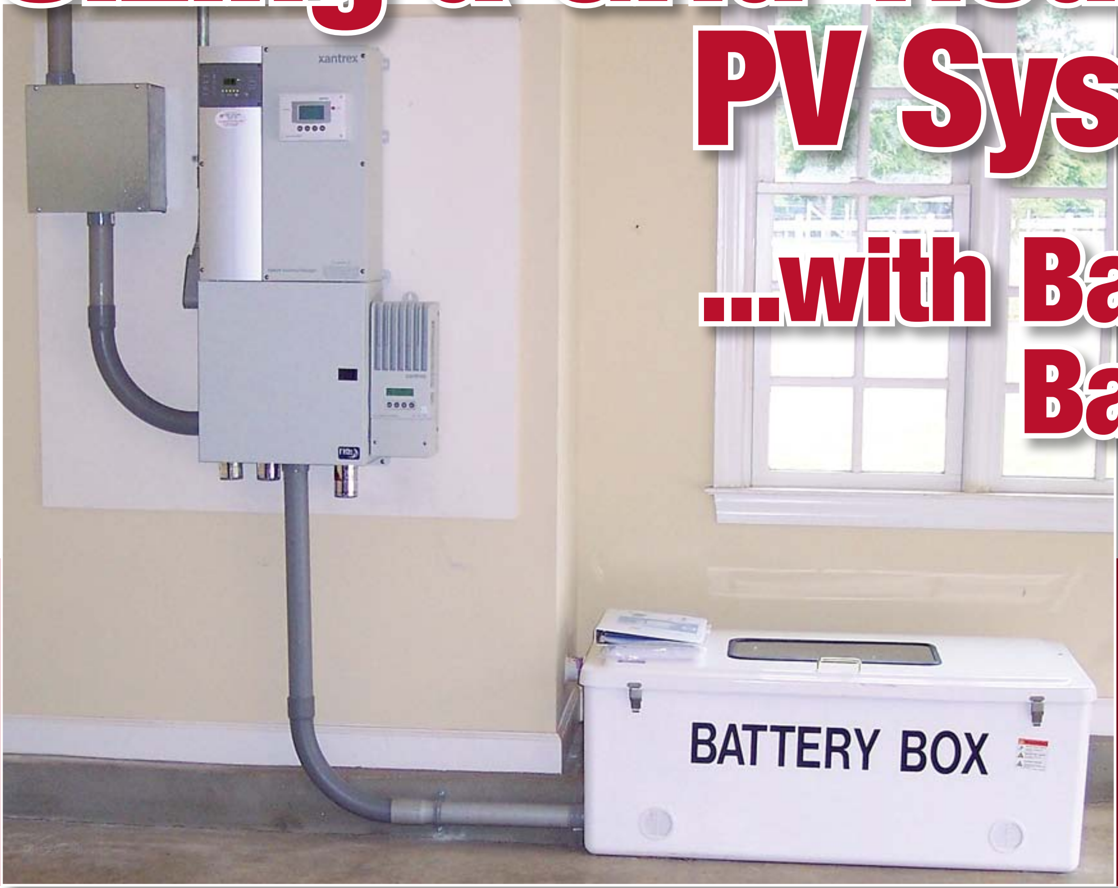
Sizing a Grid-Tied PV System ...with Battery Backup

by Flint Richter



Courtesy Honey Electric Solar

A professionally installed grid-tied PV system with battery backup using the Schneider (Xantrex) XW inverter and BOS package, with a custom battery box.

Once the decision has been made to include batteries in your grid-tied system (see "Grid-Tied…with Backup!" in this issue), next is estimating the backed-up loads' energy consumption, selecting the inverter, sizing the battery bank, and considering other balance-of-system (BOS) components.

System sizing starts with the loads, which determine system components and cost. Sizing a simple batteryless grid-tied system starts with a year's worth of household energy use data (usually from electric bills) and a budget (see "Sizing Batteryless Grid-Tied PV Arrays" in *HP138*). Sizing the PV array (or other RE source) of a battery-based grid-tied system is done similarly, but sizing the inverter and battery bank requires more information and calculation.

Estimating/Measuring Backed-Up Loads

If you want a battery-based system, you'll need to decide what loads will be backed up and how long you need them to operate.

Nameplate ratings—volts, amps, and possibly watts—are printed on most appliances. Remember: amps (A) × volts (V) = watts (W). Watts is an instantaneous measurement of how much power is needed (or produced) at a given moment. You'll need to know how much energy (kWh or Wh) your loads use while operating over a period of time. Multiplying watts by the number of hours the load runs gives you its energy use in watt-hours (Wh) per day—then dividing by 1,000 will translate it to kWh.

Although nameplate ratings can be used for system sizing, they may lead to overestimating a load's power needs, since amp ratings are sometimes given for surge peaks—not continuous draw. A more accurate way to measure a load is with a watt meter (see "Beyond Your Utility Meter" in *HP138*). These tools measure volts, amps, watts, and cumulative kWh for each load. Measuring each load you're considering for backup will provide a better foundation for system sizing.

Inverter Sizing

The inverter in a grid-tied battery-based system must be sized to do two things: power all of the backed-up loads simultaneously and pass the energy from the renewable sources (PV array, wind generator, etc.) to the grid. To calculate the inverter power rating, sum the total backup loads. If surge loads (pumps, compressors, induction motors) are anticipated, the inverter should be sized to also handle the maximum combined surge loads. Most inverters can handle a surge twice their rated output for a few seconds. If more power is needed than a single inverter can supply, you can stack the outputs of multiple inverters to increase the total connected power and surge capabilities, or multiple inverters can separately feed separate loads.

The voltage and frequency of the inverter must also match the loads. Inverters for the United States are available in 120 and 240 VAC output at 60 Hz. If you only need to back up 120 V loads, then a 120 V inverter will be your most economical choice. However, purchasing a split-phase, 120/240 V inverter (or stacking two 120 V inverters for 120/240 V output) gives the flexibility to power both 120 and 240 V loads.

The second inverter selection factor is the ability to send renewable-made energy to the grid. If you have a PV array rated at 4,000 W, the inverter needs to be able to process the full amount. While it is true that the PV array will produce less power under normal operating conditions (due to module heating, dust/dirt, wiring inefficiencies, etc.), there are conditions (cold temperatures and clear skies) when the array can produce full power. Select an inverter that will handle the larger of the two factors: Array output and maximum combined backup loads.

Battery Bank Sizing

After sizing your inverter to fit the loads and RE sources, next size the battery bank to power the loads for a given amount of time, making sure to match the battery and inverter's DC voltage.

Begin battery bank sizing by determining how many days you want to power your backed-up loads without a charging source (days of autonomy). Since the grid will be your primary energy source, for this calculation, you only need to consider the amount of time the grid won't be available. Using historical information, you can estimate the average length of time your site experiences utility outages. You can also add in a safety factor to account for extreme situations. In arriving at a number, assume that there won't be a source of energy to recharge the batteries. Finally, if the days of autonomy exceed three, consider adding an engine generator as a third energy source. This will help keep overall system costs down, and result in a more reasonably sized and better utilized battery.

Above: Two stacked inverters are the core of this OutBack system, which integrates charge controllers and other BOS components.

Below: An SMA America Sunny Island system uses AC coupling to integrate battery charging with a second batteryless inverter.

Courtesy Honey Electric Solar (2)

Available Battery-Based

Three manufacturers dominate the grid-tied, battery-backup inverter market: OutBack Power Systems, Schneider Electric (formerly Xantrex), and SMA America. Each company offers an inverter—some with different AC outputs or in different configurations—that is listed to UL Standard 1741 for grid interconnection and has battery-based capabilities.

Courtesy OutBack Power Systems (2)

Above: GTFX/GVFX inverter.

Left: SmartRE inverter.

OutBack Power Systems

OutBack Power experienced early adoption in the off-grid market because its equipment had features and operations not yet filled by other inverter manufacturers. It soon became a player in the grid-tied with battery backup market niche with its GTFX, GVFX, and, more recently, SmartRE products.

The GT stands for grid-tie; the GV is the higher-powered, vented model—both are variations of the rugged off-grid FX inverter. The sealed GT versions are available in 24 V, 2.5 kW and 48 V, 3 kW models. The vented versions come in 24 V, 3.5 kW and 48 V, 3.6 kW models.

All versions have single-phase 120 V output. Two G-series inverters can be "stacked" for 120/240-volt split-phase output. OutBack also produces AC and DC FLEXware panels that hold all BOS components, overcurrent devices, shunts, and bypass breakers. There are many versions of OutBack-inverter-based power panels that are pre-assembled, and tested to save labor costs and on-site assembly. At least one third-party manufacturer makes power panels that integrate with the FX series of inverters.

OutBack's newest product—the SmartRE—provides easy installation with a quality battery backup grid-tied system. The SmartRE incarnation of the GTFX includes two AC inputs—much like the Xantrex XW. The combination of grid and backup engine generator inputs make this a very flexible unit. All four of the SmartRE models are 48 V with 2.5 or 3 kW and either 120 V or 120/240 V versions.

Grid-Tied Battery-Backup Inverters

Company	Model	Power	Battery Voltage (VDC)	Surge Power[1]	Output Voltage (VAC)	Stacking	Multiple AC Inputs	Generator Control	Integrated Battery SOC Meter	Integrated Charge Control
OutBack Power www.outbackpower.com	GTFX2524	2.5 kVA	24	4.8 kVA	120	Up to 2	No	No	No	No
	GTFX3048	3.0 kVA	48	4.8 kVA	120	Up to 2	No	No	No	No
	GVFX3524	3.5 kVA	24	5.0 kVA	120	Up to 2	No	No	No	No
	GVFX3648	3.6 kVA	48	5.0 kVA	120	Up to 2	No	No	No	No
	SmartRE 2500-120	2.5 kVA	48	4.8 kVA	120	N/A	Yes	Yes	Yes	Yes
	SmartRE 2500-120/240	2.5 kVA	48	4.8 kVA	120 / 240	N/A	Yes	Yes	Yes	Yes
	SmartRE 3000-120	3.0 kVA	48	5.0 kVA	120	N/A	Yes	Yes	Yes	Yes
	SmartRE 3000-120/240	3.0 kVA	48	5.0 kVA	120 / 240	N/A	Yes	Yes	Yes	Yes
Schneider Electric www.schneider-electric.com	XW4024	4.0 kW	24	8.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
	XW4548	4.5 kW	48	9.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
	XW6048	6.0 kW	48	12.0 kW	120 / 240	Up to 3	Yes	Optional	LED display	No
SMA America www.sma-america.com	Sunny Island 5048US	5.0 kW	48	11.0 kW	120	Up to 4	No	Yes	Yes	Yes

[1] Surge duration: OutBack & SMA America: 5 seconds; Schneider Electric: 10 seconds.

Grid-Tied Inverters

Schneider Electric

The company has a long history of reliable products that were the foundation of battery-based RE equipment. Its grid-tied with battery backup inverter is the XW, replacing the old workhorse SW, which was one of the first grid-tied with battery backup inverters.

The XW is a sine-wave inverter that offers split-phase (120/240 AC) voltage output and a 200% surge capacity for 10 seconds. The company offers 24 V, 4 kW; 48 V, 4.5 kW; and 48 V, 6 kW models. Any of these models can be stacked with one or two other inverters of the same type to double or triple the output capabilities. All models can accept two AC inputs—the first AC input will typically be the grid; the second may be a backup engine generator. Adding a generator can minimize battery and PV costs, since you can design for fewer days of autonomy and a smaller charging source.

The XW can be purchased with a complete integrated AC/DC power distribution panel for up to three parallel inverters and four XW MPPT 60-150 PV charge controllers.

A Schneider XW inverter and power distribution panel.

SMA America

SMA America's Sunny Island is an off-grid inverter that can function as a battery backup grid-tied inverter—but that's not all. It can be installed with the company's Sunny Boy batteryless grid-tied inverter, allowing the Sunny Boy to continue to produce power even while the grid is down.

One of the Sunny Island's outputs is wired into the same subpanel containing the grid-tied inverter's output and all of the backed-up loads. The other Sunny Island output backfeeds a breaker in the main load center. When the grid is present, the Sunny Island can charge the batteries while the grid-tied inverter "sells" power to the grid. If the grid goes down, the Sunny Island disconnects from the main load center and starts to invert battery power to the backup panel. The grid-tied inverter sees the AC, and the Sunny Boy acts as if the grid is still present, continuing to produce power. The Sunny Island prioritizes powering the backed-up loads with the grid-tied inverter's output first and will then supplement with inverted battery power if needed.

The Sunny Island output is 120 V, so if your backed-up loads need 240 V or the output of your Sunny Boy inverter is 240 V, you will need two Sunny Islands or an 120 to 240 V autotransformer between the Sunny Island and backed-up subpanel.

The Sunny Island system may not be the most cost-effective way to install a battery-backup grid-tied system—but it is the only product that is engineered to allow an existing grid-tied batteryless inverter system to add battery backup.

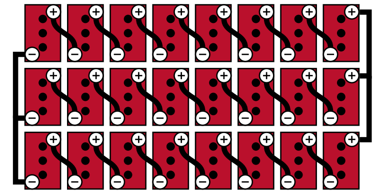
SMA America's Sunny Island inverter.

Flooded or Sealed Batteries?

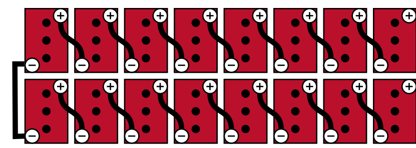
Most batteries installed today are lead-acid batteries—either flooded or sealed. Flooded batteries are used extensively in off-grid situations, when frequent cycling is part of a battery's duty and maintenance is a given. To get maximum life from this type of battery, it's important to monitor electrolyte levels and state of charge, and run regular equalization charges.

Batteries in grid-tied systems will rarely cycle and require far less maintenance, so sealed lead-acid batteries can be a good fit. Compared to their flooded counterparts, there's also very little gassing, yet batteries should still be contained, kept out of living spaces, and have sufficient ventilation. Sealed batteries are more expensive, must not be overcharged, and have a shorter life expectancy, but their low maintenance and ability to handle the small number of cycles they will see in service still makes them an appropriate choice.

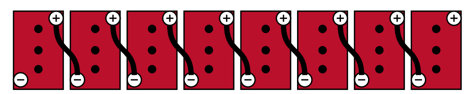
Battery String-Sizing Options



ACCEPTABLE
Three Series Strings:
Twenty-four 6 V, 350 Ah batteries in three strings of eight, for 1,050 Ah total at 48 V



BETTER
Two Series Strings:
Sixteen 6 V, 500 Ah batteries in two strings of eight, for 1,000 Ah total at 48 V



BEST
One Series String:
Eight 6 V, 1,000 Ah batteries, for 1,000 Ah total at 48 V

Batteries can only supply a limited amount of energy before they are depleted. Some deep-cycle batteries may be discharged up to 80% for about 2,000 cycles, or at 50% for about 4,000 cycles. A battery-based backup power system may undergo 10 cycles per year—often less. So sizing a battery based on an 80% deep discharge rate is appropriate for this type of infrequently cycled system. (For an off-grid home that cycles batteries often daily, a more conservative approach may be necessary.)

Once you know the desired days of autonomy, possible battery discharge level, and the energy requirements of your loads, you can size the battery. Start with the total Wh per day for backed-up loads and divide by 0.85 to correct for inverter loss (assumes an 85% efficient inverter). This results in DC Wh per day, which we will divide by our nominal battery voltage—usually 24 or 48 V (dictated by your inverter's nominal DC input). That computes the total DC amp-hours (Ah) per day. Divide this by 0.80 to account for the maximum DOD of 80% (i.e., to leave our battery 20% full after a day of discharge). Then multiply this total by your days of autonomy to get the adjusted DC Ah total.

Battery capacity in Ah is rated at several different discharge rates. For general sizing, use the Ah capacity at a 20-hour discharge rate; this is a realistic discharge rate for batteries in an RE system. Once a battery has been selected, divide your

The Trojan L16 is a classic flooded lead-acid battery used in renewable energy systems—420 Ah at 6 V.

This sealed gel-cell by FullRiver Battery requires less maintenance, but more delicate treatment than flooded batteries.

This 2 V flooded lead-acid battery by Surrette provides 1,766 Ah, giving high capacity with a single series string.

autonomy-adjusted DC Ah per day by the Ah capacity rating of your chosen battery to determine the number of parallel battery strings needed. If this number is greater than three, select a larger-capacity battery to promote a balanced charge across all strings. Each parallel string of batteries will contain as many individual cells as needed in series to reach your nominal battery voltage.

For example, assume that the backup load daily requirement is 8,000 Wh. First, correct for inverter loss by dividing by 0.85. This gives you 9,412 DC Wh per day. Dividing this by the nominal battery voltage of 48 equals 196 Ah per day. For an 80% depth of discharge, divide by 0.80, which equals 245 Ah per day. Multiply that by 4 days of autonomy (this home tends to be among the last reconnected to the grid after an outage) for a total of 980 Ah—the minimum size battery needed.

Eight 350 Ah, 6 V batteries in series yields 48 V at 350 Ah. Divide the 980 Ah total capacity by 350 Ah series battery capacity, which equals 2.8. Round up to 3 since batteries cannot be divided—the total bank (consisting of 24 batteries) will provide a capacity of 1,050 Ah. If the number of paralleled strings needed is greater than three, then source a higher-capacity battery as the basic building block.

Choosing a Charge Controller

A charge controller's main function is to keep the battery from being overcharged and potentially damaged. The two common styles of charge controllers used with these systems attain this goal differently. Either type can be used in battery backup grid-interactive systems.

Pulse-width-modulation (PWM) charge controllers regulate charging by adjusting the width and frequency of the full current pulses sent to the battery. The closer a battery is to full, the farther the pulses are apart, effectively lowering the charging current.

Maximum power point tracking (MPPT) charge controllers have several advantages. Their software algorithms can operate a PV array at its MPP over a wide range of operating conditions and at a voltage much higher than the battery voltage. This improvement increases power harvest by up to 30% (with greatest gains attained with cooler site temperatures) and allows longer distances or smaller wire sizes between the PV array and charge controller.

A charge controller should be sized to pass all the array's current to the battery. A 60 A controller charging a 12 V battery can only pass 750 watts but if configured to charge a 48 V battery, it can pass nearly 3,000 W. Oversizing the controller slightly can be beneficial since the controller will not have to work at the upper limits of its capabilities all the time and it can harvest any unexpected wattage that could come from extra irradiance or environmental conditions.

If the PV array is capable of producing more power than one charge controller can handle, consider upgrading to a larger-amperage controller, installing multiple controllers, or increasing the battery bank voltage to get more wattage out of each controller.

Both OutBack and Schneider Electric make MPPT charge controllers that integrate directly with their inverters. SMA America's AC coupling technology has built-in charge controlling.

BOS Components

Bypass breakers allow bypassing the inverter and battery-based system to power all loads directly via the grid. Most commonly, these are installed for inverter or other removal and repair. Bypass breakers are usually located in the battery/inverter power panel, and limited to 60 A or smaller.

A **battery meter** is critical to understanding a battery bank. Much like a fuel gauge in a car, a meter will report your battery's state of charge and help you determine the need for other charging sources or to conserve during an extended power outage. These meters are your window into your battery bank's world and commonly display the battery voltage, amperage in or out, and state of charge.

Schneider Electric's LinkLITE battery monitor.

Most systems include a **production meter** to measure the amount of energy produced by your renewable energy system. Incentive programs commonly require a utility-grade kWh meter. In a batteryless system, the production meter is installed between the inverter and the grid connection to measure all energy flowing between the inverter and the grid. But in a battery-based, grid-tied system, this would only measure the net difference between your system's renewable production and energy consumed by the backed-up loads.

To get a true reading of how much energy is being produced, a special kWh meter must be used. A "Form 12S" kWh meter measures both the grid input/sell circuit to the inverter, and the inverter to backed-up loads circuit. For 240 V systems, two of these meters are needed.

All electrically live parts are kept in **enclosures** of some type. The backed-up AC loads have their own panel; DC inputs or loads have another; and batteries are in their own enclosure. Batteries can discharge massive amounts of current if shorted—via a dropped wrench or other conductive materials—so their terminals must be protected. When charging to a high voltage batteries give off hydrogen gas, which must be vented outdoors to lower the risk of fire or explosion. The battery enclosure must be sealed but vented passively or mechanically from its high point. Incoming air should be introduced at the bottom of the enclosure, and wire conduit should also extend to the bottom.

Putting It All Together

A grid-tied with battery backup system is one of the most complicated RE systems to install—if you plan to hire a local installer, do your homework, and ask pointed questions about their related experience. The recent boom in PV installations has led to many new companies that have done *only* batteryless grid-tied work, which is much simpler and requires comparatively little design work. A North American Board of Certified Energy Practitioners (NABCEP) certification is good sign that the prospective installer has been tested on the basics of battery-based systems, but not a sure sign of an extensively experienced installer in that field.

Access

Flint Richter (flint@rockygrove.com) lives and writes off-grid in Arkansas' Boston Mountains. He is a partner and NABCEP-certified PV project manager with Rocky Grove Sun Company, and a contracted instructor for Solar Energy International. He is teaching his young daughters the difference between a solar module and a solar panel.

Battery Backup Inverter Manufacturers:

OutBack Power Systems • www.outbackpower.com

Schneider Electric • www.schneider-electric.com

SMA America • www.sma-america.com