiency of the battery charging and discharging cycles. Of course, for grid-connected systems, you can simply review your monthly utility bills to get an accurate idea of monthly energy consumption.

1.b. Determine Available Sunlight. The amount of useful sunshine available for the panels on an average day during the worst month of the year is called the "insolation value." We use the worst month for analysis to ensure the system will operate year-round. In most of Texas, average solar insolation values range from about 3.3 to 5.0 hours per day in December, with the lowest values in east Texas and the highest values in the Panhandle and far west Texas (see Figure 1). The insolation value also can be interpreted as the kilowatt-hours per day of sunlight energy that fall on each square meter of solar panels at latitude tilt.

1.c. Determine PV Array Size. For a PV system powering loads that will be used every day, the size of the array is determined by the daily energy requirement (1.a.) divided by the sun-hours per day (1.b.). For systems designed for non-continuous use (such as weekend cabins), multiply the result by the days per week the loads will be active divided by the total number of days in the week. For example, for a weekend cabin, multiply by 2/7. Generally, grid-connected systems are designed to provide from 10 to 60% of the energy needs with the difference being supplied by utility power.

1.d. Determine Battery Bank Size. Most batteries will last longer if they are shallow cycled–discharged only by about 20% of their capacity–rather than being deep-cycled daily. A conservative design will save the deep cycling for occasional duty, and the daily discharge should be about 20% of capacity. This implies that the capacity of the battery bank should be about five times the daily load. It also suggests that your system will be able to provide power continuously for five days without recharging, such as during a winter storm. Multiply the daily load (1.a.) by 5, and then divide the result by the voltage of the battery bank you will use (typically 12 volts). The result is the recommended amp-hour rating of the battery bank. If you wish to be more secure and design for more days of cloudy weather, multiply by a number greater than 5. However, it is generally not recommended to design for more than 12 days of cloudy weather unless it is a highly critical load. Of course, you can skip this step entirely if your system does not incorporate a battery bank, such as a water pump, or is grid-connected since the availability of grid power eliminates the need for storage.

STEP 2. CALCULATE PV SYSTEM COSTS

2.a. Estimate PV Array Cost. Many PV modules can be purchased at retail for about $5 per watt for most small systems in the 150 – 8,000 watt range. Of course, there are opportunities to purchase modules for a lower price, especially when your system is larger and you can buy in bulk. When purchasing modules, look for a UL listing, which certifies that the modules meet electrical safety standards, and long-term warranties. Manufacturers typically offer modules with 25-year warranties.

2.b. Estimate Battery Bank Cost (if needed). Many flooded lead acid batteries designed for use with PV systems can be purchased at retail for under $1 per amp-hour.

2.c. Estimate Inverter Cost. An inverter will be needed for systems that output AC power, the current used by the most common appliances and electric devices. For stand-alone systems the inverter should be sized to provide 125% of the maximum loads you wish to run simultaneously at any one moment. For example, if the total loads you wish to run will be 1,600 watts (a dishwasher, television and ceiling fan from Table 1) choose an inverter with a rated continuous power output of 2,000 watts. For grid-connected systems the maximum continuous input rating of the inverter should be about 10% higher than the PV array size to allow for safe and efficient operation. The input rating of the inverter should never be lower than the PV array rating. For more information contact an inverter supplier. Inverters designed for residences and other small systems can be purchased at retail for about $1 per rated watt.

2.d. Estimate Balance of System Cost. Besides PV modules and batteries, complete PV systems also use wire, switches, fuses, connectors and other miscellaneous parts. We use a factor of 20% to cover balance of system costs.

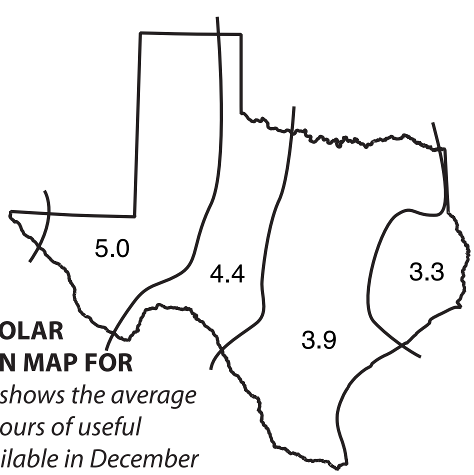


FIGURE 1 SOLAR INSOLATION MAP FOR TEXAS *This shows the average number of hours of useful sunlight available in December for a PV module at latitude tilt.*

CALCULATIONS

Step 1. Determine the load, available sunlight, array size, battery bank size:

a. Determine the energy load required in watt-hours (Wh) per day. Multiply the number of watts the load will consume by the hours per day the load will operate (see Table 1 in the Reading Passage). (Based on your teacher's directions, you can use the Wh energy load in Table 1 or create a new chart with your own values.) Multiply your result by 1.5.

Total Wh per day required ___ x 1.5 = _______Wh

b. Determine the hours per day of available sunlight at the site (see Figure 1).

Total available sunlight: ______ hrs/day

c. Determine the PV array size needed. Divide the energy needed (1.a.) by the number of available sun hours per day (1.b.).

Total array size required: ______ Watts

d. Determine the size of the battery bank (if one is desired). Multiply the load (1.a.) by 5 (result is watt-hours, Wh). Then divide by the battery voltage (for example, 12 volts) to get the amp-hour (Ah) rating of the battery bank.

Total Battery Bank Required: ______ Ah

Step 2. Calculate the cost of the PV system needed for this application:

a. Multiply the size of the array (1.c.) by $5 per watt.

Cost estimate for PV array: $ _________

b. If a battery bank is used, multiply the size of the battery bank (1.d.) by $1 per amp hour.

Cost estimate for battery bank: $ _________

c. If an inverter is used, multiply the size of the array (1.c.) by $1 per rated watt.

Cost estimate for Inverter: $ _________
Subtotal: $ _________

d. Multiply the subtotal above by 0.2 (20%) to cover balance of system costs (wire, fuses, switches, etc.).

Cost Estimate for Balance of System: $ _________
Total Estimated PV System Cost: $ _________

COMPARE TO ALTERNATIVES

Once you have estimated the total cost of a PV system that meets your needs, a final step in an economic feasibility study is to compare estimated costs of the PV system to other alternatives. The most common alternative to off-grid PV is a line extension from an electric utility company. Utilities in Texas typically charge anywhere from $5,000 to $30,000 per mile for line extensions; so for many small- or medium-sized loads in remote locations, PV systems are the economically feasible choice. For this reason, several rural electric cooperatives in the State now offer their customers PV systems in lieu of more costly line extensions. Line extensions also may be prohibitively expensive even when the distance traveled is short, such as in urban areas where pavement cuts are required.

Other alternatives include on-site diesel generators, hybrid wind-solar systems, or simply making biodiesel energy improvements such as installing energy-efficient appliances, improving insulation and sealing ducts. Each alternative comes with its own benefits and drawbacks, many of which are difficult to quantify. For example, the cost of purchasing and delivering diesel/biodiesel fuel to a remote generator should be considered in an economic analysis of alternatives, as well as the noise and exhaust generated as byproducts of the energy production.

STICKER SHOCK? THE IMPORTANCE OF EFFICIENCY

Once you have estimated the cost of a PV system for your home, chances are the price will seem a bit high. This is why most people who use PV to power their homes design them to be energy efficient. This means they build their homes with excellent insulation, take advantage of energy efficient designs, and pay attention to important factors such as site selection, shading, and orientation. With some careful planning, it is possible to reduce a home's electrical loads by 50 to 80 percent without sacrificing comfort and convenience.

RESOURCES

FREE TEXAS RENEWABLE ENERGY INFORMATION

For more information on how you can put Texas' abundant renewable energy resources to Use in your home or business, visit our website at **www.InfinitePower.org** or call us at 1-800-531-5441 ext 31796. Ask about our free Teacher Resource Guides and CD available to teachers and home schoolers.

ON THE WORLD WIDE WEB:

National Renewable Energy Laboratory
www.nrel.gov/solar/

Sandia National laboratory
www.sandia.gov/Renewable_Energy/renewable.htm

Florida Solar Energy Center
www.fsec.ucf.edu

U S Department of Energy Solar Program
www1.eere.energy.gov/solar/

Texas Solar Energy Society
P.O. Box 1447
Austin, TX 78767-1447
(800) 465-5049
e-mail: **info@txses.org**
www.txses.org

Texas Renewable Energy Industries Association
P.O. Box 16469
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