A SunCam online continuing education course

Solar Power Part III
Design Considerations

by

R. S. Wilder

COURSE DESCRIPTION

Note: This course assumes that you have a working knowledge of Solar Photovoltaic (PV) design and are familiar with the terminology and components found in a typical system. ***If not, you should first take the SunCam course "Solar Power Part I: Design for Small Structures – An Introduction".*** This course is intended to provide a quick refresher to those who haven't designed solar power systems or kept up with the new products or current pricing of the various components. Much of the basic explanations are not included in this course but are found in the "***Solar Power Part I"*** course. However, this course also includes additional components that were omitted in the first course (due to time/space limitations) but are used in many systems today.

The interest and use of solar PV power is continuing to grow throughout this country and the rest of the world. It is still the one energy source that cannot be decreased, restricted, or embargoed. In recent years, the focus on climate change and energy consumption… worldwide and in the United States… has rapidly spurred growth in the research and development of cheaper and more efficient solar power systems. And today, because of that focus, the prices continue to drop while solar power efficiencies steadily increase. As a result, solar power remains a rapidly growing and popular ***green*** energy source.

Figure 1 - An off-grid solar powered shop and fire fighting water well

Also, the U.S. tax credits still exist. The American Recovery and Reinvestment Act of 2009 and the Emergency Economic Stabilization Act of 2008 extended the tax credits to the year 2016. This includes tax credits for solar water heaters and solar electricity.

The SunCam courses "***Solar Power Part I: Design for Small Structures***" covers the basics of a PV power system, "**Solar Power Part II: Design of Grid-Tie Systems**" covers systems connected to the Grid, and "***Solar Power Part IV: Inspecting and Evaluating Systems***" covers the inspection and evaluation process. In this course, we will briefly review the common terminology and explanations of the system components but delve more deeply into some of those components, options, and considerations.

Once again, we will start "at the beginning" and then briefly refresh you with the basic system components… from the solar panels to the actual electrical appliances and the design involved in each of these components. This course is not intended to be all-inclusive in the design and installation of any solar electrical system but is intended to provide you with information on additional considerations, optional products, and sources.

Figure 2 - An off-grid solar powered building in Punta Gorda, Florida

Before we get started, please note that some of the new material presented in this course is a response to requests and questions submitted by previous readers. So, please continue to submit your course suggestions to me. Now... to begin …

THE BASICS

A typical solar PV system is comprised of solar panels (a.k.a. photovoltaic or PV panels), a charge controller, batteries, a power inverter, a meter or monitor, and the electrical distribution system (the electrical wiring). Like many technologies, there are multiple manufacturers for each component offering different levels of quality, features, and, of course… price. Below are two basic PV schematics showing the essential components needed to supply AC and DC power. The type of inverter used will determine whether it is an Off-Grid or a Grid-Tie system.

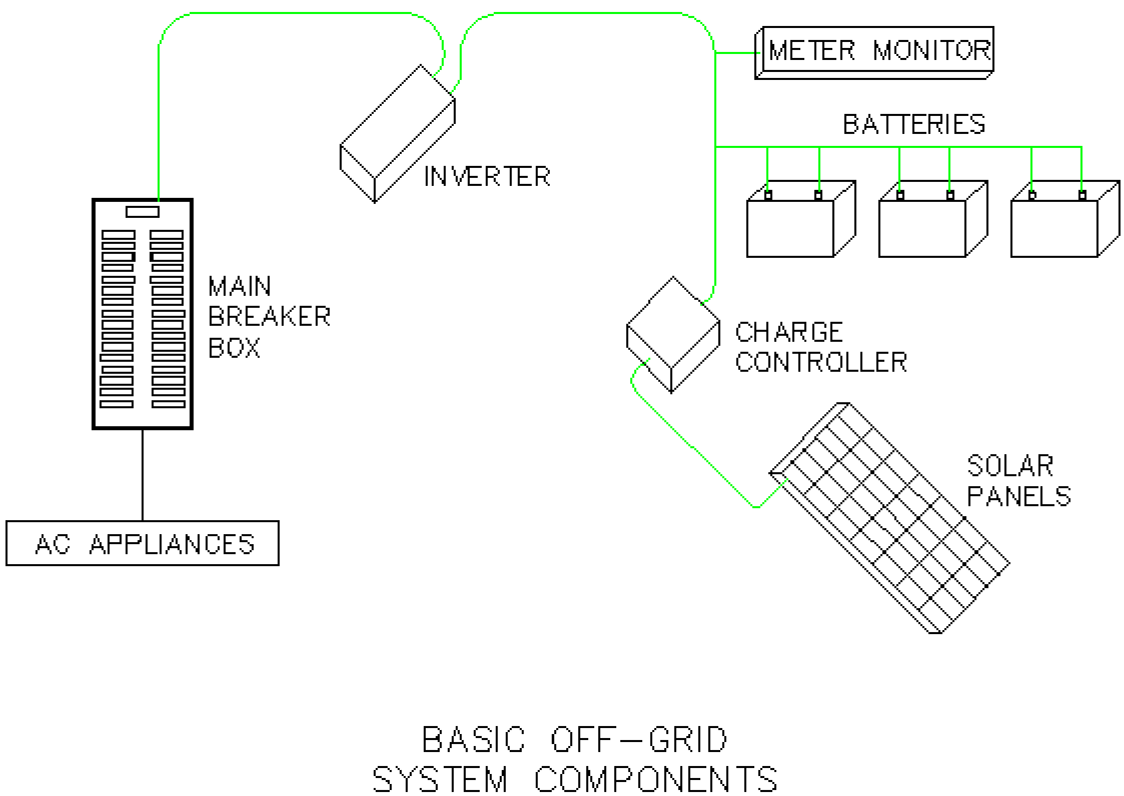
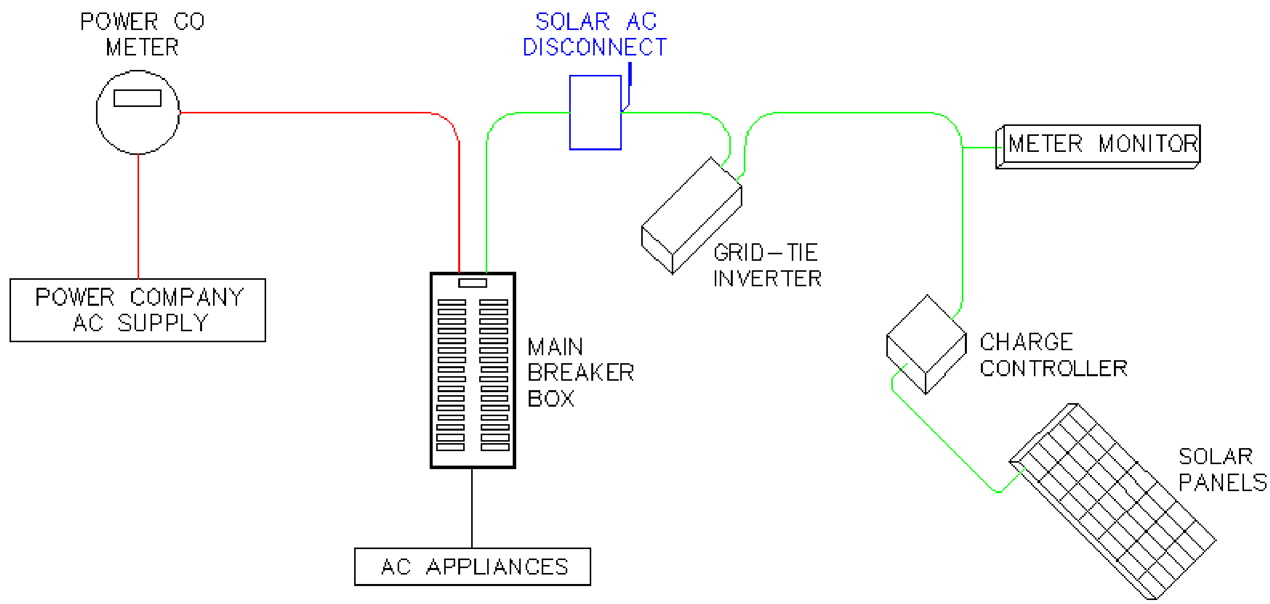


Figure 3



BASIC GRID–TIE
SYSTEM COMPONENTS

Figure 4

From these schematics, we will review the components and then discuss some additional components that you will likely want to incorporate into your system designs. These will include surge protectors, lightning arrestors, circuit breakers, PV combiner boxes, etc.

But, first, some considerations...

PV Panels – Photovoltaic panels are available in different sizes, voltages, and amperages. They are available as Monocrystalline, Polycrystalline, or *Amorphous* panels. Most systems will use Polycrystalline panels since recent advances in technology have increased their efficiencies to almost equal that of the Monocrystalline panels. However, in those rare situations where maximum performance is needed, the Monocrystalline panels are still used. And the Amorphous panels are still a consideration for unusually shaped spaces.

Polycrystalline panel

Charge Controllers – The charge controller monitors the electricity produced by the solar panels and then regulates the electricity to charge the batteries and prevent them from becoming overcharged. Different technologies are available for selection, but today, rarely will you choose one without the Maximum Power Point Tracking (MPPT) capability.

Figure 5 - Morningstar MPPT Controller

Batteries – You will need batteries unless... you have a need for daylight operations only or if you have a grid-tie connection. The batteries are available in different voltages and varying amp-hour ratings which we'll also discuss in more depth later. Then also, the new Lithium-Ion batteries are beginning to enter the solar PV market.

Figure 6 - Fullriver AGM battery

Inverter – The inverters convert the system's DC volts into AC volts. Some inverters can also be used to charge the batteries when connected to a backup generator or another AC electrical source. Choosing the right inverter for the demand and power requirements of the system is critical for the components to function properly. And microinverters are available and are worth considering for new installations.

Figure 7 - Image SMA

Solar Technology AG

Monitor meter – A monitor meter is used to monitor the condition of the batteries, the power being generated by the solar panels, and the user's current consumption rate. It will provide you with the information you need to protect the batteries, help you locate the source of any system problems when they occur, and more efficiently use a generator when charging the batteries. Therefore, select a good one.

Figure 8 - Morningstar Remote Meter

Generator – A gas powered generator is recommended for keeping the batteries charged during extended rainy/cloudy periods and for providing a boost for those temporary high power demands. Without sunlight or a grid-tie switch, a generator is the only thing that will ensure the electricity remains available for use. Unless you have an unusual situation, always purchase a Pure Sine-wave generator for the reasons discussed in the *Solar Power Part I* introduction course.

Figure 9 - Coleman Generac Generator

On-Grid / Off-Grid / Grid-tie – These are terms used to identify whether a system is connected to a utility company providing AC power. An off-grid system would be a system without a connection to a standard electrical service provided by a power company. An on-grid system is your typical building which uses power from a utility company only. A grid-tie system can allow you to use both the solar energy when it's available and when it's not available, have the system automatically switch to the on-grid electricity.

SOLAR SYSTEM SIZING

When you design a solar system, remember to account for ***every*** demand the end user has for power. Every light bulb, radio, fan, air conditioner, computer, toaster, whatever....

Step 1: Know your end users. This is still a critical step. Know *what* they will be using and *how* they will be using the electricity... now and in the future. This is critical. Not knowing this information is setting your system up for failure, and unhappy clients. And when your clients are unhappy... well... you're going to be unhappy.

Step 2: Quantify *EVERY* item that will require power. You will need to know the wattage of each appliance and the hours it will be used each day. This will provide the amp-hours you will use for the design.

Example project:

Appliance	Quantity		Watts		Hrs/day		Watt-Hrs
Lights	4	*	15	*	10	=	600
Lights	2	*	15	*	4	=	120
X	X		X		X		X
X	X		X		X		X
							4,000 watt-hrs/day

Complete this appliance list for every item using power and then provide an additional buffer based on your best estimate of the end users. Note that people will ***ALWAYS*** use more electricity than you expect. Consider adding a 20-25% buffer for those "surprise" loads that someone will eventually use.

REVIEW OF SOLAR PANELS

Solar panel arrays are wired in parallel to increase the current capacity. They will also be wired in series to increase the voltage to 24, 48, or higher. They may also be combined in parallel and series to increase both amperage and voltage.

Solar panels vary in length and width depending on the manufacturer but most are about 1 to 2 inches thick. And they can weigh up to 30-50 pounds or more, so the larger ones (up to 5' x 3') can be difficult to work with if mounting on a pole or on a steep roof.

Figure 10 – Roof-mounted solar panels

Remember Figure 11 below? Both have 4 individual cells with the same area of shading occurring horizontally on both but the voltage output will differ significantly. Even partial shading will drastically reduce the power output of the impacted cells.

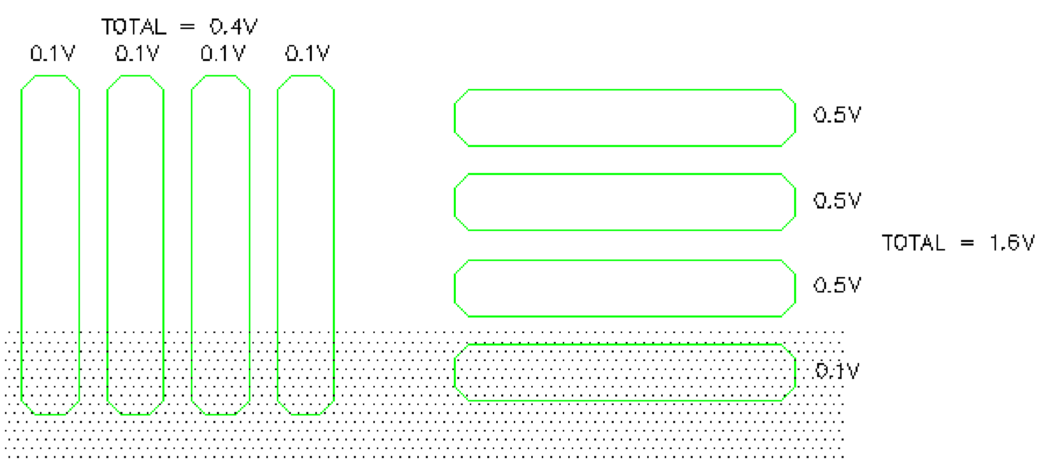


Figure 11 – Solar cell shading

Panel Considerations

Shadows. It is critical to minimize or eliminate any shadows that can impact the solar panel array… especially during ***peak*** sunlight hours (10am to 3pm). Not only will shading of the solar panels significantly reduce their output, but it could also damage them because of differential heating.

Temperature is another issue that must be addressed. Solar panel efficiency decreases as temperature increases. So the solar panels should be mounted in such a way as to allow for air flow around the individual solar panels to help with their cooling.

Wind is yet another issue that needs to be considered. Wind can aid in cooling the panels in the hot sun but too much wind… i.e. hurricanes, tornados, gales… can damage the panels with flying debris or actually ripping the panels from their mounts. Always check the local codes to determine the requirements for securing solar panels to a building or a pole.

Access to the panels must also be evaluated when considering where to install the solar panels. To maintain peak performance from the system, the panels need to be checked and cleaned on a regular basis. A monitor meter will also help determine when maintenance is needed.

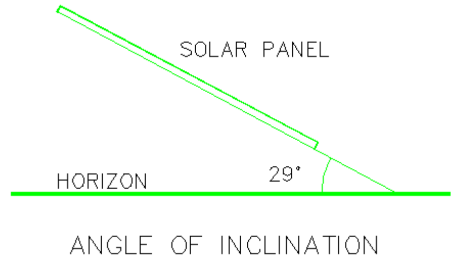
SOLAR PANEL MOUNTS

Solar panels should face true south in the U.S. And there is a difference between true south and magnetic south. Obviously, this is not an issue for tracking mounts. One internet source for determining the magnetic variation is:
http://www.ngdc.noaa.gov/geomag/img/DeclinationMap_US.png

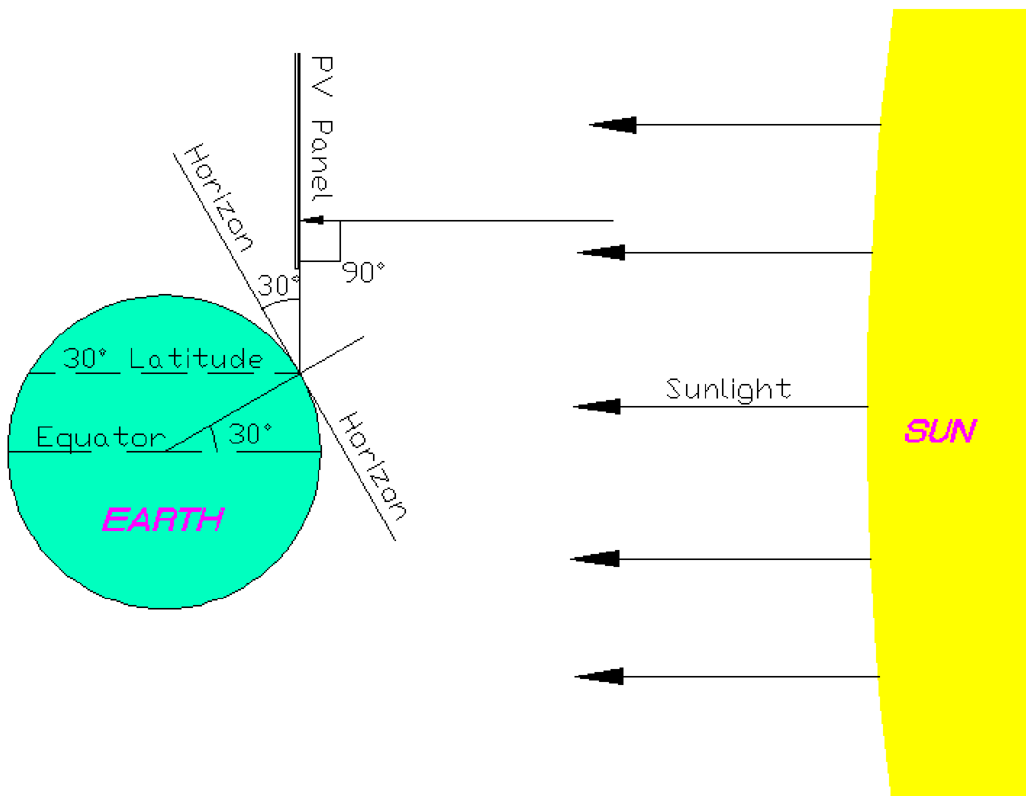
The angle of inclination is another factor in obtaining maximum panel output. As a ***Rule of Thumb***, the solar panel's angle of inclination (tilt) should be set equal to your latitude. If your installation is at latitude 29 degrees North, then set the solar panels at 29 degrees of inclination. The actual inclination for your location, if needed, can be obtained through various online website sources.

One internet source for determining the angle of inclination is:

http://www.srrb.noaa.gov/highlights/sunrise/azel.html



So why does the ***Rule of Thumb*** work? Well... it's time to use a little geometry. Look at Figure X below. Using a latitude of 30° North, the horizon is at a 30° angle from the sun's rays. Now obviously, this doesn't account for the slight tilt or wobble the earth has as it orbits the sun but it is close enough to be useable. But if you're concerned about either of those, use a tracking mount for your PV panels and you won't have to worry about it.



MACS Lab has the best useable information I've found to use in setting the optimal Tilt Angle (angle of inclination). Visit their website for more detailed information at http://www.solarpaneltilt.com/. They also provide seasonally tilt change dates.

For **fixed panel mounts** in latitudes between 25° and 50° that will not be adjusted seasonally, they have a formula which supposedly better captures the PV energy:

(Latitude x 0.76) + 3.1 degrees

For example, at a latitude of 30 N, the panel tilt would be:

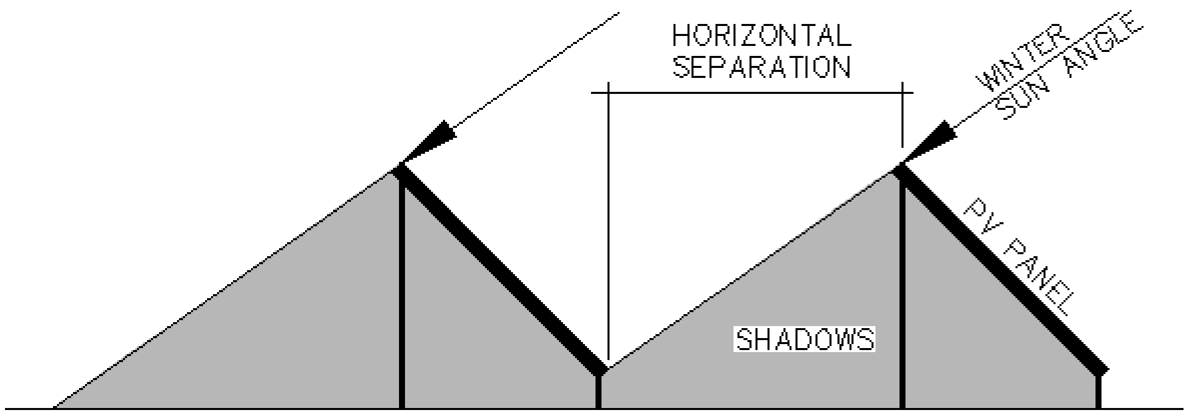
(30° x 0.76) + 3.1 = 25.9 degrees

So, we would set our fixed panel mount at an angle of 26 degrees. This is easily determined in the field using an inclinometer. For installation purposes, if the panel inclination is within a few degrees, the contractor has done a pretty good job.

For **adjustable panel mounts**, using the easy to remember ***Rule of Thumb***... we would decrease the angle slightly during the summer months to boost the output and then increase the angle in the winter months to obtain optimum performance. In March and September the tilt angle should be adjusted to equal the location's latitude. In June, it will be necessary adjust the tilt angle to the latitude minus 10 degrees and then in December, the tilt angle gets adjusted again to the latitude plus 10 degrees. With these minor seasonal adjustments, the solar panel's efficiency can be increased throughout the year.

Fixed solar panel mounts are the simplest and least expensive way to mount solar panels. Typically, they will be attached to a building's roof which is convenient if the roof pitch is appropriate. Note that ground mounted panels are more susceptible to shading issues and impact damage.

Using fixed (or adjustable) mounts on the ground or on a flat roof where you have multiple panels mounted behind each other requires a little more planning. Why? Because you don't want the front row casting shadows on the second row of panels in the winter months (northern hemisphere). To calculate the minimum distance between rows requires that you determine the height of the solar panel in the front row, the lowest angle of the sun during the winter, and the distance that the solar panel will cast a shadow. Obviously, this takes a little geometry and some time to calculate properly but it does reduce the area to the absolute minimum needed to properly space each row and avoid substantial (and embarrassing) power losses caused by shadows from the row in front.



A cautionary note... There are some alternative ***Rule of Thumb*** formulas floating around for setting the horizontal separation distance. Don't get yourself into trouble by using one of these formulas. Basically, they set the separation between rows by multiplying a stated factor times the height of the front solar panel. So, if the Factor is 1.5 and the height of the solar panel (when set at the proper inclination) is 2-ft, then the calculation is:

Factor x Panel Height = spacing between rows
1.5 x 2 ft = 3.0 ft

Just note, that this is a quick estimate for ***a specific latitude only***. The factor actually varies and if you don't know the specific latitude for its use, the result may take more area than is really necessary or it may cause substantial shadows on the second row. Again, the longest shadows will occur in winter... *if* you're located in the northern hemisphere. So be careful with your calculations... especially if you're also using adjustable solar panel mounts since their height changes 2-4 times a year.

Adjustable solar panel mounts allow you to adjust the angle of inclination (tilt). For adjustable mounts, the angles are typically adjusted 4 times during the year to account for the seasonal angles of the sun. These mounts can increase the overall solar panel output by as much as 25% as compared to fixed mounts… which is sufficient to warrant an evaluation of the adjustable mounts.

Tracking solar panel mounts allow the solar panels to follow the path of the sun during the day, which maximizes the direct solar light that the panels can receive. A one-axis tracker will track the sun from east to west at a fixed angle of inclination. The two-axis tracker will track the sun's east to west movement as well as the seasonal declination movement of the sun. Many of the trackers advertise a 20 - 30 percent gain in output that the solar panels provide as compared to non-tracking mounts.

An alternative to the tracking mounts is to simply consider purchasing additional panels instead.… provided you have the room to install them.

Solar powered exhibit hall in Denali National Park, Alaska

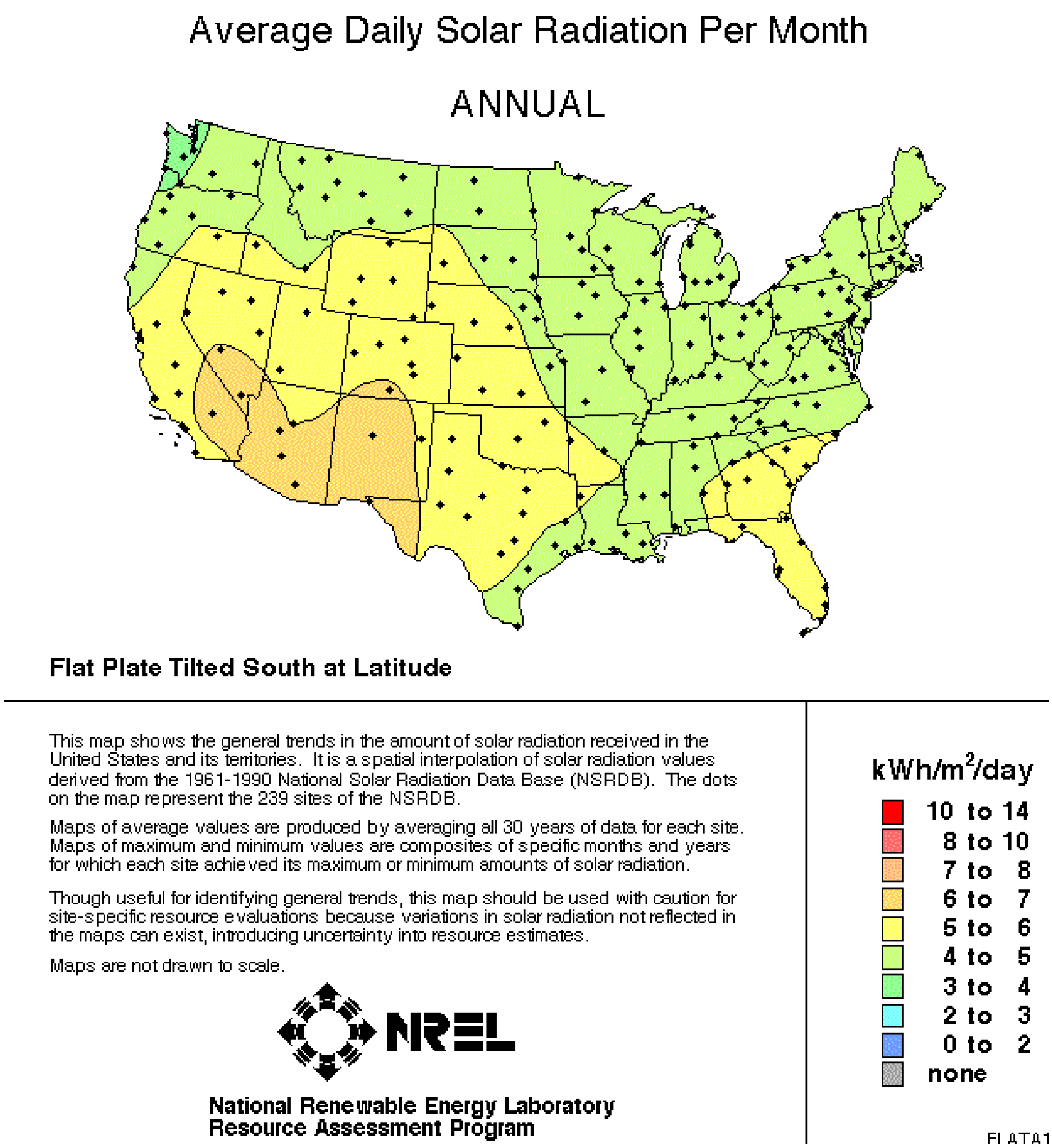
Costs – Since a solar system uses many solar panels and with the average cost of a panel being hundreds of dollars, the cost may seem to be expensive. However, when you factor in the energy savings over the lifespan of the panel (20-30 years) you begin to see the real cost savings. In 2010, the cost of solar panels was about $4-$5 per watt. By 2012, the cost had dropped to around $2-$3 per watt. Now, the cost is almost $1 per watt. A perfect example of supply and demand… and better technology.

REVIEW OF SOLAR EXPOSURE

The yearly average of the approximate hours of daily sunshine in the Southeast U.S. is about 5 to 5.5 hours. The northern states average about 4 to 5 hours per day and the Southwest will see 5 to 6 hours per day. So if you have an installation in the Southeast consisting of six 100 watt solar panels (in the 5.0 hour zone), you can figure 6 panels times 100 watts times 5 hours equals 3000 watt-hours per day or 3.0 KiloWatt-hours per day. See the map below from the National Renewable Energy Laboratory Resource Assessment Program for the number of hours in your location or visit their website for more information at http://www.nrel.gov/gis/solar.html .

6 panels * 100 watts * 5 hrs = 3,000 watt-hrs

The solar exposure map below is based on the **average** number of hours you can expect to receive the sun's rays for a particular location. The map does not take into account solar obstructions in the form of adjacent buildings, trees, terrain, signs, etc. Also, consider the changing inclination of the sun due to seasonal changes. Just because that tree doesn't cause problems in the summer, doesn't mean it won't be a problem in the winter months.



Step 3: Solar panel sizing. Even with the increased wattages available today, this step remains the same. Knowing that our sample project needs 4,000 watt-hours and assuming that our site has 5 hours of sunlight available, we calculate that we need a supply of 800 watts per hour.

Watt-hrs / sunlight hrs = watts needed → 4,000 / 5 = 800 watts

Now that we know our panel wattage requirements, we can start evaluating our solar panel options. Let's evaluate the following panels for our example project.

Watts req.		Panel watts		No. of Panels req.
800	/	200	=	4
800	/	250	=	4
800	/	300	=	3

If you're working with a conventional PV system design and using more than one bank of panels to obtain higher voltages, you will have to stick with pairs of panels rather than an odd number of panels…. We would not use an odd number of panels when we have multiple banks... i.e. one bank with 4 panels and the other bank with 5 panels. However, if you're using Microinverters or a SolarEdge system, an odd number of panels is possible. We'll look at these more later.

Step 4: Select solar system voltage. Again, in a conventional PV system, selecting the most efficient voltage involves an evaluation of the distance from the panels to the charge controller and the costs of the voltage options available. Remember, increasing the voltage decreases the wire diameter size required and that can be a significant cost savings in itself.

Again, the system voltage considerations are different for the Microinverters and the SolarEdge system.

Step 5: Account for bad weather days. Since our example system is designed for 4,000 watt-hrs per day and if we want to provide for 3 days of no sunlight, the battery bank needs to be capable of providing 12,000 watt-hrs… or mathematically…

4,000 watt-hrs * 3 days = 12,000 watt-hrs

Jumping to batteries… While the charge controller would be next in the normal wiring sequence of a solar powered system, we need to determine the most effective and efficient battery voltage before selecting our charge controller.

REVIEW OF BATTERIES

Batteries provide the power for those times when there is no sunlight for the solar panels to function. Car batteries should never be used because they cannot be discharged much more than 10% without internal damage. Also, RV or Marine type batteries should not be used since they do not have the capacity for continuous service with many charge and discharge cycles. One acceptable type for **small** solar systems is a golf cart battery since it is designed for repeated long discharge cycles.

By contrast, the deep-cycle batteries used in solar systems are designed to be discharged by about 80 percent. For all batteries, the expected battery lifetime depends on the charge and discharge cycles. The deeper the battery is discharged... *and* the more frequently the battery is discharged... the shorter the useful life of the battery. Typically, 12 Volt batteries are generally preferred for off-grid systems though 2, 4, or 6 volt solar batteries will work fine. The smaller volt batteries will simply require 2 - 6 times as many as the 12-volt batteries.

Flooded lead-acid batteries have the longest track record in solar electric use and are still used in solar powered systems. Flooded type batteries are lead acid batteries that have caps to add water. They have the longest life and the least cost per amp-hour of any of the choices. However, the big negative with them is that they require regular maintenance in the form of maintaining proper water levels, equalizing charges, and keeping their caps and terminals clean. If the required maintenance is not going to be willingly provided by the end user, do not specify a flooded lead-acid battery.

Special care is required because flooded batteries release hydrogen gas when charging and should not be used indoors. If they are installed in an enclosure, a ventilation system ***must*** be used to vent out the gases which can be explosive.

Sealed Gel type batteries are good because they have no vents and will not release gas during the charging process like flooded batteries. Because they don't require venting, they can be used indoors. This provides two big advantages: 1) it allows the batteries to maintain a more constant temperature which helps them perform better; and 2) because they're indoors, the batteries are more secure.

Absorbed Glass Mat (AGM) batteries are great batteries for solar power use. They are leak proof, spill proof, and do not give off gases when charging. Basically, they have all the advantages of the sealed gel types plus they are of higher quality, maintain voltage better, and self discharge slower. Because of their increased availability, their prices have dropped substantially which makes them an even better value.

Lithium Ion Batteries: Not surprising is the progress being made in batteries for solar systems. With the increased demand for solar systems comes an increased demand for efficient, economical, and compact batteries. Lithium-Ion batteries, which are lighter and capable of many more recharge cycles, have now entered the market. While they are currently more expensive than the lead-acid batteries, the tremendous demand for efficient batteries for electric cars and solar power systems is helping to reduce the cost of these batteries. Along with the progress being made in the battery designs, new technologies are being employed in the software control systems to make them even more efficient with increased performance.

Step 6: Determine the battery bank size. Since you want to avoid damaging these expensive batteries, you never want to reduce your battery charge below 50%. For our example design...

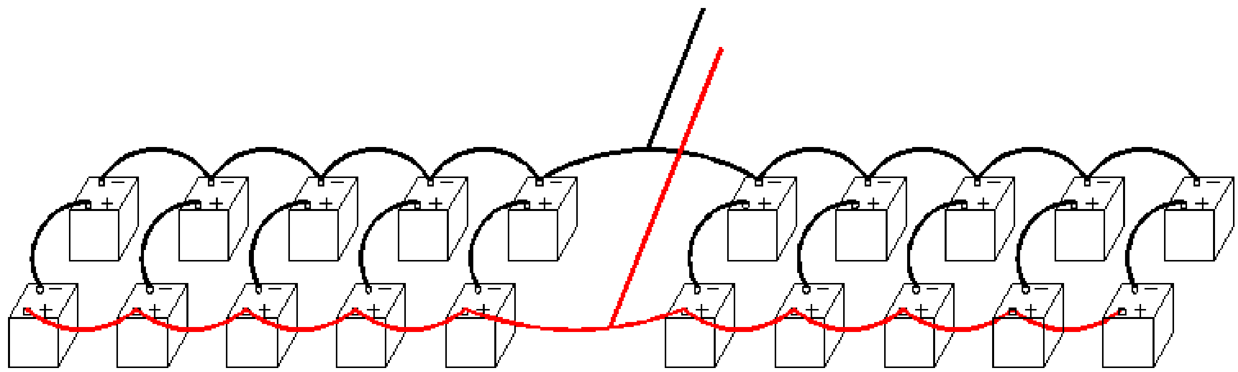
12,000 watt-hrs / 50% = 24,000 watt-hrs

Using 24,000 watt-hrs and 12-volt batteries, we determine the required amp-hrs:

P = E * I or P / E = I

24,000 watt-hrs / 12 v = 2,000 amp-hrs
2,000 amp-hrs / 105 amp-hr = 19

Using 105 amp-hr 12-volt batteries, you will need 2,000 / 105 = 19 batteries. Since the batteries are being wired in pairs to provide 24 volts, you will need to specify 20 batteries. These batteries would be connected in series to make the 24-volts that are being used in the system and in parallel to provide the total power needed. So they would be wired as 10 banks of two as shown below.



12V BATTERIES WIRED FOR 24V
SERIES & PARALLEL WIRING

REVIEW OF CHARGE CONTROLLERS

Now we go back to the charge controller. The primary purpose of a charge controller is to maintain the proper charging voltage on the batteries. Simply stated, as the input voltage from the solar panels increases, the charge controller adjusts the charge to the batteries to prevent over-charging.

Preventing Overcharge Conditions. The voltage parameters that the controller uses for switching the charge rates are called set points. If the charge controller includes an internal temperature sensor, it must be mounted in a place where the temperature is close to that of the batteries, or it must have an optional remote temperature probe. The probe would be attached directly to a battery which reports the temperature to the charge controller.

Set Points and Battery Type. The type of battery will determine the set points for the charge controller. *Sealed gel* and *AGM* batteries need to be regulated to a slightly lower voltage than flooded cell batteries or they may be damaged. Some charge controllers have a switch to select the type of battery. ***ENSURE that the specified controller is intended for the type of batteries being used in the system.***

Overload Protection. Any controller that includes overload protection is helpful, but most systems will also require the use of additional circuit breakers. The controller's overload protection is typically for the system and not for separate circuits within the system or the structure.

The newer **Maximum Power Point Tracking (MPPT) controllers** are preferred over the older multi-stage charge controllers because they match the output power of the solar panels to the battery voltage to obtain the maximum charging amps. The reason is MPPT charge controllers allow your solar panels to operate at their optimum power output voltage, improving their recharge performance by as much as 30%.

Step 7: Charge controller design.

In our example design, we are choosing between eight 100-watt panels or four 200-watt panels. So we will evaluate the amps required by each selection to determine our charge controller design.

From the solar panel's specifications, we determine the following results:

Panels	Voltage	Amperage	Design amperage
(8) 100-watt	12-volt	8.3 amps	= 4 banks at 33.2 amps

Once they are wired, we will have:

(8 panels / 2 (2 panels is 24 volts) = 4 banks * 8.3 amps = 33.2 amps)

OR

(4) 200-watt 12-volt 16.7 amps = 2 banks at 33.4 amps

(4 panels / 2 = 2 banks * 16.7 amps = 33.4 amps)

Since the maximum amperage produced by either option is approximately 33 amps, if we select a 40-amp charge controller, just one charge controller is all that is required.

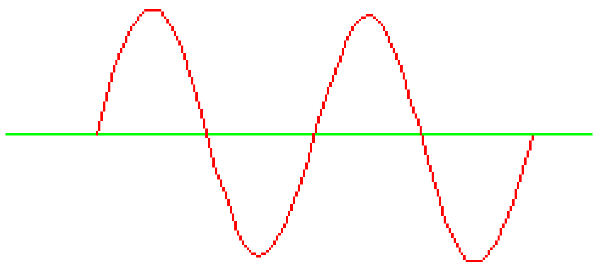
Morningstar controller

REVIEW OF INVERTERS

If you don't need AC power then you won't need a power Inverter. Since the majority of modern appliances run on 120 volts AC, an Inverter will likely be a necessity. It not only converts (or "inverts") the low voltage DC to the 120 volts AC that is required for most appliances, but the inverter can also be used to charge the batteries as we mentioned previously.

The 24-volt and 48-volt systems have become the standards now because the higher voltages reduce the wire diameter size (which reduces cost) and the smaller wire diameters are easier to work with. Consequently, many DC appliances are now more easily obtained in the higher voltages than in their previous 12-volt rating.

Always use a Pure or True Sine wave inverter. A Pure Sine wave is what is provided by the power company to your home and business. On an oscilloscope, the wave looks like the following:



Avoid *Square* and *Modified Sine* wave inverters because they can be harmful to many types of equipment... particularly to electronic equipment with transformers, timers, or motors. Also, appliances that use motor speed controls or timers **may not** work properly or at all. Audio devices can give off an annoying buzz from the speakers and can also be heard from some fluorescent lights, ceiling fans, and transformers. Even microwave ovens will buzz and produce less heat. Electronic TVs and computer monitors will likely show rolling lines on the screen. And surge protectors should be avoided as they can overheat when using these inverters.

Grid-Tie Inverters are required to connect to the grid (the power company). With a Grid-Tie Inverter, you may also be able to sell any excess power produced by your solar array back to the power company. These systems are easy to install and, since the on-grid system is available, back-up batteries are not a requirement. A grid-tie inverter provides the option of not having to purchase costly batteries ***but*** note that if you don't have any batteries, then you also won't have any electrical power when the utility power is out. *So*... a small battery bank may still be desired to cover any short-term power outages.

If a grid-tie system is of interest, you **must** contact the utility company to see if they will allow you to connect a solar system to their electrical grid. Note, that while there is a U.S. law that *requires* **investor owned** utility companies to allow interconnection of a solar system, **rural electric cooperatives** are exempt from this law. If allowed by the power company, they will specify which grid-tie inverter models are allowed on their system. Also, take the SunCam course "***Solar Power Part II – Design for Grid-Tie Systems***" which introduces you to the components needed to connect a solar PV system to the power grid.

If you are allowed to connect to their grid, the next question is… will they buy the energy back at the retail or wholesale rate. Ideally, you want the utility company to buy any excess electricity produced at the same retail rate that you buy electricity from them. This is commonly referred to as "net metering" and is the simplest way to set up a grid-tie system. This way, you only have one electric meter and it can record whether you are buying or selling electricity. To find out if your state offers any incentives or "net metering", visit www.dsireusa.org.

Inverter Input Voltages. What should be used… a 24 or 48-volt inverter? The higher the voltage, the lower the current… which means the smaller the electrical wiring can be.

SMA Sunny Boy inverter

Inverter Stacking is using multiple inverters to provide more power or higher voltage (i.e. 240 VAC). If two compatible inverters are stacked in series, you can double the output voltage. This would be the technique used to provide 240 VAC. On the other hand, if you configure them in parallel, you can double your amperage. Two 4000 watt inverters in parallel would give you 8000 watts (8KW) of electricity. Typically, a cable must be connected directly between the inverters to synchronize them so they act as a single unit.

Step 8: Inverter design. Again, using our example design calculation thus far, we have a solar system charging our battery bank which is providing us with 2,000 amp-hrs of power. Some of this may be used by DC circuits… if used… and the remainder will be with the AC circuits. The inverter must be sized large enough to handle the total amount of AC watts *that you will be using simultaneously*.

Assuming you need an inverter that can handle at least 2800 watts, you will select an inverter that has the same nominal voltage as your battery bank or in our case 24 VDC. Unless you have reason otherwise, choose an inverter that provides True Sine Wave outputs as we discussed previously.

So... we would look for an Off-grid 2,800 watt 24-volt True Sine Wave inverter and specify something like an Outback VFX3524 (3,500 watt 24-volt).

DISCUSSION ON METERS AND MONITORS

Monitoring battery voltage and system performance is very important to determine the current state of the solar system. Many charge controllers display Amps, Watts, Volts, Amp-Hrs, and Total Amp-Hrs to provide easy monitoring of the system status. It is recommended that you select one that does, or install an independent monitor.

Step 9: Select a Meter & Monitor. Depending on the charge controller and inverter chosen, you may or may not need an independent meter or monitor. Just ensure that you include a good meter in your design if your charge controller doesn't provide one.

TS-M-2 Monitor Meter on
Morningstar TriStar
MPPT-60 charge controller

Note: If you're using the Enphase Microinverters or the SolarEdge system, you will need to use their monitor & management systems.

DISCUSSION ON GENERATORS

Generators are best used for backup power during long periods of little or no sun. Ideally, if and when you need to run the generator, you want to run it just long enough to provide the batteries with both the *Bulk* stage charge and the first portion of the *Absorption* charging stage. Then shut it off! Once in the *Absorption* stage, the current will begin dropping as the batteries approach a full charge so most of the generator's power is not being used and is simply being wasted.

Be careful when sizing a generator. Many inverters require the generator to be oversized because of its low power factor. Always check the specifications first before selecting a backup generator.

Step 10: Select a Generator. If needed, small generators can be found starting at $350 and go up in price depending on brand & features. Again, choose a Pure Sine generator.

REVIEW OF WIRING

Step 11: System Wiring. Correct wire sizes are essential for wiring the various components of a solar PV system. If you're using a 24-volt system, make sure you use a 24-volt wire size chart. Also note the allowable voltage drop when using any chart and be sure you account for the voltage drop in your design. Never use more than a 2% voltage drop when sizing wire from the solar panels to the charge controller. A 3% - 5% DC voltage drop may be acceptable between the batteries and the appliances.

It is also important to note that when selecting circuit breakers, AC and DC breakers are ***NOT interchangeable***. So be careful in the selection of breakers, and only allow DC rated products on DC wiring.

See the example wire sizing chart below for the impacts of amps on various wire gauges for 12-volt and 24-volt wiring. The Voltage Loss chart values below were calculated using Ohm's Law as shown:

From Ohm's Law, we can calculate: **E = IR**

where: E = Voltage Loss (volts)

I = Current (amps)

R = Resistance (ohms)

Therefore, using a manufacturer's specifications for the Resistance values of their different size wires, we can calculate the allowable wire lengths for various amperages.

Voltage Loss = 2 * I * R (per 1,000 ft) * Dist (per 1,000 ft)

Dist = (1000E) / 2(IR)

The results of these calculations (for use in this course only) are for a 2% voltage drop and are in the chart on the next page.

The top row represents the Wire gauge size, the left column is the maximum number of amps, and the chart cells show the distances in feet allowed for a 2% voltage drop. For all numbers, use the next higher value in choosing amps or distances.

If you have 3 solar panels rated at 24 volts 6 amps each, mounted 30 feet from the Charge Controller, then you would move down the chart to 20 amps (3 panels * 6 amps and then round up), and across to 45 (closest to 30), and then up the chart to 4 ga. You would need at least #4 AWG gauge wire to move 18 amps 30 feet with a minimum voltage drop of 2% or less. I would much rather wire with #4 AWG than #2 AWG which is what would be required for a 12-volt system.

Remember, if you can't find the exact values, choose either a larger gauge wire (smaller number) or select a distance longer than your actual distance. Using a larger gauge wire will also reduce the voltage drop for the same length of run.

24 Volts - 2% voltage drop

		AWG Wire Gauge										
		18	16	14	12	10	8	6	4	2	1/0	2/0
	1	35	56	90	143	228	363	577	915			
	2	17	28	45	71	114	181	288	457	730		
	4	8	14	22	35	57	90	144	228	365	581	730
	6	5	9	15	23	38	60	96	152	243	387	487
	8	4	7	11	17	28	45	72	114	182	290	365
A	10	3	5	9	14	22	36	57	91	146	232	292
M	15	2	3	6	9	15	24	38	61	97	155	194
P	20	1	2	4	7	11	18	28	45	73	116	146
S	25		2	3	5	9	14	23	36	58	93	116
	30		1	3	4	7	12	19	30	48	77	97
	40			2	3	5	9	14	22	36	58	73
	50			1	2	4	7	11	18	29	46	58
	100				1	2	3	5	9	14	23	29
	150					1	2	3	6	9	15	19
	200						1	2	4	7	11	14

Disclaimer:
The values listed above are approximate values only and intended to demonstrate the voltage drop for various wire gauges. Use of the values for actual wire sizing is at the sole risk of the user.

Solar Panels to the Charge Controller and Batteries

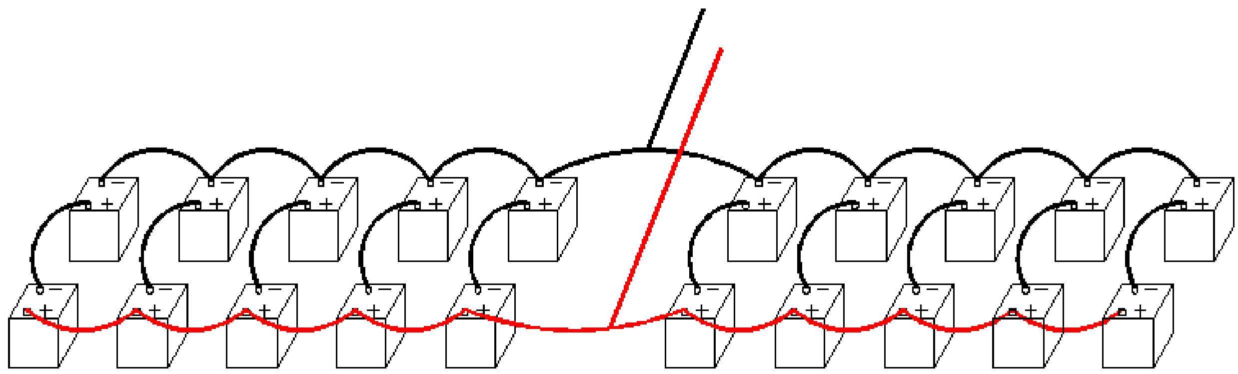
After selecting the proper wire size to connect the Solar Panels to the Charge Controller, use the same size wire to connect the Charge Controller to the batteries since these wires will carry no more current than the solar panel wires *as long as the distance to the batteries* is less than *the distance to the solar panels*.

Batteries to the Inverter

Both the Inverter and the Batteries require the largest size of wires in the system. During operation, the Inverter can draw a tremendous number of amps from the batteries to produce the AC required.

STEP 12: Battery wiring

Parallel wiring to increase current is obtained by connecting the positive (+) terminals of multiple batteries together and then connecting the negative (-) terminals together.



12V BATTERIES WIRED FOR 24V
SERIES & PARALLEL WIRING

Remember: Parallel wiring → Voltage stays the same and the Current is additive.

Remember: Series wiring → Current stays the same and Voltage is additive.

SELECTING THE RIGHT BATTERIES

So you've finished your design and a contractor submits his shop drawings and product selections... including his selection of batteries. You had specified 105 amp-hr 12-volt batteries and the contractor says he has two models for your approval. One is a 105 amp-hr 20-hr rating and the other is a 105 amp-hr 100-hr rating. So which do you want to use in your system? A quick glance and you see the only difference is that one is a 20-hr rating and the other is a 100-hr rating. Pretty obvious... right? You want your batteries to last as long as possible and 100 hours *is* much longer than 20 hours. So… you want to use 100-hour batteries, right? After all, amp-hours are amp-hours, right? *Not so fast!*

Let's look a little deeper into how batteries are rated and tested and then the answer to the question as to which battery is better will be obvious.

Deep cycle batteries are rated in amp-hours by the manufacturer... which is why we determined our battery amp-hour requirements in Step 6. Simply put, an amp-hour is one amp for one hour or put another way... amps times hours. So, 20 amps for half an hour equals 10 amp-hours (20A x 0.5 hr), simple enough. The manufacturers test the batteries by discharging the batteries down to 10.5 volts over a 20-hour time period and recording their performance. Discharging a 12-volt battery down to 10.5 volts over a 20-hour period will be substantially different from discharging the *same battery* down to 10.5 volts over a 100-hour period.

Which brings up the next question... Why do manufacturers use the 10.5-volt threshold for 12-volt batteries? Well, at 10.5 volts the battery is essentially fully discharged. The *rate* of voltage drop *increases* as the battery discharges. Below 11.5 volts, the voltage begins to plummet and the battery is being permanently damaged.

Now... on to the next question. Why do manufacturers use the 20-hour and 100-hour ratings... or even 8-hour ratings? Well, this is for convenience. A typical work day is 8 hours and a full day is 24 hours. So they use the 8 and 20-hour tests for simplicity sake for battery sizing. Some will even use a 6-hour rating for situations where the batteries aren't being used the entire day. The 100-hour rating only gives you a 'feel' for the reserve capacity of the battery.

Now it gets interesting because if you have a 100 amp-hr battery, mathematically speaking... that would be 100 amps for 1 hour or 25 amps for 4 hours, right? Wrong! "Wrong?" you ask and then you add "But that's what my calculator says, too." True, that's what your calculator says but your calculator doesn't know about something called the Peukert Effect. The Peukert Effect has to do with the internal resistance of the battery. The higher the internal resistance of the battery, the higher the losses will be when charging or discharging... especially at higher currents. So, the net result is that the **faster** a battery discharges, the **lower** the amp-hour capacity. The **slower** it is discharged, the **higher** the amp-hour capacity. So, in marketing a battery, many manufacturers will advertise the 100-hour rating because it makes them *appear* better than their competitors. Many people only look at the advertised amp-hour rating of the battery but have no idea what the hour rating is or how to use it.

Some sample battery capacities as published by the manufacturers are listed below for a comparative analysis.

Battery	100-hr rate	20-hr rate	
Crown 12CRP165	165 AH	115 AH	
Deka 8A31DT	110 AH	104 AH	
Sun Xtender 1040T	120 AH	104 AH*	* 24-hr rate
Surrette 27 HT 105	140 AH	105 AH	
Trojan 31-AGM	111 AH	100 AH	
Trojan IND23-4V	1500 AH	1233 AH	
Crown 2CRP1880	1880 AH	1300 AH	

As you can see, the Peukert Effect can cause substantial differences in the amp-hour ratings of the different batteries. So never compare 100-hour rated batteries with 20-hour rated batteries. As seen above, there may be a 15-20% difference between the two ratings. If a contractor can't supply the battery data, reject the battery and have him replace it with one that you can accept.

Now... in answer to the question that started this discussion, you would *obviously* choose the 105 amp-hr 20-hour battery for better performance. The *estimated* 100-hr rating of that battery *might* be about 120 amp-hrs. Always use the 20-hour ratings for battery selection in small structures since that will more closely match your design calculations.

A couple of more notes about batteries...

> Most batteries must be cycled (discharged and then charged) approximately 10-30 times before they will perform at their rated capacity. This is normal and not cause for concern.

Not using a battery for extended periods of time can damage the battery. Also, buying a new battery to store away as a backup for future use is not good either, unless you maintain it with the appropriate 'trickle' charge for that battery. So, if you're going to spend the money for a battery, then use it!

In a bank of batteries, all batteries should be approximately the same age. Since a new battery performs differently than a used battery, you should not place a new battery in a bank of used batteries. If an old battery needs to be replaced, run a new battery through a series of cycles first or replace it with a good used battery. This will allow the charge controller to perform its job more efficiently.

DISCUSSION ON POWER PANELS

Power panels can be used to provide an efficient method of managing your solar system wiring and space. A power panel can contain inverters, low voltage disconnects, over-current protection devices, grounding, and charge controllers … all in a single mount. These power panels can save a considerable amount of time on the installation labor and save floor space, too.

USING SURGE PROTECTORS

Most solar PV installations provide power for electronics which don't handle power surges or lightning strikes well at all. Surge protection devices (SPD) and lightning arrestors are now available for solar systems at a very reasonable cost and installation is simple. These are NOT the surge protectors you find in your local hardware stores. These are specifically engineered to provide protection to service panels, load centers, or even connected to a specific electronic component.

While DIN rail mounted SPDs are available, they are enclosed within an electrical box, which means they can't be readily monitored. They are usually small in size and small in capability. On the other hand, externally mounted SPDs are larger, visible, and have much higher capabilities... clamping as much as a 115,000 amp surge. A quick glance at it will let you know if it has stopped working. Don't use your expensive electronic component as your indication of the SPD not working.

I've had multiple calls about inverters, electronics, and wiring that were damaged by near lightning strikes. I discovered none of them had a SPD installed to protect the system and the repair costs were 7-10 times as much as the cost of a good surge protector. It's cheap insurance since they are easily installed and only cost around $100. And how much did you pay for that inverter?

MidNite Solar Surge Protection Device

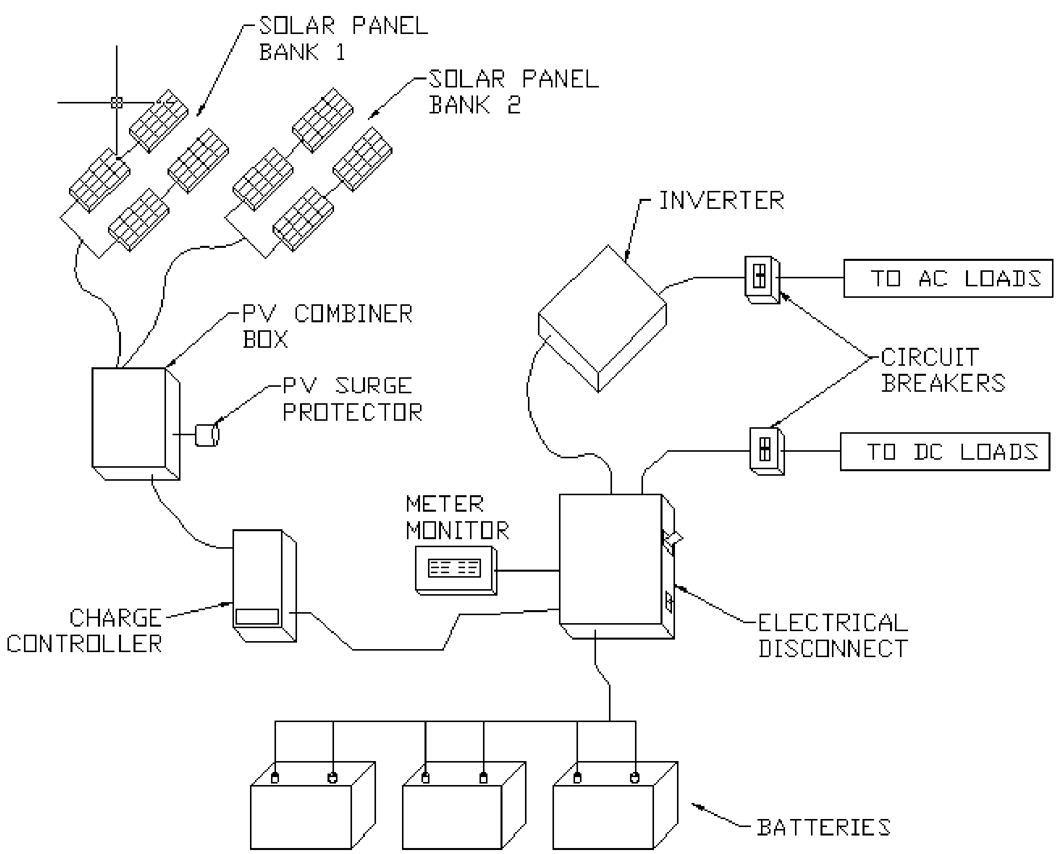
DC POWERED ALTERNATIVES

Many DC powered appliances are now easily obtained for use in PV supplied structures. They range from ceiling fans, fluorescent lighting, LED lighting, refrigerators, freezers, even coffee makers... and the list goes on. And most are readily available in 12 and 24-volt models. For example, a 24-volt compact fluorescent light (CFL) bulb is available and a 12-volt version is available. Also, 12-volt and 24-volt LED bulbs are now becoming available. Ceiling fans can be purchased in both 12 and 24-volt versions. While these costs are currently higher than their AC versions, increased demand for these energy efficient models will drive prices down.

A good source for many of these DC alternatives is www.altestore.com . They have a good selection of products of both solar components and appliances. Another good source is http://store.sundancesolar.com/12vdcap.html . Even air conditioners and heaters can now be installed in remote structures. One source is from http://www.securusair.com/ . They have air conditioners available which use 48-volt DC power. The list of products and suppliers continues to grow and we will likely see their prices drop as the supply and the demand increases.

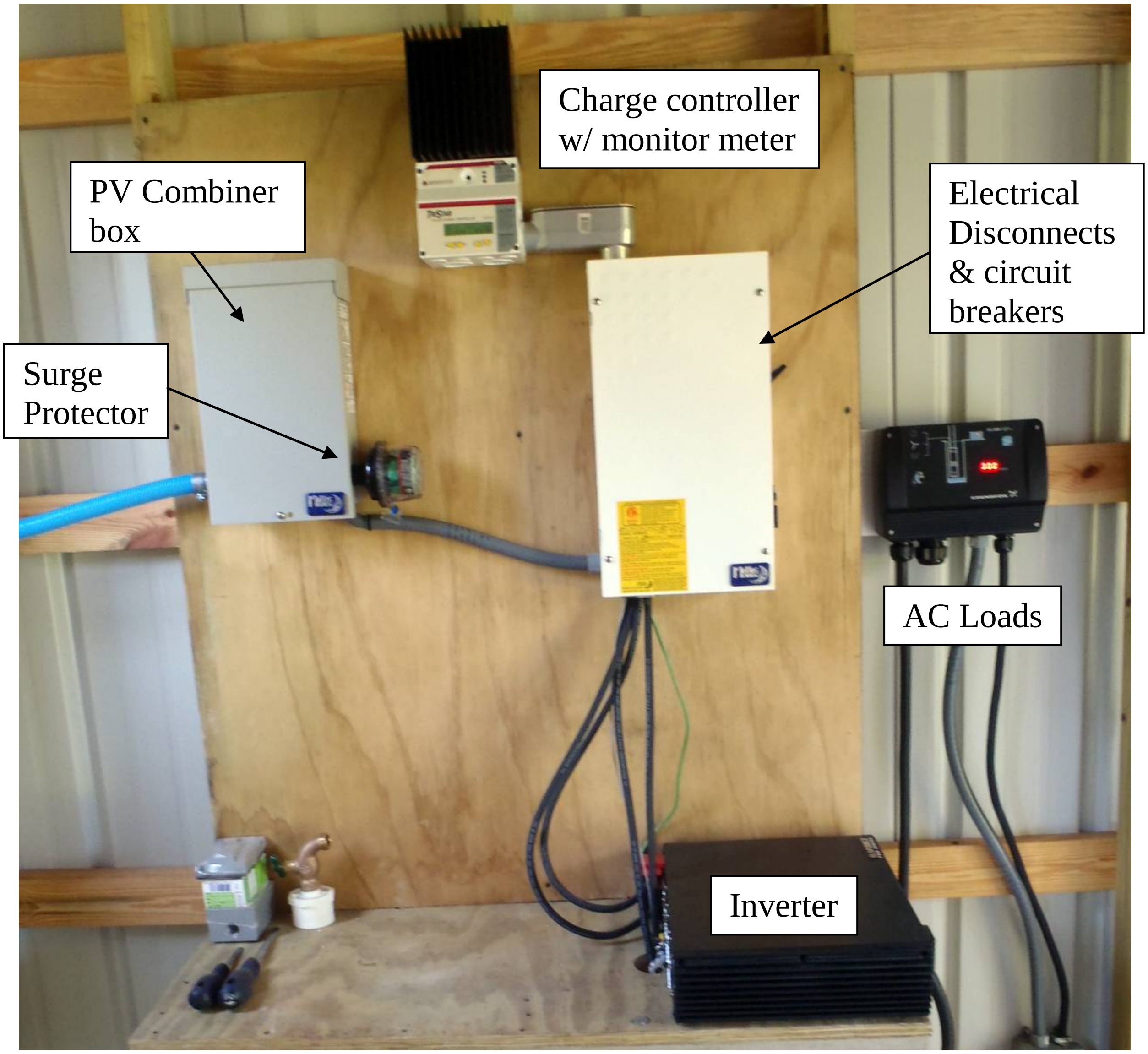
SOLAR POWER SCHEMATICS

The basic PV schematic was provided in the first course. However, a complete system will also typically include multiple solar arrays, a PV combiner box, a surge protector, an electrical disconnect, and circuit breakers. The system schematic becomes the following...



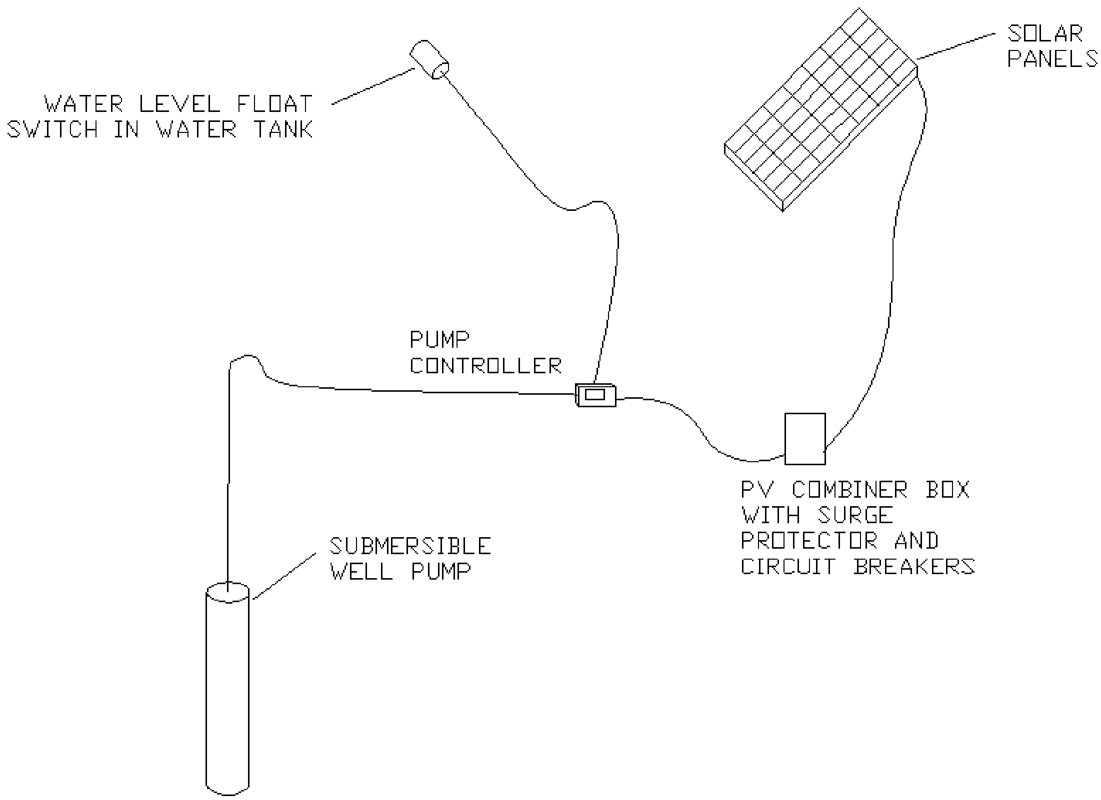
OFF-GRID PV SCHEMATIC

The photo below shows this schematic wired up and installed on a wall. The major components have been noted for comparison with the schematic on the previous page.



Note... the batteries are located outside of the area pictured above

If you only need DC power during daytime hours, the solar power design becomes much simpler. In these types of situations, there is no need of a charge controller or batteries or an inverter. An example of this would be a solar powered water well for irrigation, livestock watering, etc. The system schematic becomes the following...



Problems with Traditional PV Systems

Technology changes… and so do solar PV systems. Conventional solar PV systems might produce about 5-25% less power than they could because of various issues. These issues can be any combination of solar panel mismatches, partial shading of panels, wiring losses, damaged wiring, MPPT inefficiencies, soiled surfaces, and/or a lack of proper maintenance caused simply by not knowing there is a problem with one of the components.

Also, traditional solar components have many limitations that must be addressed… like maintaining minimum and maximum voltages or amperages, having matched banks of solar panels, having systems designed in series or parallel, etc. And years later, when you need to replace a solar panel, it may be difficult to find a panel with the same voltage and amperage outputs. However, new technologies are now addressing many of these issues.

Emerging Technologies

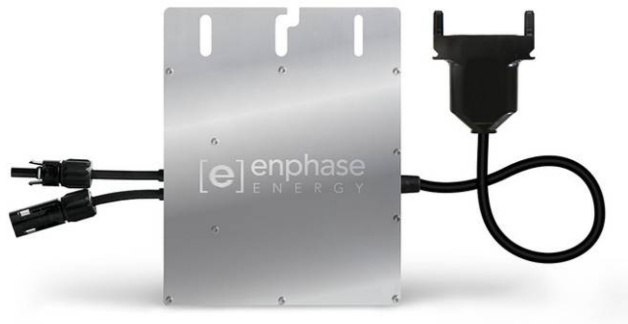
Enphase Microinverters are one of these exciting technologies. Would you prefer to not deal with high voltage DC power at all? Well, *Enphase Energy* has developed a system that delivers grid-compliant AC power right from the microinverter while also increasing the output from each solar PV panel. The Enphase microinverters can produce more watts than traditional systems even on cloudy days or periods of partial shade. This is accomplished by converting the DC into AC electricity at each module for optimal energy harvest regardless of factors like mismatch, shading, and debris. One big advantage to this type of system is the elimination of a single point failure found in conventional systems using 1 or 2 inverters. In a conventional system, if you lose the inverter… the consequences can be catastrophic. However, if you lose one Enphase Microinverter, you only lose the power from that one solar panel… but not the whole system… so you might not even notice it without the monitoring system.

The Enphase Microinverters provide an AC-electric system… from the solar panel to the building's Main Distribution Panel. There are no high voltage DC circuits to keep track of during the installation or during repairs. From start to finish, Enphase keeps everything simple. And simple is good.

The microinverters also allow mismatched solar panels to be used in the system which is significant if you need to replace an older panel with a new one with a higher efficiency and higher output. *And* the microinverters come with a 25-year warranty.

The Enphase M215 Microinverter provides 215 watts of AC power… at a 96% efficiency rating. Also, they can be attached to 215-270 watt solar panels with a MPPT range of 22-36 volts.

The new Enphase M250 Microinverter provides 250 watts of AC power at a 96.5% efficiency rating. They can be attached to 250-300 watt solar panels with a MPPT range of 27-39 volts.



*Enphase M215 microinverter **

The Enphase system is monitored by the *Enphase Envoy Communications Gateway* which uses "advanced powerline communications technology". This allows each microinverter to be connected to the monitor without any additional wiring. The Envoy comes ready right out of the box and can monitor up to 600 microinverters… without any additional wiring! The Envoy includes a LCD display to check the system status and also provides internet-based monitoring via the software included with each Envoy purchase.

*Enphase Envoy **

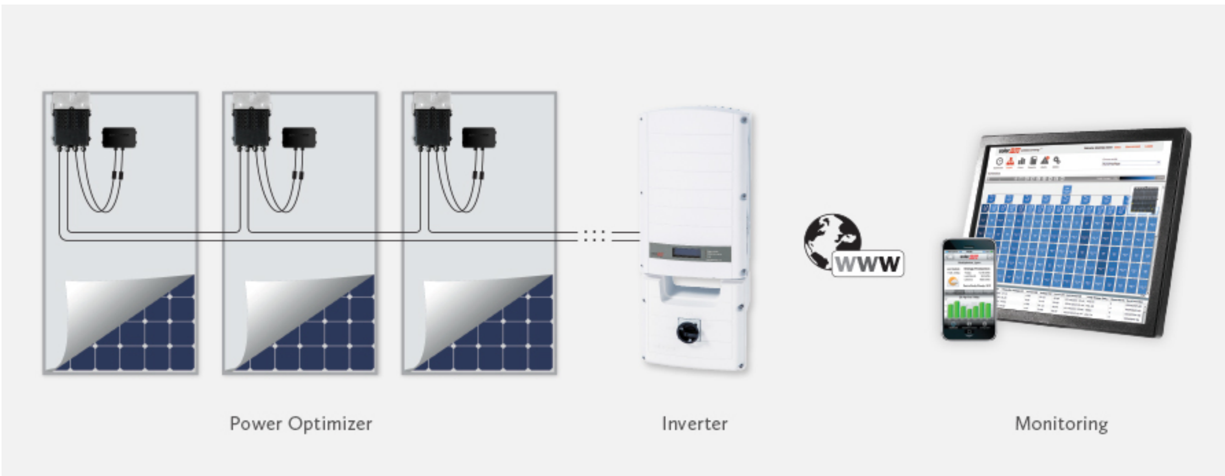
*Enphase Enlighten **

The *Enlighten* software platform provides solar professionals and system owners with ongoing operations and uptime assurance. For solar professionals, *Enlighten Manager* offers web-based tools to monitor and manage multiple installations. For system owners, *MyEnlighten* provides an engaging interface to view and share current system performance and the ability to compare current data against performance records from previous days, weeks, or months. The system also records the historical weather data to aid in interpreting the system performance.

** Images courtesy of Enphase Energy*

Visit http://enphase.com/ for more information.

SolarEdge Technologies has developed another unique approach in designing a solar PV system that incorporates three elements… *Power Optimizers*, a highly reliable inverter, and a module-level monitoring system. This system design allows for each solar panel's output to be maximized regardless of the output from other panels and allows for management of each individual solar panel. This individual management permits more flexible use of the space available for the solar panel installations.



SolarEdge Technologies solar PV system
Image courtesy of SolarEdge Technologies

Power Optimizers: While the *Enphase microinverter* system attaches to the standard junction box found on the back of each solar panel with a microinverter, the *SolarEdge* system replaces the junction box with a *Power Optimizer*. The purpose of the *Power Optimizer* is to continuously monitor the MPPT performance of the panel on which it is attached and reports its performance to the *SolarEdge Monitoring Portal*. Since each panel is monitored individually, the system's peak performance can be maintained even with different panel orientations, tilt angles, temperatures, and even different panel types… *in the same string*. This is particularly helpful when you need to add or replace a solar panel in the future since you won't have to try finding an older model solar panel to match the others in the system. The *Power Optimizers* automatically maintain a set string voltage for all panels in the string which allows longer strings of panels and strings of different lengths. This permits more flexibility in the panel layout and more efficient use of the available installation space. The *Power Optimizers* also come with a 25-year warranty.

SolarEdge Inverter: The *SolarEdge Inverter* is designed specifically for *SolarEdge Power Optimizers*. Since the MPPT and string voltage are managed by the power optimizers, the inverter's sole purpose is the DC to AC inversion. Because it is less complicated, it is a more reliable inverter and comes with a 12-year warranty which may be extended to a 25-year warranty. Once again… simple is good.

SolarEdge Monitoring Portal: The *SolarEdge PV Monitoring Portal* is an internet-based software application. The software provides panel-level, string-level, and system level monitoring for quick efficient analysis of the system performance. And, if there is a drop in performance in a panel or string, the software identifies it on a virtual site map of the system for ease in identifying the problem panel's location. Also, there is no extra wiring required for the Monitoring Panel since it used the existing power lines for communication. Another plus is the iPhone Monitoring App that enables one to remotely monitor the system performance on their phone.

Visit http://www.solaredge.us/ for more information.

* *Images courtesy of SolarEdge Technologies, Inc.*

SOLAR DESIGN CONSIDERATIONS SUMMARY

In summary, we have just completed an abbreviated refresher of the basic course, provided a little more depth into some of the design aspects, and added more internet sources and pricing. We reviewed the six basic components found in every solar powered system... the solar panels, charge controllers, batteries, monitor meters, inverters, and the electrical wiring. We have also discussed in more depth some additional items such as determining solar inclination, how to better evaluate and select a battery, and the use of system surge protectors.

As noted, while a solar system ***can*** use standard AC appliances, it is much more efficient to use DC powered appliances. Some commonly used powered appliances such as lights, fans, and air conditioners are also readily available in DC-wired models. These DC appliances can significantly reduce the size of the solar panel array and the number of batteries with no negative impact to the end user. Or, for a system that is struggling for power, switching from AC fixtures to DC appliances and fluorescent lighting might make all the difference needed to make it an efficient functioning system again.

New technologies such as microinverters and power optimizers continue to emerge that improve the solar component efficiencies, performance, costs, and warranties. And some of the new products are even changing the way we design solar PV systems.

Also, as I previously noted, some of the new material presented in this course is a response to requests for additional information or questions submitted by previous readers. So, please continue to submit your course suggestions to me.