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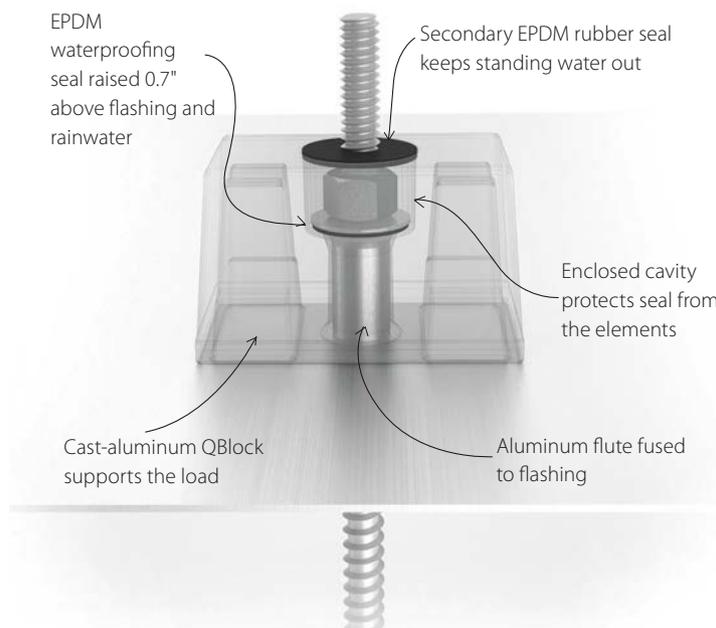
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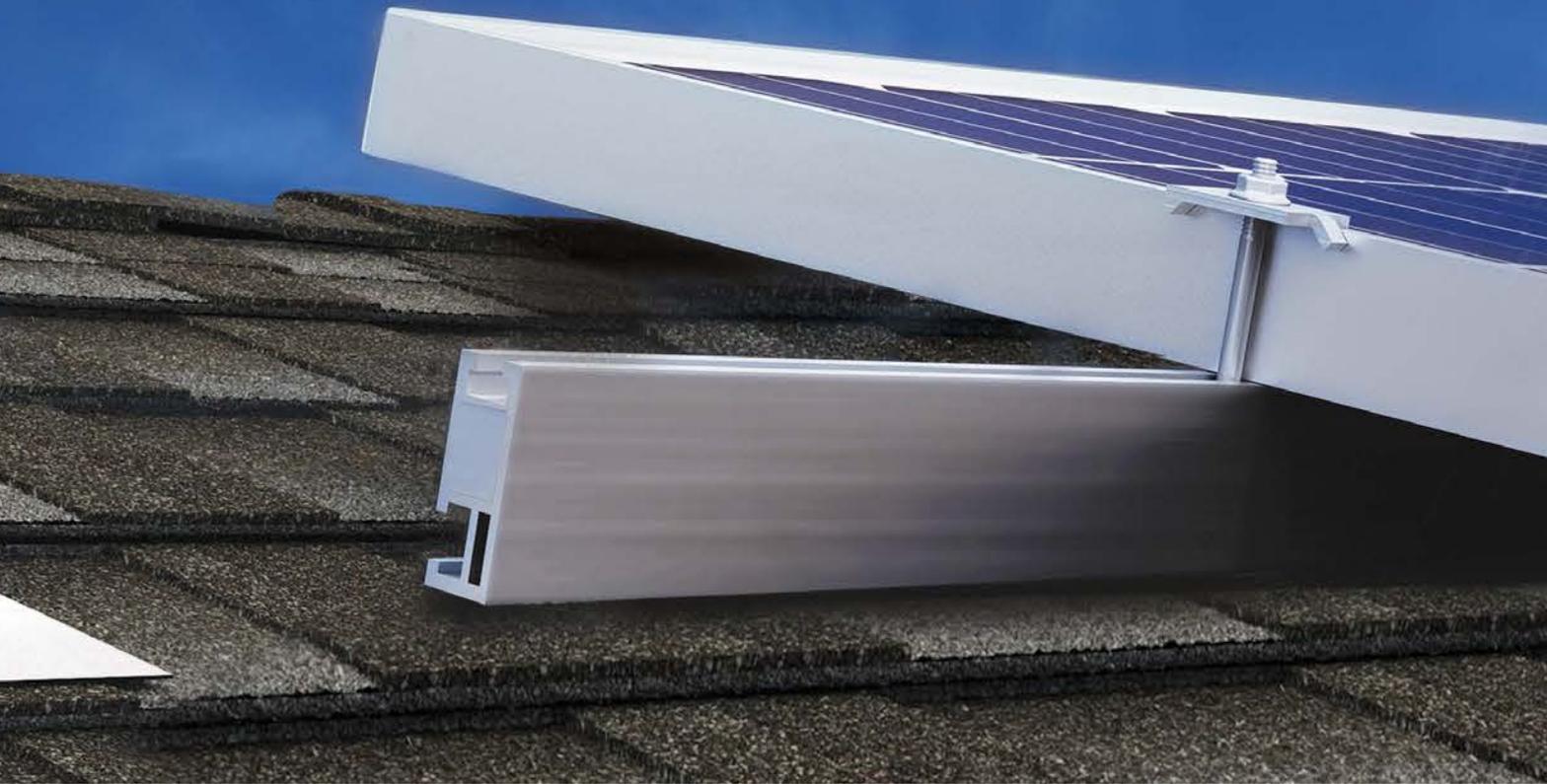
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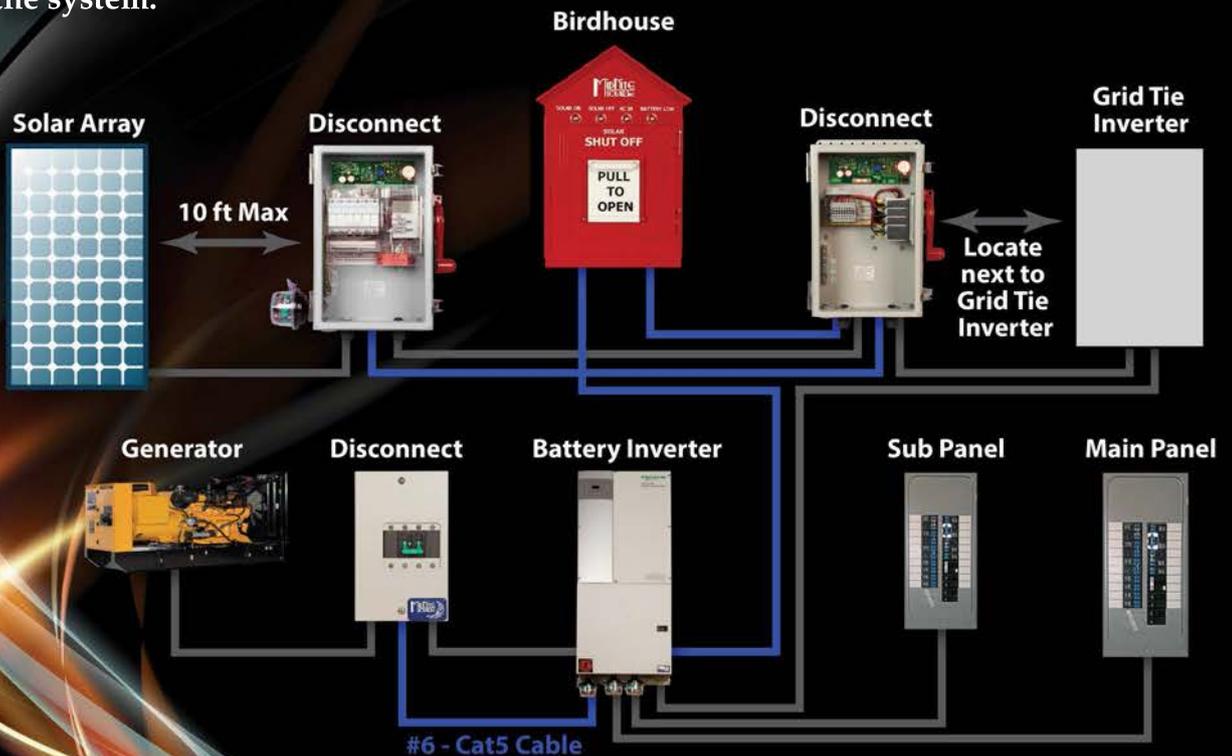
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Photo by Matt Hovermale

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Photos: Courtesy Rita Hennessy; OutBack Power; Morningstar; Amtrio; SMA America

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Home Power (ISSN 1050-2416) is published bimonthly from offices in Phoenix, OR 97535. Periodicals postage paid at Ashland, OR, and at additional mailing offices. POSTMASTER: Send address corrections to Home Power, PO Box 520, Ashland, OR 97520.

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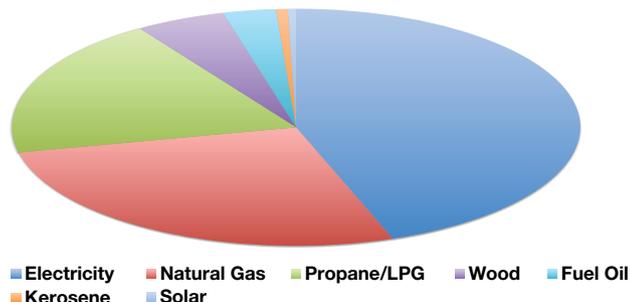
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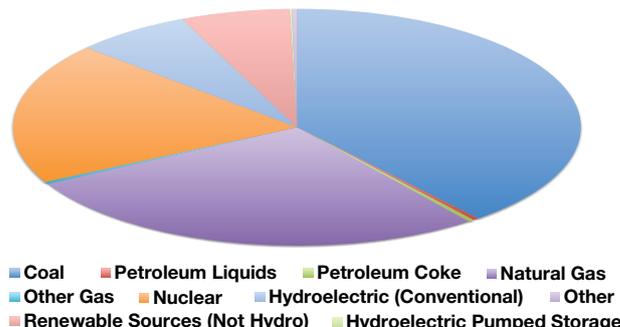
Ceiling fans

# Untangling the Energy Web

Average Household Energy Mix



Average Household Electricity Mix



Source: U.S. EIA, 2013 (2)

According to the U.S. Energy Information Administration’s Residential Energy Consumption Survey (RECS), the average household consumed 90 million Btu in 2009. This continues the downward trend in average residential energy consumption of the last 30 years. More than 30 years ago (in 1978), energy use per household was about 1.5 times this amount—138 million Btu.

That’s the good news. Even though there are now more homes (and they’re bigger, and use more electronics), efficiency improvements for space heating, air conditioning, and major appliances have all led to decreased consumption per household. More insulation and better building materials, such as double-pane windows, have also improved home performance.

Notably, the RECS data also showed that homeowners were actively involved in making energy-efficiency improvements, such as using caulk or weather-stripping to deal with air leaks (35% of those surveyed); adding insulation (23%); and using compact fluorescent or LED lighting (60%).

While efficiency gains are good news, looking at what is still fueling our energy use is more sobering. Electricity serves the majority (44%) of a household’s needs, then natural gas (27%), propane (19%), and wood (5%). Fuel oil (3%) and kerosene (<1%) aren’t fueling many homes these days. But neither is solar—a miniscule 0.4%.

We’ve still got a lot of work to do to supply ourselves with renewable energy. That’s why we shouldn’t congratulate ourselves too heartily for annually zeroing out our energy bills in our grid-tied homes. During nighttime hours or periods of heavy load use that exceed our renewable energy systems’ capacity, we’re drawing from the grid—and it’s largely fossil-fueled.

In the United States, the majority of our electricity is generated by coal (39%, as of 2013); then by natural gas (27%). Nuclear power provides 19%, while petroleum only provides a tiny amount—less than 1%. Renewably generated electricity (non-hydro) is 6%—conventional hydro is also 6%.

We also shouldn’t fool ourselves that going off-grid is a better choice for lightening our energy footprint. While you may be able to live within the *electricity* limits of your PV, wind, or microhydro system, most off-grid homes still rely on fossil-fuel sources of energy (usually propane) for space heating, water heating, cooking, and foul-weather backup. (If you’re meeting these needs exclusively with renewable energy, our hats are off to you—and we want to share your story with other *Home Power* readers!)

Obviously, there’s lots of room for improvement. Start with negawatts first—that’s pretty easy to do during the long days of summer, since you can shift your fossil-fuel loads to solar. Cook in a solar oven; hang your clothes out to dry. Next, attack the energy wasters in your home. Maybe it’s a 20-year-old refrigerator that’s eating too many electrons or antiquated lighting that’s consuming too much electricity. Add insulation to your home; caulk those cracks. Then, check out the no-down-payment financing or interest-free short loans many solar installation companies now offer, since these options can make going solar much easier on the wallet. And finally, don’t forget about your local utility—put pressure on them to invest in large-scale renewable energy systems.

Start local, but think global—so you can affect change, one electron at a time. And you can help the world go solar, one rooftop at a time.

—Claire Anderson, for the *Home Power* crew

## Think About It...

*The way to healthy living is to shift from quantitative economic growth to quality of life, food, water, and air—to shift from craving to contentment and from greed to gratitude.*

—Satish Kumar, ecological campaigner (2008)



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**Kelly Davidson** lives in Longmont, Colorado, where she and her husband are upgrading their 1970s home with insulation and new doors and windows,

in preparation for a PV system in the coming years. The upgrades are being made possible by low-interest loans through the local Energy Smart program.



**Brian Mehalic** (brian@solarenergy.org) is a NABCEP-certified PV professional, with experience designing, installing, servicing, and

inspecting all types and sizes of PV systems. He also is a curriculum developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.



**Allan Sindelar** has been designing, installing, and teaching about off-grid PV systems since 1988. He is a New Mexico-licensed contractor

and electrical journeyman, and is a charter NABCEP-certified as both a PV installation professional and a PV technical sales professional. He has lived off-grid south of Madrid, New Mexico, since 1999.



**Kathleen Jarschke-Schultze** (kathleen.jarschke-schultze@homepower.com) is making kombucha (a fermented tea) at her off-grid home in northernmost California.



**David Posluszny** works for Dolphin Insulation, helping other homeowners reduce their heating bills. David has a bachelor's degree in building

construction technology from the University of Massachusetts at Amherst. He became interested in saving energy after two military deployments overseas (Iraq and Afghanistan), where the wastefulness and energy losses were everywhere.



**Vaughan Woodruff** owns Insource Renewables, a solar contracting firm in Maine. Vaughan has developed curricula for and is currently teaching two online

courses—Solar Approaches to Radiant Heating (through Heatspring) and Solar Heating Design & Installation (through Solar Energy International).



**Christopher LaForge** is the CEO of Great Northern Solar and a NABCEP-certified Photovoltaic Installation Professional. He

is an IREC Certified Master Trainer in Photovoltaic Technologies. Christopher volunteers with the Midwest Renewable Energy Association and NABCEP. He has a master's degree in philosophy from the University of Wisconsin at Madison and is an organic gardener.



**Carl Seville** is a consultant, educator, and speaker on sustainability for the residential construction industry. His

firm, SK Collaborative, consults on and provides green certification for single and multifamily buildings. He is the co-author of the first college textbook on residential green building and contributes to GreenBuildingAdvisor.com.



**Zeke Yewdall** is the chief PV engineer for Mile Hi Solar in Loveland, Colorado, and has had the opportunity to inspect and upgrade many of the first

systems installed during Colorado's rebate program, which began in 2005. He also has upgraded many older off-grid systems. He teaches PV design classes for Solar Energy International.



**Dan Lepinski** has been involved in solar energy for more than 40 years. He lived off-grid with his family in Wisconsin for eight years, with solar

and wind energy as the only sources of electricity. Dan's 2,400-square-foot all-electric Texas home is equipped with solar electricity, solar hot water, and numerous energy-efficiency strategies.

## Contact Our Contributors

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09/20/14	Fort Collins, CO	Sustainable Living Fair
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Whether you're building new or retrofitting the home you have, learn how other energy-wise homeowners have integrated efficiency measures into their lives at [homepower.com/efficiencyprojects](http://homepower.com/efficiencyprojects).

## Get Inspired!

Courtesy David Lewis

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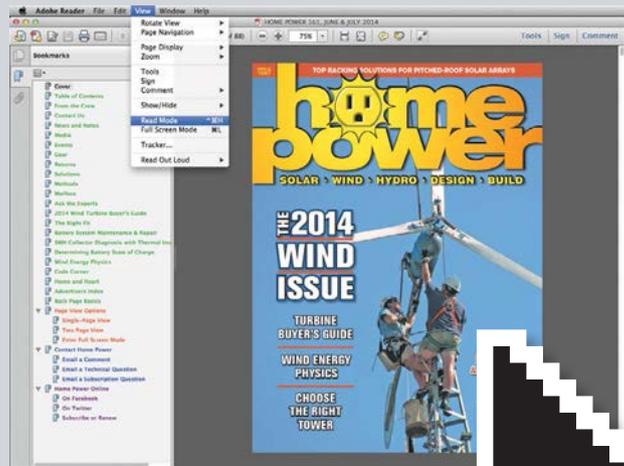
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# Building Efficiency

## Stock or Custom Solar Plans?



**H**ome Power spoke with architect and author Debra Rucker Coleman, who designed the RISE house (featured in this issue). Coleman specializes in passive solar design and offers more than 50 “sun-inspired” designs through her website at sunplans.com. Here, Coleman shares her best advice for building a passive solar home.

**Home Power (HP):** With pre-designed home plans now readily available, is it even necessary to work with an architect these days?

**Debra Rucker Coleman (DRC):** Pre-designed plans are a wonderful resource, but they’re really just a starting point. A key objective in striving for sustainability is designing a house to be as small as possible while still meeting your needs. Most homeowners typically do not find a pre-designed plan that fits their needs perfectly. Often the homes are either too small or too big, and when faced with the choice, most people opt for bigger. However, it is shortsighted to decide that an architect’s fee is unaffordable and then purchase a pre-designed plan for a larger home, since the extra construction costs will easily exceed the fee for a custom design that would better fit your needs. Enlisting an architect to create a smaller home can reduce construction costs and the home’s lifetime energy costs by many times the architectural fee.

There’s also a middle-road option: Save money by hiring an architect to adapt a pre-designed plan. Working from an existing plan is far less expensive than a custom, start-from-scratch design.

**HP:** What is your best advice for someone starting the design process?

**DRC:** Keep the complexity of the design in line with your budget. Creating a home plan or selecting a pre-designed

home plan that is too complex in shape and style can lead to high construction costs. Your builder can provide early and valuable insight into the labor and materials costs, and help keep your plans grounded. It is equally important to have an architect that understands and respects your budget.

**HP:** What is a common mistake people make when working with pre-designed plans?

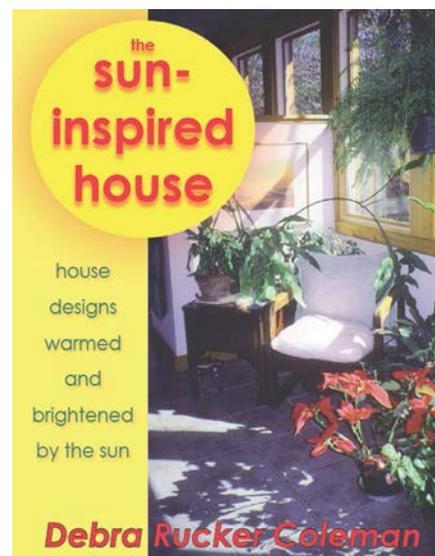
**DRC:** People often think that the house plans contain everything they need to begin building. For those engaging an architect, the house plans are a milestone in the planning process—the end result of weeks or months of planning and thinking. However, if you choose to purchase a pre-designed plan, the drawings are merely the start of the planning process. You will need to study and analyze the plans with your builder, and determine if you need to make any possible changes due to budget restrictions or local codes.

A knowledgeable builder steps in where the plans leave off. They know how to modify and adapt for the local particulars, and will be coordinating with material suppliers and subcontractors. They also know when to contact the architect for clarifications or implications of proposed changes. No one builds a home exactly as it appears on paper.

**HP:** You tend to favor the use of conventional building methods and materials in your designs. Why?

**DRC:** To make a home easier and less costly to construct, I design with as many conventional construction materials

*continued on page 16*



Courtesy Sun Plans, Inc.



“ We have been installing solar for over 10 years and have worked with most of the distributors out there. We now work exclusively with AEE Solar because of their outstanding customer service, quick response time and selection of top tier solar products at the best prices.

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JOSHUA MILLER  
Sales and Project Manager  
WESTERN SOLAR

For over 30 years AEE Solar has delivered the products, training and support our customers need to succeed. Through market and technology changes, AEE Solar has been there for our customers, every step of the way. Let us help you succeed.



continued from page 14

and technologies as possible. People often assume that the newest materials and technologies on the market are the best, greenest choices, but what they don't realize is that conventional methods and local materials can be as good, if not better, in some cases. Insulated concrete forms (ICFs) and structural insulated panels (SIPs) offer several advantages, but they might not be available in your area or they might not fit your budget. Conventional building methods can be just as good—it's all about the quality of work, which makes your builder choice especially important. In the case of the RISE home, doubling up the exterior studded walls allowed for additional insulation that fit the budget and performed as well as alternatives.

**HP:** Speaking of choosing a builder—any advice?

**DRC:** A home may be designed to be passive solar and energy-efficient, but it is typically beyond the responsibility of the architect to assure that the house performs as designed, especially when site visits may be cost-prohibitive. For example, thick insulation won't work as specified if it is carelessly compressed into cavities or installed with voids, and a high-efficiency HVAC system will not perform well unless it is properly designed and installed.

Choose a builder with experience in energy-efficient construction. If none are available, choose one who seems open-minded and willing to learn. Whether your builder

is experienced or not, hire a third party, such as a home energy rater who is certified under the RESNET program or one who will guarantee that energy bills do not exceed their estimates. Energy raters usually perform blower door tests and supervise the installation of the HVAC system, as well as inspect the insulation and caulking details.

**HP:** When building a home, homeowners often end up making budget concessions at some point. Where should homeowners absolutely *not* skimp when aiming for an energy-efficient, passive solar home?

**DRC:** Talk to your builder and architect, and ask for suggestions. Slight modifications to the design could bring your costs down substantially. Buy the most energy-efficient windows you can afford, and don't skimp on insulation and sealing. Perhaps, most importantly, save room in the budget for a third-party home energy rater that will oversee the insulation and sealing of the home. Fees range between \$500 and \$2,000 based on the distance needed to travel, particular design, and services chosen, but it is money well spent. Over a home's lifetime, more energy—and consequently more money—is lost through infiltration than through the insulation, so at a bare minimum, have a third-party rater perform a blower test to identify any leaks in the completed home. The results can be truly eye-opening and save you big in the long run.

—Kelly Davidson

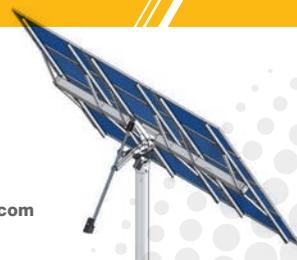
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### **RESIDENTIAL INVERTERS**

#### **FEATURES**

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- Highest industry peak & CEC efficiencies
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- 3Ph Transformerless Inverters (14-28 kW)
- 3Ph Central Inverters (50-500 kW)
- Utility-Scale Inverters (500 kW-2 MW)
- Disconnecting & Arc-Fault Combiners
- Web-based Monitoring

# SMA America

## Expands Sunny Boy TL-US Inverter Line



Courtesy SMA America

SMA America ([sma-america.com](http://sma-america.com)) released two new TL-US models: the 3800TL-US and 6000TL-US. These batteryless string inverters have dual multiple power point trackers and integrated arc-fault protection. Their secure power supply (SPS) feature allows limited backup capability (up to 1,500 watts) during sunny conditions—without a backup battery bank (see “Backup Power without Batteries” in *HP159*). With an ambient temperature range of -40°F to 140°F, these inverters can be mounted outdoors, even in cold climates. The inverters have a CEC efficiency of 96.5% at 240 VAC output. The 3,800 W model is suitable for use with a 100 A main service panel. With a 16 A AC output, requiring a 20 A breaker ( $16 \text{ A} \times 1.25 = 20 \text{ A}$ ), this inverter is well-matched to the 120% busbar allowance (per *National Electrical Code* Section 705.12(D)—see “Code Corner” in *HP151*).

—Justine Sanchez



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# Schneider Electric

## Next Generation Conext XW+ Inverters



Courtesy Schneider Electric

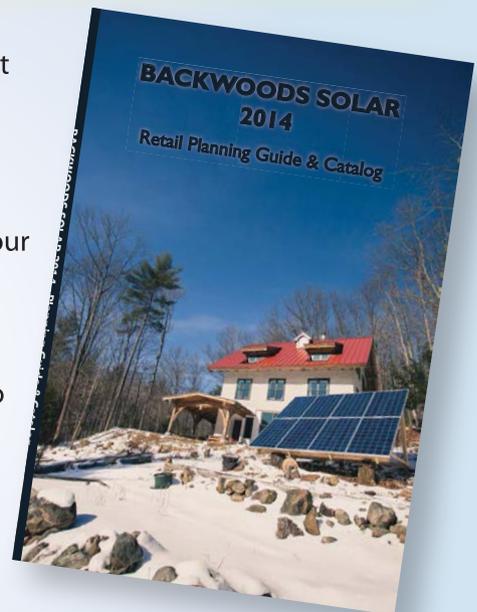
Schneider Electric ([sesolar.com](http://sesolar.com)) introduced the Conext XW+ 5548 NA and XW+ 6648 NA battery-based inverters. These multimode inverters can be used in both residential and commercial off-grid and grid-tied renewable energy systems. The XW inverters have split-phase 120/240 AC output and dual AC inputs, so systems can be connected to both the utility and a generator for additional backup. The 48 VDC battery charger provides 110 A for the 5,500 W model and 140 A for the 6,600 W unit. The XW+ models include options for peak-load shaving (to avoid utility peak rates), support for lithium-ion batteries, and a self-consumption mode (to minimize grid-energy consumption via cycling the battery bank). Additionally, a new feature can use frequency shift with compatible batteryless inverters to support AC-coupled systems in both on- and off-grid modes (see “Methods” in this issue). The CEC efficiency is 93% and 92.5% for the 5,500 W and 6,600 W units, respectively.

—Justine Sanchez

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# Extreme Efficiency

Last year, I designed and built my high-performance home in Shirley, Massachusetts. The design goal was a net-zero energy (NZE) house that would be comfortable, easy to build with low-skilled labor, and very affordable (around \$100 per square foot, including the PV system that would offset 100% of the home's energy use).

The NZE construction method that made the most sense was a simple wood-framed home with lots of insulation. I did several heat loss calculations, and compared different heating systems' costs of installation, maintenance, and fuel. In the end, I decided to forgo purchasing a fossil-fuel-burning heating system. I estimated that I saved more than \$20,000 by making this choice. Saving this money allowed me to spend more on insulation—and afford a solar-electric system. I chose dense-packed cellulose to insulate the walls (to R-42) and the roof to an average of R-100. There is just over 16,000 pounds of cellulose in the house.

One of the main benefits of cellulose is its ability to manage moisture. Many moisture-related problems are caused by air leaks, which bring moisture in with the air. Since dense-packed cellulose does not support convective air movement, the moisture-laden air cannot reach the condensing surface of the exterior plywood. With the help of National Fiber's technical manager, we tested the wall assembly this past winter with a moisture meter. The testing revealed dry framing and dry exterior sheathing.

Most projects I've been a part of have considered the air-sealing separately from other construction. With my home, I integrated the air-sealing details into the building process. In the crawlspace, I installed a 16-mil vapor barrier against the ground and up the foundation walls. It's reinforced and the seams are double-taped. The vapor barrier is mechanically fastened to the top edge of the block wall with plastic clips tapped into holes in the concrete.

## web extra

For more on measuring a home's airtightness, see "Tight Houses, Efficiency & Indoor Air Quality" in *HP148*  
 • [homepower.com/148.120](http://homepower.com/148.120)



David Postlusny

**The small house was built for about \$100 per square foot, including the PV system that covers all of the home's energy needs.**

Slight adjustments to the framing can result in better energy performance. For example, a common detail in homes is to have a central girder under the floor joists that is set into a pocket in the foundation wall. However, this leaves the girder subject to thermal bridging. My home has this central girder, but the connection between the girder and foundation was eliminated. Instead, an additional pier in the crawlspace handles the load. This allowed me to run a continuous layer of insulation up the foundation wall, and tie seamlessly into the rim-joist insulation. All this work is code-approved and requires no extra engineering—simply some forethought.

Exterior sheathing is 1/2-inch plywood covered with Grace Ice & Water Shield. Designed for use as roofing underlayment, this self-adhering product seals its own overlaps, and every puncture from nails and screws. I wrapped it around the house starting at the bottom, working up the walls and over the roof. Directly above each window and door, I left some paper on the backside so that I could lap window flashing under the higher course. This shinglelike lapping is the proper way, and the opposite of reverse-flashing, which will direct water into the structure.

*continued on page 22*

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# NABCEP™

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continued from page 20

The bottom edge of the wall membrane was attached to the vapor barrier inside the crawlspace with a transitional piece. This had to be pre-planned. After the foundation was finished, but before the sill plate was attached, I laid a strip of shield down over the top of the foundation. This gave me something to tie the wall membrane to on the outside, and something to attach the vapor barrier to on the inside. This means the air barrier is unbroken, from inside the crawlspace to outside the house and up and over the roof. Air leakage will transport moisture, so if you eliminate air leakage, you also eliminate potential structural water damage.



**Double-stud wall framing and a gable roof with scissor trusses create ample space for blown-in cellulose insulation.**



**Meticulous installation of high-quality vapor barrier prevents air exchanges and moisture transfer.**



**A 4.9 kW PV system provides 100% of the home's energy needs, including space heating.**

David Posluszny (3)

## Overview

**Project name:** Posluszny residence  
**System type:** Batteryless grid-tied PV  
**Installer:** New England Clean Energy  
**Date commissioned:** March 2013  
**City:** Shirley, Massachusetts  
**Latitude:** 42.6°N  
**Average daily peak sun-hours:** 4.4  
**PV system capacity:** 4.9 kW STC  
**Average annual production:** 4,998 kWh  
**Annual utility bill offset:** 100%

## Equipment Specifications

**PV modules:** 20 Canadian Solar, 245 W STC each  
**Inverters:** 20 Enphase M215 microinverters, 215 W each  
**Array installation:** Two strings of 10 modules, mounted on 45° roof facing 170°

I control the humidity and ensure adequate fresh air in this extremely tight house with a Venmar heat recovery ventilator, which creates nice cross-flow in the house. The home has a 0.1 ACH50—compared to Passive House's 0.6 ACH50 requirement. ACH50 measures air changes per hour at 50 pascals of pressure—the lower the number, the more airtight a house is.

The entire heating system is a single 6-foot, 240-volt standard electric baseboard heater mounted in the crawlspace. It cost only \$80, including the thermostat. This setup works in my situation because the crawlspace lies *inside* the thermal envelope, which means that the crawlspace and living space are close to the same temperature. I set it to keep the crawlspace about 75°F, and that warms the underside of the first floor and keeps the home at 68°F. In the future, I am planning to install a ductless minisplit air-source heat pump, which will use even less electricity to do the same job.

Two windows in my home face south and have a solar heat gain coefficient of 0.65, so I get some free heating from passive solar (an estimated 20%). About 70% of my heating load is handled by internal gains (anything that gives off heat as a byproduct of doing something else, including refrigerators, TVs, computers, cooking appliances, lights, and people). The remaining 10% is provided by the baseboard heat.

Electricity is the home's only energy source besides the passive solar. My grid-tied PV system with net billing offsets all of my energy needs. After doing some initial heat-loss calculations, I found that adding a PV array was less expensive than buying windows with lower U-factors. Finding the least-expensive way to arrive at a NZE home is not always the most energy-efficient way.

—David Posluszny

We don't manufacture a "hybrid."



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# AC Coupling

Even though they usually include an inverter, most battery-based PV systems are “DC-coupled”—the PV array sends DC electricity to the system through a charge controller to the battery bank. That DC power is then drawn from the batteries for the loads, including through a battery-based inverter for AC loads.

AC-coupled PV systems are gaining wider acceptance and support through several battery-based inverter manufacturers. In AC-coupled systems, the DC power from the array is first converted to AC by a batteryless inverter, to be used by the AC loads through an AC load panel. Any unused energy is used by a separate battery-based inverter that either converts the AC to DC to charge the batteries, or, if it is a grid-tied system, it can also pass through to additional AC loads and/or the grid.

A batteryless inverter would normally not turn on without the utility grid present, but many battery-based inverters create a quality sine wave that’s good enough for the batteryless inverter to synchronize with. In grid-tied systems, when the grid goes out, the battery-based inverter isolates both the load subpanel and the batteryless inverter from the utility grid via an internal transfer switch allowing the batteryless inverter to remain on without being connected to the grid.

For residential systems, a primary advantage of AC coupling over the traditional system design is that you can add battery backup to an existing batteryless grid-tied PV system without changing the existing system’s wiring. An AC-coupled system can also be more efficient than a typical battery backup system because the batteryless inverter is doing the majority of the power conversion. Efficiency is generally in the 96% to 98% range compared to 90% to 95% for a typical battery-based inverter.

Disadvantages are a more complicated system to design and program, and more expense, since you’ll need two inverters (or more) instead of a single inverter and a charge controller. In off-grid use, AC-coupled systems are not self-restarting if the battery-based inverters happen to shut down because of low battery voltage. If this happens, the

batteryless inverter does not sense AC voltage, and thus does not turn on to send array energy to the batteries. A DC-coupled system can self-restart even if the inverter shuts down from low battery voltage, because the charge controller can still charge the batteries.

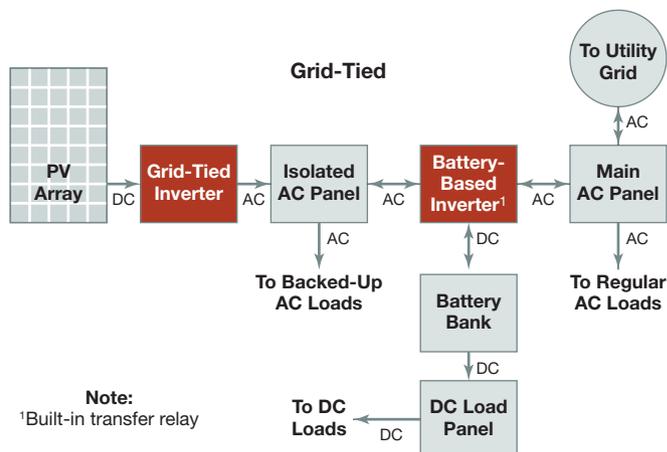
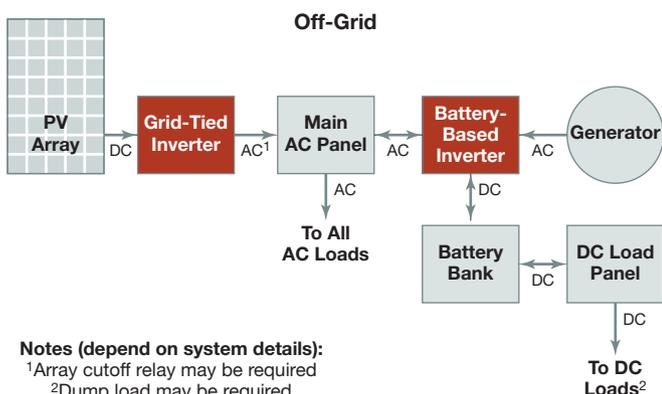
Different inverter designs handle AC-coupling differently—mostly in how they control the system in “off-grid” mode—when the batteries are at 100% state of charge (SOC). The batteryless inverter is designed to extract as much energy as possible from the array and send it into the “grid”—in this case, the battery-based inverter. When the batteries are fully charged and there are not sufficient loads, the batteries can overcharge since there is no way to slow the charge rate.

Normally, the charge controller in a DC-coupled system includes the function of reducing output from the array when the batteries are full. Most batteryless inverters do not include this function. When used with Sunny Island inverters, SMA America’s Sunny Boy inverters include it. (Note: Sunny Island inverters output 120 VAC, so either the Smartformer or a second Sunny Island inverter will be required to produce 240 VAC to match the output of a 240 VAC grid-tied inverter.) The battery-based inverter communicates with the batteryless inverter to restrict incoming power to only what is needed. Other models, such as those from Magnum Energy, OutBack Power, and Schneider Electric, support AC-coupled systems but use less-sophisticated control methods to force the inverter to go offline. This happens either by adjusting the frequency of the AC power, which indicates an “out-of-spec” waveform to the batteryless inverter, or by using a relay to disconnect. This on/off control of the array versus a multistage charge controlling is harder on the batteries. Because of this, some manufacturers support using their battery-based inverters only for grid-tied AC-coupled systems, where excess energy is sent to the grid—but not for off-grid systems, where charge control is important.

For more information, see “Choosing a Battery-Based PV Inverter” in this issue.

—Zeke Yewdall

## AC-Coupled System Configurations



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PVX-2580L | 12 Volt  
258 Ah (24 Hr Rate)  
8D case

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## Tough Turbine in Venerable System

A couple of months ago, I read an article describing Arthur and Maxine Cook's off-grid 70-acre farm in Somerset County, Pennsylvania ("120 VDC Wind and PV Hybrid" in *HP29*). Their hybrid power system consisted of a Northern Power Systems HR3 wind turbine, 3,000 watts of Kyocera PV modules, 20 Surrette 6-volt, 200-amp-hour batteries, and the associated charge controllers, inverters, disconnect switches, etc.

Here is some background, directly from their 1992 article:

*"Our first wind generator was a 115 VDC rebuilt Jacobs [Wind Electric]. It was destroyed in a terrible blizzard in January 1980. The wind that day gusted to 82 mph and the temperature was -27°F. The Jacobs' governor failed due to the cold; the springs lost their tensile strength, the rotor overspun, and the machine flew apart.*

*We replaced the "Jake" with our present HR3, an 825-pound, direct-drive, 120 VDC alternator with a 5-meter (16.4-foot) diameter, three-bladed rotor. We mounted her atop a 60-foot Rohn self-supporting tower. This magnificent machine will produce 3,500 watts at 25 mph, and requires only one hour of maintenance per year. It hasn't missed a beat in 11 years."*

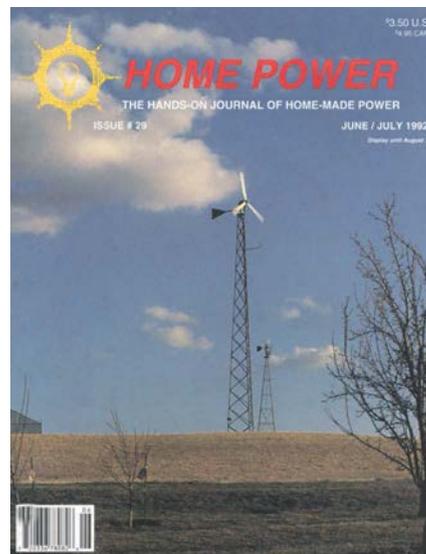
With another person, I recently bought the assets of the HR3 wind turbine manufacturer to start Black Island Wind Turbines (BIWT), so I decided to call the Cooks. Their article was 22 years old, and I wondered what I'd discover.

Arthur shared with me that his climbing days are over. The turbine needs a new set of bearings after 33 years, and so it has been idle for awhile. He indicates that he would like to see it find a good home. If by chance you're looking for a used HR3, contact me.

Bill Stein • Black Island Wind Turbines

*Art Cook adds: We've made a lot of changes since we were featured in Home Power. The HR3 ran from 1982 until its retirement in 2008, when we went to co-generation. We live in an extremely harsh environment—ice, snow, wind, electrical storms, etc. The HR3 handled everything that was thrown at it. I think that its survivability should put it at the top of anyone's wind turbine list. We're not averse to finding our HR3 a new home, but it's always welcome to live out the days here as a classic lawn ornament, too. It's still quite useful as a weathervane.*

*Even though some of our PV modules are more than 25 years old, the 4,500 W system is still producing more than 4,000 W AC, and we often get a total of 30+ kWh per day.*



*We still use our 36-year-old Aeromotor 8 for water pumping, with gravity feed to the house and outbuildings. We heat primarily with wood using an HS-Tarm 2000 wood boiler, with oil-fired backup. We also have an Avalon high-efficiency wood stove that can heat our 3,000-square-foot home by itself—even in -10°F weather.*

*We've used a solar domestic hot water preheating system—50 evacuated tubes—since 2008. It heats 80% of our domestic hot water during three seasons, and does an impressive job even in the cloudy days of winter. Backup power is via a 7 kW continuous-duty, water-cooled diesel generator.*

*At 71 years of age, I can still climb towers, but I choose not to! We still live on our 70-acre farm as we have for the past 44 years. My wife Maxine and I pioneered co-generation and net-metering on the GPU Energy grid back in 1978—before the PURPA laws—with a Gemini synchronous inverter, before we went to a stand-alone battery system. We proved to our utility that it was safe and do-able. I still have the paperwork from Penelec permitting us to proceed with our demonstration project in the late 1970s. I remember their senior engineer telling me that it was impossible to run their meters backward. After they learned that I was right, they never bothered me about anything. I don't have an engineering degree, but I can read a schematic.*

*Best regards to the crew at Home Power. I read the magazine cover to cover, and have kept every back issue from almost the beginning days.*

Art Cook • Somerset County, Pennsylvania

*continued on page 28*



Courtesy Art Cook



# PowerSpout Hydro Turbines

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Name	Now		Yesterday		Today		Lifetime		kWh	Status
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh		
Cathedral Grammar School	5.647	0.369	48.17	3.148	48.17	3.149	15234.97	995.75	15.3	<span style="color: green;">●</span> <span style="color: gray;">○</span>
CGS1	1.883	0.369	16.1	3.157	16.1	3.157	5075.84	995.263	5.1	<span style="color: green;">●</span> <span style="color: gray;">○</span>
CGS2	1.844	0.362	16.02	3.141	16.02	3.141	5073.55	994.814	5.1	<span style="color: green;">●</span> <span style="color: gray;">○</span>
CGS	1.917	0.376	16.05	3.147	16.05	3.147	5085.58	997.175	5.1	<span style="color: green;">●</span> <span style="color: gray;">○</span>
<b>TOTAL</b>	<b>11.333</b>	<b>1.476</b>	<b>96.34</b>	<b>12.593</b>	<b>96.34</b>	<b>12.594</b>	<b>30566.28</b>	<b>3983</b>	<b>30.6</b>	



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continued from page 26

## Solar Hot Air

Not mentioned in Chuck Marken's "Ask the Experts" on "Solar Space Heating" (*HP161*) is how simple and maintenance-free solar hot-air systems are. These are nonpressurized systems that use a nontoxic, noncorrosive, freeze-resistant heat-transfer fluid (HTF) that is free—air. Also important, the HTF is returned to the collectors at room temperature. You'd need a pretty big heat exchanger to accomplish that with hot water collectors.

Readers should be advised not to judge a book by its cover nor a product by its website. Judge the product. That's what the people at SRCC are there for. That a company doesn't have a distribution network means you get to talk to the company and buy from them directly.

Like Chuck, I have a few years on me. I remember the 1980s and the mandate that anything purchased get used extensively. It's pretty smart that we now base our financial decisions on return on investment. The hot air collectors on my shop have paid off very well, especially this year, with propane prices being out of sight. The hot water collectors that provide heating for my house have paid off very well also.

Formerly subtitled "The Hands-On Journal of Home-Made Power," *Home Power* could

have pointed out that hot air solar collectors are the nearly ideal introduction to renewable energy. They are so simple that they don't even require storage.

Pete Gruendeman • via email

*Thanks for your comments, Pete. I agree with you! I've had three large air collectors heating my house for the past 30 years, and seven heating my shop.*

Chuck Marken •  
Home Power solar thermal editor

## web extra

See Stephen Hren's article on how to build a solar hot air collector at [homepower.com/145.112](http://homepower.com/145.112).

## Kudos for Mass Heaters

I enjoyed Stephen Hren's "Efficient Heating with Wood" in *HP159*. We bought a Tulikivi soapstone heater about seven years ago, and it is the best thing that we have ever purchased. It makes firewood work—it burns very efficiently and does not require tending after the initial 1- to 1½-hour burn cycle. It provides instant heat and a cheery fireplace

glow through the glass door, and long-lasting radiant heat from the soapstone mass.

For a season's worth of heating here in the foothills of the Alaska Range, we burn about 3 cords of split and seasoned aspen, birch, and spruce. Harvesting wood locally is central to the economy. If you have to burn all kinds of fossil fuel in a truck to harvest the wood far away, you might as well just heat with fuel oil.

You'll spend between \$12,000 and \$15,000 to have a Tulikivi built by a mason. But the heater will pretty much last forever, and you'll save big bucks after the initial investment while making your home a cozy fortress against economic cycles and fuel crises.

"NorthPilot" • via homepower.com

## write to:

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## PV Grounding

I need to “Ask The Experts” to help solve the conflict I find between required PV array grounding, and grounding for lightning protection. We are building a grid-tied, 5 kW pole-mounted PV system with four trackers and a string inverter.

*National Electrical Code (NEC)* and inverter instructions call for the PV ground to be carried back to the inverter ground connection to provide ground-fault protection. That is a recipe for disaster with a lightning strike on the rack or modules, because it invites the lightning to seek its only way to ground at the AC mains panel ground—through the inverter, and through the house. The farm has been hit by lightning six times in the last 20 years, and to minimize damage, I’ve learned to liberally use surge protectors (MOVs and GTRs) with the right clamping voltage, and provide multiple paths to earth on ground lines, as close to the point of strike as possible.

For good lightning protection, it seems like the PV array ground wire should be bonded to a ground rod at each pole, tied to the array’s emergency disconnect switch box and that box bonded to its own ground rod. The ground wire should then be coiled into a choke and bonded to another ground rod just before it enters the house and goes to the inverter.

With our history of lightning strikes, a PV array and rack with multiple paths to ground—starting with the first ground as close to the panel as possible for maximum lightning protection—would seem to be more important than a single ground point at the inverter for GFDI. How do I deal with this dilemma?

David DeJong • Dickens, Iowa

I believe the confusion is over what “ground” is connected where. There are actually at least four different electrical terms that include the word “ground,” and it’s important to understand the distinctions between them.

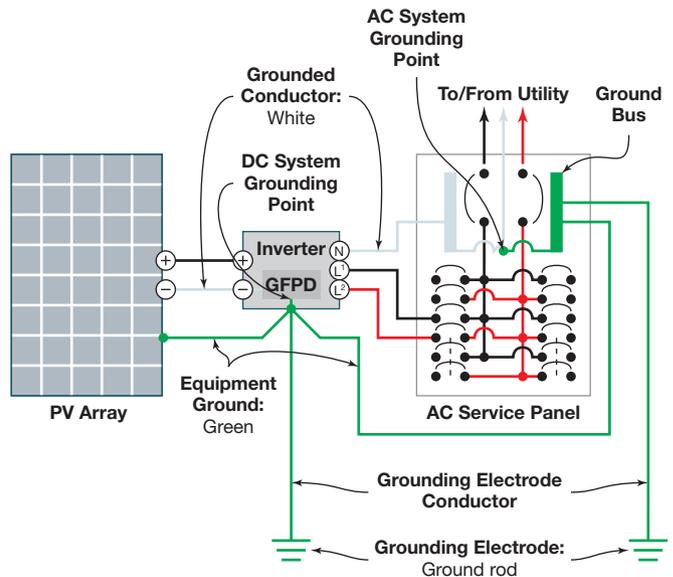
The “equipment ground” is the typically green wire that travels through the conduit along with the current-carrying wires. It connects all of the metal parts of the equipment together, to make sure that one exposed metal part cannot be at a different potential than other metal parts. This is also what WEEB clips, module racking, and bare copper wire connecting module frames together, or bare wire inside of Romex, do. The equipment ground connects to the “grounding electrode” either directly, or indirectly through the “grounding electrode conductor (GEC).”

The grounding electrode is the point of connection to the physical earth—usually a ground rod, or a UFER (connection to rebar embedded in the concrete foundation). There can be more than one grounding electrode—in your case, you want one at each pole mount to give lightning the most direct path to earth.

The GEC connects the “system grounding point” to the grounding electrode. It can also connect between one grounding electrode and another, if you have multiple grounding electrodes. It may look similar to an equipment ground, but must follow *NEC* requirements for sizing, continuity, and how it is run through conduit. For example, the GEC must be continuous (or irreversibly spliced) between the system grounding point and the grounding electrode, even if it goes through other boxes. Equipment grounds are allowed to have junctions if they pass through a box.

In addition, the equipment ground can connect to the GEC and hence the grounding electrode at more than one point. If you have an outbuilding fed from a house, for example, the *NEC* requires that a second grounding electrode be installed at the outbuilding, with a grounding electrode conductor run between it and the grounding electrode on the house. Then, the equipment grounds in the outbuilding must be connected to the grounding electrode at

## Parts of a Grounding System



the outbuilding. This is very similar to your case with multiple poles, where each one has its equipment ground connected to its individual grounding electrode.

The grounded conductor is a current-carrying conductor under normal operation—but the equipment grounds only carry current in case of a fault. For DC systems, the grounded conductor is usually the negative wire; in a SunPower system, it may be the positive wire. With some of the newer transformerless inverters, neither current-carrying conductor is grounded. For AC systems, it is the neutral wire. The grounded conductor should have only one connection to the GEC—at the system grounding point.

The system grounding point (aka “system bonding point”) is the place where the connection between the grounded conductor and the GEC is made. For a grid-tied PV system with multiple inverters, there will be one system grounding point for the AC system and one for the DC system of each inverter. In the case of a grid-tied inverter, the DC system grounding point is the internal ground-fault protection device (GFPD) fuse or GFPD system. This is what the *NEC* and the inverter manual are referring to when they say that there can only be one ground connection. To be more precise, it should say that only one DC system grounding point per inverter is allowed.

On the AC side of the system, there is also a system grounding point—usually inside of the main circuit breaker panel of the house, where a wire connects the grounding electrode conductor and the neutral, or grounded, conductor. This is why you’ll often see neutral and equipment ground wires sharing a busbar in a main AC panel—but it is not acceptable in a subpanel. You would have a second system grounding point on the same AC system if the equipment grounds and neutrals shared a busbar in the subpanel.

If you’re using an ungrounded inverter, your system will still have a grounding electrode, an equipment ground, a GEC, an AC system grounding point, and a grounded AC conductor. It is only missing the DC system grounding point and the grounded DC conductor. It still needs the rest for the internal ground-fault protection circuitry to do all of its tests to make sure there are not inadvertent connections between the high-voltage DC-carrying conductors and an exposed piece of metal that someone might touch.

Zeke Yewdall • Ward, Colorado

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## Understanding Net Metering

I recently had a 3.2-kilowatt, battery backup solar-electric system installed at my home in western Montana. My OutBack meter is telling me that I sold back 626 kWh for the past month's service, yet the electric co-op I belong to only reduced my usage by 97 kWh—the reading they claim on my meter. The amount purchased was listed as 851 kWh, leaving me a net purchase of 754 kWh, according to them.

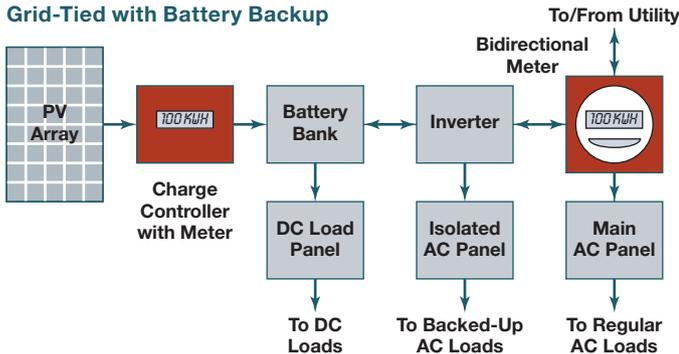
Do you have any ideas why there is such a great discrepancy? On most days with full sun, the meter displays 20 to 22 kWh "sold," with 11 to 16 kWh on cloudy or smoky (forest fires) days. Since my system is capable of putting out much more than the roughly 3 kWh per day the utility credits, it seems like either their meter is not registering the electricity the system is feeding onto the grid, or the electricity somehow isn't getting fed back onto the grid. Could my installer have misconnected or misconfigured the wiring?

Reg Thibodeau • Hamilton, Montana

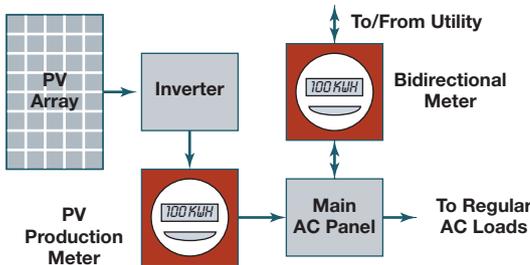
Battery-based systems have multiple meters that report various values from different points of the system, and thus understanding the actual output of a battery-based system can be confusing. Some meters report information from the DC side of the system and, for example, show instantaneous power (kW) and daily energy (kWh) from the charge controller, as well as kWh in and out of the battery. Other meters measure power and energy on the AC side of the system.

## System Energy Flows & Metering

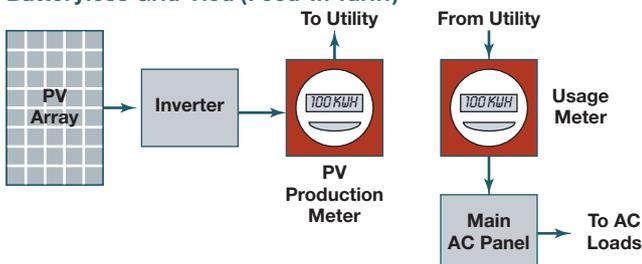
### Grid-Tied with Battery Backup



### Batteryless Grid-Tied (Net-Metered)



### Batteryless Grid-Tied (Feed-In Tariff)



So the first challenge is making sure you are getting the correct information from the correct meter. A quick check on PVWatts at what we would expect your PV system to produce shows us that even a batteryless 3.2 kW system should produce about 450 kWh during the best month (July) for your area. (Note: A battery-based system such as yours will be slightly less efficient and thus have slightly lower production.)

The next challenge in reading the meter that you have is knowing where the solar energy produced actually goes. Once your grid-tied battery backup system generates energy, it has two ways to be consumed at your site before the excess can be sold back to the co-op. Both of your load panels—the panel that distributes battery-sourced energy during power outages and the main service panel—will consume energy from your array *before* any remaining energy moves across the utility meter and onto the grid for credit.

Commonly, if there is confusion about how much energy should have been exported to the grid, the discrepancy is explained simply by realizing the difference between the kWh reported by the OutBack meter and the utility credit, which is affected by the energy being consumed by both the critical loads subpanel and the main service panel. For the sake of this discussion, we will assume the information you provided is correct; using those numbers, it would look like your house consumed approximately 1,380 kWh—626 kWh from the PV array plus 851 from utility. Subtracting the 97 kWh credit gives you 1,380 kWh. (Note: The 626 kWh displayed for the PV system's production is measured on the DC side of the system—that is, it doesn't take into account inverter inefficiencies or the energy used to keep the batteries topped off.)

We see this same type of confusion with grid-tied batteryless systems when a client's loads consume most of their system's production, and the client only sees a small credit on their bill from the utility.

The only system in which a client sees the system's total production credited on their utility bill is when the interconnection contract is based on a feed-in tariff (FIT) incentive. Under a FIT contract, all of a PV system's AC production is fed onto the utility side of the service and logged on a separate meter. This meter reading should closely match the kWh production shown on a batteryless inverter (although it can slightly vary depending on the accuracy of the inverter meter). Under a FIT scenario with a battery-based system, a special production meter is required that can account for the kWh being sent from the inverter to the main service panel/grid *and* the kWh going to the critical load subpanel. In this case, the kWh reported by the OutBack meter will be close to the kWh total shown on the production meter. The difference represents the inefficiency of the inverters' conversion of DC kWh into AC kWh, and any energy used to keep the batteries full.

Going back to your particular situation, if you think that your loads did not use the 1,380 kWh, checking previous utility bills (prior to the installation of the PV system) would be worthwhile. This should give you a baseline for comparison. However, if the household loads have changed since the PV system installation, then the way to test this would be to establish some means to track them independent of the sources (your PV system and the utility). This can be accomplished by measuring the loads in the two panels with a recording amp-hour meter for a day or more and calculating the load; or by obtaining a data-logging system that will collect the load data independent of the two sources. Your RE installer or an electrical contractor should set up this metering and data collection, since it requires working with equipment that can be an electrical shock hazard.

One simple method for completing this load analysis is to shut off your PV system (putting the critical load panel on the utility source with the bypass switch) and monitor your consumption at the utility meter for three to five days to achieve a representative sample. Then you can calculate the monthly total.

Christopher LaForge • Great Northern Solar

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## Voltage-Drop Calculations

There have been numerous discussions in *Home Power* about voltage drop in DC or AC circuits. The calculations have all been very useful for me. However, I have a concern that has not been addressed, or perhaps it has and I have just missed it.

It seems as though the data used in these equations is always “best-case-scenario” information. For instance, in calculating voltage drop on a DC circuit from array to inverter, STC  $V_{mp}$ ,  $I_{mp}$ , wire distance, and desired voltage drop is used. It seems that using worst-case-scenario data— $V_{mp}$  on the hottest day for your location; projected voltage and amperage of the string at, say, 20 years—would provide more accurate values that reflect real-world conditions.

Steven Johnson • via email

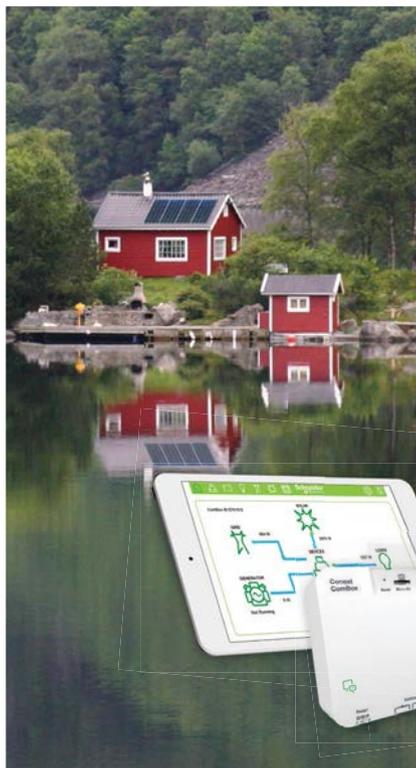
You are wise to design the system for at least a 20-year life, and to estimate cumulative losses and compensate for them. And you are correct—wire-sizing calculations at the full rated power of the modules for a new system will result in “oversizing” as the array ages and its output decreases.

Every string inverter has a minimum and maximum input voltage range. The maximum may be hit on a record-low-temperature, sunny winter morning when the sun first strikes the array. During this short period at dawn, the current is very low. As soon as the sun’s intensity and array current increase, the modules warm up just enough to drop the voltage below that maximum. Calculating maximum low-temperature VOC is necessary to size the equipment to handle that maximum voltage. The array’s DC voltage will gradually decrease over time due to normal PV module degradation, so this calculation covers the best-case situation when the PV modules are new.

## Direct-Current Resistance

Copper at 75°C (167°F)

Size (AWG)	Number of Strands	Ohm/1,000 Ft.
18	1	7.77
	7	7.95
16	1	4.89
	7	4.99
14	1	3.07
	7	3.14
12	1	1.93
	7	1.98
10	1	1.21
	7	1.24
8	1	0.764
	7	0.778
6	7	0.491
4	7	0.308
3	7	0.245
2	7	0.194
1	19	0.154
1/0	19	0.122
2/0	19	0.0967
3/0	19	0.0766
4/0	19	0.0608



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Calculating minimum DC voltage is of greater concern, as all inverters have a minimum acceptable voltage for establishing full maximum power-point tracking (MPPT). Good design practice is to maximize the number of modules in each series string to reduce the potential for the inverter's DC input voltage to ever drop below the minimum necessary for efficient operation.

With inverter AC voltage, the concern is voltage rise, not drop, because (due to Ohm's law:  $V = I \times R$ ) the AC output wire's resistance causes the inverter to see an elevated AC grid voltage at the inverter's AC output terminals. The same calculations for voltage drop are used when considering voltage rise, though, and typically designing for 1.5% as a maximum voltage change will minimize the possibility of the inverter shutting off due to combined high grid voltage and undersized conductors. Here too, degradation of output power would only improve this problem, since again looking at Ohm's law, the voltage rise will decrease further with less current flowing.

Amperage is less of a concern. When the system is new, an array capacity that is oversized relative to inverter wattage may experience power clipping during midday periods of high insolation. Normal degradation over time will decrease this power clipping and voltage drop.

With battery-based systems, the old rules about sizing conductors to minimize voltage drop do not apply to most modern controllers. Past systems required large-gauge wires to keep the voltage from a 12 V array high enough to equalize a flooded battery in the summer heat. Most modern MPPT charge controllers allow maximum array VOC to reach 150 V to 250 V (with some allowing up to 600 V) to charge a 24 V or 48 V battery bank. The fact that these charge controllers can use

higher-voltage arrays to charge lower-voltage batteries has changed the equation.

As with inverter PV string sizing, as long as the input is within the charge controller's range, using worst-case data would have little effect. A reduction in array current would actually reduce voltage drop, and a reduction in array voltage would have no consequence on wires and equipment sized to handle the initially higher voltage.

Finally, the *National Electrical Code* "Conductor Properties" table used in voltage-drop calculations assumes a wire temperature of 167°F. When annual production is considered, wire temperatures are, on average, much lower, and therefore actual voltage drop year-round is less.

Allan Sindelar • [sindelarsolar.com](http://sindelarsolar.com)

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# Mountain Solar

by Kelly Davidson



In the coal-heavy state of West Virginia, solar shines at Rita Hennessy and Sean Palmer's new custom-built home in Shepherdstown.

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Matt Hovermale (2)

After nearly two decades living in a drafty, 1940s Cape Cod-style home on the outskirts of Charles Town, West Virginia, Rita Hennessy and Sean Palmer were ready for an upgrade from the post-war cinder block and brick construction. "Even though we had made improvements through the years, it was still leaky and incredibly inefficient—cold in the winter and hot in the summer," Palmer says.

Planning for retirement, the couple—Hennessy, a National Park Service park ranger with the Appalachian National Scenic Trail, and Palmer, an engineer for a biotech company—paid off their mortgage ahead of schedule. In the years that followed, they focused on saving to realize their dream of buying land and building a home that better suited their lifestyle and values. After relying on West Virginia's coal-powered grid electricity for nearly two decades, the couple made energy conservation a top priority, vowing to reduce their carbon footprint with passive solar design and a rooftop solar-electric system. "We are very concerned about climate change, and we want to do our part," Palmer says.

## Site & Design

"Our mission was to find a property with good southern exposure that was close to the Appalachian Trail (AT) and near protected lands," Hennessy says. The couple focused their search along the AT corridor—looking first in

Maryland, hoping to move closer to Palmer's parents. "In Maryland, all the available land near the AT had steep slopes that were either east- or west-facing, which wouldn't work for our solar plans," Hennessy says. "We started looking in Virginia along the AT, but we didn't find anything suitable there either."

About two years into the search, the couple returned their attention to West Virginia, and in the fall of 2010, found a site just outside of Shepherdstown—14 wooded acres with southern exposure on a three-acre clearing. Hennessy and Palmer took more than a year to consider their building options. Finding a local architect with passive solar expertise proved more difficult than they expected. When their local search came up empty, they researched Web-based design firms and found Alabama-based architect Debbie Rucker Coleman, who specializes in passive solar and sun-tempered homes (see "Media" in this issue). "She had good reviews, and we were impressed with her credentials," Palmer says. "The only real downside to working with a remote architect is that it takes a little more time to exchange ideas through emails and phone calls."

The process began with Coleman's 20-page questionnaire in which the couple described their lifestyle, and outlined their budget priorities and energy-efficiency goals. Initially, Hennessy and Palmer envisioned a smaller, single-story

home—roughly 1,500 square feet—but answering the questionnaire made them realize that they wanted about 600 more square feet to accommodate a larger kitchen, a walk-in closet in the master bedroom, and a more spacious common area for entertaining. “We host a lot of parties. We’ll have 35 or more people in the house on any given occasion,” Hennessy says. “It became clear that we wanted a little more space.”

They browsed the plans available on Coleman’s website, and while they found inspiration in several designs, none were quite right. “We thought we would adapt one of the existing plans to meet our needs, but our list of modifications ran quite long, so it made more sense to start from scratch,” Hennessy says.

### Maximizing Passive Design

With the exception of a loft, the 2,148-square-foot design remains true to Hennessy and Palmer’s original vision for a one-story house. In viewing plans online, the couple loved the second-floor towers and atriums featured in several of Coleman’s larger home designs, but the complexity of the roof and window schemes came with high construction costs that would have exceeded their \$350,000 construction budget. Coleman came up with an affordable compromise—a 287-square-foot loft featuring a row of south-facing clerestory windows for daylighting and fresh air, and for providing summer passive cooling. “Even though the air-conditioning needed in this well-insulated home would probably cost less than \$100 per year, Rita and Sean wanted the clerestory to keep the house cool without electricity,” Coleman says.

**Large windows on the home’s south face provide ample daylighting to interior spaces. They also admit solar gain in the winter, reducing the home’s need for supplemental heating.**



Courtesy Rita Hennessy



**Clerestory windows, which are opened and closed by remote control, aid in cooling the house by venting any accumulated hot air.**

Dozens of emails over the course of one year gave way to the “RISE” design (a combination of the first two letters of the homeowners’ names), and the home’s ability to take advantage of rising air for passive cooling. A key feature is a series of seven operable clerestory windows at the peak of the south roof—which are opened and closed by remote control. At night, when outside temperatures drop below indoor temperatures, both the clerestory windows in the loft and the awning windows that sit low on the first-floor wall are opened to naturally cool the home. As the warm air in the home rises and is drawn through the clerestory windows, cooler air enters the lower windows, creating a thermosyphon of air movement. To capture the “coolth,” the windows are closed as early in the morning as possible, typically by 7 a.m. However, Hennessy says that “once the nighttime temps climb above 75°F, the passive cooling is no longer effective.”

Instead of a true south orientation, Coleman recommended that the house be oriented 10° east of south. In their West Virginia climate, having the façade favor a more easterly direction can help minimize afternoon heat gain during the summer and maximize early morning heat gain in the winter. Overhangs also help minimize heat gain in the summer, keeping



## High-Performance Glazing

For energy efficiency and passive solar gain, the home uses double-pane, fiberglass-framed casement and awning windows from Inline Fiberglass. All of the RISE windows have a maximum U-factor of 0.28—the lower the U-factor, the greater a window’s resistance to heat transfer and the better its insulating value. The south-facing windows have an SHGC of 0.42 (meaning 58% of solar heat is blocked), and the other windows (east, west, and north) have an SHGC of 0.24 (blocking about 76%). Inside, honeycomb shades or interior shutters further reduce summertime heat gain and provide a small amount of insulation during the winter.

“At the time of window selection, Inline was one of the few companies that made windows that met the solar heat gain coefficient (SHGC) and U-factors required by the home’s design specifications. Other U.S.-based companies have since improved their specs,” Palmer says.

Courtesy Rita Hennessy

**Thick, insulated walls and double-pane windows slow heat transfer, keeping the house cool in the summer and warm in the winter. The 4-inch-thick concrete floor acts as a thermal battery, storing and releasing passive solar heat gain.**

the sun from shining directly into the windows throughout the afternoon. Oriented with its long dimension to capture the winter sun for free heating, the home features a 4-inch-thick concrete slab-on-grade floor, which is insulated with 3 inches of rigid-foam insulation (R-15). The thick concrete floors provide thermal mass to absorb solar gain in the winter and also help moderate temperatures during the summer. The foundation stem walls are also insulated with 3 inches of rigid foam.

The home uses doubled, 2-by-4 stick-frame walls on 16-inch centers with a 1/2-inch space between to form an 8-inch-thick wall. The air space between the stud walls creates a thermal break between the interior and exterior. With fiberglass batts between the studs to total R-30, and 1 inch of closed-cell spray foam to the exterior, the walls total about R-36, almost triple the code minimum (R-13 in their county) for wall insulation. “While spray foam isn’t all that green—it is petrochemical-based and has a high embodied energy—the amount we used is far less compared to the amount of foam used in structural insulated panels, which we had considered as a wall option,” Palmer says.

The roof is framed with manufactured wood trusses, which allow lots of insulation in the flat ceilings. In the bedroom wing, for example, 15 inches of blown-in fiberglass insulation were applied over 1-inch closed-cell spray foam (for R-60). A combination of fiberglass batts and spray foam were used for the vaulted, sloped ceilings throughout the rest of the house, for about R-66 total.

### Auxiliary Cooling & Heating

Given West Virginia’s hot and humid summers, keeping the house cool was a priority. While the operable windows provide some passive cooling, a 22-inch-diameter whole-house fan mounted in the attic boosts ventilation, helping move air throughout the house. Most effective whenever outdoor temperatures drop below indoor temperatures, the AirScape fan draws fresh, cooler air into the living space through open windows, the warmer air exiting through the roof vents. The fan can move 725 to 2,590 cfm, drawing 21 to 210 watts—far less power than a central air-conditioning system. At about \$1,300, it is also significantly less expensive.

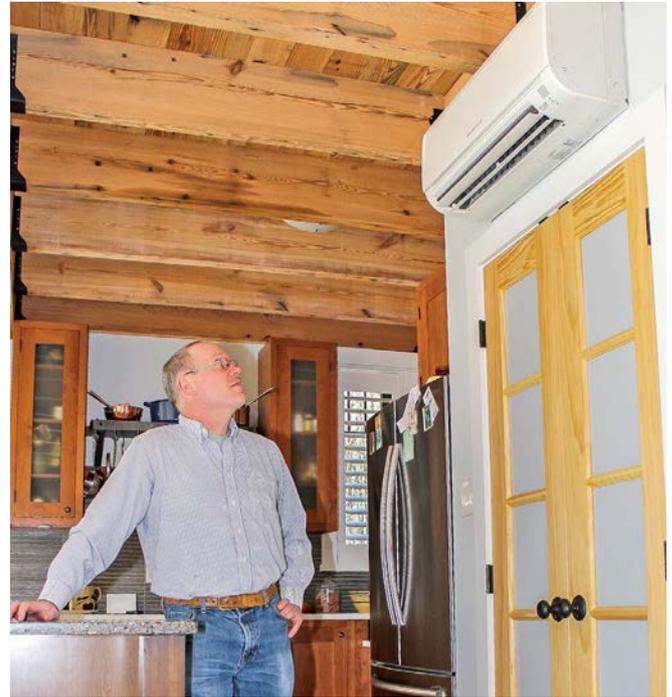
While the couple says that the fan works well for cooling, the window-opening strategy moves enough air so they rarely need it. However, in late July and August, when the humidity peaks and night temperatures remain in the 80s, they use a minisplit heat pump to keep the indoor temperatures cool and comfortable.

In the winter, they typically keep the house at about 69°F with one firing per day in their masonry heater. When outside temperatures drop below zero, they burn two or three fires. Popular in the wood-sparse tundra of Scandinavia and Russia, this massive heater works by directing the heated gases from a small, hot fire through baffled chambers, where nearly all the heat is absorbed by the masonry. Usually, one or two fires will provide enough heating for a 24-hour period. Because the fires burn at very high temperatures, very little ash or smoke is produced. The couple purchased a kit from Empire Masonry Heaters, and hired a mason to assemble the core. A subcontractor hired by the builder finished the exterior with river stones collected from the property. The Phoenix kit, roughly \$4,800, included the core, doors, cleanouts, damper, and a pizza/bread oven.

Rita pulls a pizza from the Empire masonry heater, which serves as a backup source for space heating.



Matt Hovermale (2)



Sean checks out the minisplit multizone heat pump, which provides auxiliary cooling during the hottest part of summer.

For backup cooling and heating, they consulted with building systems engineer David Butler of Arizona-based Optimal Building Systems. This service is part of Coleman’s design package. Based on information provided on the plans and specifications, as well as phone calls and correspondence with the couple, Butler developed the home’s heating, ventilation, and air-conditioning (HVAC) system specifications. “More often than not, passive solar and other high-performance homes end up with grossly oversized HVAC equipment. This not only undercuts potential energy savings, but can lead to comfort and moisture-related problems,” Butler says.

Butler used Manual J protocol (often called “heat load calculation” or “cooling load calculation”) to estimate how much heating and cooling the home might require. However, based on his experience, the Manual J “significantly overstates” heating loads, even for conventional homes, and ignores internal and solar gains. Knowing that, he says, the numbers are merely a starting point. Given the low electricity rates in the area (about 9.5 cents per kWh), Butler calculated that a ground-source heat pump would be less expensive to operate than most other HVAC options. However, with the home’s small heating and cooling loads, it would have taken the couple many years to recover the system’s high installation costs. Instead, he recommended an electric Mitsubishi Mr. Slim multizone minisplit heat pump, with two ductless wall-mounted units (for loft and living areas) and a small ceiling-mounted ducted air handler for the bedrooms—all supplied by a variable-capacity outdoor unit. The system has a SEER rating of 17.5.

Minisplit systems work like a standard air-source heat pump, with an outdoor condenser/compressor, but without



Courtesy Rita Hennessy (2)

The 2,148-square-foot floor plan includes three bedrooms and two bathrooms on the main level. The home's semidetached garage can be accessed via a workshop space off the laundry and mudroom.

Sean and Rita's dog guards the air-source heat pump's outdoor unit.

the expense or space required for ducts. The systems are more efficient, with fewer conditioning losses than with a conventional furnace. However, without ducts, there was the problem of getting conditioned air to the bedrooms. With each distribution unit costing about \$3,500 installed, it would have been too expensive to put individual wall units in each bedroom. Even the smallest minisplit unit, he says, would have had several times more capacity than a bedroom's peak load need—thus leading to large temperature swings as the unit cycles.

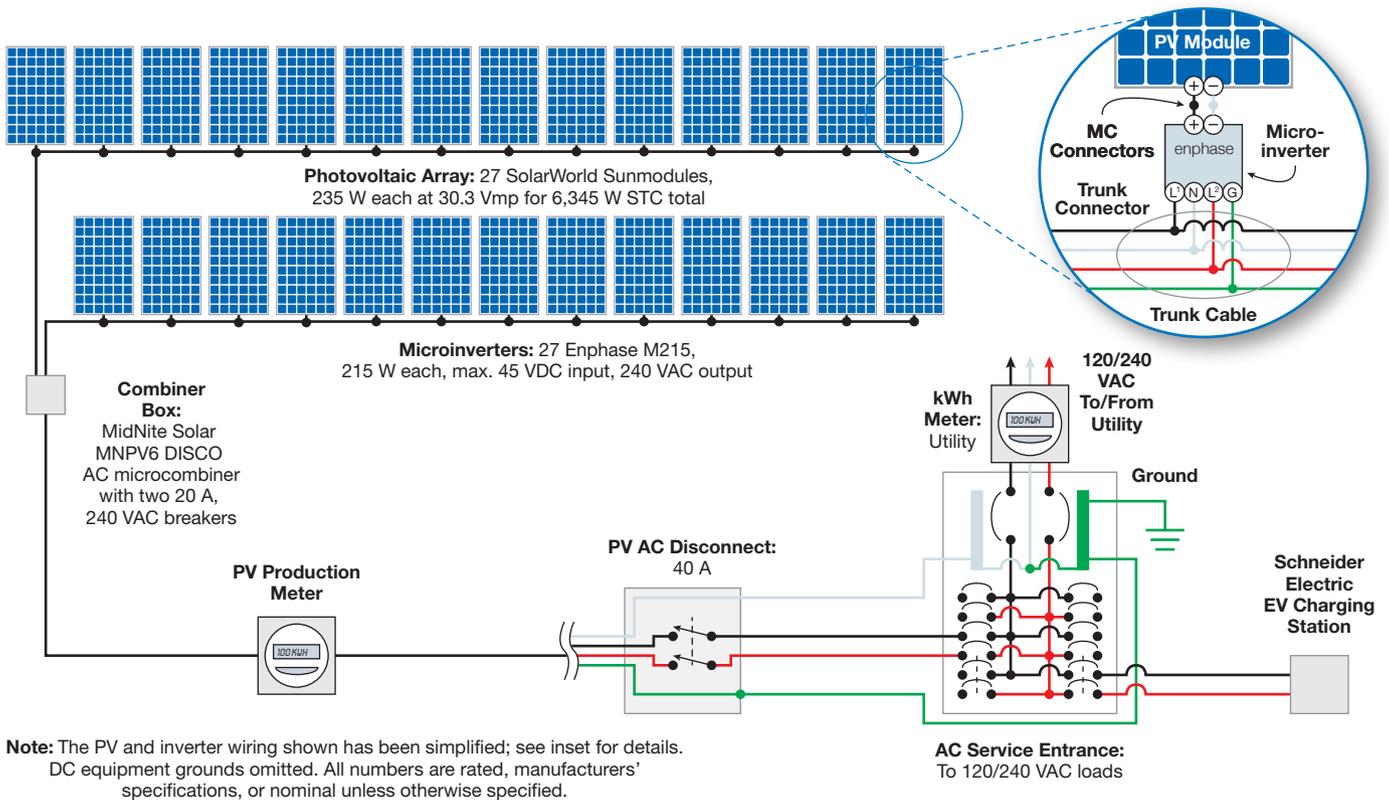
Instead Butler recommended ducted air distribution. The 8-inch-tall Mitsubishi ducted air handler, concealed in the hallway's dropped ceiling, preserves the thermal integrity of the primary ceiling. The duct runs down the hall, feeding the bedrooms, where ducts are routed in the attic above the primary ceilings and buried under 16 inches of blown-in fiberglass insulation.

### Beyond Passive

Hennessy and Palmer were determined to offset any electricity their home used with a batteryless grid-tied PV system. They turned to Mountain View Solar (MTVSolar) in nearby Berkeley Springs, West Virginia.



# Hennessy/Palmer Batteryless Grid-Tied PV System



**Note:** The PV and inverter wiring shown has been simplified; see inset for details. DC equipment grounds omitted. All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

“With a new home, there’s always some guesswork involved in adequately sizing a PV system,” says Pablo del’Aguila, the crew lead/field engineer at MTVSolar. “We used the electricity bill from their old house and then made adjustments based on the new home’s specs. Based on the size of the house and the loads of the more efficient appliances, we came up with a conservative estimate.”

The guesswork paid off. The couple records daily system production data from the Enlighten website. Since its installation in July 2012, the system has produced more electricity than the home has used. Since November 2012, when the couple moved in, the 6.3 kW system has generated an average of 700 kWh per month, while the home consumed an average of 563 kWh per month. Thanks to the excess generation, the couple has never paid an electricity bill for the home. The microinverter-based system allows for module-level monitoring, making any future troubleshooting easier. An additional tie-in point was also added to accommodate system expansion.

With the exception of a propane cooktop and the wood-burning masonry heater, the home features all-electric appliances, including one of Hennessy’s favorite items—a Thermador steam and convection oven, which cooks food more efficiently with steam and reduces baking and roasting

## Tech Specs

### Overview

- System type:** Batteryless, grid-tied solar-electric
- Location:** Shepherdstown, West Virginia
- Solar resource:** 4.6 average daily peak sun-hours
- ASHRAE lowest expected ambient temperature:** -0.4°F
- Average high temperature:** 91.4°F
- Average monthly production:** 700 kWh
- Utility electricity offset annually:** 125%

### Photovoltaic System Components

- Modules:** 27 SolarWorld Sunmodule, SW 235 W STC, 30.3 Vmp, 7.77 A Imp, 37.5 Voc, 8.19 Isc
- Array:** Two microinverter strings—14 module/inverter pairs and 13 module/inverter pairs—or 6,345 W STC total, 240 VAC
- Array combiner box:** MidNite Solar MNPV6-DISCO AC microcombiner with two 20 A breakers
- Array installation:** Iron Ridge XRS Rail mounts installed on roof facing 10° east of south, 33.75° tilt (parallel to roof)
- Microinverters:** 27 Enphase Energy M215, 215 W each, 215 W rated output, 45 VDC maximum input, 16 to 36 VDC MPPT operating range, 240 VAC output

## Mountain State Solar

Although West Virginia leads the nation in underground coal production (coal is found in 53 of West Virginia's 55 counties) and 99% of the state's electricity is derived from coal, the state is a good candidate for solar electricity.

With 4.6 average daily peak sun-hours, West Virginia had an estimated 1.7 MW of PV capacity in 2012.

The 2012 edition of *Freeing the Grid*—a report produced by Interstate Renewable Energy Council and Vote Solar Initiative—grades all states on the effectiveness of their net-metering and interconnection practices in promoting rooftop solar and small-scale renewable energy. West Virginia earned an "A" for net metering, which is available to residential consumers with systems rated up to 25 kW. Net excess generation is credited to a customer's next bill at the retail rate with no annual true-up (perpetual rollover). The state also earned a "B" for interconnection policies.



Matt Hovermale (2)

In addition to powering their home, Rita and Sean's PV system also provides the power for an electric car-charging station. Here, Sean plugs in a friend's EV.

Rita stands in the kitchen, which features a Thermador steam oven and other Energy Star appliances.



time compared to a conventional oven. "We cooked a 14-pound stuffed turkey about half the time (in 2.5 hours), and it was golden-brown and fabulously moist inside," Hennessy says.

The PV system's gross cost was \$34,860, or \$5.50 per watt. After rebates and incentives, the net cost was \$14,402—\$2.28 per watt. The couple benefited from a \$10,458 federal tax credit and \$4,000 state tax incentive (including a state tax credit for the 240-volt car charging station in the garage). The couple currently owns a Prius but does plan to buy a plug-in vehicle in the near future. "The state tax credit for the charging station was so good we couldn't pass it up. It just seemed easier to install one during construction while the walls were opened up rather than to add it later," Hennessy says. "We planned for the future."



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- **Has a fourth charging stage that boosts voltage** (for wet cell batteries) to accomplish more charging during a limited solar day — also recommended by some battery manufacturers.
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- **Without TM-2030** connected works at a more basic level of charging.

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# CHOOSING a Battery-Based PV Inverter

by Zeke Yewdall

The inverter is the heart of a battery-based PV system, converting DC from the batteries into AC for lights and appliances. High-power options, better surge capacity, lower cost per watt, and more bells and whistles are now available.

## Matching the Inverter to the System

There are basically two different system configurations that utilize battery-based inverters: “off-grid” (also referred to as “stand-alone”) and those that have utility power available. Within the two system types are numerous variations. Determining which inverter is appropriate for your system requires answering several questions:

- Is there is access to a supplemental power source, such as the grid or a generator?
- What are the goals for your system? If you’re planning an off-grid system, do you want to minimize generator size? If you are on the grid, do you want to maximize the

solar power that’s exported to the grid? Or do you want to maximize your on-site consumption of energy produced by your system?

There are myriad possibilities. Some inverters are built to serve only one or two system configurations, while others can accommodate several different system types—and selecting how the system functions can be as simple as a quick programming change. The basic battery-based system configurations are discussed below. However, selecting the best inverter for your system requires spending some focused time with inverter cut sheets and manuals, and/or working with an installer who has solid experience with battery-based systems.



## Magnum Energy

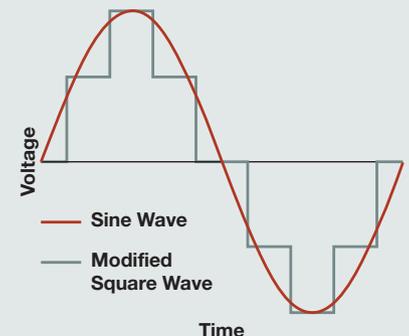
magnumenergy.com



Magnum Energy makes a variety of inverters for off-grid and mobile applications, including options like remote monitoring, battery monitoring, and automatic generator start.

## Waveforms

Years ago, modified square-wave inverters served most loads in off-grid homes, sometimes with a smaller sine-wave inverter to power specific appliances (such as sensitive electronics). But the decreased cost of modern sine-wave inverters with their better efficiency has made modified square-wave, whole-house inverters more rare.



**Off-grid.** As the name suggests, these systems do not have access to utility power. Off-grid homes commonly use a generator for supplemental power for large AC loads or during times of little sun. These systems require an inverter/charger that can operate in off-grid mode *and* can use outside AC input from the generator for charging the battery bank. Several battery-charging inverters have expanded programming options, optimizing the working relationship between the generator and the inverter. As a result, the generator capacity needed can be reduced (see “Generator Support”).

**Grid available.** If there is utility power available, you can design a grid-tied system where excess energy is sold back to the grid, but a battery bank is available for backup (aka “grid-tied with battery backup”). These systems require an inverter that has a grid-interactive mode, but can be configured several different ways. The most common method is to have the inverter operate in parallel with the grid when it is available, and to provide backup power to specific AC loads when the grid goes down. This minimizes battery use, since it only draws from them if the grid is down.

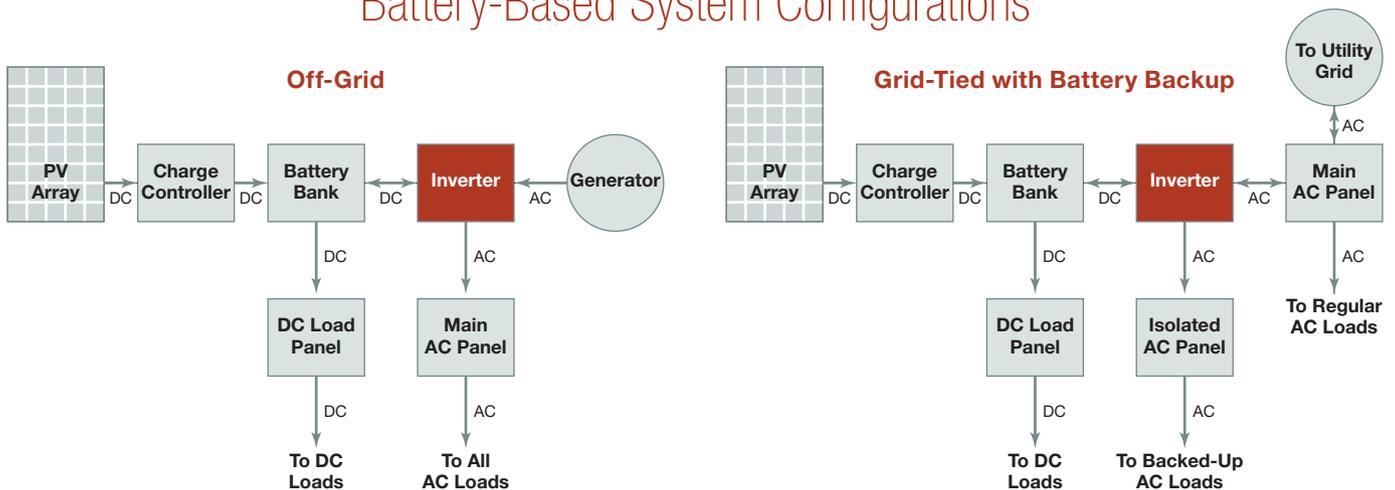
There are also newer options for systems—“grid support” and “grid zero.” These are programming modes for some grid-interactive inverters that allow you to fine-tune how your system interacts with the utility. These options can be useful in areas where rules and incentives for grid-interactive systems have changed, such as not allowing exporting of PV energy to the grid or not allowing net metering, making consuming energy from the on-site solar and battery bank more desirable. Some inverters can also accommodate a second AC power source, such as a generator, to provide another level of backup power.

Alternatively, an inverter/battery system can function as a backup system to the grid (i.e., a UPS system) or can use the grid as a backup power source to a solar/inverter/battery system—without exporting any energy to the grid. These systems require inverters that can accept AC power from the grid for battery charging, but do not have to be listed as “grid-interactive.”

# OutBack Power [outbackpower.com](http://outbackpower.com)



## Battery-Based System Configurations



# Schneider Electric

sesolar.com



Courtesy Schneider Electric (3)

**Schneider Electric has expanded its XW line of grid-interactive inverters and added new advanced grid features and Internet monitoring. Its SW line of off-grid inverters has been expanded as well.**

## Surge Capacity

Inverter surge is a measure of how much power the inverter can put out to start motor loads that may draw much higher than normal power upon startup. Depending on the particular motor, this may take from less than a second to tens of seconds, and may be from 1.5 times to 7 times the motor's normal load. There is no standard in rating inverter surge capacity, so what one inverter reports as "surge" may not directly compare to another one. A "surge duration" is more useful information than a generic "surge" rating with no specs on duration. One way to determine how an inverter handles surge is reflected in its weight—heavier transformer-based inverters can sustain a good surge for much longer (minutes versus seconds) than a lighter-weight high-frequency inverter. This is one large difference between the inverters designed for whole-house use included in this article compared to many RV and consumer-electronics inverters.

## Generator Support

Many off-grid inverters can operate in parallel with a generator, instead of just switching the loads to generator power when the generator comes on. This allows an inverter to "assist" a small generator with large loads. Historically, generators were sized to simultaneously power the largest loads and charge the batteries. Now, with greater inverter capacity, the inverter may be sized to serve the largest loads, with a small generator sized to handle only battery charging. The inverters that can operate in parallel with a generator (often called "generator support") can help a smaller generator start a large load like a well pump or table saw by briefly drawing power from the batteries.

## Off-Grid Inverter Capacity & Large Loads

What used to be considered a sizable off-grid whole-house inverter 20 years ago (1,500 W continuous output power) is now considered a small inverter that would be suitable to serve cabin or RV loads. Today, inverter capacity of 4,000 to 8,000 W is common for residential-scale off-grid PV systems, and many of them can be stacked to provide 24,000 W or more. But just because higher-power inverters are available doesn't mean that all high-power loads are appropriate for an off-grid home that relies solely on a PV system.

For example, electric heating loads should still be avoided. In this case, it is the runtime, or total energy use in kWh that we are concerned with. While a 6 kW inverter could power an electric water heater or some

electric baseboard heaters, running those types of loads requires a larger PV array and battery bank. This strategy is generally not cost-effective. For example, a standard electric water heater would draw 10 to 20 kWh per day, requiring \$15,000 to \$20,000 of extra PV array and battery storage capacity. A \$10,000 solar water heating system would probably be a better investment. Well pumps, which used to be the killer load for off-grid inverters, are no longer as hard on systems as they used to be. Much larger inverters are available that have better surge capacities than 12- and 24-volt ones (though not always). While this does mean that a 3/4 or 1 hp well pump is now operable without the help of a generator, you should still use the smallest well pump possible, since it will put less stress on the batteries and use fewer kWh per gallon of water.

## AC Coupling?

Battery-based systems can be arranged in two different ways—they can be “DC-coupled” (most common) or “AC-coupled.” While this article focuses on systems that are DC-coupled, many of these inverters can be utilized in AC-coupled systems. See “Methods” in this issue for information on inverters and AC-coupling.

using a single 4,000 W 120/240 VAC inverter to power it, rather than two 3,600 W 120 VAC inverters. On the flipside, these split-phase inverters won't put out full power on a single leg—they are usually limited to about 67% or 75% of full power on a single leg. So if you have a very large 120 VAC load, a single 120 VAC inverter may be better than a split-phase inverter of the same rating. For example, a 4,000 W, 120 VAC load could not be powered by a 4,000 W, split-phase inverter.

- If you need 240 VAC and the combined power of two inverters, there are two options. One is to use two 120 VAC inverters stacked in series, and the other is to use two 120/240 VAC inverters stacked in parallel. Using two 120/240 VAC inverters gives redundancy—if one fails, you can still get 240 VAC from the other inverter. This method can also be more efficient, because, for small wattage loads, only one inverter needs to be on. Sometimes the choice depends on the model. Some, notably SMA America's Sunny Island series and OutBack Power's line of FX inverters, only come in 120 VAC, so you will be selecting one inverter per phase when using multiple inverters.

## Beware: Multiwire Branch Circuits

In off-grid systems, a 120 VAC inverter commonly provides power to equipment that is designed for connection to 120/240 VAC, split-phase utility power. This is accomplished by using a jumper to connect both busbars in the service equipment to the same single 120 VAC phase from the inverter. However, to reduce wire expense, multiwire branch circuits—in which a single neutral conductor is used with two “hot” conductors on separate phases—are commonly installed in new construction. With split-phase 120/240 VAC, the neutral conductor never carries the sum of the current from the two circuits, since they are out of phase with each other. However, if the two hot conductors are on the same phase—for example, being supplied by a single 120 VAC inverter—then the currents will be additive on the neutral conductor, possibly overloading it. Allowing standard wiring of the house is one reason for the popularity of the new inverters that provide 120/240 split-phase.



**SMA America's Sunny Island inverters are optimized to work in AC-coupled systems with its grid-tied inverters. System monitoring can now be accomplished via a smartphone.**

## AC Output Needs

Some inverters provide only 120 VAC output; if your off-grid house (or the critical loads subpanel in your battery backup system) requires 240 volts, a second inverter is added to provide the other phase. Instead of adding a second inverter, an external step-up transformer can be used to get 240 VAC from a 120 VAC inverter. The efficiency is reduced, but the cost may be quite a bit lower than adding a second inverter. Some inverters come with 120/240 VAC split-phase output. Which is best depends on your situation.

If you have no 240 VAC loads, you can use a single 120 VAC inverter to energize both 120 VAC legs of your load panel (see the “Beware: Multiwire Branch Circuits” sidebar). If you have an appliance that requires 240 VAC, such as an existing well pump, you have a couple of choices:

- If you need 240 VAC, but don't need the combined power of two inverters, then it can make sense to get a single 120/240 VAC split-phase inverter. For example, if you have a 1 hp deep well pump that draws 2,000 W with a 7,000 W surge at 240 VAC, you could save money by

Manufacturer	Model	Continuous Power (W)	Surge Watts						
			3 Sec.	@ 5 Sec.	@ 10 Sec.	@ 30 Sec.	@ 1 Min.	@ 30 Min.	
<b>Magnum Energy</b> magnumenergy.com	MS2012	2,000	N/A	3,300	N/A	3,100	N/A	2,200	
	MS2812	2,800		3,900		3,800		3,000	
	MS4024PAE	4,000		5,800		5,200		4,500	
	MSH4024RE					5,400			
	MS4024					5,400			
	MS4448PAE	4,400		8,500		6,000		4,800	
<b>OutBack Power</b> outbackpower.com	GFX1312	1,300	N/A	2,900	N/A	N/A	N/A	1,800	
	GFX1424	1,400		2,900				2,000	
	GFX1548	1,500		2,900				2,500	
	FX2012T	2,000		4,000				3,100	
	OBXIC2024S <sup>3</sup>			4,800					
	GTFX2524	2,500		4,800				3,200	
	FX2524T			4,000					
	VFX2812	2,800		4,000					
	GTFX3048	3,000		4,800					
	FX3048T			4,800					
	GVFX3524	3,500		5,000					4,000
	VFX3524			5,000					
	OBXIC3524P <sup>3</sup>			5,000					
	GVFX3648	3,600		5,000					
	VFX3648			5,000					
	Radian GS4048A <sup>2</sup>	4,000		6,000				4,500	
Radian GS8048A <sup>2</sup>	8,000	12,000	9,000						
<b>Schneider Electric</b> sesolar.com	Conext SW 2524	2,400	N/A	4,000	N/A	N/A	N/A	2,700	
	Conext SW 4024	3,400		7,000				4,000	
	Conext XW4024	4,000		8,000				N/A	
	Conext XW4548	4,500		N/A	9,000			7,000	
	XW+5548 NA <sup>2</sup>	5,500			N/A			N/A	
	Conext XW6048	6,000			12,000			N/A	
	XW+6848 NA <sup>2</sup>	6,800			N/A			8,500	
<b>SMA America</b> sma-america.com	SI4548 <sup>1</sup>	4,500	11,000	N/A	N/A	N/A	8,400	5,300	
	SI6048 <sup>1</sup>	5,750						7,000	

<sup>1</sup>Advanced AC-coupling controls with Sunny Boy inverters; <sup>2</sup>Advanced battery charging option for lithium-ion batteries; self-consumption/grid-zero; <sup>3</sup>Rugged, outdoor; <sup>4</sup>From SunWise dealer price list—actual costs may vary significantly

A 120/240 VAC inverter is often selected for a battery-backup grid-tied system because it's cheaper and easier to install. The amperage of the tie-in is half as much at 240 V compared to the tie-in at 120 V. This means you can fit twice as much PV power on a given service size following NEC 705.12(D), which commonly limits the size of the solar input to 20% of the busbar amperage.

## Balance of System

Remember that an inverter is only one part of the system—many people focus on selecting and buying the inverter, and then face the challenge of

## UL1741 vs. UL458

Inverters—both batteryless and battery-based—used in residential-scale RE systems must be listed to UL1741, as required by the *National Electrical Code*. Inverters listed to UL458 are designed for mobile use—for example, on boats and RVs, which are sometimes off-grid and sometimes connected to a power grid (for battery charging and to supply supplemental energy for AC loads, but not for selling energy back to the grid).

The two UL standards differ in how they handle AC system grounding: UL1741-listed inverters must allow for the neutral-to-ground bond to *only* occur at the main AC service panel. UL458-listed inverters have internal neutral-to-ground switching relays to allow for this bond to occur at the inverter if in off-grid mode, OR at the utility power service if it is connected to a utility hookup. Some inverters are listed under both standards, so you'll need to read the installation instructions carefully. Many Internet sources market off-grid inverters as "UL-listed," but don't clarify the actual listing, so they may not be appropriate for residential use.

DC Input (V)	AC Output (V)	MSRP <sup>4</sup>	Utility-Interactive (Grid-Tied)	Off-Grid (Can Accept Generator Input)	Battery Charger (A)	AC Coupling	Remote Display Required		
12	120	\$2,149	No	Yes	100	No	Yes		
		2,479			125				
24	120/240	2,699			105	110		Yes	
	120	2,899						No	
48	120/240	2,599			60	Yes		105	
		2,699						Yes	
12	120	1,399	Yes	No	70	No	Yes		
24					40				
48					20				
12		2,369	No	Yes	80				
					55				
24		2,369	Yes	No	55				
		2,369	No	Yes	55				
12		2,569	Yes	No	125				
48		2,369			35				
24		2,569	No	Yes	35				
					85				
					82				
					85				
48		2,569	Yes	No	45				
					45				
120/240		3,995	Yes	Yes	58			Yes	
		6,495			115				
24		120/240	1,750	No	Yes			65	No
	2,050		90						
	3,950		150						
48	N/A		Yes	Yes		85	Yes		
						4,500		110	
						N/A		100	
48	120	5,250	Yes	Yes	85	Yes <sup>1</sup>	No		
		5,690			110				

Below: Several manufacturers produce balance-of-system components that integrate gracefully with their inverters to make installation clean and easy. OutBack Power's FLEXware (shown here) includes metering, AC and DC overcurrent protection and disconnects, and charge controllers.

Right: Third-party manufacturers like MidNite Solar also produce packaged balance-of-system components designed to integrate with the major inverter brands.



Courtesy OutBack Power



Courtesy MidNite Solar

### web extras

“Grid-Tied...with Backup!” by Flint Richter in *HP139* • [homepower.com/139.60](http://homepower.com/139.60)

“Sizing a Grid-Tied PV System...with Battery Backup” by Flint Richter in *HP139* • [homepower.com/139.66](http://homepower.com/139.66)

“Battery Based Inverters: Using AC Power Sources & Other Tips” by James Goodnight in *HP137* • [homepower.com/137.92](http://homepower.com/137.92)



integrating it with rest of the equipment. Magnum Energy, OutBack Power, and Schneider Electric offer wiring solutions (aka “power centers” or “power panels”) for use with their inverters, simplify the wiring considerably. There are also third-party options, such as MidNite Solar’s E-Panel, which provide complete *Code*-compliant wiring systems

to simplify an inverter’s installation. Most inverters from Magnum Energy, OutBack Power, and Schneider Electric require a separate system control panel for programming and monitoring. There are no controls or displays on the inverter itself. This can be good when the inverter is located in a utility room, but, for example, you also want an inverter control/monitor in the living room. This functionality comes at an extra cost—between \$150 and \$400 depending on the model.

Many of the advanced functions, such as automatic generator-start, are part of the system control panel, not the inverter firmware—without the control panel, you may be limited to just turning the inverter on and off, and not be able to adjust the settings.

Many battery-based inverters can connect to a computer for remote monitoring, control, and data logging. Some allow users to remotely monitor the inverter’s operation via the Web. This usually requires an extra communications box (which may or may not be the same as the remote system control panel).



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# MPPT Charge Controllers

by Zeke Yewdall

In a battery-based PV system, a charge controller is used between the PV array and the battery bank to monitor battery voltage, optimize charging, and keep the array from overcharging the batteries.

There are a few common types of charge controllers: single or two-stage (shunt or relay type); pulse-width modulated (PWM); and maximum power-point tracking (MPPT). While non-MPPT charge controllers are less expensive and still have their place in the battery-based PV market—especially for lighting and small developing-world systems—just about all modern home- and cabin-scale PV systems include an MPPT charge controller, as they offer several advantages.

## MPPT Advantages

**More watts.** Recall the power equation—volts × amps = watts. The more voltage captured from an array, the more power (watts) can be sent to the battery bank. An MPPT charge controller keeps the array operating at the peak of the current-voltage curve, and converts array voltage above battery voltage into extra amperage, thus absorbing more

watts from the array. A non-MPPT charge controller chains the array's voltage to the battery's voltage, effectively limiting the array's power output.

Array voltage varies with cell temperature. For example, when the cells are cold during winter, yet receiving full sun, the array voltage is higher. Higher array voltage translates into greater wattage. Here's an example: Considering average winter and summer temperatures in Boulder, Colorado, there would be about a 12% difference between average winter versus summer array power output, and up to a 25% difference on a cold winter day versus a hot summer day. For off-grid systems that have higher loads in the winter, the extra energy input offered by MPPT-based systems can be a big benefit. At higher temperatures, which usually occur in the summertime or year-round in mild climates, array voltage drops, and an MPPT controller may be less advantageous.

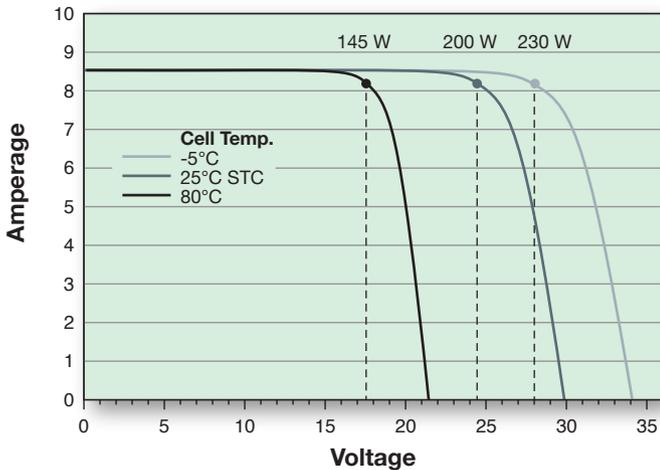


[blueskyenergyinc.com](http://blueskyenergyinc.com)



Blue Sky Energy makes a variety of MPPT charge controllers for small PV systems, including the 2512i-HV and 3000i, which are designed for use with 60-cell modules with 12-volt battery systems.

Maximum Power Point & Cell Temperature



**Step-down.** Voltage conversion is another benefit that is built into MPPT charge controllers. An MPPT charge controller is a DC-DC converter—with computerized controls. It can take a higher voltage and lower amperage, and convert those to a lower output voltage at higher amperage. For example, instead of an array producing a nominal 24 V and charging a 24 V battery, an MPPT controller can step-down an array producing 60 V to charge that battery. This frees the array from having to be matched to the battery voltage, and mitigates some wire-sizing (and cost) issues.

In that example, pushing 30 A at 24 V a distance of 40 feet would require large-gauge (expensive) cable—2 AWG—to keep voltage drop under 2%. For the same amount of power, pushing 12 A at 60 V that same 40 feet with 10 AWG will keep voltage drop under 2%, with the MPPT charge controller stepping the output voltage down to 24 V for the batteries. THHN #2 wire retails for about \$1.24 per foot, and #10 sells for about \$0.19 per foot, saving \$84.00 on that two-way wire run, even without considering conduit size and the physical difficulties of pulling large wire.

**Temperature Compensation**

The internal resistance of a battery fluctuates with battery temperature, so charge controllers are most effective if they adjust their charge-termination (voltage) setpoints to accommodate this changing internal resistance. Understanding how temperature compensation works requires Ohm's law:

**Voltage (V) = Current (I) x Resistance (R)**

When a battery is cold, its internal resistance increases, which causes the voltage to rise (assuming a constant current). Charge controllers use voltage to determine the shutdown point when the battery is full. Without temperature compensation, a false high-voltage reading would shut down charging too soon, resulting in an undercharged battery. Conversely, high temperatures cause a battery's internal resistance to drop. This causes a false low-voltage reading, and thus charging gets terminated too late, causing the battery to be overcharged.

Temperature compensation allows a charge controller to increase the charge-termination setpoint for a cold battery and decrease this setpoint for a warm battery—resulting in an appropriate charging regimen. A battery temperature sensor, which provides a charge controller with a more accurate temperature value to use for charging adjustment, can be attached to the battery's side (see "Battery Assessment" in *HP159* for more information).

**MIDNITE SOLAR**

midnitesolar.com

MidNite Solar's Classic line of controllers (far right) includes ground-fault and arc-fault protection, high-voltage input, advanced data logging, battery monitoring, and a computer interface. The KID controller (right) is for use with small PV systems.



## Higher Input Voltages

Until recently, most charge controllers could accept a maximum input voltage of only 150 V. Today, one manufacturer has models that accept 200 or 250 V input, and two have models that accept up to 600 V input. Having these options provides more flexibility in designing module strings for battery-based systems. For example, instead of designing strings of three modules in series, strings of six modules in series are possible. This reduces the number of strings needed by half. At half the amperage and twice the voltage, the same size wire can be used, but at four times the distance—without losing power. A 600 V charge controller may be able to accommodate a single series string of 12 modules, negating combiner boxes completely. This translates into less equipment, wire expense, and labor.

The 600 V charge controllers may be used for transforming batteryless grid-tied PV arrays to grid-tied with battery backup. In many cases, rewiring the array is unnecessary.

A disadvantage to using a controller with a higher input voltage is that the disconnects and combiner boxes (if required) are typically more expensive and harder to find. Note that one of the 600 V input charge controllers (Morningstar's TS-MPPT-60-600) has an optional integrated DC disconnect, which can help mitigate sourcing and finding space on the wall for an external 600 V DC disconnect, though the controller's additional cost is similar to the cost of a separate DC disconnect.

## Integrated GFP & AFP

Ground-fault protection (GFP) and arc-fault protection (AFP) are two other features that may be included in a charge controller—potentially saving the cost of a separate unit to meet *National Electrical Code* Article 690.5 and 690.11 requirements.

## Single-Module PV Systems

Most module manufacturers have switched to a 60-cell design, resulting in modules in the 200 W to 300 W range with a maximum power point of 25 to 35 V. Nominal 12 V and 24 V modules (having 36 and 72 cells, respectively) are harder to find and more expensive per watt. Several manufacturers have introduced MPPT charge controllers to accommodate a single 60-cell module on a 12 V battery system (which might power, for example, remote lighting or communications, or an off-grid cabin). Blue Sky Energy offers several products for 12 V systems, and MidNite Solar and Morningstar have introduced smaller (30 A) MPPT controllers, which will work for a single module on a 12 V system.

These charge controllers cost more than a simple PWM charge controller that you might use on a system with 36-cell (12 V nominal) modules. However, when you take into account

## MORNINGSTAR

[morningstarcorp.com](http://morningstarcorp.com)

Morningstar offers a range of charge controllers, from its SunSaver MPPT for small systems to its TriStar MPPT 600 V, which can accept a high-voltage PV array or can be used with an existing grid-tied PV array converted to battery backup, without requiring array reconfiguration.



Courtesy: Morningstar (2)

## Programming Charge Controllers

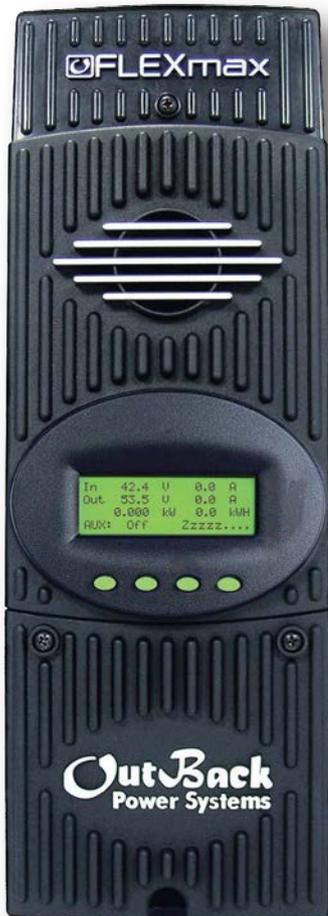
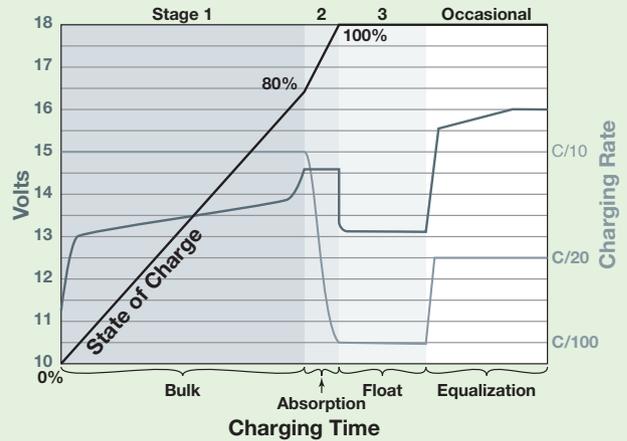
Programming some simple charge controllers is limited to selecting battery type, but other charge controllers offer a dizzying array of options—absorb voltage, float voltage, absorb time, float time, and equalization voltage, to name a few. Many complex charge controllers also come with detailed instructions on settings for specific battery types, and can accommodate less-common battery types, such as nickel iron or lithium ion, automatically setting most of these parameters once the battery type is selected. (Many also allow you to customize these parameters.)

Battery manufacturers may also provide specifications on setpoints for their batteries. However, if these batteries are not marketed as “solar” batteries, be aware that their recommended setpoints may not be correct for solar charging. A PV system charge current varies with how much sun is available, and the system may alternate between charging and discharging several times in a single day. This is much different than the uniform charge a grid-powered charger provides. Seasoned installers might even use slightly different settings with exactly the same array, charge controller, and batteries, depending on whether the system provided electricity for a weekend cabin or a full-time residence.

The most important basic features in a charge controller are separate absorb and float settings, which will effectively act to curb water use in flooded batteries. Ability to set equalization charges is also handy—with a large-enough solar array, batteries

can often be equalized with only the array, not a generator. For batteries in unconditioned spaces, a remote temperature sensor is important, especially for sealed batteries, which are more sensitive to overcharging in high temperatures and can be subject to thermal runaway if a temperature-compensated charge controller is not used.

### Typical Charge Regime



## OUTBACK POWER

outbackpower.com



OutBack Power makes several MPPT charge controllers, including the 80-amp FLEXmax 80 (left) and the outdoor-rated FLEXmax Extreme (right).

Courtesy: OutBack Power (2)

Manufacturer	Model	Battery Voltage	Max. Voc	Max. Output (A)	Max. Watts <sup>1</sup>			Digital Display
					12 V	24 V	48 V	
<b>BLUE SKY ENERGY</b>	Solar Boost 3000i <sup>3</sup>	12	50	30 (22 / 60-cell)	290/400	N/A	N/A	Included (on DiI); optional (on iL)
	Solar Boost 2512i-HV <sup>3</sup>			25 (20 / 60-cell)	270/340			
	Solar Boost 2512iX-HV <sup>3</sup>			270/340				
	Solar Boost 1524iX	12, 24	57	20 (15 at 24 V)	250	370	800	
	Solar Boost 3024iL, 3024DiL, Duo	12, 24		30 (40 at 12 V)	540	800		
Solar Boost 3048	24, 48	140	30	N/A		1,560		
<b>MIDNITE SOLAR</b>	MNKID-B or -MNKID-W <sup>3</sup>	12, 24, 48	162	30	400	800	1,600	Included
	Classic 150	12, 24, 36, 48, 72	150 <sup>2</sup>	96	1,200	2,400	4,800	
	Classic 200		200 <sup>2</sup>	79	1,000	2,000	4,000	
	Classic 250		250 <sup>2</sup>	63	800	1,600	3,200	
	Classic Lite 150		150 <sup>2</sup>	96	1,200	2,400	4,800	Optional
	Classic Lite 200	200 <sup>2</sup>	79	1,000	2,000	4,000		
	Classic Lite 250	250 <sup>2</sup>	63	800	1,600	3,200		
<b>MORNINGSTAR</b>	TriStar TS-MPPT-60	12, 24, 36, 48	150	60	800	1,600	3,200	Optional
	TriStar TS-MPPT-45		150	45	600	1,200	2,400	
	TriStar TS-MPPT-30 <sup>3</sup>		150	30	400	800	1,600	
	SunSaver SS-MPPT-15L	12, 24	75	15	200	400	N/A	
	TS-MPPT-60-600	48	600	60	N/A	N/A	3,200	
	TS-MPPT-60-600-DB	48	600	60	N/A	N/A	3,200	
<b>OUTBACK POWER</b>	FLEXmax 60	12, 24, 36, 48, 60	150	60	750	1,500	3,000	Included
	FLEXmax 80			80	1,000	2,000	4,000	
	FLEXmax Extreme							
<b>SCHNEIDER ELECTRIC</b>	XW-MPPT-60-150	12, 24, 36, 48, 60	150	60	800	1,600	3,200	Included
	MPPT 80 600	24, 48	600	80	N/A	2,560	4,800	Optional

<sup>1</sup>Manufacturer recommendation; may clip under full sun conditions; <sup>2</sup>Plus battery voltage; <sup>3</sup>Suitable for use with a 60-cell module and 12 V batteries;

the total system cost—PV module(s) plus charge controller—it can be 10% to 20% less expensive to use the 60-cell module with the MPPT charge controller. Plus, you get the advantage of MPPT. In addition, the wiring of the system often is simpler, since it involves one large module and no combiner boxes.

## Matching Controllers to Inverters

For off-grid systems, matching the brand of charge controller to the inverter isn't usually important, since there is very little coordination between these two. The charge controller routes energy into the battery, and the inverter takes it out—neither of them really cares what the other is doing. However, for a grid-tied system, synchronizing them can matter. While there are thousands of battery-based grid-tied systems that operate without communications between the charge controller and inverter, system programming can be simplified and efficiency can be improved if they are matched. Compatible communications systems enable the inverter to tell the charge controller that the grid is available. At this point, the charge controller's job is not to regulate battery charge but to track the array's MPP and get the most energy out of the array that it can. (The inverter will regulate the battery voltage by selling excess energy to the grid.)

Many charge controllers have the option for a remote display, such as this one from Blue Sky Energy, enabling users to monitor their systems more easily.



Courtesy Blue Sky Energy

Indoor/ Outdoor	Computer Monitoring	Data Logging	MSRP <sup>4</sup>	Charging	Aux. Relays	Remote Temp. Sensor	Max. Temp @ Full Power	Cooling	Ground- Fault Protection	Arc-Fault Protection	
Indoor	Optional <sup>5</sup>	No	\$319	3-stage + eq.	20 A lighting or LVD or 2 A 2nd battery charger	Optional	45°C	Passive	—	—	
			\$213	3-stage	25 A lighting or LVD or 2 A 2nd battery charger						
			\$254	3-stage + eq.							
			\$299		15/20 A LVD or a 2 A 2nd battery charger						
			\$399		20 A LVD, or a 2 A 2nd battery charger						
			\$569								
Indoor	Yes	Yes	\$399	3-stage + eq.	Lighting or LVD	Optional	40°C	Passive	Optional	—	
			\$850		Yes	Included		40°C		Fan	—
			\$850								
			\$950								
			\$700								
			\$700								
			\$800								
Indoor	Yes	Yes	\$689	3-stage + eq.	Optional	Included	45°C	Passive	Optional	—	
			\$547								
			\$445								
		Yes (with company Web connection)	\$286		Lighting control 15 A	Optional	60°C				
			Yes		\$1,689	Optional	Included	45°C			
					\$1,985						
Indoor	Optional <sup>5</sup>	Yes	\$749	3-stage + eq. + silent	Yes	Included	40°C	Fan	—	—	
Outdoor			\$849								
			\$1,049								
Indoor	Optional <sup>5</sup>	Yes	\$685	3-stage	Yes	Included	45°C	Passive	Yes	—	
			\$1,599		No			Fan			

<sup>4</sup>From manufacturers' dealer price lists (Blue Sky Energy; MidNite Solar) and SunWise dealer price list—actual prices may vary significantly;

<sup>5</sup>Extra equipment, such as a remote display or system controller, is required to connect

## Monitoring & Data Logging

All but the most basic charge controllers come with some system monitoring. All of the charge controllers included offer remote display options, enabling you to monitor the system's operation in the house, for example, rather than at the controller's location. Most of the MPPT charge controllers include a digital display on the controller as well. If your system has multiple charge controllers (from the same manufacturer), they can communicate with each other to coordinate charging, and can all send data to a single remote monitor.

MidNite Solar offers an amp-hour-counting state-of-charge meter with their Classic charge controllers, and as an option on its smaller KID controllers. Battery state-of-charge (SOC) metering, which shows battery SOC as a percentage, is an important tool that enables users to easily see how full (or empty) their batteries are. But it is often left out of systems because it comes at an extra cost.

Data logging can be another important feature, especially with systems that are not monitored daily. The larger MidNite Solar, Morningstar, OutBack Power, and Schneider Electric charge controllers include data logging, so you can see how



Many charge controllers come with computer connection capabilities to help users monitor their systems' operation. These screen shots show MidNite Solar's simple computer/smartphone monitoring.



Courtesy MidNite Solar (2)



Courtesy Schneider Electric (2)



Schneider Electric makes a 150-volt MPPT controller for use with its battery-based inverters. Its high-voltage MPPT controller, which can accept 600 volts, can be used with longer wire runs or for converting existing grid-tied arrays to battery backup without array reconfiguration.

## SCHNEIDER ELECTRIC

sesolar.com

many kWh the system produced over a period of time. Having access to this data can be useful for installers when troubleshooting a system.

MidNite Solar, OutBack Power, and Schneider Electric's charge controllers can be connected to a computer or smartphone (directly for MidNite Solar, and through an extra communications device for OutBack Power and Schneider Electric charge controllers) for monitoring, programming, and accessing historical data.



### web extras

Need to brush up on your RE terms? Check out *Home Power's* online glossary at [homepower.com/glossary](http://homepower.com/glossary)

"Charge Controller Buyer's Guide" by Dan Fink in *HP146* • [homepower.com/146.106](http://homepower.com/146.106)

"PV Systems Simplified" by Justine Sanchez & Ian Woofenden in *HP144* • [homepower.com/144.70](http://homepower.com/144.70)



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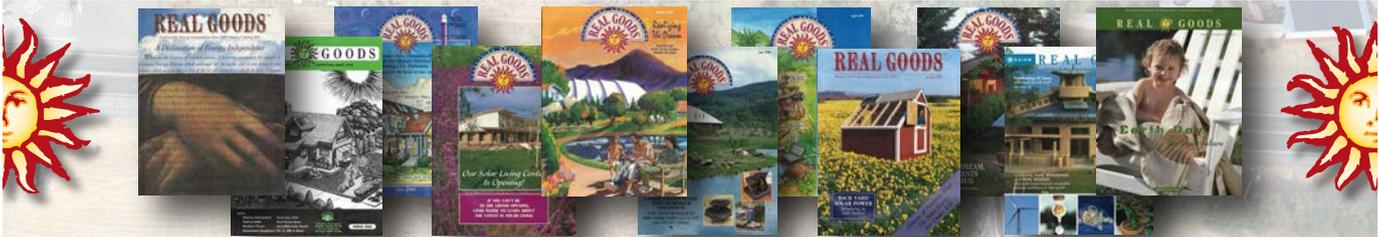


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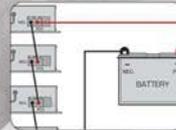
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Courtesy Amtrol



# Protecting Water Heating Systems with Expansion Tanks

by Vaughan Woodruff

**W**ater expands when it is heated and it is nearly incompressible. These two properties can create a powerful force in a water heater. The water in a standard 80-gallon solar storage tank may expand by as much as 2.5 gallons as it is heated, and this thermal expansion will cause a significant increase in the pressure in the plumbing system unless the extra fluid volume is accommodated. In a now-infamous episode of “Mythbusters,” a residential electric water heater was turned into a rocket by disabling its high-limit thermostat and temperature and pressure (T&P) relief valve.

In some homes, this thermal expansion is absorbed by pushing pressure back to the public water supply. But in homes where check valves are required to either maintain the water pressure from a well pump or to protect the public water supply from possible contamination, a device is needed to absorb this expansion. For some water systems, like those that are supplied from a well, the pressure tank often serves this purpose. For homes that have a check valve installed at the public water supply, a potable water expansion tank (aka xtank) is required.

A potable water expansion tank is typically a 2- to 5-gallon steel tank containing a flexible membrane (either a bladder-type or diaphragm-type) that divides the tank. One side of the tank, connected to the pipes of the hot water system, contains water. The other side contains air. The membrane in a bladder-type expansion tank resembles a balloon, while the membrane in a diaphragm-type tank

is sealed to the wall of the tank. Since the potable water in a diaphragm-type tank could otherwise be in contact with the steel tank, a liner made from a material such as polypropylene is required to resist corrosion.

Air is compressible and, as the volume of water in the storage tank expands, the volume of air in the expansion tank will decrease. This leads to increases in the air pressure and—as a result—increases the potable water pressure. That’s where proper selection and proper sizing of the expansion tank come into play. If the expansion tank is undersized and cannot absorb the additional pressure, the potable water pressure may exceed allowable limits and activate the storage tank’s T&P (aka relief) valve. This is a problem since the relief valve is a safety device; constant operation of the valve can lead to its failure, and to potentially dangerous consequences.

Selecting an expansion tank for an SWH system is similar to selecting one for a conventional water heating application, but with two distinct exceptions: SWH storage tanks tend to be larger than conventional water heaters and the maximum temperatures in a SWH tank may be 50°F to 60°F higher. This can translate into thermal expansion that is four to 10 times greater than the expansion in a conventional water heater. This needs to be considered when sizing the expansion tank, along with the system’s normal operating temperatures, standard water pressure, and the water heater’s volume. Expansion tank manufacturers typically provide sizing charts that account for these variables.

## Solar Expansion Tanks for Closed-Loop SWH Systems

In closed-loop antifreeze-based (aka glycol) SWH systems, solar expansion tanks (aka solar xtanks) are required to absorb the expansion of fluid in the solar loop. The solar collectors, piping, and heat exchanger are filled with a glycol solution that—like water—expands as it is heated. Though the volume of glycol in the solar loop is far less than the volume of water in a solar storage tank, solar expansion tanks tend to be the same size or larger than the expansion tanks used on the system's potable water side to handle the normal expansion of fluid and steam expansion, which can occur if a system stagnates.

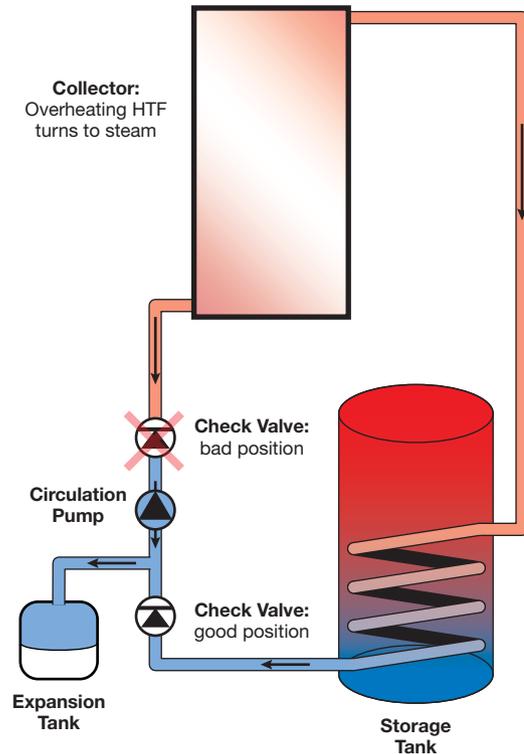
Stagnation occurs when there is sufficient solar radiation available but the heat-transfer fluid is not flowing through the collectors. This can occur when a component fails, such as a controller or a pump; or during a power outage, since the circulator pump will no longer have power; or under standard operating conditions, when the system has heated the water to the storage tank's maximum temperature limit and the controller shuts off the pump to prevent overheating of that tank. All antifreeze-based systems must consider stagnation in their designs.

**A solar expansion tank (solar xtank; circled) is a critical component of a solar water heating system. The solar xtank pictured is sized to maintain system pressure during stagnation.**



Vaughan Woodruff

## Check-Valve Position

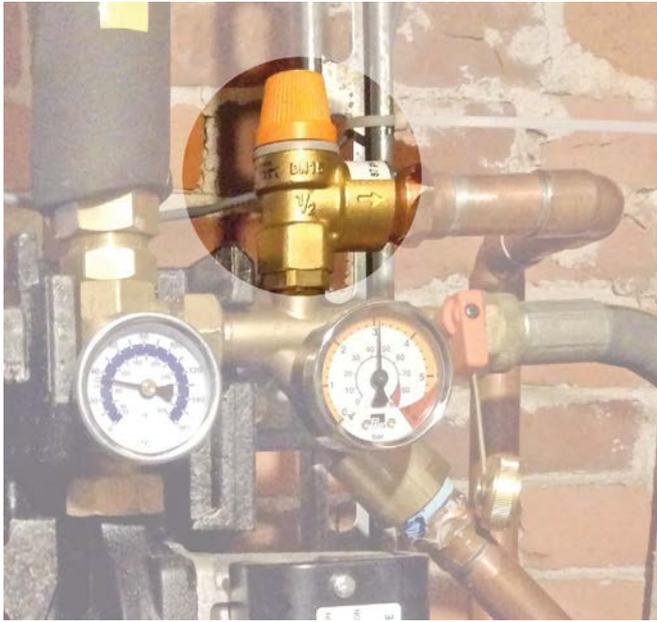


**When steam forms in the collector during stagnation, it is critical that the fluid forced out of the collectors can exit both the collector outlet and inlet. If the check valve is in the wrong location, more liquid will be forced into the collector and more steam created.**

When stagnation occurs, the fluid temperature in flat-plate collectors can reach temperatures of roughly 350°F. In evacuated-tube collectors, the fluid temperature can exceed 400°F. In most antifreeze systems, these temperatures will cause steam to form in the collector array. When water turns to steam, its volume increases by a factor of 1,700. As a result, a teaspoon of water that turns to steam will force out the total fluid volume of two standard-sized flat plate collectors.

This fluid must go somewhere, otherwise the system pressure will increase and the pressure-relief valve will open, releasing fluid from the system. If this occurs, glycol will need to be added to the system and the system will need to be repressurized to ensure proper operation. But an appropriately sized and properly located solar expansion tank can maintain system pressures and avoid activating the relief valve.

**Solar expansion tank location.** To handle stagnation, the expansion tank must be placed where it can prevent the expelled fluid from pushing more fluid into the collectors and generating more steam. By locating the solar expansion tank between the check valve and the collector inlet, glycol can be pushed out of the collector inlet and outlet to the solar expansion tank, and the steam will remain at the top of the system. If the check valve is located between the expansion tank and the collector inlet, the fluid is only able to exit the



Vaughan Woodruff

**Manufacturers use a variety of pressure-relief valves for their pump stations. The rating for the valve (circled) in this PAW pump station is 87 psi.**

collector array through the collector outlet, which then forces more fluid into the collectors.

It is also important to install the solar expansion tank where its bladder will be protected from exposure to steam. The bladders of solar expansion tanks are typically rated for maximum temperatures of 200°F to 210°F and can fail if exposed to higher temperatures. If the piping between the solar expansion tank and the collectors is short, then a prevessel (aka cooling vessel)—a small tank installed on the piping stem leading to the solar expansion tank—may be required. The prevessel holds enough room-temperature glycol solution to offset that which would be forced into the solar expansion tank if steam forms in the collectors, and protects the solar expansion tank from excessive temperatures. But for most domestic SWH systems, 50 feet of 3/4-inch piping will contain enough fluid to avoid needing a prevessel.

If the solar expansion tank is able to maintain adequate system pressures during a steam event, the system should return to normal once the temperature in the collector decreases and the steam condenses back into liquid. Using a high-temperature propylene glycol will help prevent the heat-transfer fluid from degrading.

**Solar expansion tank sizing.** By sizing the solar expansion tank to accommodate steam formation in the system, some system designers are able to eliminate the need for any type of heat dump or other overheating protection. Thus, taking some time to familiarize yourself with the proper solar expansion tank selection can reduce these costs and simplify the system (and its installation), as well as reduce the system’s maintenance requirements.

## Stagnation, Solar XTanks & Pressure-Relief

While most antifreeze systems rely only upon a properly sized solar expansion tank to accommodate the expansion cause by the formation of steam, there are other approaches. By utilizing a pressure-relief valve with a 150 psi rating, Heliodyne’s system is able to accommodate larger swings in system pressure. Since higher pressures raise the boiling temperature of the glycol solution, Heliodyne’s approach is to permit higher pressures and prevent steam formation. For example, a 50:50 glycol-and-water solution boils at 220°F at atmospheric pressure (14.69 psi). In a system that reads 65 psi on the pressure gauge at sea level, the boiling temperature of the same glycol solution is approximately 320°F. In a Heliodyne system, since the system pressures are able to increase up to 150 psi, the boiling temperature of the fluid remains higher than the system’s stagnation temperature. This is a delicate balance—if the expansion tank is too small, the pressure will climb too fast and the pressure-relief valve will open; if the expansion tank is too large, the pressures will not be high enough to keep the glycol from boiling. As a result, it is critical to follow the expansion tank sizing guidelines provided by Heliodyne.

A few other companies utilize methods that provide passive cooling of the collectors or provide a reservoir where fluid can be held during overheating conditions. When installing a system, it is critical to understand the manufacturer’s approach to addressing overheating and solar expansion tank sizing. While many systems will allow erring on the side of oversizing the solar expansion tank, there are a few where installing a larger solar expansion tank may affect system operation and performance.

To size a solar expansion tank so that system pressure stays below the pressure-relief valve’s rating, you must calculate the maximum amount of fluid that could be forced into the solar expansion tank. For most systems, the worst-case scenario occurs when the system stagnates due to reaching the solar storage tank’s high-temperature limit. At this point, all of

## Thermal Expansion of Glycol

System Fluid Volume (Gal.)	Glycol Expansion (Gal.)*
2	0.15
3	0.22
4	0.30
5	0.37
6	0.45
7	0.52
8	0.60
9	0.67
10	0.74

\*Assuming a temperature range of 60°F – 240°F



Vaughan Woodruff

**Some residential SWH systems may require the use of a larger, floor-mounted expansion tank (circled) to accommodate the steam expansion that occurs during stagnation.**

the glycol in the system has reached its maximum thermal expansion, but stagnation has not yet occurred.

The glycol's expansion (prior to steam formation) can be estimated by multiplying the glycol solution's coefficient of expansion by the change in temperature. If the initial fluid temperature in the system was 60°F and the fluid is expected to boil at 240°F, then the glycol can be expected to increase in volume by 7%. For a system with a fluid capacity of 8 gallons, this would be an increase in volume of 0.6 gallon (see "Thermal Expansion of Glycol" table, previous page).

The collectors' fluid capacity is the amount of fluid that is expelled from the collectors when steam forms. For certain heat-pipe-style evacuated-tube and serpentine-style flat-plate collectors, this volume may be as low as 0.3 gallons per collector. For individual harp-style flat-plate collectors, this volume may exceed 1 gallon.

Adding the glycol's thermal expansion to the steam expansion equals the total amount of fluid that the expansion tank must be able to absorb. The membrane in the expansion tank must be able to stretch enough to accept this fluid volume. Expansion tanks have an *acceptance volume* specification. Even if an expansion tank is rated as a solar expansion tank by the manufacturer, it is important to verify that its acceptance volume is large enough—

some larger solar expansion tanks have larger air cushions than smaller models, but have the same acceptance volume.

Any reserve volume that is stored in the solar expansion tank when the system is initially charged must be factored into the acceptance volume. In cold climates, it is common for installers to inflate the air cushion to 2 to 3 psi below the initial system pressure. When the system is filled with glycol and pressurized, the air cushion will compress a bit and allow the solar expansion tank to hold a small amount of glycol. On cold nights, when the collector fluid cools, some of this reserve volume of glycol will enter the system piping to accommodate any glycol contraction. You may need an additional 0.1 to 0.2 gallons of acceptance volume for each collector in the system to account for the reserve volume.

Once you have identified a solar expansion tank with a sufficient acceptance volume, it is important to ensure that the air cushion is large enough. As the fluid expands, the air cushion in the solar expansion tank will compress. If there is a relatively small range between the system's normal operating pressure and the pressure at which the pressure-relief valve opens, a larger air cushion is needed to accommodate the expanded volume of fluid. If the difference between the normal operating pressure and the relief-valve rating is high, then the air cushion can be smaller.

If you multiply the factor in the "Solar XTank Pressure Factors" table by the minimum acceptance volume due to thermal expansion, steam expansion, and the reserve volume of glycol in the solar expansion tank, you can determine the minimum tank volume required. For example, if the initial system pressure is 25 psi and the pressure-relief valve is rated at 87 psi, a system with a minimum acceptance volume of 2 gallons will require an expansion tank with a nominal volume of 2 gallons times 2.4, or 4.8 gallons.

**Installation considerations.** Since solar expansion tank sizing depends upon the system's initial pressure, the air cushion's charge pressure, and the pressure-relief valve's pressure rating, be sure to pay attention to these details during the system's installation.

The initial system pressure is influenced by the difference in height between the top of the system and the pressure gauge, which is typically located near the solar storage tank.

## Solar XTank Pressure Factors

Initial System Pressure (psig)	Solar XTank Sizing Factor* Per Relief-Valve Pressure Rating			
	75 psi	87 psi	145 psi	150 psi
20	1.9	1.8	1.6	1.6
25	2.6	2.4	2.1	2.1
30	3.5	3.2	2.6	2.6
35	4.7	4.1	3.2	3.2
40	6.2	5.3	3.8	3.8
45	8.3	6.7	4.5	4.5
50	11.4	8.6	5.3	5.2

\*Multiply factor by the minimum acceptance volume to determine needed expansion tank size.



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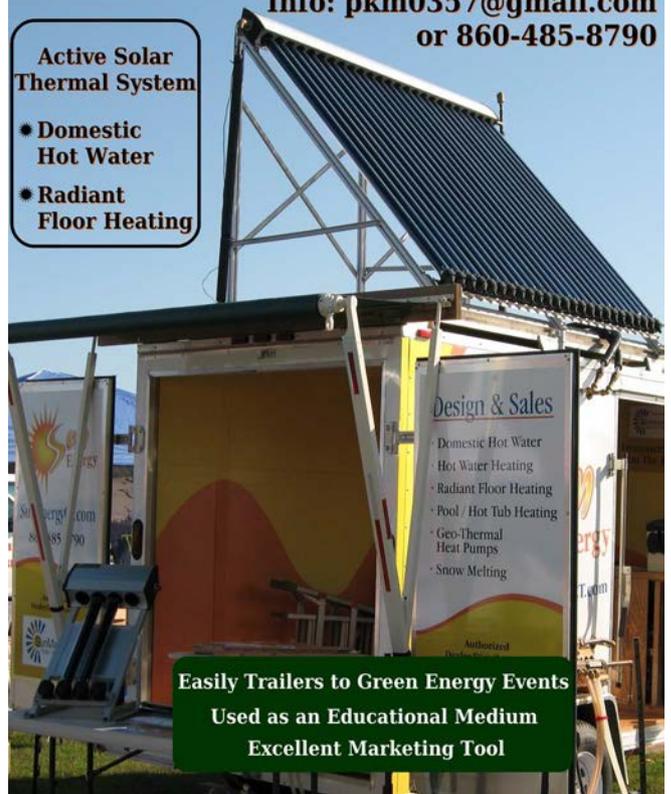


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# Module-Level Performance

by Dan Lepinski

Courtesy Enphase

Module-based microinverters, AC modules, and DC optimizers can help systems make the most of the solar resource by maximizing each PV module's individual performance. But is the added expense and complexity worth it?

Microinverters, AC modules, and DC optimizers—module-level power electronics (MLPEs)—are gaining in popularity for their ability to squeeze the maximum energy out of a PV system, especially in sites with partial shading. Here's what you need to know to determine if MLPEs are right for your system and situation.

## Microinverters

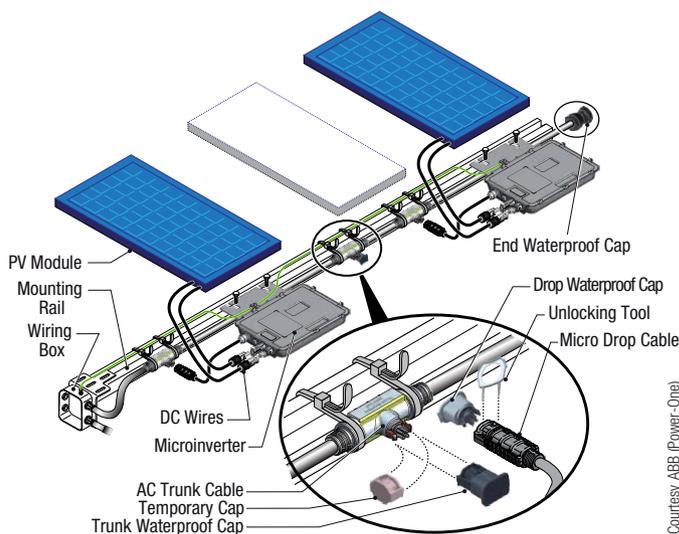
Microinverters are small, self-contained inverters, ranging from 200 to 400 W AC, that are paired with a PV module to produce grid-tied AC. They mount on the PV module's frame or the rack where the module is attached. The microinverters' outputs are wired in parallel by their shared AC power cable.

Microinverters accomplish their function using four basic circuits which:

- Change the PV module's low-voltage DC to high-voltage DC (typically 250 to 450 VDC)
- Change the high-voltage DC to sine-wave AC
- Use MPPT to squeeze out the maximum power from the PV module
- Detect the presence of the utility grid before feeding power to the grid

A PV module must match the microinverter's input specifications for voltage range and/or number of PV cells in the module (i.e., 60, 72, or 96 cells). Micros have some mounting flexibility, and may be attached to the PV frame or mounting rack.

## Typical Microinverter System Configuration



Courtesy ABB (Power-One)

Courtesy SMA America



Microinverter examples: SMA America Sunny Boy 240-US (above), Enphase Energy M250 (upper right), and ABB (Power-One) Micro-0.25-1 (right).

Courtesy Enphase



Courtesy ABB (Power-One)



## MPPT & Shading

String inverters, microinverters, AC modules, and optimizers use maximum power point tracking (MPPT) to find and use the maximum power available from a PV array, since it varies with sunlight intensity, haze, clouds, sun angle, dirt and debris on the modules, module-cell temperature, and shading. Because MLPEs are paired per module, they avoid the energy penalties incurred when one or more modules in a series string are shaded.

In a string-inverter-based system, shade on one PV module can affect the current in all PV modules in that series string. Bypass diodes in the modules provide electrical detours, allowing current to flow around the string of cells containing the shaded area. But in doing so, that string of cells doesn't contribute any power. The PV output voltage for that module can drop by 15 to 20 volts—by 25% to 35%. And, if two or three PV modules are partially shaded, voltage can decrease by 60 V or more. That can be enough to turn off some string inverters.

MLPEs all have MPPT circuits, which automatically adjust for changes in PV output current, electronically converting a higher PV voltage at a limited current to a lower voltage at a somewhat higher current. Though less voltage is provided, the current matches exactly that of the other PV modules in the array. This maximizes the available power (power = voltage × current).

Guy Mansden



Even minor shading can have a big effect on string-inverter-based systems. The MLPEs prevent shade on one module from affecting the output of the others.

ABB (Power-One)

APS America

Enecsys

Enphase Energy

<a href="http://power-one.com">power-one.com</a>	<a href="http://apsamerica.com">apsamerica.com</a>	<a href="http://enecsys.com">enecsys.com</a>	<a href="http://enphase.com">enphase.com</a>
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Inverter

No. of Models	3	2	8	2
Nominal Power Output (W)/# of PV modules	265, 320, 320	225, 500 (2 PV modules)	200, 217, 240, 263; 360 or 480 (with 2 PV modules)	215, 250
DC Startup Volts	25	16	22	22
Input V Range (Lowest – Highest Models)	12 – 79	16 – 55	20 – 44	16 – 48
MPPT Tracking V Range	25 – 75	22 – 45	23 – 42	16 – 48
Rec'd. Max. Input Power (W)	320	310	335	320
Max. PV Modules	1	2	1	1
Output Volts (Lowest-Voltage Model)	208	208	240	208
Output Volts (Highest-Voltage Model)	240	240	240	240
Output Amps (Lowest-Current Model)	1.04	0.94	0.94	0.90
Output Amps (Highest-Current Model)	1.44	1.87	1.88	1.10
Output Watts (Lowest-Power Model)	260	225	240	215
Output Watts (Highest-Power Model)	310	450	480	250
Three-Phase Available	No	Yes	No	Yes
CEC Efficiency (Lowest-Rated Inverter)	96.0%	95.0%	93.0%	96.0%
CEC Efficiency (Highest-Rated Inverter)	96.0%	95.0%	96.0%	96.5%
Operating Temp. Range	-40°F – 167°F	-40°F – 165°F	-40°F – 185°F	-40°F – 165°F
Nighttime AC Consumption (W)	< 0.05	0.12 – 0.15	0.03 – 0.06	None
Enclosure Rating	NEMA 4X	IP 65, NEMA 4X	NEMA 4X / IP66	NEMA 6
Comm. Modes	Wireless	PLC, ZigBee (optional)	Wireless - ZigBee IEEE 802.15.4	PLC
PV Connectors	PLC	MC4	MC4	MC-4, Tyco Solarlok
Mount Bolts	2	2	2	1
Units per 20 A Branch Circuit	11 – 15	6 – 17	8 – 17	17 single-phase, 25 three-phase
Portrait or Landscape	Both	Both	Both	Both
Equipment Ground or DC Ground Required	Yes	Yes	Yes	Integrated ground
AC Ground Through Bus Cable	Yes	No Bus Cable	Yes	Yes
Misc. Info.	Monitoring included, wide module compatibility range	YC500 handles two modules (up to 310 W each); w/ dual-MPPT & 500 W max. output	Connects to two PV modules, touchscreen monitor setup	“Burst Mode” for increased production
Warranty (Yrs.)	10	10, 25 extended	25	25

Monitor

Model	Aurora CDD	Energy Communication Unit	Gateway	Envoy
Power Consumption (W)	2.5, 5 max.	2.5	1.3	2.5
Enclosure Ratings	NEMA 1 / IP20	NEMA 1 / IP 30	UL94/HB, IP42, NEMA 2	NEMA 1
Operating Temp. Range	-4°F – 131°F	-4°F – 185°F	32°F – 122°F	-40°F – 149°F
Comm. Inverter to Monitor	Wireless	PLC	Wireless	PLC
Comm. Monitor to Computer	Wi-Fi, Ethernet	Ethernet, USB, RS-232	Ethernet	Ethernet, Wi-Fi, LAN
Bidirectional Comm.	Yes	Yes	Yes	Yes
Needs Internet	No	No	No	No
Max. Distance to Inverter (Ft.)	165	1500	Not Specified	250, 600 filtered
On-Board Data Storage (Days)	None	30	90	365
Max. Number of Inverters	30	16	100	600
Revenue Grade Accuracy	None	0.2% to >10%	None	Optional, 2%
Basic Fee	Free	Free	Free	Free
Monitor Warranty (Yrs.)	10	1	2	2

	i-Energy i-energyinc.com	ReneSola renesola.com	Samil Power samilpower.com	SMA America sma-america.com	SPARQ Systems sparqsys.com
	1	2	1	1	4 (1 CEC)
	230	217, 225	240	240	215
	25	22	25	23	23
	25 – 59	22 – 60	21 – 48	15 – 45	22 – 50
	25 – 50	22 – 55	27 – 40	23 – 32	22 – 50
	265	250	Not Specified	Not Specified	250
	1	1	1 / 250 W	1	1
	240	208	208	240	240
	240	240	240	240	240
	0.96	1.00	1.16	1.00	0.90
	0.96	1.20	1.27	1.00	0.90
	230	217	240	240	190
	230	225	240	240	215
	No	Yes	Yes	No	No
	92.0%	95.0%	95.5%	96.0%	93.0%
	92.0%	95.0%	95.5%	96.0%	93.0%
	-40°F – 149°F	-40°F – 165°F	-40°F – 185°F	-40°F – 149°F	-40°F – 149°F
	0.15	< 0.17	0.05	< 0.03	0.025
	IP67	NEMA 6	NEMA 6	NEMA 3R	NEMA 6
	PLC	PLC	Wireless	PLC	PLC
	MC4	MC4	MC4, 4-plug wire	MC4, Tyco Solarlok	MC4, Tyco Solarlok
	2	2	1	2	2
	17	12 – 15	17	12	13 – 15
	Both	Not Specified	Both	Both	Both
	Yes	Yes	No	Yes	Yes
	No	No	Yes	No	No
	Lightest microinverter (2.2 lbs.)	—	—	Monitor filters PLC for reliability	—
	10	25	12	10, 20 extended	25

	i-Manager	Replus Monitor / Gateway	Solarwatcher 100	Sunny Multigate	Communication Hub
	6.0	< 5.0	2.5, 5.0 max.	Not Applicable	3.0 Ethernet, 3.7 Wi-Fi
	NEMA 1 (indoor only)	IP20 (indoor only)	NEMA 1 (indoor only)	NEMA 1	NEMA 1 (indoor only)
	14°F – 104°F	-4°F – 131°F	-4°F – 122°F	-40°F – 113°F	32°F – 149°F
	PLC	PLC	ZigBee	PLC	PLC
	Ethernet	Ethernet	Wi-Fi, Ethernet	Ethernet	Wi-Fi, Ethernet
	Yes	Not Specified	No	Yes	Yes
	Yes	Not Specified	No	No	No
	33	30	Not Specified	100	100
	No Limit	20 Yrs.	30	63	25 Yrs.
	72	80	50	48	200
	0.5%	Not Specified	None	None	None, 5%
	Free	Not Specified	Free	Free	Free
	2	1	2	10, 20 extended	1

## AC Modules

An AC module is a PV module with a factory-attached microinverter—a close cousin of the microinverter, but with some important differences. AC modules are tested and certified to Underwriters Laboratories (UL) standards as a complete product. They bear three certifications—one for the PV module; one for the inverter; and a third for the pair as a complete product stating the required limitations (like maximum number of AC modules that can be paralleled).

To remain in compliance with the product's UL certification, failed AC modules must be replaced as a complete unit, regardless of whether the inverter or the PV module is at fault. Field replacement of either item alone invalidates the product's UL safety certification.

Microinverters that are not sold as part of an AC module are required to incorporate a ground-fault detector and interrupter circuit to turn off the inverter should an unwanted current path develop within the PV module. AC modules are exempt from this requirement. The *National Electrical Code (NEC)* also differentiates AC modules from microinverters—Section 690.6 of the *NEC* states: "The requirements of Article 690 pertaining to PV source circuits (the DC side of the PV module) shall not apply to AC modules." This simplifies and lowers the cost of installation of AC modules compared to microinverters.

Another advantage with AC modules is that because the inverter doesn't have to be mounted separately, installation time is reduced. Additionally, there's a single point of warranty contact for both the PV module and the inverter.

**AC modules are tested, UL-listed, and sold as a single, complete product. Because they negate the need to mount and wire the PV module and microinverter separately, AC modules can reduce installation time and cost.**



Courtesy SolarBridge (2)

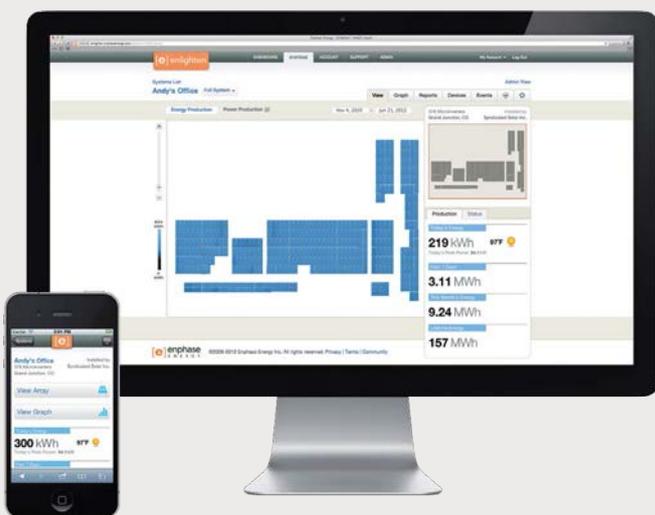


## Monitoring MLPEs

Microinverters, AC modules, and optimizers include performance-sensing and communication to monitor each PV module. Communications may be through the power-line communications (PLC), Ethernet, or a wireless radio in each unit, similar to the Wi-Fi in laptop computers. The communications schemes are proprietary to each manufacturer. Optimizer manufacturers are collaborating with string inverter makers to provide compatible products that recognize each other's communication methods, and can thus work together for even higher performance.

PLC-based monitors are generally reliable up to 150 feet from the microinverters. Distance is reduced by interference sources on the power line, such as light dimmers and electronic power supplies. Manufacturer-supplied power-line filters may help in such cases.

Wireless communications systems don't suffer from interference sources on the power line, but can be affected by large metal objects and metal roofs. To counter this, manufacturers such as Enecsys offer "repeaters" for installation between the array and monitor to boost the signal. APS America's repeaters allow the monitor to be located up to 1,500 feet from its microinverter installations.



Courtesy Enphase

**Monitors offer power and cumulative energy stats about individual module/MLPE pairings in a system. Apps are sometimes available for monitoring via handheld devices like smartphones.**

Andalay BenQ Solar ET Solar Hareon Solar MAGE Solar Phono Solar Talesun Solar

andalaysolar.com benqsolar.com us.etsolar.com hareonsolar.com magesolar.com phonosolar.com talesunusa.com

## AC Module

<b>Models Offered</b>	1	1	4	5	1	2	1
<b>Qualifies for "Made In America" Act?</b>	No	No	Yes	No	Yes	Not Specified	No
<b>Weight (Lbs.)</b>	51.6	48.5	47.6	47.6	47.0	Not Specified	48.6

## Inverter

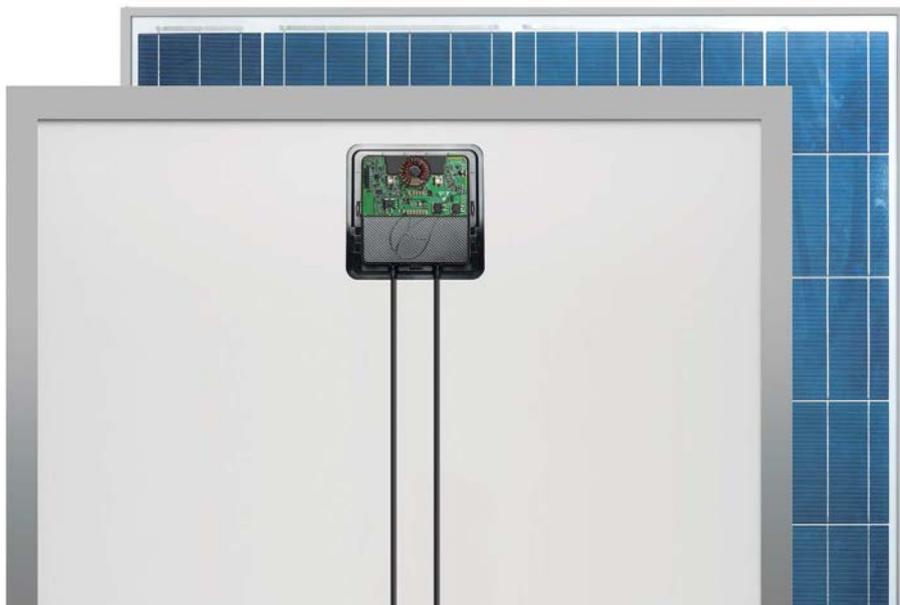
<b>Manufacturer</b>	Enphase	SolarBridge	SolarBridge	SolarBridge	SolarBridge	Enphase	SolarBridge
<b>Model</b>	M215	P235LV-240	Pantheon II	Pantheon II	Pantheon II	M215 or M250	Pantheon II
<b>Output (VAC)</b>	208 or 240	240	208 or 240	208 or 240	208 or 240	240	240
<b>Output (A)</b>	1.0 or 0.9	0.9375	1.14 or 0.99	1.14 or 0.99	1.14 or 0.99	0.93 or 1.04	0.93
<b>AC Power Out (W)</b>	215	225	238	238	238	215 or 250	225
<b>CEC Efficiency</b>	96.0%	94.5%	95.0%	95.0%	95.0%	96.0%	94.5%
<b>Operating Temp. Range</b>	-40°F – 185°F	-40°F – 149°F	-40°F – 149°F	-40°F – 149°F	-40°F – 149°F	-40°F – 185°F	-40°F – 149°F
<b>Nighttime Power Draw (W)</b>	0.046	0.02	0.02	0.02	0.02	0.046	0.02
<b>Max. Inverters / Branch</b>	15 or 17	17	16	17	16	17 or 16	17
<b>Inverter Enclosure Rating</b>	NEMA 6 (IP67)						
<b>Inverter Warranty (Yrs.)</b>	25	25	25	25	30	25	25

## Monitor

<b>Manufacturer</b>	Enphase	SolarBridge	SolarBridge	SolarBridge	SolarBridge	Enphase	SolarBridge
<b>Model</b>	Envoy	Power Manager	Power Manager	Power Manager	Power Manager	Envoy	Power Manager
<b>Power Consumption (W)</b>	2.5, 7.0 (max)	12	12	12	12	2.5, 7.0 (max)	12
<b>Network Conn.</b>	Ethernet	Ethernet	Ethernet	Ethernet	Ethernet	Ethernet	Ethernet
<b>Operating Temp. Range</b>	-40°F – 149°F	-4°F – 122°F	-4°F – 122°F	-4°F – 122°F	-4°F – 122°F	-40°F – 149°F	-4°F – 122°F
<b>Enclosure Rating</b>	NEMA 1	NEMA 3R	NEMA 3R	NEMA 3R	NEMA 3R	NEMA 1	NEMA 3R
<b>Inverter Comm. Type</b>	PLC	PLC	PLC	PLC	PLC	PLC	PLC
<b>Bidirectional Comm.</b>	Yes	Yes	Yes	Yes	Yes	Yes	Yes
<b>Max. Distance PV to Monitor (Ft.)</b>	Varies by location	300	300	300	300	Varies by location	300
<b>Max. Modules / Monitor</b>	600	150	150	150	150	600	150
<b>Revenue-Grade Monitor</b>	No	No	No	No	No	No	No
<b>Basic Fee</b>	Free	Free	Free	Free	Free	Free	Free
<b>Monitor Warranty (Yrs.)</b>	1	3	3	Not Specified	3	2	Not Specified

## Module

<b>Cell Count</b>	60	60	60	60	60 or 72	60	60
<b>Cell Technology</b>	Polycrystalline	Monocrystalline	Polycrystalline	Polycrystalline	Mono or Polycrystalline	Polycrystalline	Polycrystalline
<b>STC DC Power (W)</b>	245	255	250	250 to 270	250	245 to 265	250
<b>STC Power Tolerance</b>	-2% / +2%	-0% / +3%	-0 W / +5 W	-0 W / +5 W	-0 W / +5 W	Not Specified	Not Specified
<b>Snow-Load Rating (Lbs./Ft.<sup>2</sup>)</b>	112.8	112.8	112.8	112.8	Not Specified	112.8	112.8
<b>Fire Rating</b>	Class C	Class C	Class C	Not Specified	Class C	Class C	Not Specified
<b>PV Frame Dimensions (In., L / W / H)</b>	65.30 / 39.30 / 2.00	65.00 / 39.06 / 1.57	64.57 / 39.06 / 2.26	64.41 / 39.06 / 1.77	65.15 / 38.94 / 1.54	64.60 / 39.10 / 1.60	64.57 / 39.00 / 1.60
<b>Weight (Lbs.)</b>	51.6	48.5	47.6	47.6	47	Not Specified	48.6
<b>Warranty (Yrs.: Workmanship / 90% Power / 80% Power)</b>	10 / 10 / 25	10 / 10 / 25	10 / 12 / 25	10 / 10 / 25	10 / 12 / 30	10 / 12 / 25	10 / 25 / 25



This Tigo Energy optimizer (below) is used in “smart modules” (left). Module manufacturers (such as Jinko, Trina Solar, and UpSolar) replace the normal module junction box with this field-replaceable Tigo optimizer to create a “smart module.” Similar to AC modules, this approach reduces MLPE installation time and cost. (Note: The smart module optimizer is shown as a cutaway in this photo.)

### DC Optimizers

DC optimizers adjust the output from each PV module to match the other modules in the system. But unlike microinverters, they output DC—not AC. Subsequently, they work only with string-inverter-based systems, shifting the task of maximizing PV power from the string inverter to the unit connected to each PV module for module-level MPPT. The result boosts power production from a few percent up to 25% or more, depending on shading or other issues.

Since they adjust each PV module’s current to match other modules in the string, optimizers may simplify system design in the event of shading or mounting orientation differences, such as roof planes that face different directions. While the net system output power may be less than the maximum available, it will still be greater than if optimizers weren’t used. In cold climates, they can help regulate the PV modules’ output voltage, preventing it from exceeding the inverter’s maximum DC voltage input. This allows “extra” PV modules to be connected into a circuit without exceeding that maximum voltage. An array that was limited to 12 PV modules might be expanded to 14 modules without danger of excessively high voltage in the winter, while yielding 16% more energy output. As long as the inverter capacity is large enough, those two extra modules will offer that additional capacity year-round. Over the lifetime of the system, this can add up.



Courtesy Tigo Energy (2)

Optimizers attach to PV modules or the rack much in the manner of microinverters, or may be pre-attached to modules in place of PV junction boxes (Tigo Energy and SolarEdge). Like microinverters and AC modules, optimizers also offer module-level performance monitoring for tracking the performance of each PV module in your system.

The optimizers’ MPPT may not co-exist with a string inverter’s MPPT, in which case the string inverter MPPT should be disabled. String inverters from ABB (Power-One), Fronius, KACO, SolarEdge, and others are “optimizer-aware” and can either have their own MPPT disabled or changed to allow the optimizers to function. When optimizers are present on every PV module in a system, the string inverter’s MPPT isn’t needed. Under less-than-ideal PV conditions, optimizers will outperform the string inverter MPPT. Under perfect conditions of no shade and an ideal operating environment for the PV modules, however, the improvement with optimizers will be minimal.

### Backup Power from MLPEs?

Microinverters and AC modules cannot be used to power your home when the grid fails. In a batteryless grid-tied system, when the utility power goes off, so do your grid-tied inverters. Your system could only keep running if it: has battery backup; can automatically disconnect your home loads from the utility grid; or has an inverter that can operate independently from the grid.

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### Optimizer

Models Offered	2	11	3
Stand-Alone Units Available	Yes (External diode required)	Yes	Yes
Integrated Units Available	Yes (External diode required)	Yes	Yes
Input V Range	46 – 102	5 – 125	0 – 150
MPPT Range (V; Lowest-Voltage Model)	10 – 38	5 – 55	16
MPPT Range (V; Highest-Voltage Model)	25 – 80	12.5 – 105	65
Max. Power Input (W; Smallest Model)	260	250	375
Max. Power Input (W; Largest Model)	360	700	375 (× 2)
Max. Power Output (W; Lowest-Power Model)	260	250	375
Max. Power Output (W; Highest-Power Model)	280	700	750
Output (VDC)	33.3, 36.0, 40.6, 63.6	5 – 85	104 – 150
Max. Output Current (A)	9.4, 9.2, 9.2, 6.7	15	9.5
Max. System Voltage	Not Specified	1,000	600 / 1,000
Enclosure Rating	Not Specified	NEMA 4 (IP 65)	NEMA 3R (IP 65/67)
Cables	Not Specified	12 AWG, double-insulated	PV1-F, PV Wire, 12 AWG
Connectors Available	Not Specified	MC4	MC3, MC4, Tyco
Operating Temp. Range	-40°F – 185°F	-40°F – 150°F	-40°F – 158°F, -40°F – 185°F for integrated model
Warranty: Materials & Workmanship / Power Output (Yrs.)	25 / 25	25	10 / 25

### Monitor

Models	StringView	Monitoring Portal	Gateway or Management Unit
Enclosure Ratings	NEMA 3R, IP 42, UL 94-5	N/A	IP65 / NEMA 3R
Power Consumption (W)	Not specified	N/A	<4
Ambient Temp. Range	-40°F – 185°F	N/A	-22°F – 158°F / 32°F – 158°F
Data Interface to Monitor	Not Specified	PLC over DC Line	Wi-Fi
Data Interface to Computer	Ethernet	Ethernet / ZigBee / Wi-Fi	Ethernet
Compatible with Third-Party Monitoring	Yes	Yes	Not Specified
Max. Comm. Distance, Optimizer to Gateway (Ft.)	N/A	N/A	4,000
Max. Comm. Distance, Optimizer to Monitor (Ft.)	Not Specified	1,000	50 (line of sight)
Comm. Bidirectional	Yes	Yes	Not Specified
Max. Modules Per Unit	2,000	N/A	840
Data Storage (Days)	45	30	30
Basic Fee	Free	Free	Free
Warranty (Yrs.)	Not Specified	25	5

### MLPE Advantages

**Maximum power from each module.** MLPEs allow each module to operate at its maximum potential—regardless of its neighbors. String inverters typically require modules to be wired in strings of eight to 14 modules, and the weakest-performing module in the string limits each module. This could be a weak module from the factory, or one with shade or orientation problems.

**Incremental design.** Microinverter and AC module systems can be built with as few as one module at a time. This is

helpful to deal with budget constraints, or if there’s not enough room for the number of modules required to power a string inverter. They also can be used to supplement a string-inverter system that’s electrically maxed out, but when there’s still roof space remaining for additional modules.

**Easier system expansion.** Integrating microinverters or AC modules into an existing larger system can usually be done by connecting them into the existing utility service with other inverter equipment. Additional breakers are required for each separate circuit.



**While optimizers and microinverters offer several system advantages, consideration should be given to the additional planning and installation time required to mount the units and manage the extra cabling.**

**Accommodates various module orientations.** Microinverters and AC modules are very effective in systems where the PV modules can't all be in the same plane.

**Safer.** High-voltage DC is eliminated in microinverter and AC module systems, increasing safety. The highest DC voltage in such systems is that of a single PV module. With no high-voltage wiring, and with DC cables from one PV module connected to one microinverter, the likelihood of DC-side "ground faults" and "arc faults" are reduced.

**Field-programmable.** Except for ReneSola and Samil Power, all other microinverters and AC Module products listed here can be remotely programmed to meet utility requirements. This can be important for grid-tied systems in certain regions. For example, the state of Hawaii requires that grid-tied inverters operate over wider voltage and frequency ranges than the UL1741 Standard stipulates. In Hawaii, nearly 15% of the utility power is produced by solar sources, with the rest supplied by diesel generators. If inverters in grid-tied systems in Hawaii were held to the values in the UL1741 Standard, during instances of abnormally low line frequency (which are more common with diesel generators), they would turn off, removing all of the solar-electric power from the utility grid.

**Module-level monitoring.** Module-level monitoring allows Web-based viewing of how each MLPE combination is performing. Since it presents a real-time, side-by-side comparison of each module/inverter pair, if something fails, it will show up on the monitor. The software can pinpoint exactly where the failure has occurred.

But variations in output power are normal in any system—two otherwise-identical units can have different power outputs. For example, one may show 210 W and another 194 W. Is the unit at 194 W malfunctioning? Probably not, yet the difference may cause a customer to worry—and possibly even contact the installer for a fix where there is none required.

If the difference in performance between two MLPE units is more than 25% and there is no obvious cause, keep an eye on it—even though it likely is temporary. If an output is 50% or more than other units, then take steps to get it corrected. While it could be a malfunctioning module, it also could simply indicate leaves or other debris on the array.

## MLPE Disadvantages

**Replacement.** Though many microinverter companies and AC module manufacturers offer reimbursement for warranty service call labor, it still takes time and effort to deal with them, and the reimbursement may not fully cover time and travel.

Failure within an AC module can require more effort to replace than a microinverter failure. To remain in full compliance with UL safety standards, the entire PV/inverter unit must be replaced.

Depending on the installation site and where the failed microinverter or AC module is within the array, it can be difficult and time-consuming to replace; multiple PV modules may have to be removed to reach the failed unit. On the other hand, if there are 20 PV modules in the system, and one microinverter fails, it represents an output loss of only 5%. If a string inverter fails, the output reduction is 100% until the inverter can be repaired or replaced.

**Connectors.** There are no "universal" connectors for PV modules. Microinverters and optimizers must be "connector-matched" to the PV module to which they'll connect.

**Exposure.** PV-mounted electronics are outside where they experience wider extremes of heat and cold, and may fail sooner than components that are weather-protected. But units made with quality parts and manufacturing conditions should mitigate this. "Accelerated-life testing" of MLPES has shown they can function properly over the life of the PV modules.

Improperly installed microinverters that come into contact with the backsheet or are placed in areas without adequate airflow may run hotter than intended, which will shorten their life.

**New NEC requirement.** The 2014 NEC requires AC arc-fault protection for wiring between microinverters and AC modules (see "Code Corner" in this issue).



**Because they are manufactured for specific MLPES, cables and connectors match their products' requirements exactly.**

**To Go MLPE—or Not**

The amount of power production improvement from microinverters, AC modules, or optimizers depends on many variables. According to studies by the National Renewable Energy Laboratory (NREL), if a completely unshaded PV system receives full sunshine year-round, the differences in power production between MLPE and string-inverter systems is negligible.

Systems that experience even a little shade may benefit considerably from the use of MLPEs. NREL tests reported up to a 13% power production gain under laboratory-controlled conditions in string-inverter systems that used optimizers.

Quality microinverters and AC modules used within their specifications can provide many years of trouble-free operation. Calculations and extensive testing show they'll work for 25 years or longer.

Optimizers may be excellent add-ons for older PV modules, which NREL testing has shown degrade at slightly differing rates. As age-induced imbalance increases, so will the advantage of optimizers. However, PV modules made in the past 10 years show slower degradation, with less difference between modules, so adding optimizers may not provide as much of a boost compared to using them with older systems.

String-inverter systems tend to be less expensive than those with microinverters or AC modules, which is their main advantage. With microinverters and optimizers, there is no economy of scale, since each must be mounted, increasing installation costs. With string inverters, jumping from one size to the next often only incurs a minimal cost increase. However, as the minimum power range for string inverters creeps upward, small systems can make microinverters or AC modules increasingly attractive.

Is there a best product type to use? There's no "yes or no" answer. It depends on the system, and where and how it's installed. A need exists for each of these technologies in the renewable energy industry. There's no one clear choice to fit all cases.



**web extra**

"Partial Shade Evaluation of Distributed Power Electronics for Photovoltaic Systems" • [nrel.gov/docs/fy12osti/54039.pdf](http://nrel.gov/docs/fy12osti/54039.pdf)

"Expanding Your PV System" by Brian Mehalic in *HP147* • [homepower.com/147.42](http://homepower.com/147.42)

"Potential PV Problems & New Tools for Troubleshooting" by Justine Sanchez in *HP143* • [homepower.com/143.78](http://homepower.com/143.78)

"Distributed MPPT: New Hardware to Maximize Module Output" by Justine Sanchez in *HP137* • [homepower.com/137.56](http://homepower.com/137.56)



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# Article 705: Interconnected Electric Power Production Sources

by Brian Mehalic

Article 705 of the *National Electrical Code (NEC)*, “Interconnected Electric Power Production Sources,” has expanded and contains some significant changes. This Code Article applies to any power-production system connected to the utility through an inverter, regardless of the energy source—examples include generators, PV systems, wind turbines, and fuel cells. Some general requirements are that interactive systems must:

- Use interactive and/or multimode inverters “listed and identified for interconnection service” (705.4)
- Be compatible with the electrical characteristics (voltage, wave shape, and frequency) of the primary power source, meaning the utility (705.14)
- Address all potential fault currents (705.16)
- Interconnect on the supply (line) side of ground-fault protection equipment (705.32)
- Disconnect upon loss of the primary power supply (705.40). This includes disconnecting all ungrounded conductors when one phase in a three-phase system is lost (705.42).

Article 705 also stipulates that all power sources on the premises need to be marked per the requirements of Sections 705.10 and 705.12(D)(3):

- At the service equipment (in the case of the utility);
- At any interconnected power production sources (the “point of connection”)
- When equipment contains multiple sources of supply (such as utility-supplied breakers and a back-fed breaker from a PV system).

Article 705 applies to any interconnected source, but its evolution has paralleled the development of Article 690 from the tremendous growth in PV installations—so some content is duplicated. These include equipment disconnecting means (690.15 and 705.21), circuit sizing (690.8 and 705.60), overcurrent protection (690.9 and 705.65), and grid-tied inverters in non-readily accessible locations [690.15(A) and 705.70].

New in Section 705.2 is the inclusion of “multimode inverters,” which can operate as both stand-alone and grid-tied inverters (examples include OutBack Power’s Radian series and Schneider Electric’s Conext XW inverters). PV systems with multimode inverters are subject to the requirements of Articles 705 and 690, including Section 690.10, “Stand-

Alone Systems” (see “Additional Fasteners,” below). Section 705.80 pertains to interactive systems with energy storage, and dictates that the maximum operating voltage (including any equalization voltage) and the polarity of the grounded conductor be marked.

## Load-Side Connections

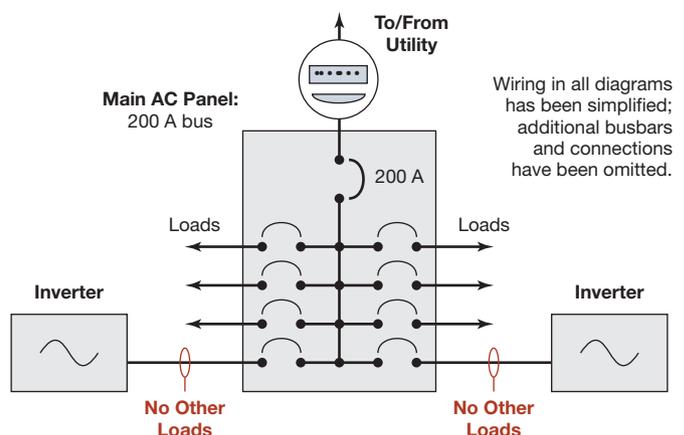
The 2014 *NEC* now addresses feeders, taps, and busbars in systems that are interconnected on the load side of the main AC service. Also new is the requirement to use 125% of the inverter output circuit current, rather than the size of the overcurrent protection device (OCPD) in the circuit, for determining the required busbar and conductor ampacity ratings.

## Dedicated OCPD & Disconnect

The language in 705.12(D)(1) referring to “one or more inverters installed in one system” means that the interconnection circuit be dedicated to the PV system up to the disconnecting means and OCPD required by 705.20 and 705.65.

Defined in 705.2 as a “utility-interactive inverter output circuit,” these conductors—between the inverter and its interconnection OCPD—cannot supply power to any other loads, nor can they extend past the inverter to supply loads. They are strictly dedicated to the connection of an electric power production source to the primary source. This point of connection can occur at “any distribution equipment on the premises,” such as a subpanel. There also can be multiple PV systems interconnected through their own separate, dedicated means.

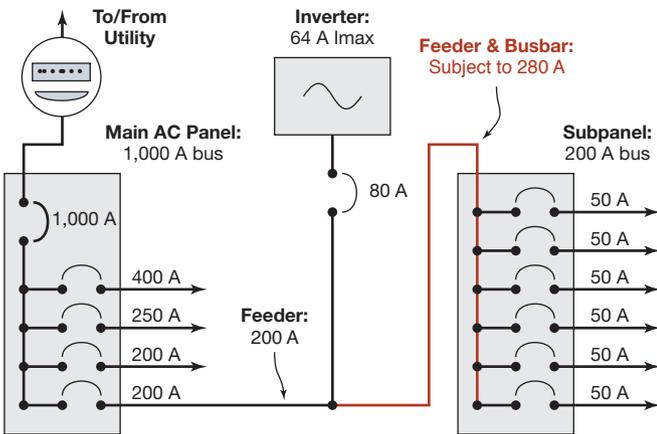
## Dedicated OCPD & Disconnect



## Feeders

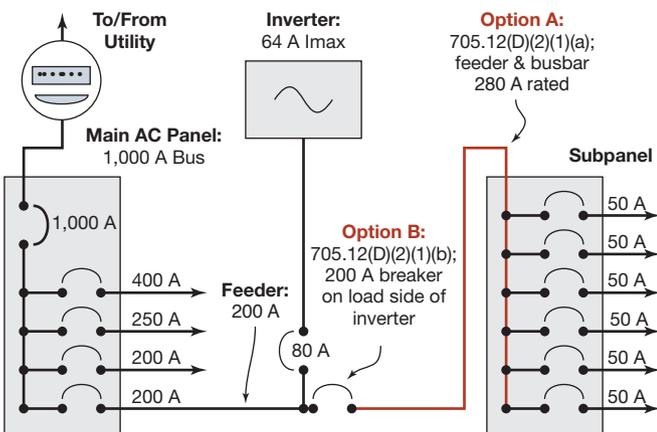
Section 705.12(D)(2)(1) addresses protecting feeder conductors, which are defined in Article 100 as “conductors between the service equipment...or other power supply source and the final branch-circuit overcurrent device.” A common example would be the conductors between the main service panel and a subpanel in a home or building. The concern is that if a PV system is connected to a feeder at some point other than its opposite end, some section of the feeder could be subject to higher, additive currents: from the primary source OCPD supplying the feeder and from the inverter output.

## Feeder Overload Concern



There are two methods for protecting the portion of the feeder which is subject to the combined output of the supply breaker and the inverter. One option is to add another OCPD—rated to protect the feeder conductor and typically the same size as the feeder’s existing primary supply breaker—on the load side of the inverter connection to the feeder. In the other method, the feeder ampacity (as well as the busbar rating, if

## Feeder Protection Options: 705.12(D)(2)(1)(a) & (b)



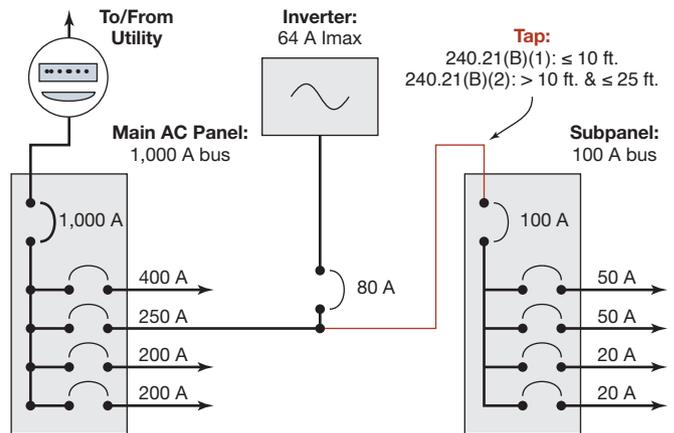
there is a main lug-only panel) can be increased so that it has an ampacity greater than or equal to the primary supply breaker plus 125% of the inverter output current.

## Taps

Tap conductors, defined in Article 240, “Overcurrent Protection,” are addressed in Section 705.12(D)(2)(2). Essentially, a tap is a conductor, smaller than the feeder conductor, that is connected to the feeder without overcurrent protection at that point of supply; as such, it is subject to current that could exceed its ampacity. The tap conductor then terminates in a piece of distribution equipment (such as a subpanel) that contains a main breaker. Sizing requirements for tap conductors, which are very common in commercial buildings, are found in Sections 240.21(B)(1) and (2).

Like protecting the feeder conductor, the concern is the addition of a second source of current on the feeder to which the tap is connected. Provided the numerous requirements of Section 240.21(B) are met, a tap up to 10 feet long must have an ampacity equal to or greater than 10% of the feeder supply breaker’s ampacity, and equal to or greater than the ampacity of the OCPD at the tap conductor’s terminal end. For taps between 10 and 25 feet, the ampacity has to be at least one-third (or 33.3%) of the feeder supply breaker’s ampacity (and greater than or equal to the terminal OCPD). When a PV system is connected to the feeder supplying the tap, Section 705.12(D)(2)(2) requires that 125% of the inverter’s output current must also be included in the calculation for the tap conductor ampacity.

## Tap Conductor Sizing: 705.12(D)(2)(2)



### Tap Ampacity Calculation:\*

Taps ≤ 10 ft: (125% inverter I<sub>max</sub> + Feeder OCPD) x 0.10

(80 A + 250 A) x 0.10 = 33 A

Minimum tap conductor ampacity = 100 A due to 100 A terminal OCPD in subpanel

Taps > 10 ft and ≤ 25 ft: (125% inverter I<sub>max</sub> + Feeder OCPD) x 0.33

(80 A + 250 A) x 0.33 = 109 A

Minimum tap conductor ampacity = 109 A

\*Provided 240.21(B) requirements are met

## Supply-Side Connections

Section 705.12(A), in conjunction with the allowance in 230.82(6), permits power production systems to be connected on the supply side of the main service disconnect, typically between the meter and the premise's main breaker. The system size that can be connected on the supply side is limited by the size of the existing service. For example, a building with a 200 amp (A) service could have a PV system connected on the supply side through a 200 A fused disconnect, which computes to a maximum inverter output current of 160 A ( $160 \text{ A} \times 1.25 = 200 \text{ A}$ ).

Section 705.31, new to the 2014 *NEC*, stipulates that overcurrent protection for supply-side interconnections must be located within 10 feet of the point of interconnection, unless cable limiters (devices that isolate conductors from short circuits, but don't necessarily provide overcurrent protection) or current-limited circuit breakers are installed. This helps reduce the risk from fault current sourced from the primary electricity source (the utility). For general information on supply-side connections, see "Code Corner" in *HP150*.

## Additional Fasteners

In situations using back-fed breakers, additional fasteners may be required to reduce shock risk associated with pulling an energized breaker off a busbar. Section 408.36(D) in the 2014 *NEC* dictates the requirements for additional fasteners on back-fed breakers. However, Section 705.12(D)(5) states that plug-in-type back-fed breakers used for load-side connection to the utility, and connected to listed grid-tied inverters, are not subject to the additional fastener requirements. Of course back-fed breakers have to be suitable for the application, i.e., *not* marked "line" and "load."

Per 690.10(E), these same plug-in-type breakers, when connected to a stand-alone inverter or the stand-alone output of a multimode inverter, are required to have an additional fastener. The logic is that the back-fed breaker terminals or tabs could still be energized when pulled off the busbar, posing a shock hazard—and an additional fastener provides another level of protection. This is not the case with the output circuit of a grid-tied inverter—if the breaker is pulled off the busbar, the inverter will immediately cease operation. A stand-alone inverter's output, regardless of inverter type, would stay energized—much like a breaker connected to a fossil fuel generator, and thus is required to have the additional fastener.



Courtesy Solar Energy International

**This back-fed breaker has been secured with an additional fastener, providing another level of protection against shock hazards.**

The required fasteners are available from most major equipment manufacturers. Another option is to connect the breakers to a main breaker that is fastened in place in the breaker panel, rather than back-feeding a plug-in breaker.

## Other Considerations

In many grid-tied inverters, only the ungrounded conductors carry AC output current. The AC grounded (neutral) conductor is used as a reference for "instrumentation, voltage detection, or phase detection." In this case, per 705.95(B), the neutral conductor in the inverter output circuit only has to be as large as the equipment-grounding conductor (which is typically smaller than the phase conductors). Especially on larger inverters, this can result in cost savings, as smaller-gauge wire can be used, but be sure to verify this with the inverter manufacturer.

New in 2014 is 705.12(D)(6), which requires AC arc-fault protection for grid-tied inverters, with wiring harness (i.e., "AC interconnect cable" or "trunk cabling") output circuits rated at 240 VAC and 30 A or less, unless the harnesses are installed within an enclosed raceway. This provides added protection for microinverter and AC module systems, which often have more cabling under modules than string inverter systems. This may be difficult to implement given a lack of suitable equipment for the purpose—most AC AFCI breakers are not tested for back-feed. Some jurisdictions may waive this requirement, citing the allowance in Section 90.4 for products that are required but not yet available.



## web extra

**Busbars.** The significant changes regarding calculations for busbar ratings in load-side interconnections are detailed in 705.12(D)(2)(3)(a) through (d). For more information, see "Code Corner" in *HP160* at [homepower.com/160.84](http://homepower.com/160.84).



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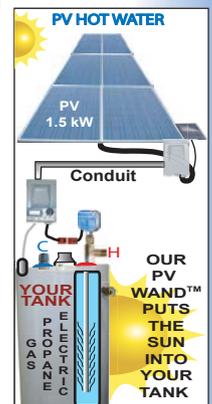


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# Well, Done

by Kathleen Jarschke-Schultze

This year, many of us are going to feel the effects of water issues. The Southwest, West, and parts of the Midwest are all experiencing drought conditions. Our area in northernmost California seems to be trending toward drier, rather than wetter. Neither of the two ski resorts within 90 minutes of us even opened last winter—there was no snow.

## Holding Water

The natural spring that provides our house water dried up last summer. In the 24 years we've lived here, it has happened twice. Just never so early, or for so long. Even throughout this winter, the spring never recovered its normal output.

Without a good snow-pack in the mountains around us, we don't expect the spring to last into summer this year. So we decided we would drill another well—our third. But well-drilling is a costly crapshoot. You might hit a gusher, get a trickle—or not find any water at all. Our second well was a disappointment. We ended up with a \$7,000 hole that gives us only about 2 gallons per minute (gpm). I realize in some parts of the world that is treasure beyond measure, but with our gardening habit, it is a paltry amount.

## Tankfull

We got a real deal on some used water-storage tanks, and added 5,500 gallons to our 2,600-gallon capacity. This sounds like a lot, and it is. We try to always keep the tanks topped off. Besides water for agricultural uses, these tanks also are a wildfire defense tool. The closest fire station, Cal Fire, is a half-hour away. An awful lot of bad can happen in 30 minutes' time.

Drilling a successful new well would enhance our ability to fight a wildfire, provide water "on tap" to grow a crop in our new pasture, and, in light of our diminishing spring, give us some water security by having another source.

## Water Witch

My Auntie Dot drilled water wells outside of Watsonville, California, for 30 years. My grandfather sometimes "witched" the well sites for her. Water-witching or dowsing means to search for underground water sources by using "dowsing rods," a forked stick or bent wires that are said to respond to the "unseen influences" of water presence by changing their direction.

The rods Bob-O made for us were two pieces of braising rod with the last 5 inches bent at a 90° angle. We each took turns with the dowsing rod, holding the short ends loosely in our fists, elbows bent, long ends pointing straight forward and close to shoulder height.



Harry Martin

We wanted the well to be closer to the new tanks, and went witching for a site around them. As one of us slowly walked the site with the rods, occasionally they would cross to make an "X." When this happened, we'd stop and put a small marker flag at that location. We both took turns with the rods, walking the entire area. When we both got a hit in the same place, we marked the existing flag.

## Which Witch?

But before we called the driller, Bob-O sought a second opinion from a local retired water-pump installer who witched wells. Ken drove up with his old dog Daisy, in an even older truck. Together with my dog, we walked out to the meadow Bob-O and I had flagged. Ken had his own dowsing rods, and they were just like ours. He also had one long, straight welding rod.

I held the straight rod while Ken commenced a slow and steady pace back and forth across a section of meadow. As he walked, the two rods would sometimes cross so deeply as to come close to his opposite shoulders. I flagged those places.

He repeated his slow pacing across the same area at a 90° angle, creating a grid. Again, where the rods indicated, I

flagged. And when the spot was already flagged, I numbered the flag. Ken explained that he was “looking” for fractures in the earth where water might be accessible. He dowsed for fractures by first walking north to south, then east to west. The marked flags indicated where two fractures met.

Next, Ken cut a small, green, forked branch from a nearby bush. He walked over each marked area holding the forked branch in both hands with the single end pointing up. When the Y pointed down, we made second mark on the flag. The green wood was to find water that may lie in the crossed fractures.

Just as we got to the last step, Bob-O joined us. I had been wondering about the welding rod and now Ken showed us how to use it.

He held one end of the straight rod waist high, parallel to the ground, with the other end over the flagged spot. The end poised over the flag started to make little circles. Ken counted each revolution and when the end hesitated or dropped down, told me at what levels the water was and what the gpm would be. As he moved to each of the four double-marked sites, I took notes on my iPhone.

Bob-O and I felt validated—we had also flagged three of the four spots that Ken had identified. Although he wasn’t aware of it, the one Ken determined as the “best”—water at 61

feet, 113 feet, and 150 feet; a total estimate of 30 gpm—was the site Bob-O and I wanted. It was the shortest distance to hook into our existing pumped water system. Ken told us that the gpm was a best guess on his part and to let him know if he was right. “I’m still working on that,” he said.

As Ken and Daisy left, Bob-O offered Ken some money for his services, but he refused, saying that being paid took all the fun out of it. We did get him to accept some gas money, as it was about a 40-mile round trip for him.

## Well Pleased

Three weeks later, we were almost \$8,000 poorer but had a new 208-foot-deep well that is rated at 7.5 gpm. Although it’s a far cry from 30 gpm, this well provides water at about double the rate of our first well and almost four times the volume of the last one, so we are pleased—just not ecstatic.

Our driller told us that last year he got four well-drilling jobs. By March of this year, he had 27 well-drilling jobs lined up. Water is increasingly a pressing issue, globally and locally. Our chosen lifestyle becomes very hard to maintain without water. Confucius, who shares my birthday, said, “A man of wisdom delights in water.” And, I’d add, uses it wisely.



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The screenshot shows the Home Power website interface. At the top, there's a navigation bar with 'home power' logo, 'Sign In', and 'Register' links. Below that is a search bar and a 'Directories' dropdown menu. The main content area displays a listing for 'Westcoast Solar Energy'. The listing includes the company logo, contact information (Year Established: 2005, 5800 Redwood DR, Ste D, Rohnert Park, CA 94928, United States), a map location, phone number (707-864-6450), email (info@westcoastsolarenergy.com), and website (http://www.westcoastsolarenergy.com). It also lists 'Renewable Energy & Related Services Offered' such as Solar Electricity, Solar Water Heating, Wind Electricity, Battery Backup / Energy Storage, Solar Home Design/Construction, and Energy Audit & Efficiency Services. Applications listed are Residential, Commercial, and Utility. A sidebar on the right contains a 'SUBSCRIBE' section with options to 'Subscribe', 'Renew', 'Give a Gift', and 'Issue Gallery', and a 'HOME POWER BASICS' section with links for 'Solar Electricity', 'Solar Water Heating', 'Wind Power', 'MicroHydro Power', 'Home Efficiency', and 'Vehicles'.

# Making the Most of Your Ceiling Fan

A ceiling fan can heat up to about 100°F when running, adding heat to a house. If no one is sitting or standing near the fan, leaving it on is counterproductive.

Many times, I have walked past my neighbors' homes and have seen their porch ceiling fans running—with no one there to appreciate them. All the fans are doing is wasting electricity and contributing a little heat to the outdoor air. I am tempted to turn the fans off, or leave the neighbors a note.

Leaving porch fans on is bad, but nowhere near as bad as doing it indoors, especially in the summer. Few people understand the basic concept of fans—that they make you feel cool due to the movement of air across your skin. This air evaporates moisture, which wicks away some heat. The same way a breeze cools you off, a ceiling fan can make you feel cooler—but only if you are close enough to feel the air blowing on you.

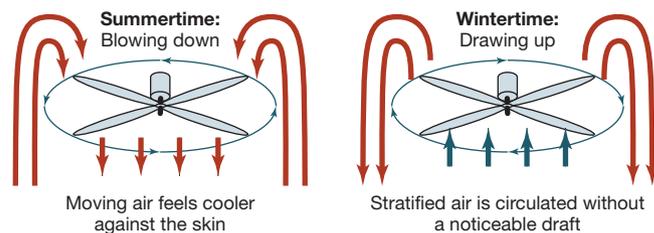
When I tell people about this concept, many say that it helps circulate the air around the room and keeps the house more comfortable. However, in the summer, there are very few situations where moving air around a house improves comfort. In the winter, if there happens to be a big temperature difference between the floor and ceiling, it might be useful to run a fan clockwise (in “reverse”) to circulate the air, but that’s not what most people do.

A 1996 study by the Florida Solar Energy Center determined that using ceiling fans appropriately for cooling could allow homeowners to raise the air-conditioner’s thermostat setting by 2°F, resulting in about a 14% annual cooling energy savings. However, the same study found that most people do not adjust their thermostats up when using ceiling fans, so using fans actually increased their overall energy use.

Obviously, running a fan when no one is in the room wastes electricity, but the dirty little secret is how much heat fans can produce when running. I always knew this, but was shown the proof when I was inspecting some well-built LEED homes. One of my associates had an infrared (IR) camera with him. Scanning walls and ceilings showed that the homes were very well-insulated and air-sealed, but when the camera caught the running ceiling fan, the camera image revealed a hot motor.

The temperature of the motor was far higher than anything else in the room, including windows exposed to direct sunlight. Not only was the fan not cooling the people who weren’t in the room, but it was also working as a little space heater.

I am not suggesting that we should stop using ceiling fans—just that they shouldn’t be on if no one is in the room. If people only use them when necessary in the summer and set their thermostats a bit higher, then the extra heat is a small price to pay for the comfort and overall energy savings.



## Efficient Fans

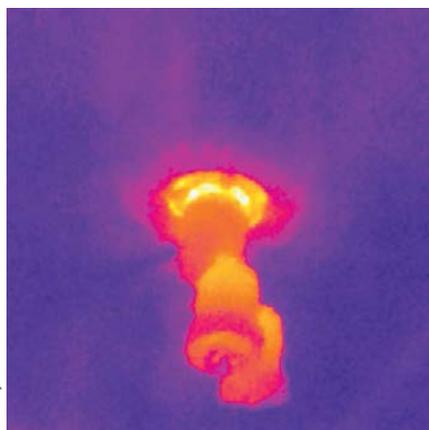
When selecting a ceiling fan, look at the fan’s efficiency, usually expressed in cubic feet per minute (of airflow) per watt. The Energy Star website provides a list of all labeled ceiling fans in a downloadable Excel spreadsheet, which can be sorted by efficiency ([bit.ly/EnergyStarFans](http://bit.ly/EnergyStarFans)).

The most efficient fan on the list, and among the most expensive, is the Haiku S3150. Looking at an IR image of one of the fans showed the temperature of the fan’s motor at high speed is only about 81°F. If (like me) you keep your house in the high 70s to low 80s, a fan motor like this won’t impact your home’s temperature much.

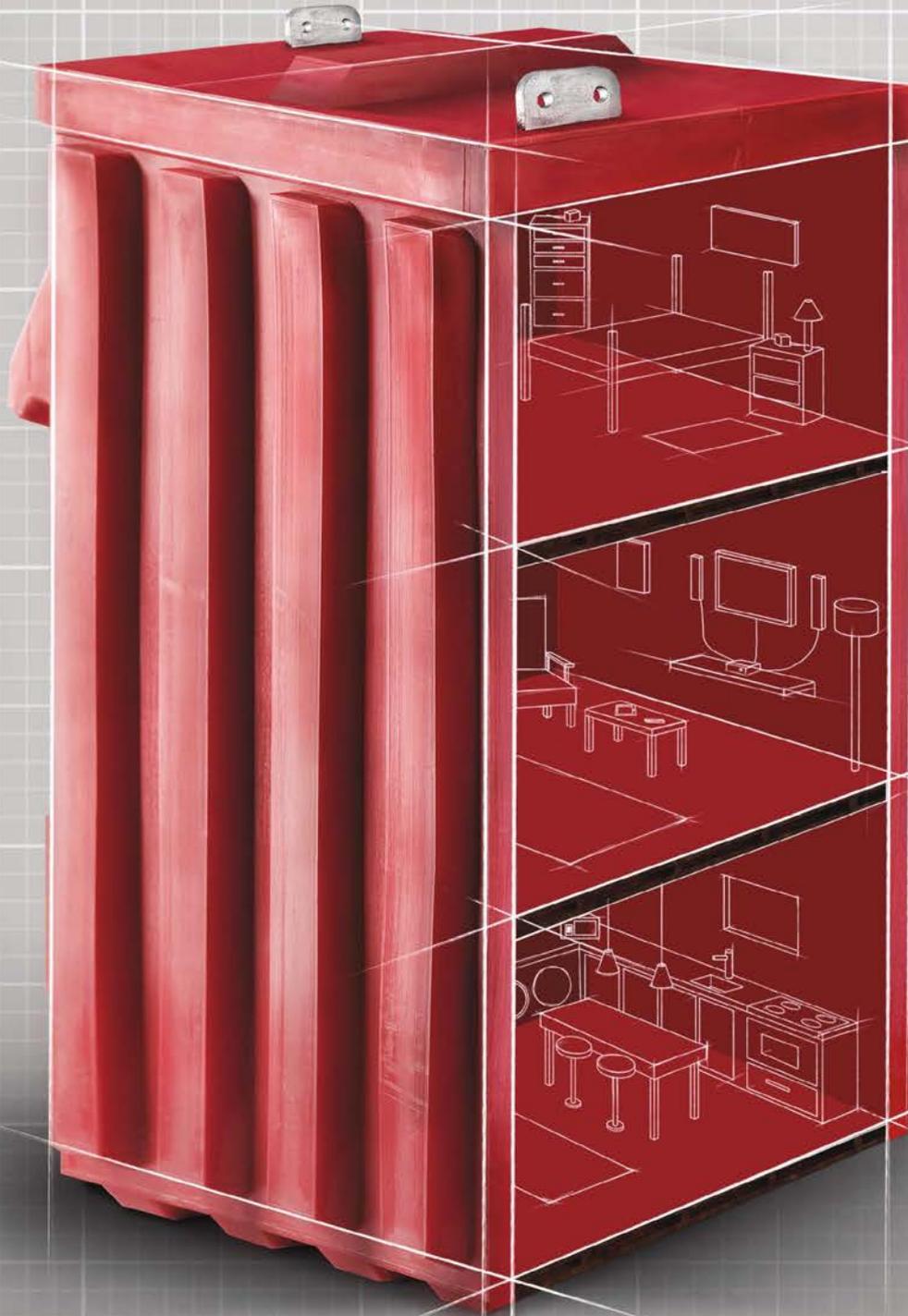
You don’t need to spend a fortune on a ceiling fan. There are many efficient models that are reasonably priced, and there is no reason to get rid of those that are working fine. You should, however, only use them when they will keep you cool, and raise your thermostat when you do.

—Carl Seville

*This article was adapted from Fine Homebuilding’s GreenBuildingAdvisor.com.*



**A fan motor (and two lightbulbs) glow “hot” in an infrared photograph. Unless it’s used properly, a ceiling fan may cost you energy and comfort.**



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