A remote solar power system correctly deployed at a northern location. The array is facing due south, the tower does not cast any shadow on the solar panel, and the panel array tilt angle is correctly callibrated for the latitude less 15°.

Solar power systems deployed to remote rugged areas provide critical power where no other source of power is availble. Sending technicaians to these remote areas to troubleshoot faulty systems is costly, so correctly designing, installing, and maintaining these systems must be carefully considered. Photo courtesy of Cirt Yancy, Seattle Public Works

ESSENTIAL INPUTS FOR SOLAR DESIGN

by Robert F. Collins

Solar electric power is a practical, and in some cases the only, solution for powering remote equipment. Reliable, continuous, autonomous operation of end-use equipment is possible when a robust solar electric system is in place. Proper system design requires essential inputs: careful choices in end-use equipment, a trustworthy estimation of power requirements, an understanding of the available solar resource, and a description of the potential site. This article outlines the choices that must be made, and the data the solar power user should assemble before starting a solar design.

SELECTING LOAD EQUIPMENT

The design of the solar power system naturally follows the selection of end-use, or "load", equipment. However, selecting the right load equipment up front can go a long way in reducing the complexity, size, and cost, of your solar powered system. Selection of load equipment should be driven by high efficiency and low power consumption. When you purchase a solar system, you are essentially buying a 20 to 30 year supply of energy in one shot. Power wasted is money wasted.

Solar electric power systems are by nature DC systems. At the same time, prospective or desirable pieces of load equipment may require AC power. It is important to know that with few exceptions (such as motors, transformers, and lighting) nearly all electronic devices use DC power internally. This DC power is converted, usually at low efficiency, from the incoming AC power. To compound matters, any AC power required by load devices in a solar system must be provided by a DC to AC inverter.

DC to AC inverter manufacturers strive for efficiency… and 80 to 90% conversion efficiency, near peak output, can be expected. Quiescent power consumption (power lost while no load, or a small load, is present) reduces this efficiency greatly. Worse still, the AC to DC conversion inside a piece of load equipment may be as low 50%. When converting from DC to AC only to convert back to DC again within the same system, the losses compound. The final system may be 2 to 3 times larger than an equivalent DC only system.

To build the most efficient system, use AC powered equipment only when there is no other choice. Consider swapping AC motors in favor of DC motors. Avoid inefficient "wall warts" and other small AC to DC power supplies; obtain the proper DC input specifications and power the equipment directly. Look for equipment that is designed to operate from battery supplies; 12, 24, or 48 Volts DC. Look for equipment that can operate from a range such as: 10 to 16 Volts, or 20 to 32 Volts. This tells you the equipment is intended to be operated from batteries and is often a hint that the internal power supply in the device is an efficient switching converter. Avoid equipment with an input voltage listed over a narrow range such as: 12.0 +/- 0.2 Volts. These loads can be accommodated using a DC to DC converter as a voltage stabilizer. Like inverters, DC to DC converters carry a penalty in efficiency and quiescent power consumption.

When possible, choose every piece of load equipment with the same DC operating voltage. Your solar system will have one main battery bus voltage… usually 12, 24, or 48 Volts. This voltage should coincide with the input voltage of the largest power consumer in the system. Other lesser loads operating at different voltages can be accommodated, but this will require a DC to DC converter, and its associated losses for each separate voltage.

This solar power system for an AC power application required a second enclosure and battery bank to compensate for the power lost in conversion from AC to DC.

CALCULATING THE LOAD

The most important aspect in reliable solar design is quantifying the load – defining the average power consumption of the end-use equipment. This is often made difficult because manufacturer's data for power consumption may be misleading or missing entirely. Many types of loads draw varying amounts of power over the course of normal operation. It is then important to know what the various duty cycles are in order to derive the average power consumption. For a given site location, average power consumption ultimately determines the "size", and therefore the cost, of your solar system.

It is often just as important to know the peak power demand of a load device. Devices such as DC to DC converters, DC to AC inverters, fuses, and wiring must be sized with sufficient capacity to handle peak power cycles. Telemetry equipment is a prime example of this. A certain radio may require 50 mA at 12.5 Volts DC for receiving or idle operation, but require 8 Amps while transmitting. Perhaps the transmit time is only 10 seconds per day; this will hardly affect the average power consumption of the device. However, this requires that any device powering this radio is rated for 100 Watts.

Underestimating load power requirements will create a system that will fail in winter or perhaps not work at all. However, overestimation leads to excess system cost. This may not be an issue when only one or two systems are required and the time and effort required determining exact power consumption exceeds the cost of a larger solar system… brute force is sometimes cost effective. Regardless, it is usually worth the time to derive a reasonably accurate value for power consumption. In the case of systems built in quantity, a

Solar panels mounted to the enclosure produce shade, and additional side sun shade panels create passive cooling to help moderate interior temperatures in battery enclosures. Keeping the battery enclosure cool extends the life of the batteries.

thorough profiling of power consumption will always pay off.

Seasonal loads, for example heating and cooling, can pose challenges to system design. These loads must be estimated at least on a monthly basis for proper system sizing. As always, the best strategy is to eliminate the need for them in the first place.

Manufacturers can usually provide more precise power consumption data when asked for it. Some can even offer simulations based on customer usage patterns for power consumption. While too often considered a last resort, the best solution may be to construct a system and measure the power consumption.

DETERMINING THE SOLAR RESOURCE

Once the power requirements of a system are been established, the next task is to determine the available solar resource for a particular location. In general, more sunlight means more energy. There are many variables: cloud cover varies widely from region to region and day to day, days grow shorter in the winter and longer in the summer, and this variation becomes more extreme as we move farther from the equator. The type of solar "array" also affects energy production. Fortunately, solar resource maps are available; some difficult work has been done for us. We first have to establish what type of solar array we are using.

Solar modules require full direct sunlight perpendicular to their surface to produce their maximum power. The sun's angle changes with the time of day and season. Various devices, so called "solar trackers", are available to track the sun with the solar array and maintain maximum power production. Unfortunately, the increased cost of tracking devices and related structure does not usually offset the value of the increased power production. In most circumstances, it is simply more cost effective to deploy a greater quantity of solar modules in a fixed flat plate array.

Given a flat plate array with a clear horizon to the east and west, the best choice is to angle the array toward the equator… due south in the northern hemisphere. The angle chosen between the array and the ground depends upon how we require power produced during the course of the year. To favor maximum annual power production, an angle of site latitude minus 15 degrees is usually chosen. This makes the solar modules nearly perpendicular (at solar noon) to the sun's rays during summer.

However, for stand alone applications with fixed, constant loads, we may wish to ensure minimum power production during winter. This is accomplished by mounting the array at angle of latitude plus 15 degrees. Keep in mind, if your system has seasonal loads, and your power requirement is something other than the two scenarios outlined above, your system designer can optimize a fixed array angle to accommodate this.

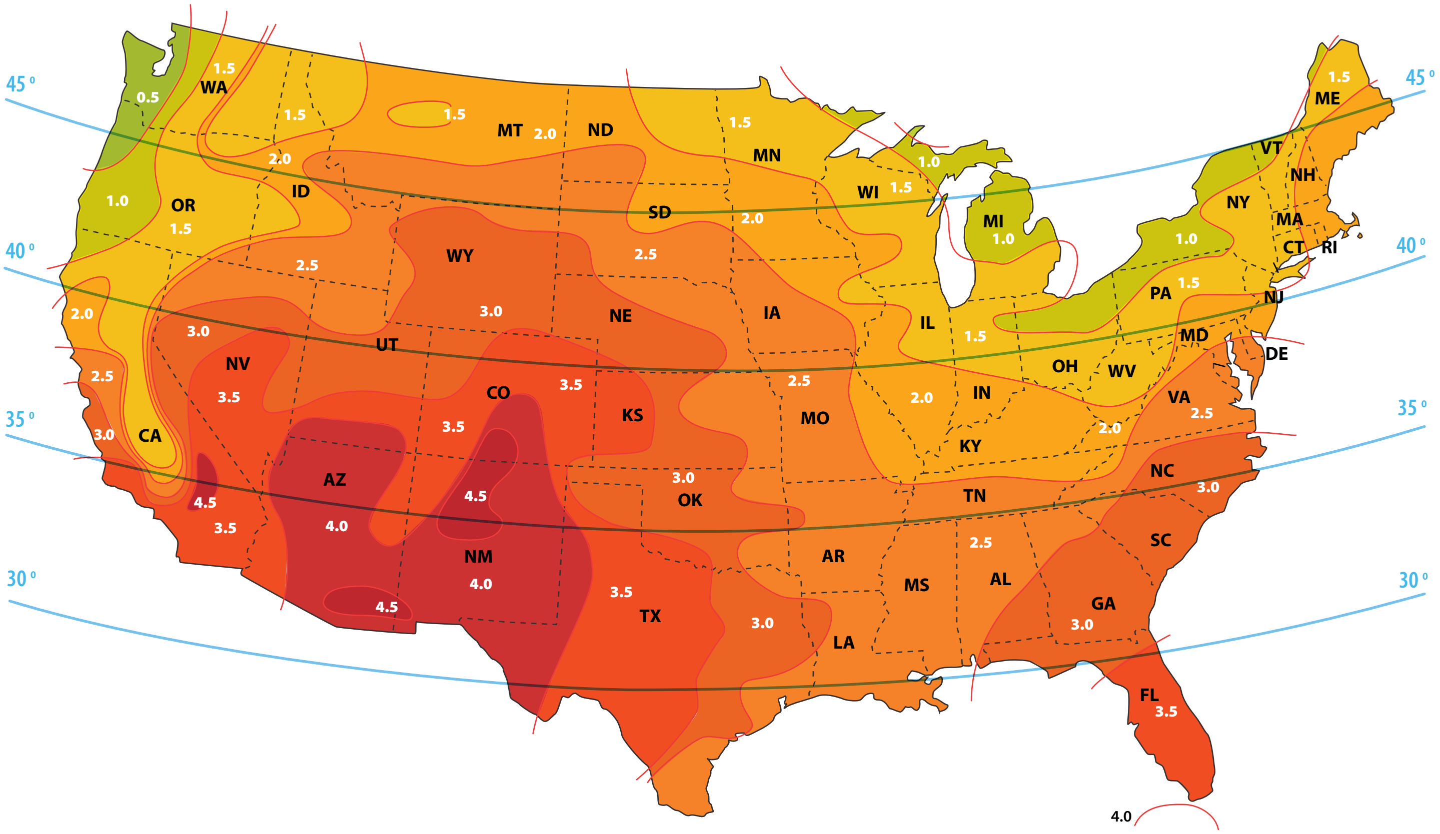
Shading, even small area of the solar panel, greatly decreased power production. This power system will not perform well due to shading from nearby vegitation and improper orientation.

This system is well placed away from obstructions and is oriented to receive maximum solar radiation.

In equatorial regions, this strategy tends to collapse somewhat. The lines between winter and summer blur. Additionally, solar modules should never be placed horizontal except in certain mobile or marine applications. A minimum angle of 5 to 10 degrees must be maintained to prevent build-up of dirt, mold, or debris.

With a location, a flat plate array and an angle in mind, we can now consult any number of "insolation" databases or maps for a value of "peak sun hours" based on the array type and angle. This value is used by the system designer to determine the quantity of solar modules required to power your load throughout the year. Values for peak sun hours are available in averages or minimums based on 30 years of historical data. Minimums are the norm when designing critical systems; and even this data must be used wisely.

Insolation maps refer by nature to large areas while charts refer to specific locations. Both provide the potential for a serious error in system design: the "microclimate". Data has not been gathered for every square meter of the planet. A microclimate is a location with weather that is not typical for the greater area or nearby locations. Certainly a microclimate with more sunlight than a map or chart would suggest poses no problem because the solar system would not likely be underpowered. This is not usually the case with microclimates; consider the valley with fog that does not burn away until noon, and the foothills upwind of a large peak that gather clouds. These situations undermine the value of the insolation data and create the potential



Solar Hours are measured in kilowatt hours per square meter per day (kWh/M2/day)

Solar panel tilt angle: Latitude + 15°

The information on this map is interpreted from solar insolation data from National Renewable Energy Laboratory, www.nrel.gov., and represents average Winter Sun Hours over a thirty year period.[1]

for an underpowered system. These conditions must be understood by the user and brought to the system designer. The system designer can compensate for these issues.

DESCRIBING THE SITE

Finally; what about the site itself? Mountains, forests, jungles, plains, deserts, swamps, oceans, vehicles, boats, offshore platforms, and even spacecraft will require different system enclosures and array structures.

A thorough description of the site conditions should include: the ambient temperature extremes, ground and soil conditions or mounting and structural requirements, information about snowfall, rainfall, and extreme winds, the likelihood of lightning, earthquakes, severe storms or flooding, obstructions that may shade the array such as antennas, trees and towers. Consideration should be given to the potential for theft and vandalism. All of these factors will influence the system design.

CONCLUSION

Assembling these data will support and speed the design of a reliable solar electric power system. Be certain your solar designer is asking these questions or gathering this information for you. Essential outputs, power for your equipment, are the product of essential inputs.

About the Author

Rob Collins is Solarcraft's lead design engineer, and has directed R & D and system design in the Solar industry more than 20 years.

End notes:

[1] Averages of solar radiation for each of 360 Months, 1961-1990 for 239 U.S. sites; and thirty-year averages of monthly solar radiation, 1961-1990 for 239 U.S. sites

Marion, William and Stephen Wilcox, 1994: "Solar Radiation Data Manual for Flat-plate and Concentrating Collectors <http://rredc.nrel.gov/solar/pubs/redbook/>." NREL/TP-463-5607, National Renewable Energy Laboratory, 1617 Cole Boulevard, Golden, CO 80401.

Pictured is a submersible system enclosure built to survive underground seismic measurement vaults that occasionally become flooded. All the seismic instruments in the vault are powered by solar panels. Photo courtesy of Incorporated Research Institutions for Seismology (IRIS) and the EarthScope Project, sponsored by the National ScienceFoundation.