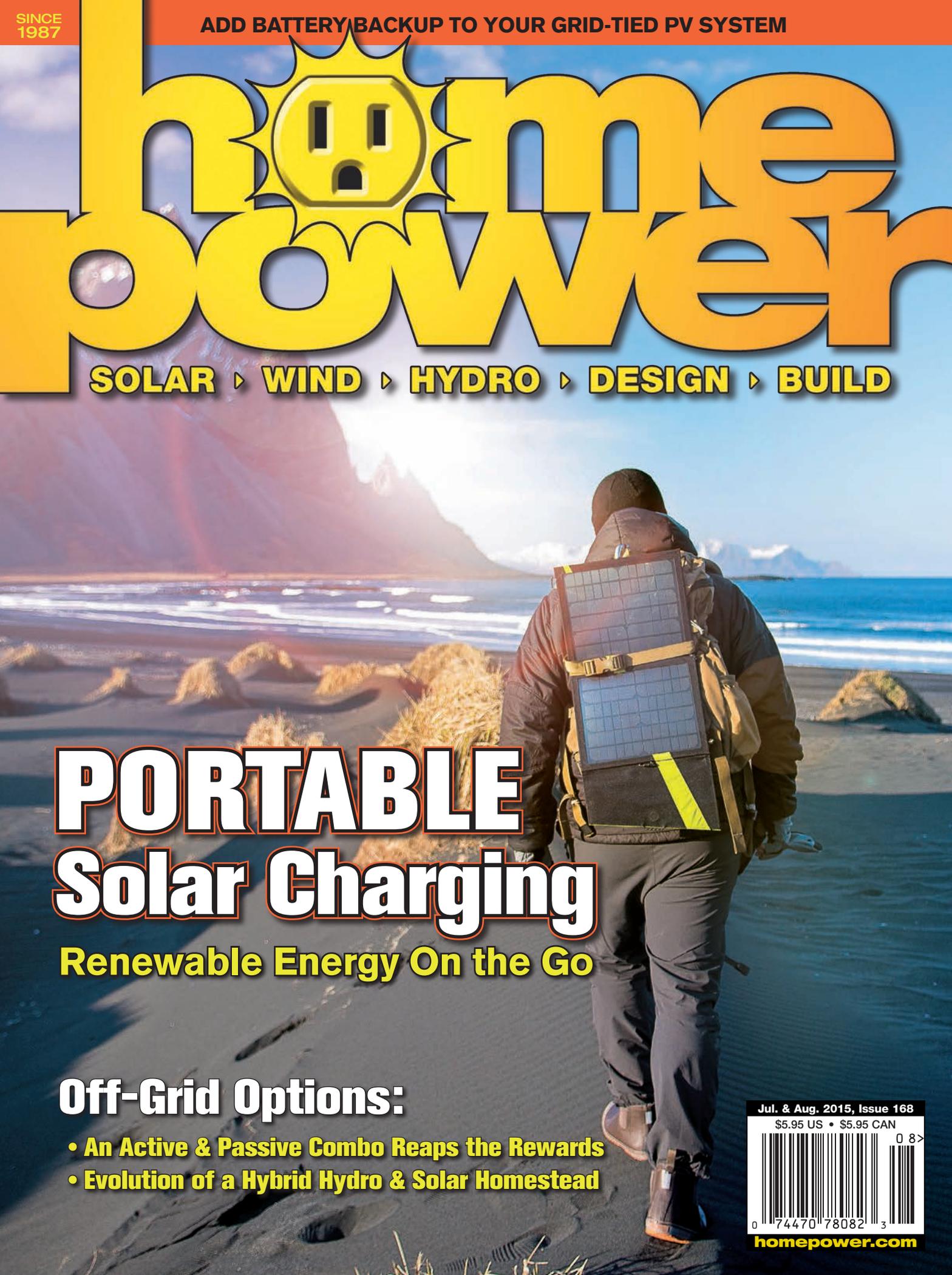


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28



Main Features

28 **portable** solar **Jeff Yago**

New portable PV charging products—handheld chargers, fold-up flexible modules, PV backpacks, and solar trailers—keep electronic devices going, no matter the location.

38 **AC-coupling** **Justine Sanchez**

Adding batteries to an existing grid-tied system so you can access electricity when the grid goes down can be accomplished with AC-coupling equipment. Learn if this approach is right for your system.

46 **passive** & active **Ian Woofenden**

Passive solar design and a small off-grid, battery-based PV system meet almost all of the energy needs of this South Dakota home.

46



38

On the Cover

Solar power—take it wherever you roam. Chris Burkard with Goal Zero's Nomad 13 in Iceland.

Photo by Chris Burkard



Up Front

6 **from the crew**

Home Power crew
Grid defection

10 **contributors**

Home Power's experts

12 **gear**

Primo SnapINverter
Fronius

Pole mount system
MT Solar

14 **solutions**

Patrick Snowden
Smart solar at Evergreen
Community College

16 **mailbox**

Home Power readers

22 **ask the experts**

RE industry pros
Renewable energy Q & A

54



More Features

54 **hybrid life**

Mickey Janowski

A microhydro system has provided the bulk of this rural West Virginia home's electricity for several decades.

In Back

60 **code corner**

Ryan Mayfield

PV disconnecting means

64 **home & heart**

Kathleen Jarschke-Schultze

Homestead water-wizardry

67 **advertisers index**

68 **back page basics**

Ian Woofenden

Micro off-grid system design

14



Photos (clockwise, from opposite page, bottom right): MidNite Solar/Tommy Jacoby, Don & Kim Kelley, Suntactics, Mickey & Jennifer Janowski, Everett Community College

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Off-Grid, On-Grid, or Somewhere In Between

In a few, more-expensive utility districts, a milestone with its own buzzword has recently been reached: grid parity. That's the time when the cost of making your own electricity with a grid-tied PV system becomes as cheap—or cheaper—than what the utility charges. Without batteries, grid-tied system costs are low enough to justify rooftop solar electricity purely on an economic basis.

However, as grid-tied PV systems are becoming more popular, some utilities are starting to penalize them—charging higher electricity rates and higher monthly connection fees, and supporting legislation attempting to hobble net-metering programs. To some customers, grid defection—leaving the grid by installing batteries and a battery-based inverter with a PV array—is looking more attractive.

Some say the utilities are worried about grid defection—if it takes off, their economic hit could be huge. Others say that a critical mass of disconnecting customers will never happen—Americans are too accustomed to the seemingly endless electricity in a nearly effortless grid.

While significant grid defection isn't likely to happen anytime soon—it's too expensive to justify in most locations—historically, *Home Power* readers have been early adopters in making changes. Inexpensive, more user-friendly batteries

and the continued decreasing cost of PV systems may help drive change, too.

Instead of total defection, some utility customers are considering a middle road—load defection, which some folks define as picking and choosing appliances within the home to remove from grid power. This tactic is similar to the old “Take Your Bedroom Off the Grid” concept (*HP60* and *HP73*), where homeowners would isolate electrical circuits from the grid and install a stand-alone battery-based system to power those circuits, usually with a PV system.

Another, larger-scale means of defection is the concept of neighborhood microgrids. The technology is already developed that, in the future, could allow neighborhoods to disconnect from their existing energy providers and create localized energy distribution systems, with PV arrays on every rooftop and energy storage strategically distributed throughout the microgrid. Rules to separate electricity distribution ownership from centralized energy production are being considered by utilities and regulators, and what they allow and disallow will be key to the implementation of microgrids within utility territories.

—Michael Welch, for the *Home Power* crew

Think About It...

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—George Gobel

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Publisher

Richard Perez

Executive Editor & CEO

Joe Schwartz

Managing Editor

Claire Anderson

Art Director

Ben Root

Senior Editors

**Michael Welch,
Ian Woofenden**

Senior Technical Editor

Justine Sanchez

Building Technology Editor

Alex Wilson

Solar Thermal Editor

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**Kim Bowker,
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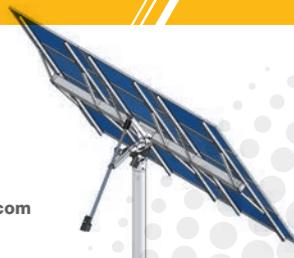
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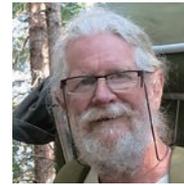
Author and educator **Dan Fink** has lived off the grid in the Northern Colorado mountains since 1991, 11 miles from the nearest power pole or phone line. He started installing off-grid systems in 1994, and is

an IREC Certified Instructor for both PV and Small Wind. His company, Buckville Energy Consulting, is an accredited Continuing Education Provider for NABCEP, IREC and ISPQ.



Ryan Mayfield is the principal at Renewable Energy Associates, a design, consulting, and educational firm in Corvallis, Oregon, with a focus on PV systems. He also teaches an online

course in conjunction with *SolarPro* magazine and HeatSpring.



Michael Welch, a Home Power senior editor, is a renewable energy devotee who celebrated his 25th year of involvement with the magazine in 2015. He lives in an off-grid home in a redwood forest in

Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.



Mickey Janowski (<https://wvhydro.wordpress.com>) is a retired builder, a union carpenter by trade, and a jack of all the others. When not chained to a raised organic garden bed by his wife Jennifer, he can be

found putting some kind of project together, like a big kid playing with his toys.



Chuck Marken is a *Home Power* contributing editor, licensed electrician, plumber/gas fitter, and HVAC contractor who has been installing, repairing, and servicing SWH and pool systems since 1979.

He has taught SWH classes and workshops throughout the United States for Sandia National Laboratories, Solar Energy International, and for many other schools and nonprofit organizations.



Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people power technologies. In addition

to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, lecturing, teaching, and consulting with homeowners.



Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with

him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.



Justine Sanchez is *Home Power's* principal technical editor. She's held NABCEP PV installer certification and is certified by ISPQ as an Affiliated Master Trainer in Photovoltaics. An instructor with Solar Energy

International since 1998, Justine leads PV Design courses and develops and updates curriculum. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.



Jeff Yago (pvforyou.com) is a licensed professional engineer and certified energy manager with more than 35 years of experience in the solar and emergency preparedness field.

He is also a NABCEP-certified PV installer and a licensed electrician. Jeff holds multiple patents for his product designs, and has authored numerous articles and texts.



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.



Patrick Snowden graduated from the University of Washington with a bachelor's degree in Science, Technology & the Environment and a minor in business. He is a NABCEP-certified

solar engineer and completed Solar Energy International's certificate program.



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.

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Courtesy Fronius USA

Fronius Primo

SnapINverter

Fronius (fronius-usa.com) is now manufacturing its line of Primo transformerless solar inverters, at its Portage, Indiana, facility. The Primo is part of the SnapINverter line, which has a hinged mounting system. The inverters are available in 3.8, 5.0, 6.0, 7.6, and 8.2 kW capacities. Their dual MPPT inputs allow them to maximize output in two separate module strings—for example in a system with eastern- and western-facing subarrays. The input voltage window spans 80 to 600 VDC, which allows flexibility in series-string lengths. Additional features include arc-fault circuit interruption; integrated Wi-Fi for data collection; and free lifetime monitoring through the Fronius Solar.web portal. Rapid shutdown capability, for *National Electrical Code (NEC) 2014* compatibility, can be added with the Fronius Rapid Shutdown Box (slated to be available this fall).

—Justine Sanchez

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—Brent & Erin Bibles, *Home Power Magazine*, 2015



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Courtesy MT Solar

MT Solar

Pole Mount

MT Solar (polemount.solar) offers a pole-mount system that is assembled at waist-level, then chain-hoisted to the desired height. This system is offered as a single pole mount (for two to 12 modules) or as a multipole system (stacking modules in a landscape orientation, three to four high). The pole mount uses top-clamp mounting hardware and heavy-duty rails from other solar racking companies. (MT Solar can supply rails if needed). The array tilt can be adjusted with a hand crank that's accessible from ground level.

—Justine Sanchez

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Courtesy Everett Community College

Everett Community College obtains grants to add solar energy

Everett Community College's (EvCC) Health Sciences building is filled with new labs and cutting-edge health-care equipment, but some of the most exciting technology is on the roof of the aptly named Liberty Hall. Thanks to grants from Snohomish County Public Utility District and Washington State, the college installed a 19.2 kW PV system in September 2013.

"Installing such a large solar array on a public building is an opportunity for the campus and the community to learn about the value of renewable energy," says Pat Sisneros, EvCC vice president of College Services. "Solar power reduces EvCC's carbon footprint and provides a functioning, hands-on example of a renewable energy system for students and staff to examine and discuss in class."

EvCC engineering students are studying the system as part of their class projects and information about the PV array is on public display in the building's first floor entryway. This display shows a lot of real-time data, including how much energy the system is generating.

Technical Details

The array was installed using ballasted roof mounts rather than bolted standoffs and racks like in a standard residential system. Liberty Hall's roof is flat and minimizing penetrations to the roof to avoid leaks was important. The array is oriented almost due south and tilted to 35° to maximize output during summer months at EvCC's high northern latitude (48° N). A low wall running along the perimeter of the roof conceals the array from the street below and adjacent structures, minimizing the risk of vandalism or theft.

EvCC's system is comprised of 80 240-watt PV modules and 40 microinverters wired into four-branch circuits that run into a combiner box. Each of the microinverters takes power from two modules and is wired into four circuits of 10 inverters each. The outdoor-rated combiner is equipped with a 200-amp main breaker and 30-amp breakers for each branch. From the rooftop combiner box, AC is run to the building's mechanical room, where the utility-installed production meter is located.

Overview

Project name: Everett Community College

System type: Batteryless grid-tied PV

Installer: Fire Mountain Solar

Date commissioned: September 2013

Location: Everett, Washington

Latitude: 48°N

Average daily peak sun-hours: 3.8

System capacity: 19.2 kW STC

Average annual production: 21,645 AC kWh

Equipment Specifications

PV modules: 80 Itek IT 240 W STC

Inverters: 40 APS microinverters, 500 W rated output (each)

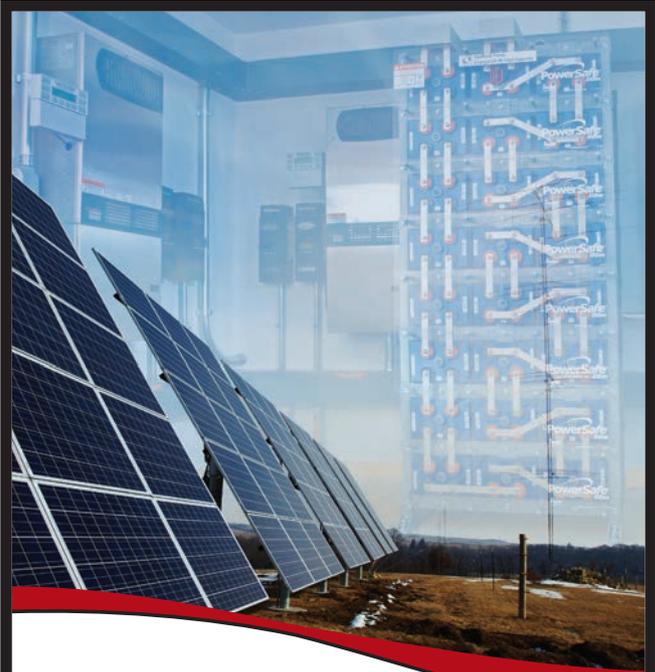
Array installation: DP&W ballasted roof mounts, south-facing, 35° tilt

Strong Incentives

Although Washington State has some of the most progressive solar energy incentives in the nation, EvCC couldn't take advantage of them because it receives the bulk of its funding from the state. Due to an error in the way the incentive law was written, many schools and colleges like EvCC cannot get the solar incentives given to other public institutions, even though that was the lawmakers' original intention. Instead, it receives the regular wholesale rate for the PV system's generation, which is about 8 cents per kWh. At this rate, the system payback period is very long.

Since the EvCC system components are made in Washington, if EvCC were allowed to take advantage of the incentives, it could capture about \$1.08 per kWh. This would reduce the payback period to about eight years. However, this system was never installed with the payback period as the major consideration. The main purpose for this array was to provide a hands-on example of a PV system to study and to lessen EvCC's carbon footprint. The state's incentive program is up for review this year and the legislature is working to resolve this problem so that schools and colleges can take advantage of these incentives.

—Patrick Snowden



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Smaller Systems

I read with interest the “Mailbox” letter from Paul Hoover in *HP164*. We are happy off-gridders since 1983 and *HP1*. Our independent (battery-based) PV system began with one 35 W module and grew to six 60 W and two 55 W (for water pumping) modules on a tracker. When we sold our first homestead and moved to our new home, we figured we were way overplanning by having twelve 110 W modules on a tracker! Yet, that system is dinky by today’s standards, and even now becoming a bit tight with our own energy use.

But to agree with Paul, living with a smaller system has its own built-in blessings. It’s self-educating regarding conservation. And it saves one’s budget and cost outlay requirements.

The only drawback we have encountered—and only recently—is the challenge of expanding our system. Way back, most systems looked more like the early versions of *Home Power*’s “Democracy Rack,” with

its three of this, five of that, and couple of another mix of modules. What we are now learning is that mixing different wattages of modules isn’t a good idea, since it seems to make all the modules operate at the power of the lowest-rated module. So if we are to add to our current system, we either have to find more 110-watt modules—which appear to be non-existent—or run separate wires from new modules to a separate charge controller. This is not an easy task for relatively small gain, due to distance and the need for buried conduit. And good luck with finding someone to sell you a “few odd modules”!

It’s this type of unanticipated surprise that has been put on the plates of off-gridders, and yet we have adjusted and grown over time. Again, I agree with Paul that small stand-alone systems are not as appreciated now that grid-tied systems have finally come into their own.

Katcha Sanderson •
Scott Valley, California

Passive Solar Design

It’s great to see new materials like climate-specific passive building standards as reviewed in the article “Passive Solar Design From a Passive House Perspective” by Katrin Klingenberg in *HP166*. I have two concerns, one important for designers, and the other more about language.

The important one is that fixed overhangs on south windows for controlling solar gain don’t work well in a passive solar house. Summer sun is high in the sky, so there is not a lot of energy hitting a vertical window anyway. Plus the sharp incidence angle causes less of the direct solar energy to pass through. So in the summer, even if you totally block the direct sun, you have not reduced the solar energy on the window a lot. Most of the solar gain in summer on a south-facing window comes from all over the sky and the light that is reflected off of the ground. An overhang does little to block these sources.

But if you did install an overhang of any projection greater than a foot or so, you can be sure that there are times that it will shade the window when you need heat. And as the sun is lower in the sky when heat is needed, blocking direct sun then is significant.

Windows facing south will need other forms of solar control than fixed overhangs—operable blinds, curtains, and/or shutters. These shading systems can also be designed to be insulating, so that they can reduce winter heat loss when placed at night. If you realize this, then a window designed to be “optimum” without moveable insulating systems will not be the best.

That is my second issue, use of the word “optimum,” especially in the context of home design. There are so many variables in the design and operation of a house—many of them unknown at the time of design—that any optimization process will always be incomplete and sub-optimal.

For example, design recommendations may be based on a 30-year life cycle cost analysis. That has to include a lot of assumptions, including mortgage rate, fuel escalation rate, and most important, discount rate. Why not the lifetime of the house instead of just 30 years? Design of a house can be done well, or it can be done poorly. The resulting design will never be optimal.

Andy Lau • Associate Professor of Engineering, Penn State University

continued on page 18



Courtesy Katcha Sanderson (2)



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- Marja Preston, Blue Frog Solar

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continued from page 16

Chevy Volt Charging

I've been charging my Chevy Volt with a grid-tied PV system since 2011. No matter how you calculate the economics, it's very satisfying in several ways:

- After all the ups and downs of the oil economy (not to mention our ongoing military entanglement in the Middle East), driving on locally harvested sun power really feels good.
- In areas with inexpensive grid power, the payback for a PV system can still be a fairly long time. Once you start competing with the cost of gas, the payback for charging your car with a PV system is much quicker.
- We've all learned to drive gently and accelerate slowly to conserve fuel—about the only way we can try to be sustainable with fossil fuels. But when you're driving on renewable energy, there is not quite the same need to drive so conservatively. In fact, I can see no reason not to have fun driving again, and indulge in the occasional spirited acceleration. My Volt won't burn rubber, but it will come pretty close!

J. Corning • via homepower.com

Grounding Concepts

On page 37 of *HP166*, there is a highlighted box talking about equipment grounding. An important distinction needs to be pointed out: Electricity does not go to earth, it goes back to its source. Yes, equipment grounds are bonded to the grounding electrode at the service entrance, but they are also bonded to the grounded conductor or neutral at the service entrance via the main bonding jumper. The grounding electrode or ground rod in this case serves a number of purposes, but it is not to clear a ground fault.

When a ground fault occurs, it gets back to its source through an effective ground-fault current path (properly done equipment grounding), through the neutral at the service to its source, and then trips the breaker on the faulted circuit, thus stopping flow of electricity and preventing non-current-carrying metal parts from being a shock hazard. Earth is never an effective ground-fault current path. Even if a ground rod has 25-ohm resistance to ground (which is rare), you would get 4.8 A—nowhere near enough to open a circuit breaker on a 15 A branch circuit to clear a fault.

In the case mentioned in the article, on the DC side, all non-current-carrying metal parts

on the array would still be a shock hazard, even if the inverter were turned off by the ground fault, until a technician finds and fixes the fault on the array. I think these distinctions are important to point out. Thanks for a great magazine—I enjoy it immensely.

Steven Johnson • Tucson, Arizona

Thanks so much for your letter. You are absolutely correct. The last part of that sidebar should have instead stated: "Equipment grounding ensures metallic objects in an electrical system are at the same voltage potential (earth) and thus is a safety measure to reduce shock hazards. Additionally, should a ground fault occur—unintentional electricity flowing, for example, to a module frame due to a nicked wire—the electricity has a pathway back to the ground-fault protection device (GFPD) so it can interrupt the flow of fault current and keep the system non-operational until the source of the fault has been corrected." The html version on our website and the downloadable PDF have been corrected.

Justine Sanchez • Home Power Senior Technical Editor
continued on page 20

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continued from page 18

Hydro Article Concerns

I have for many years tried to lift the quality of domestic-scale hydro turbine installations to ensure that they are safe and compliant with national standards and codes and generally follow best global practices. I am somewhat appalled by seven serious issues in the "Working, Playing and Living with Renewable Energy" article published in *Home Power's* May/June 2015 issue.

- The turbine's magnetic rotor is not covered and is a rotational hazard.
- Lacquer copper wire is not classed as insulation for touch safety. Exposed copper stator wire is clearly visible and could be touched when operating.
- The resistive diversion element is bolted to a plywood wall without any heat shield. This is a fire hazard and not allowed under U.S. standards/codes.
- According to the wiring diagram, the metal turbine body has no earth connection and, under a fault condition, could become a shock hazard. As the turbine is mounted on a plywood cover, it appears to have no earth connection.
- The photo on page 63 shows a red positive wire to the TriStar TS45 and a green (assumed to be the negative, as there is no other wire) to the TS45. Green wire cannot be used for negative connections.
- The TS45 is not wired per the manufacturer's advice. If the fused disconnect was opened while the turbine was running (or the fuse was to blow), the TS45 would be damaged by overvoltage.
- To comply with the intent of the *National Electrical Code*, hydroelectric systems using a diversion controller should be equipped with a second independent means of charge control to prevent overcharging the battery in the event of a component failure.

We all make the odd error; I am sure my home system has a few. However, to publish an article in *Home Power* that does not red-flag these installation issues is rather reckless. I hope you take action so that your readers do not assume such insulation practices are safe and code-compliant.

Michael Lawley • via email

Home Power takes safety very seriously. We admittedly dropped the ball in this instance. Our editorial crew enjoyed the homesteading history of the story and the authors' commitment to renewable energy. The system in question is owner-installed and has evolved over the years. While it performs reliably and efficiently, we overlooked important safety and code-compliance issues during the article's development. We'll redouble our efforts to catch issues like this prior to publication.

Joe Schwartz •
Home Power Executive Editor

write to:

mailbox@homepower.com

or Mailbox, c/o Home Power
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Module Efficiency

Where can I buy PV cells with a higher efficiency than 18%? I'm searching online, but I have not been able to find anything.

Raymond Collins • via email

We're used to looking at the efficiency of appliances, and generally, the more efficient the appliance is, the better. But for solar-electric modules, that is not necessarily the case. While that 18% efficient module might look pretty slick, it might not be the best for your situation, and may be appropriate only when mounting space is limited. Let's look at some possibilities:

The cheapest option is not using the least-expensive and least-efficient *modules*. In fact, those modules have the highest installation cost (more modules, more rack, and more installation time per rated watt). In this scenario, unless space is at a premium, it's also not worth it to buy the highest-efficiency modules—they actually cost more to get the same amount of energy than either of the less-efficient options.

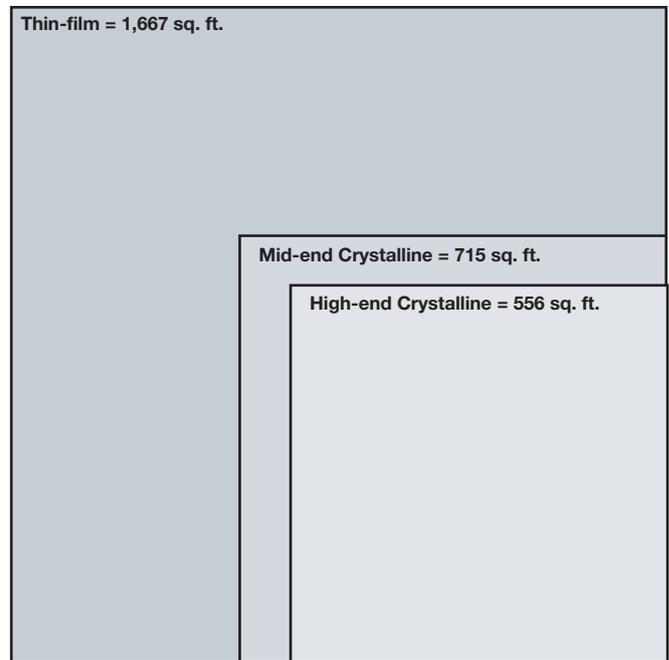
Another assumption that many people have—incorrectly, much of the time—is that they should install the highest-wattage modules available on their roof. For example, one installer might bid with 280 W modules, but another specifies 320 W modules. A higher-wattage PV module may or may not be suitable for your project. Those 320 W modules might also have a higher efficiency (reducing array size, but perhaps increasing array cost). Or maybe they have the same efficiency, but are just a larger module (possibly increasing labor costs due to being heavier, or reducing labor costs due to fewer modules being needed).

Module Efficiency Cost Comparison (10 kW)

Module	Rated Efficiency (W per Ft. ²)	Array Size (Ft. ²)	Cost per Rated W	Total PV Cost*	Racks & Installation Cost	Total Array Cost
Thin-film	6	1,667	\$0.70	\$7,000	\$6,668	\$13,668
Mid-end crystalline	14	714	0.95	9,500	2,856	12,356
High-end crystalline	18	556	1.40	14,000	2,224	16,224

*Balance-of-system components not included in these estimates.

PV Array Area (10 kW)



And at the end of the day, the number that you, as a homeowner, care about is usually how much will it cost to fit the amount of rated power you want on your roof (or in your yard). This number is affected by the efficiency of the modules, but there are a lot of other variables that go into arriving at that final number, too, so don't get hung up on looking just at the efficiency or power rating of the modules.

Zeke Yewdall • Mile Hi Solar

Solar Hot Water Collector Configuration

I'd like to mount my two 4-by-10-foot used solar water heating collectors in landscape orientation on my roof. While I've always assumed the larger pipes to be at the top and bottom on a collector, and the smaller tubes to run vertically, is there actually any reason that these collectors can't be mounted with the smaller tubes running horizontally? Assuming that they're plumbed in opposite corners, and I'm using a pump, does it matter if I'm collecting heat while the water is moving vertically or horizontally? Or do I need to get collectors designed with headers along the long axis and short risers for landscape mounting?

James Root • Redmond, Oregon

If this is an antifreeze system, the collectors will work fine in the landscape orientation. They will also efficiently produce hot water in a drainback system, but can cause future problems. After years of use, the smaller riser tubes may not have the structural integrity to withstand the

force of gravity. Most of the small tubes sag over time; this can create a "trap" that holds water and can cause freeze breaks in the tubing in the winter. Some manufacturers specifically exclude landscape drainback systems from their factory warranty due to the "tube sag" possibility. If you mount the collectors at a more radical tilt angle, like 20° to 30° from the horizontal, it will probably be enough to offset any future tube sag.

If you live in an area that requires adherence to Solar Rating and Certification Corporation standard 300 to be eligible for state, local, or utility incentives, your mounting strategy might be problematic. In this case, the manufacturers' instructions must be followed closely, including mounting orientations. However, this probably won't be the case with your used collectors since most, if not all, incentive programs require new equipment for incentive eligibility.

Chuck Marken • Home Power solar thermal editor

continued on page 24



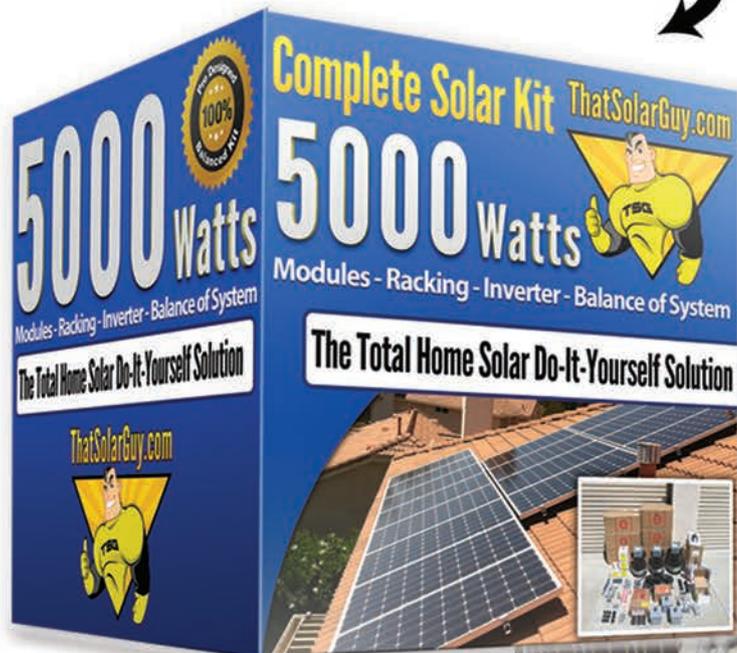
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continued from page 22

Cleaning PV Modules

My PV array is three years old and needs cleaning—I can see dirt/film on the modules and we've not had enough rain to wash them off. Plus, module output is down, according to the inverter's data. What chemicals or detergents can I use to clean the array?

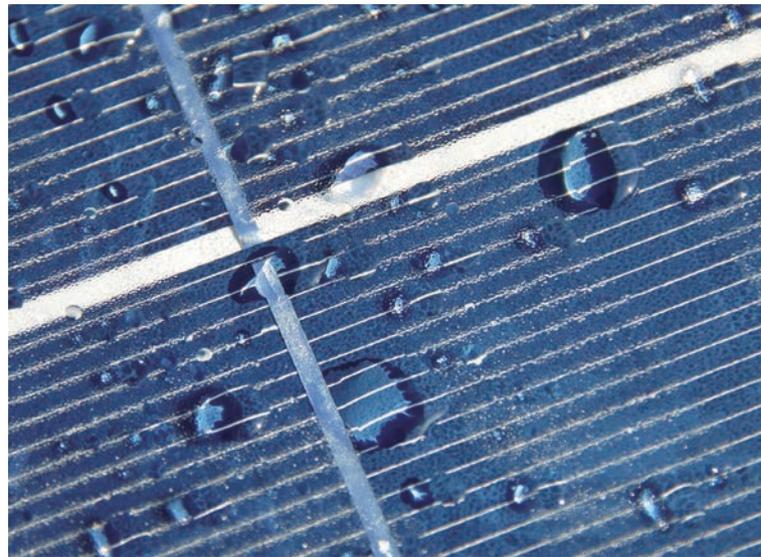
Dan White • Cat Spring, Texas

Cleaning modules in large commercial arrays is done based on a cost-benefit analysis that compares cleaning costs with the revenue increase that results from the improved array output. Most residential and small commercial users want their array to perform optimally all the time, and may therefore clean them more often than commercial arrays are cleaned.

Either way, cleaning should be done per manufacturer's instructions. For example, SolarWorld's publication, *Quick Guide for Users*, states: "Given a sufficient tilt (at least 15°), it is generally not necessary to clean the modules (rainfall will have a self-cleaning effect). In case of heavy soiling, we recommend cleaning the modules using plenty of water (from a hose), without any cleaning agents and using a gentle cleaning implement (a sponge). Dirt must never be scraped or rubbed away when dry, as this may cause micro-scratches."

Cleaning arrays can be dangerous. Clean the modules with a hose and a soft cloth if you can access them from the ground. Do this only when the modules are cool—early morning, on cloudy days, or in the evening after they have cooled. If you need to climb a structure to access the modules, use appropriate safety gear—full-body harnesses adequately secured are OSHA requirements when working more than 6 feet off the ground.

If you have hard water, be sure to squeegee off the rinse water so you don't leave mineral deposits on the glass. If you have oily or greasy stains on the modules (these can occur if the array is near roads or airports), isopropyl alcohol can be used to spot-clean stained areas. Most manufacturers do not recommend using anything other than water for general cleaning; do not use soaps, solvents, or other cleaning products.



©istockphoto.com/ Marina Lohrbach

Many people use pressure washers to clean their arrays. Manufacturers that include instructions for using pressure washers indicate that the pressure used should be less than 80 psi.

For reaching large arrays and roof-mounted PV modules, lightweight telescopic poles are available with squeegee and other cleaning attachments. Novel cleaning products claim to help keep modules from getting dirty, but with water working for most cleaning and alcohol available for tough stains, additional products are not necessary.

If you are cleaning your modules because of output degradation, it is a good idea to check the electrical connections as well. It's also a great time to check the mechanical connections.

Christopher LaForge • Great Northern Solar

Transformer for Well Pump

I have a step-up transformer that I want to use to power my 240 V well pump from my 120 V inverter. Does a transformer use energy if the output is not being used? Should I interrupt the input or the output from the transformer to control the well?

J. Oliver • via email

All transformers use some energy when connected but sitting idle. The energy is consumed by magnetizing the windings. The amount used depends on the transformer type and size.

Step-up transformers specifically designed for renewable energy systems (and often for exactly the purpose you are describing) are usually of the "autotransformer" type, where the primary and secondary coils are shared. This gives a smaller, lighter, and more affordable transformer, and offers some efficiency gains, too.

For example, the OutBack Power PSX-240 autotransformer has a no-load draw of about 10 watts. That's a minor "phantom load" for medium to large systems, but it would be enough to keep an inverter

out of "search" mode, potentially adding to the phantom load. A two-winding transformer would have a higher draw at idle.

Installing an extra circuit breaker and/or disconnect switch for your well pump transformer could indeed save energy, and also give you the flexibility to isolate that load and phantom load whenever needed. If your well-pumping system includes water storage and allows you to choose sunny days with extra energy coming in to use for pumping, all the better. This sort of "load shifting" is a common tactic in off-grid living, sparing your battery bank from heavy loads when no renewable energy is being generated.

Well-pumping systems without storage are more problematic, as the heavy load of the well pump could activate any time you open a faucet or jump in the shower—even if the state-of-charge of your battery bank is very low. This can cause dimming lights or possibly a temporary inverter shutdown, and is very tough on the battery bank, inverter, and pump. A small pressure pump feeding your house from a tank, on the other hand, is a small load easily handled no matter what the time of day.

continued on page 26

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continued from page 24



Courtesy OutBack Power Systems

OutBack Power's PSX-240 step-up autotransformer.

Smaller off-grid systems often do not include 240-volt output from the inverter—in the past that required “stacking” two 120-volt inverters through a special interface cable, at double the inverter cost. That has been changing, though—all the major battery-based inverter manufacturers now offer combined 120/240-volt inverters.

There is always the option of replacing an older 240-volt well pump with a “soft-start” 120- or 240-volt version that reduces the startup surge current—which can be three to four times the actual pump running current. However, well pump replacement is an expensive proposition and not well-suited for do-it-yourself due to the special equipment and knowledge required for working with a pump installed hundreds of feet below-ground. There are also new

retrofit pump controllers that can help almost any old well pump start with less surge. They are expensive, but still far cheaper than a well-maintenance truck, crew, and pump replacement. Ask your local RE system dealer for recommendations, and more importantly, references from happy customers.

For your situation, it's easy to test the phantom load of a transformer. Just power it up, make sure the well pump is off, and use a clamp-on multimeter to measure the no-load current on the primary side. Multiply that amperage by 120 volts to calculate the approximate wattage the transformer uses at idle.

It's not difficult to add a relay that disconnects the transformer's phantom load when your well pump is not in use, and you could even use an AUX output from other equipment to disable the well pump when your battery state of charge is low, but still allow your home pressure pump to function.

Dan Fink • Buckville Energy

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The MidNite Solar Rapid Shutdown System is a firefighter and homeowner's safety control system. This system has been designed to disconnect and isolate power from the PV panels, batteries, inverters and generators on any PV configuration.

Available in Red or Gray

In case of an emergency, or for routine maintenance, pushing the large red button of the Birdhouse sends a signal to all disconnecting modules and then returns feedback that they actually are disconnected. MidNite's Rapid Shutdown system is the only system that provides visual and audible confirmation that power has been disconnected.

The Birdhouse's LEDs display the system status based on hard wired feedback and automated speech gives further situation specific information.

The Birdhouse is UL 1741 listed 



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Portable PV

by Jeff Yago



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this article @
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Portable PV products allow you to take your technology—smartphone, tablet, laptop, and digital camera—and keep it functioning almost anywhere. Whether you want an inexpensive safeguard against power outages for your small electronics or want to keep your handheld GPS charged during an extended trek through the wilderness, these goods can fill the bill.

Jeff Yago

The portable solar market has exploded with a large selection of sizes, colors, and shapes. This article separates these portable solar products into five categories based on size and function:

- Handheld solar chargers
- Fold-up solar chargers
- Solar backpacks, briefcases, and handbags
- Solar carts and solar generators
- Trailer-mounted solar power systems

Power Traveller PowerMonkey Extreme

Solar power rating: 3 W
Battery capacity: 33 Wh (9 Ah)
Price: \$184
Weight: 2.4 lbs. (total)
Size: 6 × 2.3 × 1.1 in. (extreme unit);
 6.7 × 3.5 × 0.7 in. (solar, folded)
Warranty: 1 yr.
Charge connection: USB port;
 12 VDC outlet
Compatibility: Small electronics



Power in the Palm of Your Hand

There are many pocket-sized solar chargers to choose from, and some are built into the protective cases for phones and tablet computers, making them readily accessible. Although physically small, they can generate several watts of charging power, which can easily recharge a cellphone, LED flashlight, or small radio.

While these handheld solar chargers may be similar in size, there is a wide price range due to different solar technologies being used to increase performance and durability. Be sure to note voltage and power ratings when comparing different brands that may appear to be the same physical size.

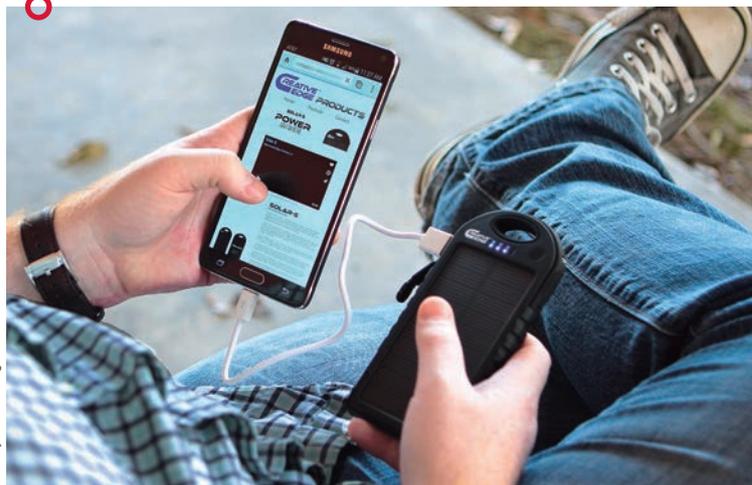
Typical Appliance Power Requirements

Appliance	Power (Watts)	Measured 12 V Battery Draw (Amps)*
DVD player	4	0.38
Cell phone charger	4	0.38
Radio	5	0.48
Light, 7 W LED	7	0.67
Tablet computer	11	1.06
Satellite receiver (off = 13 W)	15	1.44
Printer, inkjet (idle = 2 W)	15	1.44
Light, 13 W CFL	15	1.44
Computer monitor, LCD	22	2.10
Light, 25 W CFL	27	2.59
Laptop computer	34	3.26
TV, 21 in. LCD	38	3.70
Battery charger, drill	62	5.90
Light, incandescent	75	7.20
Wood heater blower	90	8.60
Light, incandescent	100	9.60
Fridge/freezer, 19 c.f. (peak = 300 W)	125	11.90
Desktop computer (idle = 85 W)	140	13.40
PA amplifier, 300 W	150	14.40
Computer projector (idle = 16 W)	260	24.90
Well pump, 1/2 hp (surge = 1.1 kW)	535	51.30
Hair dryer	745	71.40
Microwave, compact	1,030	98.70
Coffee maker, drip	1,070	102.50
Microwave, standard	1,350	129.40

*Assumes 15% losses through inverter supplying 120 VAC power from a 12 VDC battery. This table originally appeared in "Solar on the Go" in HP149.

Creative Edge Products Solar-5

Solar power rating: 1.2 W
Price: \$99.99
Weight: 5.3 oz.
Size: 5.6 × 3 × 0.5 in.
Warranty: 1 yr.
Charge connection: Built-in USB outlets
Compatibility: Smartphones & most USB-charged devices





Courtesy Solar Joos

SolarJOOS

JOOS Orange (v.2)

Solar power rating: 2.6 W

Battery capacity: 20 Wh (5.4 Ah)

Price: \$149

Weight: 1.5 lbs.

Size: 8.58 × 5.77 × 0.79 in.

Warranty: 1 yr.

Charge connection: USB ports

Compatibility: Small electronics (USB & mini-USB-compatible)

Secur

SP-3011 Solar Power Pad 3000

Power rating: 3.3 W

Price: \$69.99

Weight: 8.7 oz.

Size: 5.875 × 7.5 × 0.65 in.

Warranty: 1 yr.

Charge connection: USB port

Compatibility: Small electronics

Courtesy Secur



Fold-Up Solar Chargers

In the past, few portable solar chargers included internal battery storage. Fold-up solar chargers included a flexible PV module and adapters for connection to any small electronic device. The majority of these fold-out solar chargers have a 5- to 25-watt rating, although higher-wattage models are available that can power a laptop computer or portable communication equipment during camping trips into remote areas.

With recent advances in battery technology, many fold-out and pocket-size solar chargers now include a built-in battery. Although fairly small and lightweight, these lithium iron phosphate (LiFePO₄) batteries can store an amazing amount of power. Once full, the built-in battery can recharge your electronic devices regardless of solar access.



Courtesy Aspect Solar

Aspect Solar

Solar Power Pack 60-300

Solar power rating: 60 W

Battery capacity: 295 Wh

Inverter power rating: 200 W

Price: \$999.99

Module weight: 7.5 lbs.

Battery/Inverter weight: 12 lbs.

Module size: 17.72 × 12.60 × 1.97 in. (folded); 17.72 × 37.99 × 12.80 in. (deployed)

Battery/Inverter size: 2.25 × 16.13 × 9.63 in.

Warranty: 5 yrs.

Charge connection: USB ports; 120 VAC outlet; 12 VDC outlet

Includes: EnergyBar 300 battery/inverter pack, EP-60 PV modules, DC-154 charging adapter

Also make: SunSocket Solar Generator, \$1999.99

Enerplex

Kickr IV

Solar power rating: 6.5 W
Price: \$129.99
Weight: 0.6 lbs.
Size: 8.8 × 7.3 × 0.71 in. (folded); 30.5 × 7.3 × 0.08 (deployed)
Warranty: 1 yr.
Charge connection: USB port
Compatibility: Portable electronics



Courtesy Enerplex

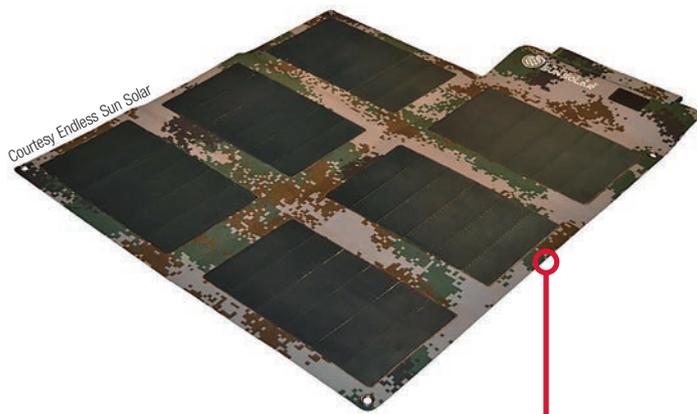
Goal Zero

Venture 30 Solar Recharging Kit

Solar power rating: 7 W
Battery capacity: 30 Wh (7.8 Ah)
Price: \$169.95
Weight: 1.5 lbs.
Module size: 9 × 6.5 × 1.5 in. (folded); 9 × 17 × 0.5 in (deployed)
Battery size: 4.5 × 3.25 × 1 in.
Warranty: 1 yr.
Charge connection: USB ports
Compatibility: Portable electronics



Courtesy Goal Zero



Courtesy Endless Sun Solar

Endless Sun Solar

Apollo 36

Solar power rating: 36 W
Price: \$499.95
Weight: 1.98 lbs.
Size: 12.6 × 8.5 × 1.6 in. (folded); 30.7 × 24.8 in. (deployed)
Warranty: 1 yr.
Charge connection: 5-piece accessory kit
Compatibility: Laptop, radios, 12 V batteries, other electronics

Courtesy P3 Solar



P3Solar

SunLinq 6

Solar power rating: 30 W
Price: \$195
Weight: 1.8 lbs.
Size: 21.5 × 44.5 × 0.1 in. (deployed); 8.5 × 10.5 × 1.2 in. (folded)
Warranty: 1 yr.
Charge connection: SAE (adaptors sold separately)
Compatibility: Small electronics; vehicle batteries

Strongvolt

Solar:7

Solar power rating: 7 W

Price: \$79.99

Weight: 12 ounces

Size: 19 x 7.25 x 0.25 in. (deployed)

Connections: USB

Compatibility: Smartphones, GPS, eReaders



Courtesy Strongvolt



Courtesy SunJack

SunJack

SunJack 14 W + 8,000 mAh Battery

Solar power rating: 14 W

Battery capacity: 8 Ah

Price: \$150

Weight: 2 lbs.

Size: 6.75 x 9.25 x 1.75 in. (folded); 30.75 x 9.25 x 1.75 in. (deployed)

Warranty: 1 yr.

Charge connection: USB port

Compatibility: Electronics; small appliances

Sol Pro

Helios Smart

Solar power rating: 4.86 W

Battery capacity: 18.5 Wh (5 Ah)

Price: \$119.99

Weight: 0.63 lbs.

Size: 5.1 x 3.15 x 0.79 in. (folded);

5.1 x 11.0 x 0.63 in. (deployed)

Warranty: 1 yr.

Charge connection: USB port

Compatibility: Small electronics



Courtesy Sol Pro

Suntactics

sCharger-8*

Solar power rating: 8 W

Price: \$159.95

Weight: 1.1 lbs.

Size: 7.7 x 7.1 x 2 in. (folded); 7.7 x 14.6 in. (deployed)

Warranty: 5 yr.

Charge connection: USB

Compatibility: Small electronics

*sCharger-5 pictured



Courtesy Suntactics

Solar Backpacks, Briefcases & Handbags

Portable options from book bags to military-grade backpacks are available with a built-in flexible solar module. Larger backpacks include lightweight, powerful batteries and some models have a small inverter to power 120-volt AC devices. Not only are more handbags and purses available with a flexible solar module, but they are available in different designs and colors.



Courtesy Eclipse Solar Gear

BirkSun Boost Solar Backpack

Solar power rating: 3 W
Price: \$100
Weight: 2.3 lbs.
Size: 18 × 12.5 × 5 in. (backpack)
Warranty: 1 yr.
Charge connection: Built-in USB outlet
Compatibility: Smartphones & USB devices



Courtesy BirkSun

Eclipse Solar Gear Slingshot Solar Sling Bag

Solar power rating: 4 W
Price: \$179.99
Weight: 3 lbs.
Size: 18 × 10 × 6 in.
Warranty: 1 yr.
Charge connection: Built-in USB outlet
Compatibility: Smartphones & most USB-charged devices

Mobile Battery Technology

The larger Li-ion batteries commonly found in manufactured EVs are not yet economical for large trailer-mounted battery banks. Li-ion is mostly used by manufacturers of smaller cart-mounted and hand-held PV chargers.

There are different types of lithium batteries in development, but the safest and most reliable are lithium iron phosphate (LiFePO₄). These batteries have a long cycle life and do not have the sulfation problems that plague lead-acid batteries. LiFePO₄ batteries can also be recharged

much faster than a typical lead-based AGM or gel battery, since they can take the full charger output throughout the entire charging process, while a lead-acid battery requires a tapered-off voltage as the battery fills.

The drawback to most lithium-based batteries is that they require a battery management system, although this is often built into the battery. This balances the charge level on a per-cell basis, and protects the battery from overheating. In addition, lithium-based batteries are still fairly expensive, especially in larger sizes.

Solar Carts & Cases

The wheeled or cart-mounted PV systems commonly referred to as “solar generators” have experienced significant size and weight reduction thanks to new battery technology.

Some include fold-out solar modules, and higher-power units may include detachable or stand-alone PV modules with plug-in connectors. Some solar cart models include status displays and the ability to recharge the internal battery from solar or other sources. Most solar carts include one or more 120-volt AC outlets, USB-style 5-volt DC ports, and 12-volt DC “cigar lighter”-style outlets.

These wheeled units can provide energy for compact fluorescent and LED light fixtures, recharge multiple phones, and keep your laptop computer, digital television, and satellite system operating during a temporary utility outage.

While larger models may have the inverter capacity for large loads like a refrigerator, well pump, microwave oven, or electric coffee pot, the capacity of the battery may not be able to do that for very long.

For example, a 100 amp-hour, 12-volt battery may sound like a significant amount of backup but consider this: a typical refrigerator may draw only 5 amps at 120 VAC during compressor cycling, but this translates into a 50 A draw on any 12 VDC battery, not including the additional inverter efficiency losses. That translates to running the fridge for only one hour at a 50% target depth-of-discharge.

Keep in mind the actual run time for larger appliance loads will be measured in hours, not days, for these carts. The amp-hour specification for lead-acid batteries should be reduced by half when estimating appliance run time, as these batteries should not be discharged below 50% or their life expectancy will be significantly shortened. More expensive systems that use the latest lithium battery technology will offer many more cycles if the depth of discharge is limited to 80% or less. Battery technology type should be considered when comparing portable power systems having the same capacity.

Courtesy Sunnr



Sunnr

Sun110

Solar power rating: 280 W

Battery capacity: 2,940 Wh (245 Ah)

Inverter power rating: 3,500 W

Price: \$4,350

Module weight: 55 lbs. (total)

Sun110 chassis weight: 260 lbs.

Module size: 59.1" × 53" × 1.8" (deployed)

Warranty: 1 yr.

Charge connection: 12 V DC outlet; four 120 VAC outlets

Compatibility: Electronics; small appliances

Portable Solar Power

LFP 40V3 with 120 W panel

Solar power rating: 120 W

Battery capacity: 512 Wh (40 Ah)

Inverter power rating: 640 W

Price: \$2,945

Module weight: 27 lbs.

LFP 40V3 weight: 19.6 lbs.

Module size: 33 × 23 × 3 in. (folded); 33 × 46 × 1.5 in. (deployed)

LFP 40V3 size: 13.37 × 11.62 × 6 in.

Charge connection: two 12 VDC outlets; two 120 VAC outlets

Compatibility: Electronics; small appliances



Courtesy Portable Solar Power

JASpak

JASpak 520

Solar power rating: 520 W

Battery capacity: 1,836 Wh (153 Ah)

Inverter power rating: 1,100 W

Price: \$4,949

Module weight: 80 lbs.

JASpak weight: 150 lbs.

Module size: 65.1 × 38.7 × 1.6 in. (folded), 65.1 × 78 × 1.6 in. (deployed)

JASpak Size: 23 × 18 × 13 in.

Warranty: 1 yr.

Charge connection: USB ports; four 120 VAC outlets; two 12 VDC outlets

Compatibility: Larger electronics/tools/appliances (limited)



Courtesy JASpak

Sol-Solutions

SolMan Classic

Solar power rating: 420 W (with two panel extension)

Battery capacity: 3,000 Wh

Inverter power rating: 1,500 W

Price: \$5,295

Weight: 310 lbs.

Size: 50 × 33 × 43 in. (folded); 50 × 87 × 43 in. (deployed)

Warranty: 10 yrs. for PV module

Charge connection: two 12 VDC outlets; four 120 VAC outlets

Compatibility: Electronics; small appliances



Courtesy Sol-Solutions

Courtesy SunReady Power



SunReady Power

SunCase SR16

Solar power rating: 16 W

Battery capacity: 115 Wh (9 Ah)

Price: \$795

Weight: 14 lbs.

Size: 13.5 × 9.8 × 6 in.

Warranty: 1 yr.

Charge connection: two USB ports; one 12 VDC outlet

Compatibility: Electronics; small appliances

Solar Trailers

There are few solar trailer manufacturers, but the features and performance of these systems have increased significantly. The smaller single-axle units typically include PV arrays in the 1 to 2 kW range, and can be towed behind an SUV. However, the larger dual-axle units have much larger PV arrays with heavier battery banks, and require a mid-sized truck to tow.

These systems can be expensive, and are typically sold or leased to government agencies for disaster response. PV trailers are also sometimes used in broadcast and entertainment situations when a noisy generator would be a problem.

In addition to large fold-out solar arrays, they often include a backup generator. The generator is used to recharge the battery bank or cover large power demands. The more sun-hours available, the fewer hours the generator is required to run to recharge the batteries.



Courtesy Greentow

Greentow GT916 Trailer

- Solar power rating:** 1,620 W
- Battery capacity:** 12,384 Wh (258 Ah)
- Inverter power rating:** 6,000 W
- Price:** \$49,900
- Weight:** 3,300 lbs.
- Size:** 9 × 5.8 × 6 ft.
- Warranty:** 20 yrs. (modules)
- Charge connection:** AC and DC outlets
- Compatibility:** Larger electronics/tools/appliances (limited)

Courtesy Mobile Solar Power



Mobile Solar Power MS-375 Solar Power Trailer

- Solar power rating:** 4,000 W
- Battery capacity:** 40,000 Wh
- Inverter power rating:** 7,000 W
- Price:** not specified
- Weight:** 10,000 lbs.
- Size:** 6 × 20 ft. trailer
- Warranty:** 5 yrs. (overall); 20-25 yrs. (modules)
- Charge connection:** AC outlets
- Compatibility:** Electronics, tools, appliances (limited)

Courtesy National Solar Technologies



National Solar Technologies Custom Dual Axle Midsize Trailer

- Solar power rating:** Varies by design
- Battery capacity:** Varies by design
- Inverter power rating:** Varies by design
- Price:** Depends on design
- Size:** 6 × 16 ft. trailer
- Charge connection:** AC outlets
- Compatibility:** Electronics, tools, appliances (limited)

Solar On-the-Go Products

Company	URL	Handheld Chargers	Fold-Up Chargers	Bags, Packs, Etc.	Carts & Cases	Vehicle Trailers
Aspect Solar	aspectsolar.com	✓	✓			
BirkSun	birksun.com		✓	✓		
Brunton	brunton.com	✓	✓			
Creative Edge Products	credgepro.com	✓	✓			
Eclipse Solar Gear	eclipsesolaregear.com			✓	✓	
Ecowatt	ecowatt.com			✓		
Endless Sun Solar	endlessunsolar.com		✓			
EnerPlex	goenerplex.com	✓	✓	✓		
Global Solar Energy	globalsolar.com		✓			
Goal Zero	goalzero.com	✓	✓		✓	
GoGreen Chargers	gogreenchargers.com	✓				
GreenTow	greentow.com					✓
Humless	humless.com				✓	
JASPAk	jaspak.com				✓	
Mobile Solar	mobilesolarpower.net					✓
National Solar Techn.	nstsolar.com					✓
P3Solar	p3solar.com		✓			
Patriot Solar	patriotsolargroup.com					✓
Portable Solar Power	portablesolarpower.biz		✓		✓	
Powerenz	powerenz.com		✓	✓		
PowerFilm Solar	powerfilmsolar.com		✓			
Powertraveller	powertraveller.com	✓	✓			
Secur	securproducts.com	✓	✓			
Solar Charge Bags	solarchargebags.com			✓		
Solar JOOS	solarjoos.com	✓				
Solio	solio.com	✓	✓			
Solpro	solpro.com	✓	✓			
SolSolutions	sol-solutions.com				✓	
Solutions from Science	mysolarbackup.com				✓	
Strongvolt	strongvolt.com			✓		
SunJack	sunjack.com		✓			
SunReady Power	sunreadypower.com				✓	
Sunrnr	sunrnr.com				✓	
Suntactics	suntactics.com		✓			
Voltaic	voltaicsystems.com		✓	✓		

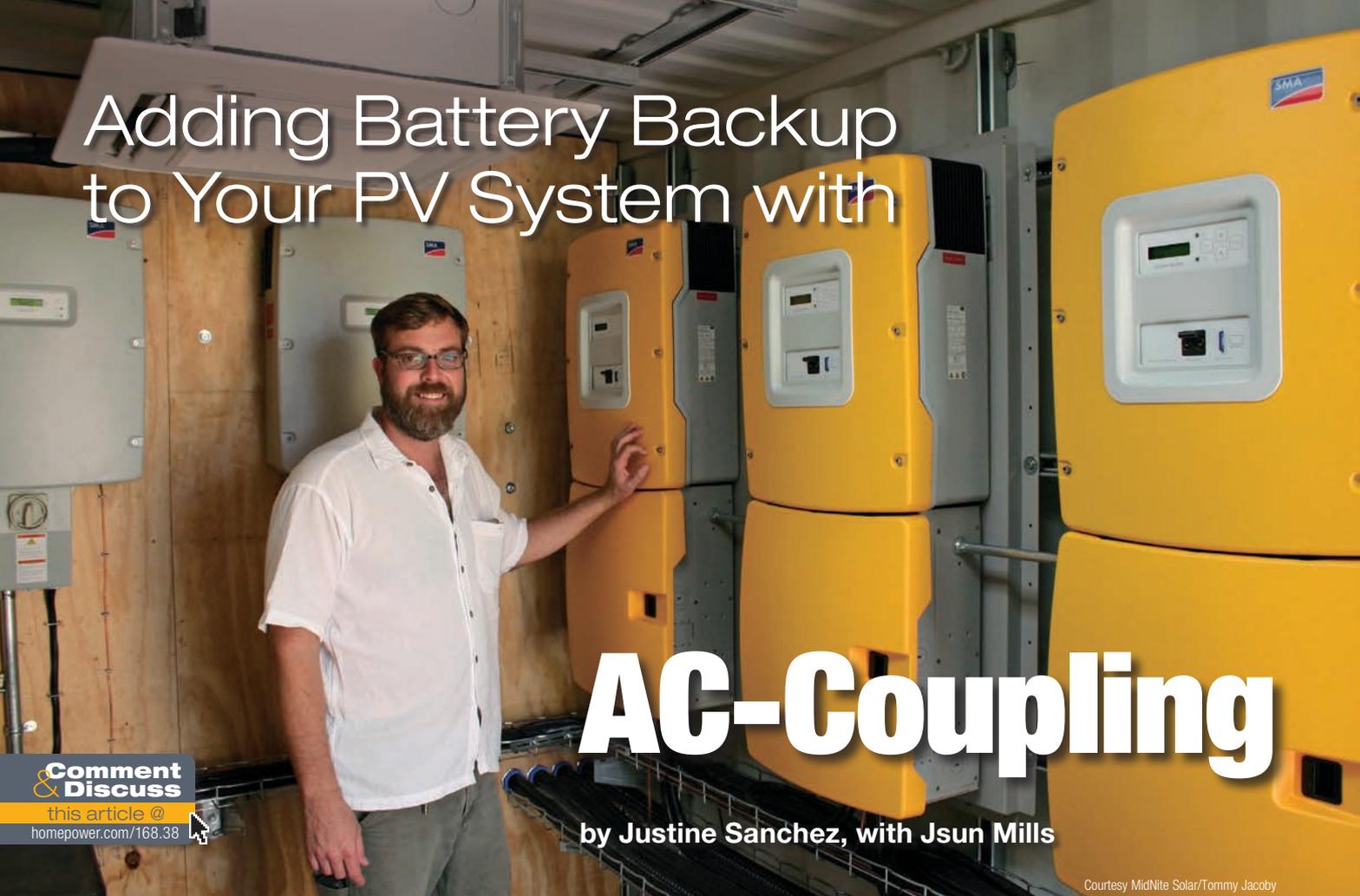
What's Right for You

The table is your first step in finding the portable solar charger for your needs. Be sure to compare more than just price—solar power ratings and battery amp-hour capacity can vary significantly.

I own several portable solar chargers, and my biggest complaint is the accessories required to connect to my

devices. A handheld or fold-out solar charger is fairly small and easy to store. But including all the connecting cables and plug adapters (which can easily get lost!) makes storage, like a bag, important. It would help if all the manufacturers would standardize on one charger plug. In the meantime, I'm looking for a fold-out solar charger that has a built-in cable and a place to stow the multiple plug adapters. ☀️

Adding Battery Backup to Your PV System with



AC-Coupling

by Justine Sanchez, with Jsun Mills

Comment & Discuss

this article @
homepower.com/168.38

Courtesy MidNite Solar/Tommy Jacoby

Batteryless grid-tied PV (GT PV) systems are affordable, efficient, and simpler than their battery-based counterparts. But when the grid goes down, the system goes offline, leaving the homeowner without electricity. Fortunately, there are solutions for those who don't want their electricity access disrupted by utility outages.

There are two different approaches to integrating battery backup into an existing GT PV system—DC-coupling or AC-coupling. Both involve adding a battery bank and a battery-based inverter-charger; plus the associated disconnects and overcurrent protection, and a backed-up (or “critical”) loads subpanel for the appliances that need to continue operating during an outage.

The DC Approach

The conventional *battery-based* PV system is “DC-coupled”—all power generation is on the DC side of the system. All sources operate at the same system input voltage, typically 12 to 48 VDC.

This strategy avoids the compatibility, technical, or warranty issues of an AC-coupled system (see below). Benefits include having the preferred three-stage (tapered off) battery charge control during all conditions and being able to recharge the batteries during a utility outage, even after they have been drained beyond the low-voltage cut-out point.

To minimize wire size, which is more economical for long wire runs, PV arrays can be wired for higher DC voltage (commonly 150 VDC but up to 600 VDC) using a step-down charge controller to convert to battery bank voltage. Energy stored in the battery bank is converted to AC by an inverter-charger, which is usually set up to provide energy first to a critical loads sub-panel, then to the grid through the main distribution panel and utility meter. In the event of a grid failure, the critical loads will continue to be powered by the inverter.

DC-coupling a grid-tied system can take two approaches. Both replace the existing batteryless inverter with a battery-based inverter-charger.

The first approach adds a standard, low-voltage (150 VDC maximum) charge controller. Depending on the number and size of the PV modules, adding or eliminating PV modules may be necessary to meet the input voltage requirements of the charge controller. The PV array's wire size may also

need to be increased (lower voltage means higher amperage, necessitating larger wire to carry the current).

The existing high-voltage (up to 600 VDC) PV array will have to be reconfigured for the charge controller's DC input voltage range. A combiner box and overcurrent protection (fuses or circuit breakers) may need to be installed if there are three or more paralleled series strings.

The second DC-coupling approach uses a higher-voltage (up to 600 VDC) charge controller. This method eliminates rewiring the array and adding a combiner box. While you may save labor and equipment costs, the more expensive high-voltage charge controller may negate these savings. Lower-voltage charge controllers can be about \$1,000 less than their higher-voltage counterparts.

High-Voltage Arrays with AC- or DC-Coupled Systems

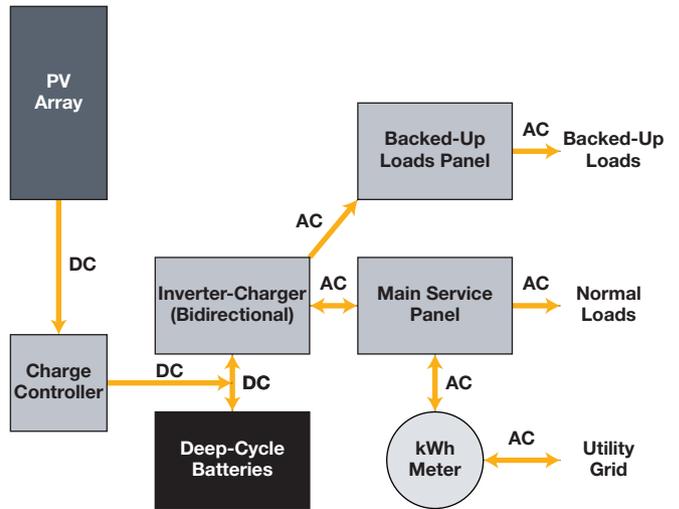
One of the main benefits of a residential AC-coupled system was that it allowed new or existing high array voltage PV systems to be outfitted with battery backup without rewiring to a lower battery-compatible voltage or having to add more DC-specific hardware. The system also retained low voltage drop, smaller (less expensive) wiring, and perhaps higher system efficiency.

However, due to the recent release of higher-voltage charge controllers (up to 250 VDC from MidNite Solar and up to 600 VDC from Morningstar and Schneider Electric) the benefit of not having to rewire the existing array can also be obtained with a DC-coupled system.



High-voltage charge controllers allow for long wire runs at a lower cost and maintaining the existing PV array's wiring configuration when adding battery backup.

DC-Coupling



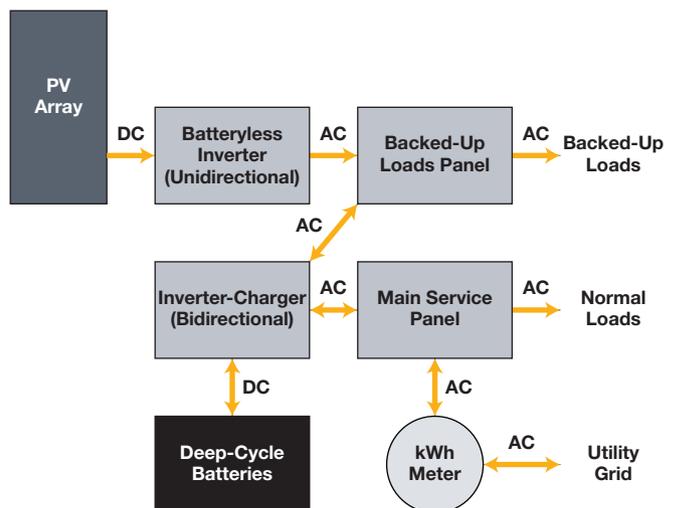
AC-Coupling

AC-coupling has been used for creating stand-alone "microgrids" in remote areas for many years. Now it is gaining wider industry acceptance as an option to retrofit battery backup into an existing batteryless system. There are unique challenges to AC-coupling, however.

The AC-coupling approach combines the AC outputs of all available sources (whether grid, generator, or RE-powered inverters). When connected to the grid, the batteryless grid-tied inverter feeds the PV array-generated energy into a critical loads panel. A separate inverter-charger is connected to the battery bank that maintains the battery bank voltage and allows AC power to pass through, either from or to the grid.

If there isn't enough PV energy to supply all the critical loads, the inverter-charger adds grid energy. Alternately, any excess energy not used by the backed-up loads is fed back through the inverter-charger into the main distribution panel. If solar-electric supply exceeds household electrical demand, then the excess energy flows to the grid.

AC-Coupling





Courtesy OutBack Power

Microinverters & AC-Coupling

Microinverters can also be used in AC-coupled systems. Just like with a batteryless string inverter, the output circuit from the microinverters will be moved to the backed-up load panel and an inverter-charger, battery bank, and associated DC safety gear will be added. You will have to investigate how excess PV array energy is handled when the grid is down and research potential equipment warranty and compatibility issues.

“tricks” the batteryless inverter into feeding its power into a “new” grid established by the inverter-charger.

If the PV array output of the batteryless inverter is connected to the main distribution panel instead of the backed-up load center, the energy from the array and batteryless inverter cannot be used by the backed-up power system because during a grid outage it becomes isolated and will not have AC line-voltage present, which it needs to work. So, when retrofitting to an AC-coupled system with battery backup, the batteryless inverter output circuit will have to be moved to a new specific backed-up load panel, along with the household circuits that you want to operate during an outage. Relocating those household circuits to a subpanel needs to happen in any retrofit, regardless if the system is AC- or DC-coupled. The inverter-charger can charge batteries from either the PV array or the utility if available. Additionally, an engine-generator can be added to the system, with all power generation sources controlled by the inverter-charger.

This AC-coupled system, installed by Gulf South Solar in Baton Rouge, Louisiana, offers backup power—an important feature to have in a place frequented by tropical storms.

In the event of a utility outage, an internal isolation relay in the inverter-charger disconnects it from the grid, and supplies the backed-up load center from the batteries. During grid failures, after the batteryless grid-tied inverter senses that the inverter-charger has begun to provide consistent power (typically after a 5-minute delay), it synchronizes with the inverter-charger and begins to also feed the backed-up load center from the PV array. The inverter-charger effectively

Inverter-Chargers for AC-Coupling

Magnum Energy

magnumenergy.com

MS4024PAE and MS4448PAE inverter-chargers.

Magnum offers tapered charge control via its AC load diversion controller (ACLD), which is networked with the inverter-charger to control excess energy from the GT batteryless inverter. Because charge control via diversion loads requires a secondary means (i.e., backup charge control, in case the diversion load or controller fails), these inverter-chargers provide a frequency shift as the secondary charge control method during a utility outage. Additionally, the batteryless inverter’s power rating should be no more than 90% of the Magnum inverter-charger’s capacity.

These inverter-chargers offer 120/240 VAC split-phase output—but they can only be used in GT applications when AC-coupled. Incorporating a generator requires additional hardware (an external transfer switch), as the inverters only have one AC input, which is needed for the connection to the main distribution panel.



Courtesy Magnum Energy

Magnum’s ACLD (upper left) is shown here installed on an MPSSL enclosure, which houses the DC and AC breakers. The MS-PAE series inverter (upper right) uses the MPXS extension kit.

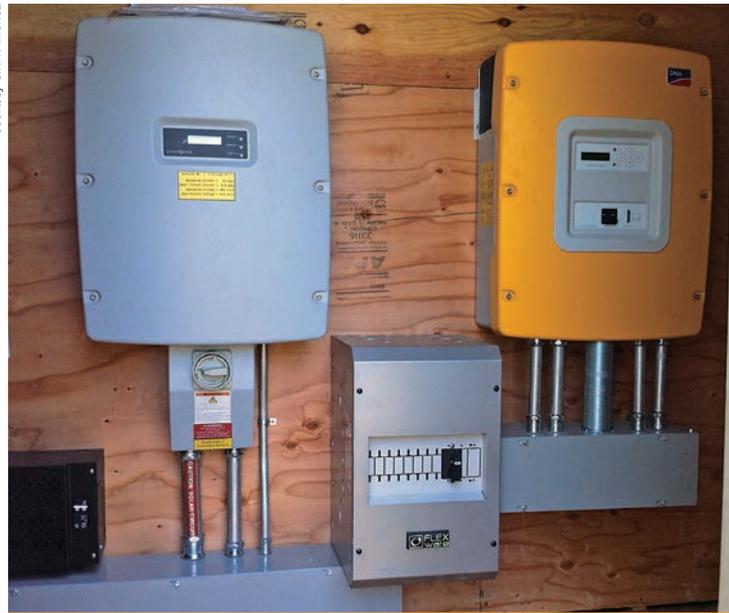
This approach offers several advantages. First, you can continue using your existing batteryless inverter. Also, there's no need to purchase a separate charge controller or combiner box, and the array doesn't have to be rewired.

Similar to DC-coupled systems, an inverter-charger is added to the system. Note, the power rating of the batteryless inverter usually cannot exceed the capacity of the inverter-charger (and in some cases, needs to be 10% to 25% less). You have to consider how excess PV array energy is handled by the inverter-charger when the grid is down, and also how to deal with a system that has shut down, should low battery cutout voltage be reached during a utility outage. And finally, potential equipment warranty and compatibility issues need to be addressed. The above AC-coupling issues are covered in detail below.

The primary benefits of AC-coupling may include higher system efficiency (especially when the AC loads are used concurrently with PV array production); the ability to use smaller array wire; and fewer DC components. Drawbacks may include lower system efficiency if energy demand doesn't align with PV production (efficiency losses from two inverters) and in some cases higher system costs.

The Complexities of AC-Coupling

Surplus energy. One challenge with an AC-coupled system is surplus energy produced by the PV array during a utility outage, which needs to be controlled to avoid overcharging the batteries. Some battery-based inverter-chargers can control the batteryless inverter, throttling back its output and/or use an AC frequency shift, which can trip the batteryless inverter offline. Other inverter-chargers use relays to shut down the batteryless inverter. However, unless the inverter-charger can



Courtesy SMA America

This AC-coupled system uses an SMA America Sunny Boy batteryless inverter (left) paired with and controlled by a Sunny Island inverter-charger (right).

throttle back PV array power, these options do not provide the preferred tapered charge controlling—they only shut the PV power fully on or off, which is not the best charging strategy for batteries. Note: There is also the possibility of using a diversion load and diversion controller, which may also offer tapered charge control.

OutBack Power

outbackpower.com

Radian GS8048 and GS4048 series inverter-chargers.

These units are configured for AC-coupling using a GSLC175-AC-120/240 load center. OutBack also offers a fully integrated 8 kW AC-coupling package, which includes batteries and battery rack.

The charge control circuit controls excess energy with two inverter-charger auxiliary ports and two relays, not a frequency shift. This approach also keeps the batteryless inverter locked out if a standby generator is running, preventing backfeeding.

The OutBack inverter-chargers need to be sized a minimum of 25% larger than the batteryless inverter. The Radian inverters have dual AC inputs, so a generator can be integrated. Because these inverters are 120/240 VAC split-phase, there's no need for an additional transformer.



The 8 kW Radian series inverter configured for AC-coupling with GSLC175-AC-120/240 load center.



Courtesy OutBack Power (2)

Their EnergyCell AGM batteries and rack configured for ~17 kWh (containing eight 12 V, 178 Ah batteries).



Courtesy MidNite Solar

MidNite Solar offers prewired AC-coupling solutions for battery-based inverters.

Low battery voltage. Without a backup generator or the ability to reduce the energy consumption of the backed-up loads (load shedding), low battery bank voltage during a grid outage may trigger the inverter-charger to go offline. This eliminates the batteryless inverter’s ability to recharge batteries from a PV source, since it depends on the inverter-charger’s continued output to stay online.

Here’s an example: A grid outage occurs at noon on a cloudy day. To keep loads running, the inverter-charger pulls energy primarily from the battery bank through the day and into the night. The next morning, the battery bank is below the inverter-charger’s low-voltage cutout point, triggering a shutdown. Although the sun is now shining, both inverters are offline and nonfunctional, and the PV source is unusable until the grid is functional again and the batteryless inverter starts up. However, in some cases the inverter-charger needs to be manually restarted before the system will operate.

Equipment compatibility. While there are a few battery-based inverter manufacturers (SMA America and Schneider Electric) that make both batteryless and battery-based inverters, in many cases, retrofitting an existing GT system means pairing different inverter brands. You will need to research if using particular equipment in an AC-coupled system could void any existing equipment warranties.

Schneider Electric

solar.schneider-electric.com

Conext XW+NA 5548 and 6848; and the SW-NA 2524, 4024, and (upcoming) 4048.

Schneider Electric’s inverter-chargers use an “active frequency shift power curtailment” that allows throttling back of a compatible batteryless inverter’s output; they trip noncompatible inverters offline. Partial power reduction (down to about 50%) is possible with “smart inverters” that can adjust output in response to frequency changes. (Note: Currently, IEEE 1547.1-compliant inverters are not likely to have this capability.)

Do not connect a batteryless inverter that has a power capacity larger than a Conext inverter-charger. Both models offer 120/240 VAC split-phase output. The SW models are not designed to sell energy back to the grid normally, but can be used in AC-coupled systems to pass energy through from a batteryless inverter to the grid. The Conext XW+ inverters have dual AC power inputs, so a generator can be integrated. However, provisions (such as interlocked disconnect switches) must be used to make sure the batteryless inverter cannot operate concurrently with the generator.



Courtesy Schneider Electric (2)

The SW-NA inverter (left) is shown preassembled, with DC and AC distribution panels (PDP) and the Conext System Control Panel (SCP). The XW+NA (right) is shown with conduit box (CB) and PDP.

SMA America

sma-america.com

Sunny Island inverter-chargers are available in 4548-US and 6048-US models and are designed to AC-couple with specific SMA Sunny Boy batteryless inverters.

SMA addresses the excess energy issue in two steps. The first uses a hard-wired RS485 communication link coupled directly to the batteryless Sunny Boy inverter, placing the batteryless inverter in “stand-alone” mode. The next step employs a frequency shift, signaling the batteryless inverter to adjust power output levels according to load demand. When Sunny Island inverter-chargers are used with non-SMA batteryless inverters, they are tripped offline via the frequency shift.

A unique detail to AC-coupling with SMA is that the Sunny Boy inverter capacity can be up to twice that of the Sunny Island capacity. When retrofitting, there needs to be a communications cable between SMA inverters. The Sunny Island is only available with 120 VAC output, while SMA (and non-SMA) batteryless inverters on the market have 240 VAC output. Because the 240 VAC output of the batteryless inverter must be matched to the AC input/output of the inverter-charger, a 120/240 VAC “smartformer” or a second Sunny Island inverter must be installed. Also, since there is only one AC input, an additional transfer switch, which can be switched between the generator or the grid, is required to incorporate a generator.



Courtesy SMA America

The SMA Sunny Island inverter-charger can be AC-coupled with SMA Sunny Boy inverters and non-SMA inverters. When coupled with Sunny Boys, a communications link is placed between the Sunny Island and Sunny Boy inverters, allowing them to adjust power output from the Sunny Boy(s) during utility outages.

Some PV batteryless inverters use a “grid-impedance check” to verify that the grid can receive energy and cannot be “tricked” by the higher impedance output of some inverter-chargers. Also, the AC output voltage of the batteryless inverter and the inverter-charger must match. For example, unless your inverter-charger offers split-phase 120/240 VAC output, you will either need to stack two 120 VAC inverter-chargers or use a step-up/down transformer to match the output of the 240 VAC batteryless inverter.

AC engine-generators can be included in an AC-coupled system, but precautions (for example, interlocked disconnects) must be taken to make sure the generator and batteryless inverter cannot backfeed each other, which could result in damaged equipment.

What Will It Cost?

Cost factors include whether an array needs to be reconfigured and distance from the array to the batteries. The array size, critical load profile, how long backup is required, and whether a generator is included determines battery bank and battery-based inverter-charger requirements. Will you use a pre-wired power panel that includes all the required disconnects, overcurrent protection, metering, etc., needed to incorporate the battery-based inverter-charger or will you piece this gear together yourself?

Given all these variables, it is tough to come to a general cost comparison. But, out of curiosity, we examined the

costs of adding batteries to a 3.5 kW batteryless system using three strategies: low-voltage DC-coupling, high-voltage DC-coupling, and AC-coupling. And for this particular example, we found that the options were within about \$500 of each other. Using AC-coupling equipment was slightly less expensive—but any option is a significant investment. The equipment cost of adding battery backup via AC-coupling to this system (19 kWh of AGM battery storage, a 4,000-watt battery-based inverter-charger; and a pre-wired power center) was more than \$10,000—using MSRP pricing and without including a battery box, battery cables, shipping, taxes, or labor.

As they say, “hindsight is 20/20”—a standard DC-coupled option would likely be less expensive than AC-coupling if the system was designed with battery backup from the get-go, since you only need the inverter-charger (and not the batteryless inverter). Additionally, when that equipment is part of a new PV installation, the additional cost (due to batteries, charge controller, associated DC disconnect gear, and installation) could be partially offset by the 30% federal renewable energy tax credit.

Beyond the cost are the details: Significant damage to both equipment and personal injury could result if the equipment is not installed or used properly. Equipment must be installed and operated in accordance with manufacturer instructions and the *National Electrical Code*.

Special thanks to Jsun Mills, who provided the original insight and information that this article stemmed from.



Could This Be the Perfect Solar Charger for You?

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TM-2030 Battery Monitor
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SC-2030 Solar Charger
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telephone cable.

TM-2030 Monitor: Like previous TM-2025 except:

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Why this SC-2030 PWM solar charger with TM-2030 monitor is exceptionally good for battery life:

- **Amp hour counting:** Every night the TriMetric measures the exact charge you take from your batteries—then the charger replaces what you used plus a measured additional percentage—to avoid undercharge or overcharge.
- **Frequent mini equalization (optional)** “Higher voltage—limited current” finish stage to safely get a defined overcharge at the end of a limited solar day—now being recommended by US Battery, Trojan, Concorde, Interstate and others for solar charging.
- **Possible to add to your present charger** Add more panels and also provide the benefit of additional higher voltage finish charging, with amp hour counting.
- **Easy battery setup profiles**—or have highly flexible options for techies.
- **Limitations: 31 amp max, 12 or 24V system PWM charger.** PWM chargers should use “12 or 24 volt” solar panels to have efficiency comparable to MPPT controllers. Without TM-2030 it’s a basic controller with bulk, absorb and float stages.

In addition, you’ll have all the benefits of the high degree of system visibility provided by the TM-2030 Battery Monitor.

more information at: www.bogartengineering.com

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Passive solar design earns high marks for heating Don and Kim Kelley's off-grid home, while a modest off-grid PV system provides 100% of its electrical energy needs.

Interview by Ian Woofenden
Photos by Don & Kim Kelley

So what got you started with renewable energy (RE)?

We began thinking about RE solutions while living and working in Grenada, West Indies, in the mid-1980s. That island's electricity came exclusively from unreliable, centralized diesel generation. Its pollution seemed out of keeping with the country's great beauty and relative freedom from resource-intensive, convenience-at-any-cost habits common in much of the industrialized world.

Kim and I envisioned a simpler, slower-paced, and more ecologically responsible lifestyle for ourselves upon our return to the United States. In 1987, we bought a small farm with an old farmhouse on 59 acres in the Black Hills of South Dakota, and began producing much of our own food. We have since left the medical world (Kim as nurse, Don as pathologist), and have devoted ourselves full-time to this pursuit.

Above: What started out as a livestock barn morphed into an off-grid, passive solar home.

Right: A DIY life—Don and Kim Kelley in front of their passive and active solar home.





The poured concrete slab on the ground floor was insulated underneath with R-10 rigid foam insulation.



Cement block foundation walls were earth-bermed to 5 feet, and insulated before backfilling.

We lived in the poorly insulated frame house while learning to grow and harvest hay, milk cows, make cheese, and raise organic vegetables. We relied on wood heat and consumed an average of around 350 kWh per month of electricity from our rural co-op. The dream of a nearly autonomous, low-maintenance house took shape during this period, although a milking-and-hay barn with attached implement shed rose to the top of the priority list. Don began leveling a pad for the barn in 1996.

This DIY barn project proceeded slowly, as we experimented with a poured-masonry wall-building technique (using big local rocks, concrete, and slip forms). The walls of this 150-foot-long building were partly built when we reluctantly decided to sell our livestock. Our plan morphed into finishing the structure as a home.

Kim and I had elected not to have children, and I guess part of the reason we “overbuilt” this structure was the hope that it would be a multipurpose building useful to future inhabitants as they deal with increasing climate and energy problems. The second story, originally intended as a drive-in hayloft, became an enormous workshop and garage adjacent to a kitchen. Much of the lower story is devoted to a woodworking and mechanical shop.

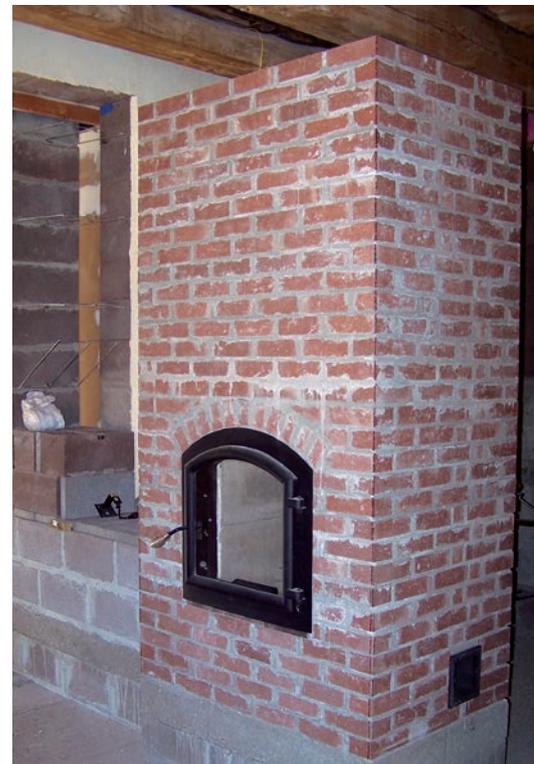
Keeping warm during South Dakota’s long, brutal winters must be challenging. How did you plan for and implement heating systems, and how are they working?

We’ve been inspired by various authors who have described sun-savvy building techniques. The footprint of the building was determined partly by a bend in the property line just to the north of the house (wanting to avoid intruding more than necessary into the meadow land), and partly by the passive-solar concept of extending the east-west axis of the building, to maximize solar exposure.

The 5-foot-deep earth berms along the north, west, and east sides help moderate interior temperature swings. In addition, the 6-inch-thick concrete slab and 12-inch-thick concrete-and-rock walls are isolated from the earth by R-10

rigid foam insulation. The ratio of south-facing glazed area to floor area is about 11% on the ground floor, and about 9% on the second story. The difference is explained by the larger sunlit thermal mass (slab and concrete walls) in the lower level. We adhered to the recommendation that north- and east-facing glass areas should be less than 4% of floor area, and west-facing glass should be no more than 2%.

Auxiliary heating is with a kit-built masonry heater, which incorporates an oven and water-heating coil. We strive to maintain warmer winter indoor temperatures only in the central living area of the building where the heater is located. We use a standard wood heater in the west wing only when those workshop areas are in use. Propane fuels our cooking range, as well as a backup water heater.



An owner-built masonry fireplace provides the backup heat to the passive solar gain. Usually, only one small fire is necessary on cold mornings.



This unique passive solar home was constructed with durable, long-lasting materials for optimal thermal mass and ease of maintenance. The narrow, long footprint maximizes each room's access to solar gain, which provides the bulk of wintertime heating.

Passive solar heating keeps the house above 52°F without any backup heating—even in sub-zero temperatures and without occupants. On very cold days, when we want interior temperatures in the high 60s, we may fire the masonry heater once in the morning and again in the evening. More typically, a single morning fire does the trick. The plan with a masonry heater is to burn a very hot, undampened fire down to embers, at which point both intake air and flue-gas exhaust are closed off, trapping the heat within the masonry mass. Radiant heat continues to emanate for at least the next 24 hours. These heaters feature a winding path through the masonry structure that the flue gases must take before exiting the chimney, thus harvesting most of the heat during that passage. Since we are surrounded by pine, aspen, birch, and spruce forest, fuel is plentiful.

Kim loves the built-in oven for wonderful pizza and deliciously browned garden veggies. I've rigged a remote-sensing thermometer within the oven chamber, so while we're upstairs in the kitchen, we know when the oven downstairs has reached proper temperature. It drops from a high of as much as 1,500°F to baking temp within the first hour or so.

And what about cooling?

Summer cooling is not needed, owing to our latitude (above 44°N) and altitude (4,860 feet above sea level). Even when outside air temperatures reach more than 90°F, the home's thermal mass keeps the building cool, as do the balcony and other 4-foot overhangs on the home's south side. The depth of these overhangs are a compromise between maximizing winter's low sun and minimizing summer heating of the thermal mass. The maximum indoor temp we've recorded is 76°F.

Why did you decide to keep the new home off-grid?

The building site was one mile from the nearest electrical utility access, which made the decision to go off-grid quite easy—the cost for underground line installation was comparable to the price of an off-grid system that would meet all our electricity needs. South Dakota has no net-metering legislation, so there is no hope of recouping the expense of a grid-tied system.

Seven years of living with our PV system have shown us the practicality and extreme reliability of this technology. It has been especially obvious when weather events have left neighboring grid-reliant homes without electricity for days at a time.

Our experiences have made us evangelists for the decentralization of energy generation in our state, and we channel this lobbying effort through a statewide organization called Dakota Rural Action. We would like to join forces with more RE enthusiasts in our region, and hope that *Home Power* readers from our area will make themselves known to our organization.

Don installed the 3.24 kW off-grid PV system himself.



What resources did you consider, and why did you end up with solar energy?

We chose solar electricity for several reasons:

- We live in a rather narrow valley, so the winds we get are mainly mild turbulent gusts rather than any sustained directional flow, evidenced by the fact that I've never been able to keep a kite airborne for more than a minute. A tower 200 feet or higher would be necessary to access prevailing winds.
- Although a small stream runs through our farm, there's neither sufficient head nor flow to justify a hydro turbine.
- The low maintenance of PV energy was very appealing.
- South of our building, a saddle in the valley rim allows good wintertime solar access for a substantial part of the day.
- We have good insolation in our area, with 5.21 average daily peak sun-hours.
- Considering that most grid electricity from rural coops in our area is coal-generated, our choice avoided not only years of future electricity bills, but also a lot of greenhouse gas.

How did you design a system to meet your loads?

My long-term subscription to *Home Power* magazine provided the bulk of the education and motivation to design and install our PV system. There were no commercial installers in our area at that time, so selecting components was an online endeavor. We sized the 3.24 kW array, and 840 amp-hour, 48-volt battery based on our electricity consumption history while living in our old farmhouse, figuring that we'd need to generate around 11 kWh per day average, year-round.

We use CF or LED lighting, and our appliances—such as dishwasher, clothes washer, fridge, and freezer—are Energy Star-rated or better. We can still use power tools, a computer, and a home entertainment system. Outlets supplying intermittently used appliances have wall switches to control phantom loads. We have yet to overtax our system.

How did you decide what PV system components to use?

My research led me to OutBack Power gear, matched with 18 Evergreen 180 W modules, and 16 Trojan L-16 6-volt batteries (wired as two 48-volt series strings). Charge control is through a single OutBack MX60 controller. Two OutBack VFX3648 inverters supply 240 VAC output balanced through an OutBack X240 transformer. Although we installed the system ourselves, I did hire a qualified electrician to check the whole system, and he gave it thumbs-up.

Kelley Off-Grid System Loads

Item	Watts	Hrs. / Day	Days / Wk.	Avg. Daily Wh
2 Crosley chest freezers	720	2.00	7	1,440.00
Submersible well pump	1,200	0.75	7	900.00
Cordless phone w/ extensions	36	24.00	7	864.00
Satellite modem & router	60	14.00	7	840.00
Microwave oven	1,500	0.50	7	750.00
CF & LED lamps	136	4.50	7	612.00
TV w/ DVD player	200	2.50	7	500.00
Sun Frost fridge/freezer	40	12.00	7	480.00
Laptop computer	24	14.00	7	336.00
Dishwasher	1,400	0.50	3	300.00
Power tools	1,000	0.50	2	142.86
Vacuum cleaner	600	0.25	3	64.29
Stereo	13	4.00	7	52.00
Staber clothes washer	540	0.33	2	50.91
Ceiling fans	25	0.25	1	0.89
Totals	7,494			7,333.00

What about backup?

We used a gasoline generator during the earliest phases of construction. What a relief it was when my friend Pete Hendricksen offered to let us use his portable solar generator (no more trips down the ladder to fire up the genset when we wanted to use a power tool, and heavenly silence was an added blessing).

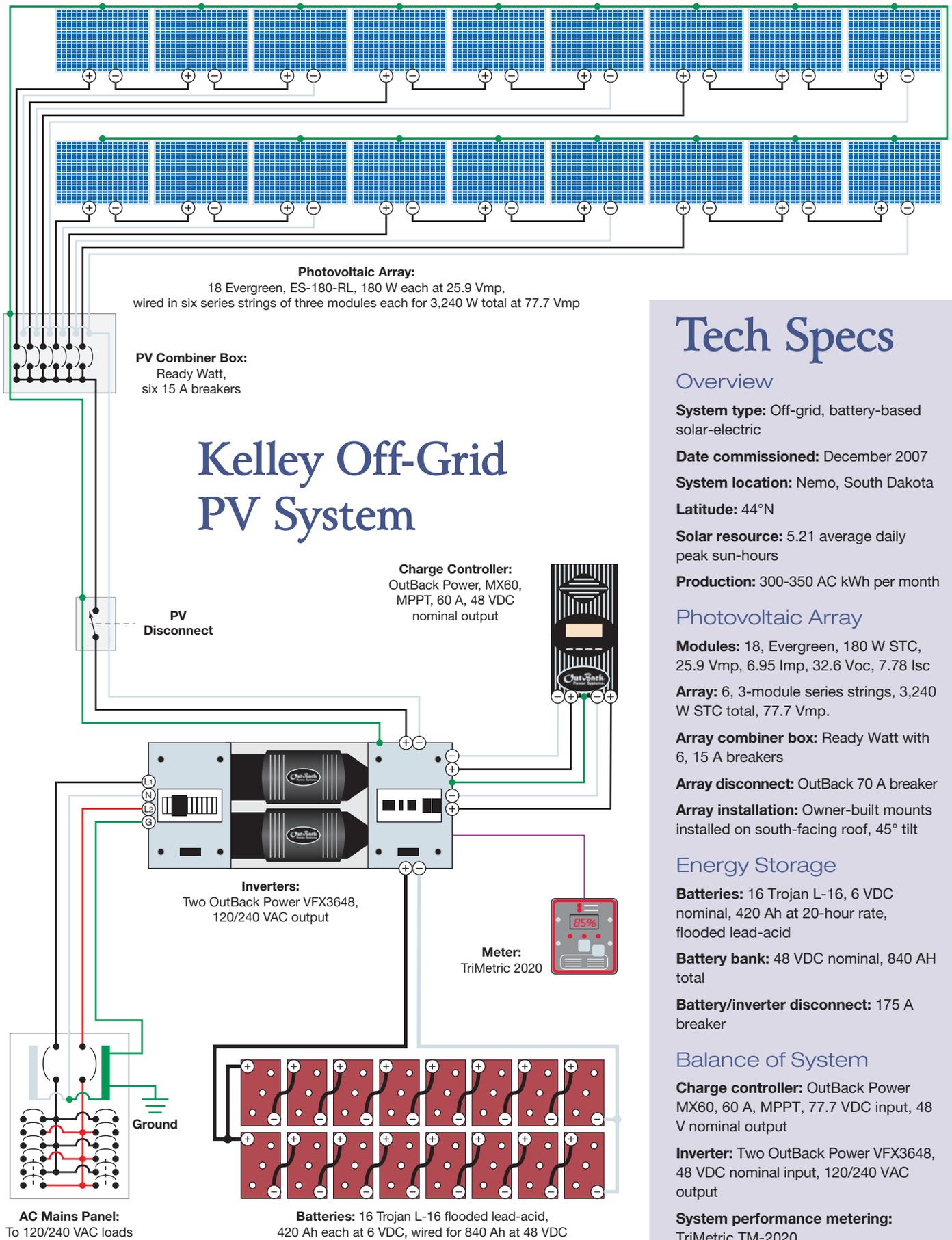
We have not yet relied on a backup generator while living in this home. Solar electricity alone has been sufficient to periodically equalize the bank during long-daylight months. We may add a generator in the future to make winter equalization of the batteries easier, and to increase battery life expectancy.



Left: Dual OutBack Power Systems VFX3648 inverters and an MX60 charge controller are the heart of the system.



Right: Sixteen Trojan L-16 batteries at 48 volts provide energy storage for at least two days without sun.



Kelley Off-Grid PV System

Tech Specs

Overview

System type: Off-grid, battery-based solar-electric

Date commissioned: December 2007

System location: Nemo, South Dakota

Latitude: 44°N

Solar resource: 5.21 average daily peak sun-hours

Production: 300-350 AC kWh per month

Photovoltaic Array

Modules: 18, Evergreen, 180 W STC, 25.9 Vmp, 6.95 Imp, 32.6 Voc, 7.78 Isc

Array: 6, 3-module series strings, 3,240 W STC total, 77.7 Vmp.

Array combiner box: Ready Watt with 6, 15 A breakers

Array disconnect: OutBack 70 A breaker

Array installation: Owner-built mounts installed on south-facing roof, 45° tilt

Energy Storage

Batteries: 16 Trojan L-16, 6 VDC nominal, 420 Ah at 20-hour rate, flooded lead-acid

Battery bank: 48 VDC nominal, 840 AH total

Battery/inverter disconnect: 175 A breaker

Balance of System

Charge controller: OutBack Power MX60, 60 A, MPPT, 77.7 VDC input, 48 V nominal output

Inverter: Two OutBack Power VFX3648, 48 VDC nominal input, 120/240 VAC output

System performance metering: TriMetric TM-2020

Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

Kelley Off-Grid System Costs

Item	Cost
18 Evergreen PV modules, 180 W	\$12,762
16 Trojan L-16 batteries, 6 V, 420 Ah	4,738
2 OutBack Power VFX3648 inverters, 48 V	4,730
OutBack Power MX60 charge controller, Mate, etc.	1,515
Shipping	629
PV module mounting materials	420
Breakers	113
Ready Watt combiner box	98
Misc. wires, connectors, etc.	50
Total	\$25,055
Federal tax credit*	-4,000
Grand total	\$21,055

*In tax years 2006-08, the federal tax credit was capped at \$2,000, with no carryover of the purchase amount to subsequent years.

What is your PV system maintenance scheme?

It's been handy to have the shallow-pitched roof in front of the PV array so we can sweep snow off the array in winter. The modules have never gotten significantly dirty, so we haven't had to clean them yet. So far, maintenance is focused on the batteries—topping up the battery water every six weeks, and occasional manual battery equalization.

A loose and corroded terminal within the DC control-breaker box resulted in a sudden, complete blackout awhile back. This required several hours for me to trace and repair. Otherwise, it's all worked like a dream.

What are your next RE plans?

We'd love to reduce our propane consumption to that required only by our kitchen range by adding a solar hot water system. Offsetting at least 70% of annual water-heating energy with solar is feasible. This seems like a brilliant investment, easily paid back over a relatively short time. So the vacant portions of our 45° pitched roof will soon be occupied by solar water heating collectors.

This system—for several hydronically warmed floor areas, a small exercise pool, and tap water—has been planned in detail but not yet implemented, as we are awaiting a response from the only qualified installer in our area. I've proposed doing most or all of the installation myself, but could sure use expert advice on designing the system and sourcing the components. I've run insulated copper lines from future collector locations to the space allocated for an 80-gallon solar storage tank.

What's day-to-day life like with your energy systems?

While living in the old, poorly insulated, wood-heated frame house during the early years here, we became accustomed to energy-conserving practices, such as minimizing pumped-water use and employing CF lighting. The root cellar in the old farmhouse for storing garden harvest was well-used, and one is planned for this house. Nevertheless, we've needed



A low-sloped roof and almost-flat south eave made array installation and ongoing maintenance easy.

Resources

Here are some of the Kelleys' resources:

Dakota Rural Action's Energy Fairness Initiative • bit.ly/SDEnergyFairness

Beyond Oil Solar • beyondoilsolar.com • Solar-electric equipment

Temp-Cast Enviroheat, Toronto, Ontario, Canada • tempcast.com • Masonry heater kit

Books & articles:

"Understanding Energy-Efficient Windows" by Paul Fiset, *Fine Homebuilding* magazine, Feb./Mar. 1998

The Solar House—Passive Heating and Cooling by Dan Chiras, Chelsea Green, 2002 • Calculations of glazing area to floor space/mass

The Book of Masonry Stoves: Rediscovering an Old Way of Warming by David Lyle, Chelsea Green Publishing Co., 1984

The Owner-Builder's Guide to Stone Masonry by Ken Kern, Owner Builder Publications, 1976 • "Poured-masonry" wall-building technique

Past Home Power articles: Members can access these articles in the full issue archives at homepower.com.

"Doing a Load Analysis: The First Step in System Design" by Ben Root in *HP58*

"Batteries: What We Know About Them; How to Use Them" by John Wiles in *HP66*

"Grounding" by John Wiles in *HP65*

"Grounding Separate Structures" in *HP65*

"To Ground or Not to Ground: That is Not the Question" by John Wiles in *HP72*

"PV Grounding on a Single Dwelling" by John Wiles in *HP73*

"Lightning Happens: How to Protect Your Renewable Energy System" in Windy Dankoff in *HP107*

"What is a Charge Controller" by Windy Dankoff in *HP72*

"How to Choose an Inverter for an Independent Energy System" by Windy Dankoff in *HP82*

"Technology Marches On" by Richard Perez in *HP106*

about 20 cubic feet of freezer space, and use our reliable, secondhand Sun Frost fridge/freezer. Water pumping and refrigeration are our largest electrical loads, and we've been able to cover all loads adequately with the PV system.

We keep the TriMetric display showing "percent battery capacity," and the batteries usually reach 100% before noon on a sunny day. In summertime, overnight drawdown is minimal—80% to 90% full is typical; but we may see 55% to 60% first thing on a dark winter morning. If we anticipate a couple of cloudy days, we'll probably defer running the clothes washer, but this rhythm becomes almost unconscious, rather than bothersome.

We've been so satisfied with our system that it's hard to imagine how we'd do it much differently. We would like to create a breakthrough in the public's awareness of utility

companies' and fossil-fuel interests' defensive posturing and disinformation as they resist change. Once we've exposed and eliminated that resistance, and federal subsidies for renewable, distributed generation become more equal to those for fossil-fuel and nuclear power, I think the public will be ready to make a rapid conversion.

Many of those advocating continued reliance on fossil- and nuclear-generated power seek to discredit environmentally responsible technologies and roll back incentives for the adoption of such systems, rather than adapting to the urgent need for change. Our off-grid lifestyle is a microcosm, showing what is also possible on-grid—thoughtfully designed systems using local resources within a more sustainable and resilient framework.



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In the Woods of West Virginia

by Mickey Janowski, with Ian Woofenden

I spent the first 19 years of my life in the Bucktown neighborhood of Chicago. In 1969, I got drafted into the army, and wound up in Vietnam, humping the bush with a light infantry brigade. When I returned, my head was a bit spun around, and I figured I needed my own little revolution, which involved getting out of the city—so I did.

My wife Jennifer and I found a beautiful 100-acre holler near Webster Springs, West Virginia, with a nice creek running through it. This part of West Virginia is blessed with good water, soil, and wood—and great mountain people. Our nearest neighbor is a mile away.

The house we built is at 2,250 feet elevation, with 50 inches of rain per year. A main reason we chose this site was its uphill water source. I buried 400 feet of 1-inch domestic water line to a spring 55 feet higher than the house that has never run dry. We also have a creek on our land, and it's now the primary power source for our home.

Solar for Little Loads

Electrical energy was one of the last types of independence on my mind when we started out. For a few years, we were content with kerosene lamps and candles. We even had a kerosene fridge—so we were off the electrical grid—but not the fossil-fuel grid.

This West Virginia homestead uses a combination of renewable sources to meet its energy needs.

Right: Jennifer Janowski beside the cookstove, used in the wintertime for space heating and cooking. The induction cooktop is used in the summer.



All photos courtesy Mickey & Jennifer Janowski

Eventually, I became aware of solar electricity, and started out with one Arco 35-watt PV module, a car battery, and a 12-volt car taillight bulb for reading and general navigation. Back in the “dark ages”—before *Home Power* and the Internet—RE info and components were hard to come by.

Over the years, I expanded the system, upgrading to 635 watts of modules and six deep-cycle L-16 batteries at 435 Ah for a total of 1,305 Ah. This setup powered lighting and a few small appliances such as a ceiling fan, food blender, mixer, stereo, and telephone answering machine. The PV array is mounted on a pole that can be manually rotated to track the sun.

I can adjust the array's tilt and access the modules while standing on the roof. My original Arco module, purchased when Jimmy Carter was in the White House, is part of the array, and still humming right along.

My house voltage is still 12 V—when we first embraced solar electricity, inverters were not very good, and the most abundant lighting option was 12 VDC. I'm slowly switching the lighting to 12 V LEDs.

Solar access is no miracle here in the woods, but we get about 3 kWh on a sunny fall day—more in the summer, less in the winter. The lay of the land from the house is a gradual slope of about 4% to the south for an average of 400 feet before the mountain gets steep. Every year, I drop a couple of sun-blocking trees that lie to the southeast and southwest, enlarging our "hole" in the woods and allowing more sun on the array and garden. During midday, most of the year, the sun is well above the treeline.

But with only a small PV system, most of our major loads—water heating, refrigeration, and cooking—were fueled by propane—about 350 pounds per year. We live in the middle of one of the best firewood-producing hardwood forests and heat the house with wood. For many years, we heated our domestic water in the firebox of the cookstove with a single loop of $\frac{3}{4}$ -inch flexible copper tubing running to a tank. That worked fine in the winter, but warmed the house too much in the summer.

Water Power for Bigger Loads

For many years, I watched the water flowing by in the creek below our house and would lament the lost energy opportunity. In early 2012, the microhydro project finally worked its way to the top of our list. I wanted to ease my way off the propane grid, add some loads (a freezer, for example), use the generator less, and treat my batteries better.

Microhydro systems can really change the face of off-grid RE systems because of the year-round resource. For \$12,000, plus my time and energy, I added an overbuilt hydro system to make a hybrid RE system that meets almost all of our energy needs. The hydro has offset about 15 pounds of propane use a year, and has increased our overall energy capacity even more.

We started the project by creating a pathway for the penstock, using a concrete saw with a diamond blade to cut channels through rocks that wouldn't budge. A chainsaw with an old chain or long reciprocating saw blades worked best on tree roots once we cleaned around them. In some places—slope permitting—retaining walls were built to avoid damaging tree roots. The electrical conduit and penstock share the same trench line for about the last 200 feet, and then the conduit heads up away from the creek and toward the house.



The concrete weir at the intake was poured during low flow. The Coanda-wire debris screen and aluminum catchment box divert 30 to 350 gallons per minute to the penstock.

A modification to the intake box adds depth above the penstock to prevent air infiltration, and makes flow changes visible from the house.





More than 500 feet of 4-inch-diameter penstock (here, inside a 6-inch sleeve) runs down the hill.



The ES&D turbine has two nozzles that can be swapped out with a variety of opening sizes to match flow.



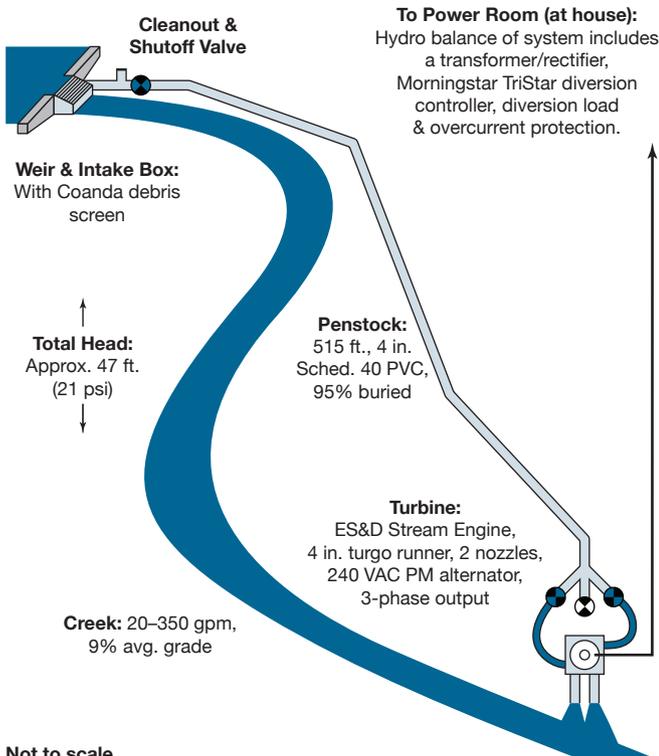
The Coleman 720-watt dump load—an air resistance heater.

Intake

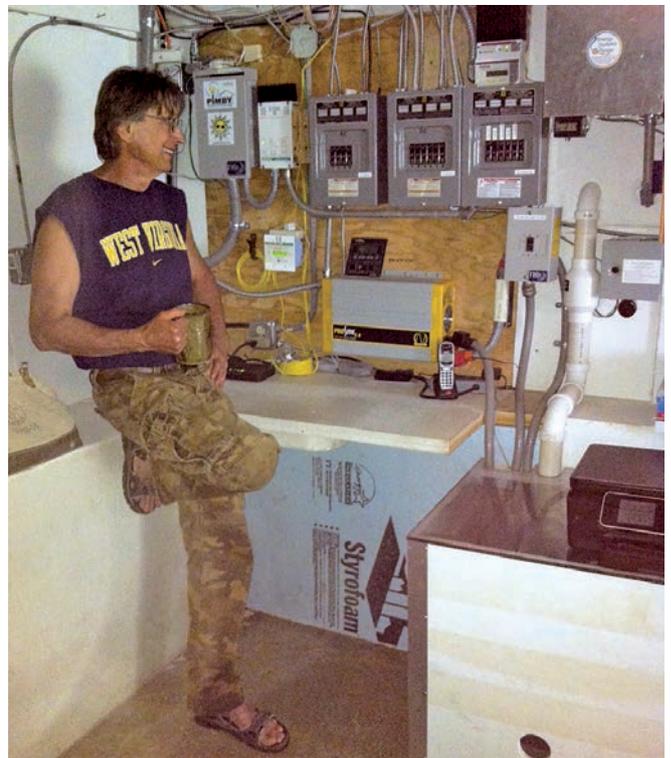
The intake box is made of 1/8-inch aluminum diamond plate. I purchased an 18- by 12-inch hydro sieve, with tilted wedge wires that create a cutting action on the upstream sides of the wires. The gap between the wires is 1.5 mm. I added an angled piece of 1/16-inch-thick aluminum at the bottom so I can view the overflow from the house. A minimal overflow can indicate that it's time to swap out the larger nozzles with smaller ones.

My biggest mistake involved the box design. I looked at some factory-made boxes and saw they had as much as 6 inches of space above the top of the penstock pipe outlet and at the bottom of the intake screen. It seemed like wasted space that lowered the height of the pipe coming out of the box. I found out the hard way that the reservoir eliminates turbulence from the falling water, preventing air from entering the penstock. Air in a hydro-electric penstock is bad news; it will reduce pressure, even to the point of shutting down the

Microhydro System Layout



In the power room, hydro and solar meet to cover almost all of the Janowskis' electrical energy needs.



Hybrid System Tech Specs

Overview

System type: Off-grid, battery-based microhydro-electric with PV

System location: Webster County, West Virginia

Date commissioned: October 29, 2012 (microhydro)

Site head: 47 ft.

Hydro resource flow: 20 gpm, dry season; 350 gpm, wet season

Hydro production: 86 DC kWh per month avg., dry season; 360 DC kWh per month avg., wet season

Solar resource: 4 avg. daily peak sun-hours

Solar production: 49.5 AC kWh per month, avg.

Microhydro Turbine

Turbine: Energy Systems & Design, Easy Tune Stream Engine, medium-head turgo

Runner diameter: 10 in.; 4 in. pitch circle diam.

Alternator: Custom ES&D permanent-magnet 240 VAC; wild three-phase output

Hydro Balance of System

Transformer/rectifier: ES&D 240 V, wild three-phase AC to 12 VDC

Diversion controller: Morningstar TriStar TS-60, 60 A

Diversion load: Coleman Air Ceramic Resistor air heater, 90 A, 12 V, modified to 720 W capacity

Circuit protection: 60 A breakers

System performance metering: Charge controllers, inverter, and the hydro transformer all have digital readouts including volts, amps, watts, temperature, state of charge

[Editor's note: Because a diversion control is used, a second means of voltage control should be added to meet Code requirements.]

Photovoltaic System

Modules: Nine total—two 35 W Arcos; three 75 W Siemens; four 85 W Shell; all 12 VDC nominal

Array combiner box and disconnect: MidNite Solar box with two 12 A and one 30 A breakers

Array installation: Custom-built aluminum pole mount, manually adjustable

PV Balance of System

Charge controller: Xantrex C-60, PWM, 60 A

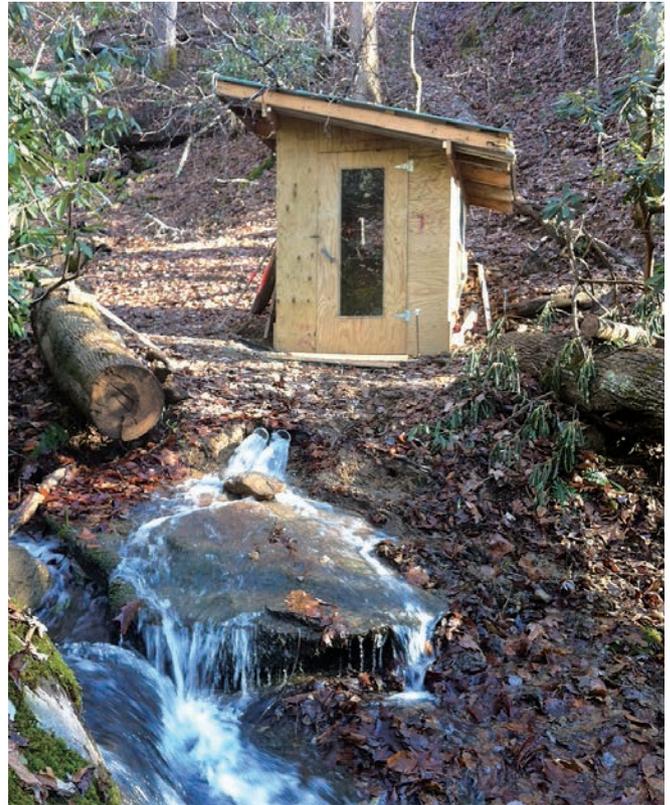
Inverter: PROSine 2.0 inverter/charger, 2,000 W, 12 VDC nominal input, 120 VAC output

Engine generator: Westinghouse, 6,500 watts rated

Energy Storage

Batteries: Six Trojan L16H-AC, 6 V, lead-acid, 435 Ah each, in series/parallel for 1,305 Ah at 12 VDC

Battery/inverter disconnect: 250 A class T fuse



The turbine shed lies 47 feet lower than the intake, creating just over 20 psi of static pressure.

system. I added a 3-inch piece of aluminum across the front of the intake box to raise the water level. This prevents air from entering the penstock.

I waited for a really dry spell to form and pour the concrete weir, channeling what little water there was through a temporary pipe under the form, since I couldn't divert it around the big rocks on each side. I installed a 4-inch shutoff valve in the penstock about 4 feet below the box in case I need to stop the flow up top. A cleanout T is just up from the 4-inch valve in case I need to clean debris from the valve seat.

I've read that air vents are recommended in hydro penstocks, but since I don't have any high spots and the downward slope is unbroken, I chose to not use any. If it turns out that I need one, I can add it later. But after almost three years of trouble-free operation, I don't think any venting is necessary.

Powerhouse

A 6-by-6-foot powerhouse protects the turbine and provides some shelter for turbine maintenance. I insulated the pipes in the powerhouse to avoid condensation during humid times. The condensation probably wouldn't have harmed anything, but I prefer things dry. The insulation also helps protect the pipes during our cold winters—it got down to -10°F twice last winter. The entire penstock is buried except for the first 8 feet, between the intake box and the creek bank. Keeping the water moving prevents freezing.



The author's friend Dave McIntire (left) and Matt Sherald of PIMBY (right) helped with installation and wiring.



The modification to the intake box adds depth above the penstock to prevent air infiltration, and makes flow changes visible from the house.

Manifold & Gauges

I built the manifold for the Energy Systems & Design Stream Engine, keeping all bends to a minimum. A double-Y splits into two 2-inch lines with a shutoff for each. I used 2-inch braided flexible hose to facilitate changing nozzles. After the water spins the turgo runner, it drops into a discharge box that has two 4-inch drain lines to return the water to the creek.

An ammeter in the house and the water-pressure gauge on the manifold help me keep tabs on the system. If the ammeter shows the current lower than expected, the first thing I check is the overflow at the weir intake box. No overflow means the nozzle(s) are too big and the pipe isn't full, which lowers the pressure. Debris blockage, which obstructs the flow to the turbine, could also cause a low amperage reading. I close both valves at the turbine and watch the water-pressure gauge climb back up (to 21 psi, which is the static pressure for the 47 feet of drop) as the penstock refills and the air bleeds out. I then put in the appropriate-sized nozzle(s).

Below 21 psi indicates a blockage or air bubble above the gauge. If it rises to 21, but the amperage doesn't correspond to the nozzle(s) size, it might indicate a problem below the water pressure gauge, such as a blocked nozzle or discharge pipe, which could cause water to back up into the turbine; an electrical issue; or something else.

Operation

Changing nozzles is a 4- to 5-minute procedure that needs to be done infrequently. Originally, I kept two $\frac{3}{4}$ -inch nozzles open, getting 12 kWh per day ($37 \text{ A} \times 13.7 \text{ V} \times 24 \text{ hrs.} = 12 \text{ kWh}$) for seven months straight—November through May. We only use about 6 kWh per day, so we can afford to run it at a lower capacity, which saves wear and tear on the machine. So more recently, I've run one $\frac{3}{8}$ -inch nozzle and one $\frac{3}{4}$ -inch nozzle. If we were selling surplus energy to the grid, we'd probably run it at a higher capacity when there's lots of excess water.

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Before the microhydro system, we ran the gasoline-powered generator at least 10 hours a week during winter. Now, this has been virtually eliminated. When the sun-hours dwindle, the precipitation increases, and the microhydro system shines. When sun-hours are abundant, the creek flow drops and the microhydro system contributes less to our energy mix, and the PV system makes up some of the difference.

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PV Disconnecting Means

by Ryan Mayfield

In the *National Electrical Code (NEC)*, methods for disconnecting PV systems are covered in Part III of Article 690, “Disconnecting Means.” The sections contained within Part III received a fair amount of updating in the 2014 *NEC*. Some of these updates were merely relocations from different sections in the 2011 version and some, specifically 690.17, are bonafide changes.

Section 690.13 lays out the general requirements for disconnecting means for a PV system’s ungrounded DC conductors. The first subsection, 690.13(A), states that the “PV disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors.” By itself, this rule would require nearly all rooftop PV systems to keep the PV circuits on the building exterior until they reach a readily accessible disconnect. Generally, rooftops are not considered readily accessible nor are the spaces directly below a rooftop, such as an attic, which is commonly the nearest point of entrance.



NEC Section 690.13 outlines the requirements for disconnecting a PV system’s DC circuit conductors.



Ryan Mayfield (2)

Commonly, batteryless grid-tied inverter manufacturers will supply an integrated DC disconnect.

The exception that follows 690.13(A) allows the PV circuits to run inside a building, provided the conductors are installed to meet 690.31(G). [Note: In the 2014 *NEC*, a typo in the exception points to the wrong section—690.31(F).] Section 690.31(G) allows DC circuits to run inside any building, provided they are installed in metallic raceway or use specific metal-clad cable. This section is specific to the DC conductors, so does not apply to inverter output circuits (as with rooftop microinverters). The section title: “Direct-Current Photovoltaic Source and Direct-Current Output Circuits on or Inside a Building,” has been modified in the last two *NEC* cycles to help clarify the application, since many authorities having jurisdiction (AHJs) were also applying these rules to AC circuits.

continued on page 62

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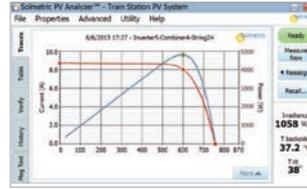
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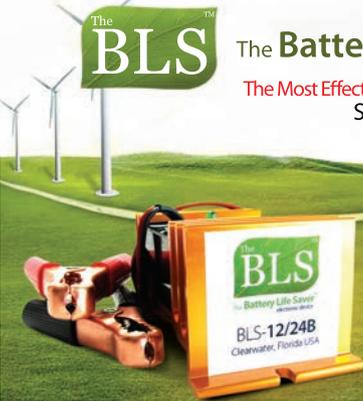
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continued from page 60

Section 690.13(B) requires permanently marking the disconnecting means. No specifics are given; you have to look at 690.17(E) and 690.53 for those details. 690.13(C) states that PV system disconnecting means do not need to be designated as “service equipment” (which is required for service conductors to a building), another point some AHJs have mistakenly tried to require.

The last two subsections in 690.13 cover the number and grouping of all the system disconnects. In short, there cannot be more than six disconnects per PV system and the disconnects need to be grouped together. The limit of six disconnects can seem troubling at first, especially for installations that use multiple inverters. But revisit Article 100, which defines PV systems as *all* of the components required to convert sunlight to electrical energy. Therefore, in a system with multiple inverters, each inverter could have up to six disconnecting means on the DC side.

Section 690.15 details the equipment that requires disconnecting means: inverters, batteries, and charge controllers. If the equipment is energized from more than one source, the disconnecting means for the equipment needs to be grouped together. In a grid-tied system, this requires placing the DC and AC disconnecting means for an inverter, for example, in proximity to each other. A properly rated circuit breaker can act as the disconnecting means, so for many installations, the point of utility interconnection will satisfy the disconnecting means as well (for example, the backfed circuit breaker for a load-side connection).

This section on disconnecting means isn’t without interpretation problems, as the last sentence of 690.15 and a provision in the next section show. The final sentence in 690.15 states that “a single disconnecting means in accordance with 690.17 shall be permitted for the combined AC output of one or more inverters or AC modules in an interactive system.” In the 2011 *NEC*, this reference to 690.17 was less contentious than in the 2014 version. The reason is, in 2014, the acceptable disconnect types are all DC disconnecting means. Therefore, the *NEC* is requiring a DC-rated switch for an AC source. As previous *NEC* cycles show, the intention was to require an approved disconnecting means be used for multiple inverters.

Section 690.15(A), “Utility-Interactive Inverters Mounted in Not Readily Accessible Locations,” was simply moved from 690.14 into 690.15. Other than abbreviations, the language did not change. In short, utility-interactive inverters can be located in not readily accessible locations, such as a rooftop, as long as they meet these requirements:

- Have AC and DC disconnecting means “within sight of or in each inverter.”
- Install an AC disconnect in a readily accessible location per 690.13(A).



Ryan Meyfield

An AC disconnect must be grouped with the inverter in the form of a switch or circuit breaker.

The final requirement in the “not readily accessible inverter” section is a plaque at the service entrance and points of utility interconnection that denotes the presence of the PV system. These can be combined with other required plaques to meet multiple *NEC* sections simultaneously.

Microinverter Disconnects

With the addition of the rapid shutdown requirement (see “Code Corner” in *HP165* and *HP166*), many more commercial systems are likely to have inverters on rooftops, requiring installers to pay attention to requirements in 690.15(A). And while this *NEC* section is indiscriminate when it comes to inverter types, it often leads to another question specific to microinverters: Can connectors be used as disconnects?

To get a clear understanding, we need to jump to the exception in 690.17(E), which allows connectors to be used as disconnecting means, but only if they comply with 690.33, and are listed and identified for use with the specific equipment. Section 690.33(E) specifies the requirements for circuit interruption using connectors: They either need a rating for interrupting the current without hazard to the user or have a marking on them indicating “Do Not Disconnect Under Load” or “Not for Current Interrupting.”

This requires verifying the manufacturer’s product listing. The major microinverter manufacturers have listed their products with specific connectors for disconnecting means and provide technical documentation to help AHJs and installers with that evaluation. The final say rests with that AHJ, so the burden of proof often falls back to the installer. In jurisdictions that do not accept the connectors as disconnects, installing a switch at the end of the microinverter’s branch circuit can provide a disconnecting means for an entire group of modules and inverters.



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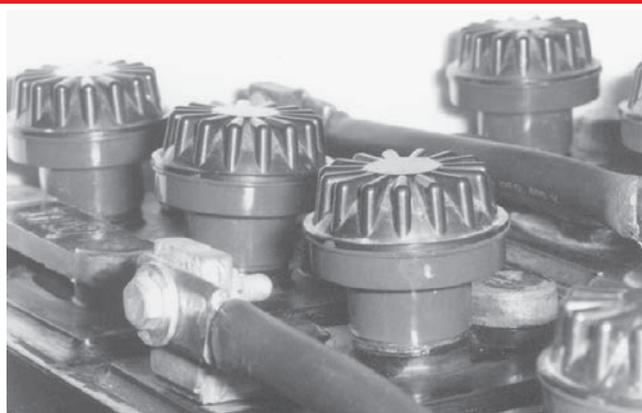
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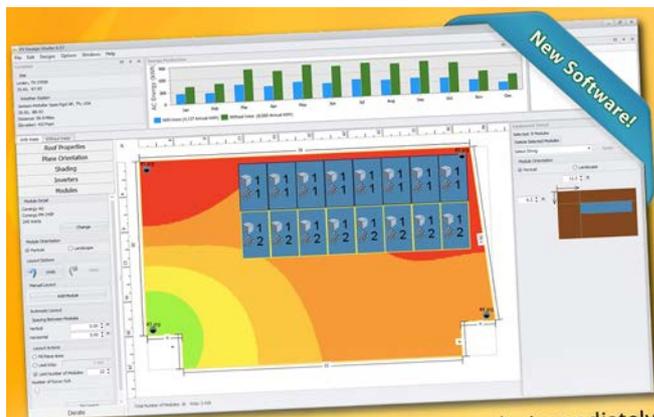
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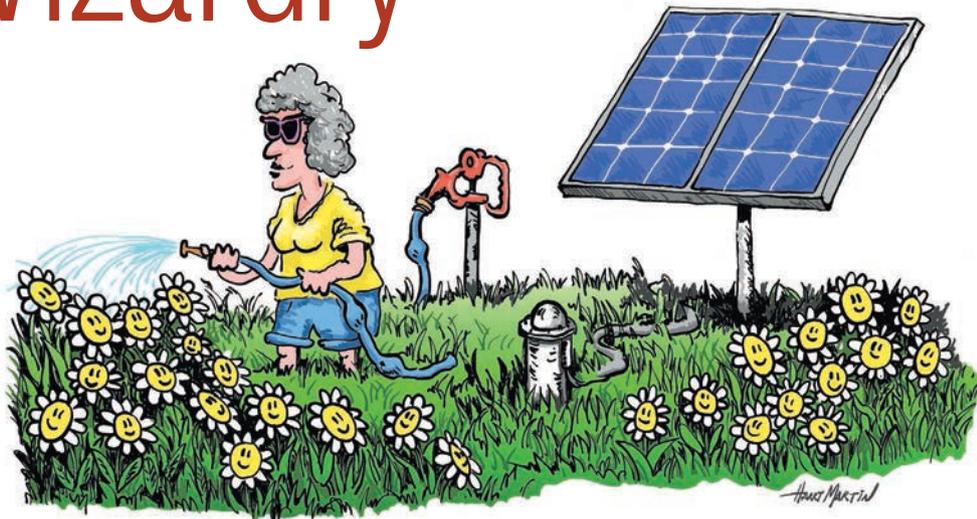
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Homestead Water-Wizardry

by Kathleen
Jarschke-Schultze

When my husband Bob-O and I first came to live on Camp Creek 25 years ago, our domestic water source was a small spring. Located up a ravine on the steep hill across the creek from us, it was the original domestic water system for our old “round-up” cabin. Locals told us, “That’s a real good spring. It’s never gone dry.”



Source

Although it’s not on our land, the spring was deeded to our parcel when this large cattle ranch was subdivided. The water from the spring seeps into a small steel pipe. As the pipe fills, the water level grows, eventually reaching a small outlet to a buried pipeline, where it conveys water down the steep hill to a 1,000-gallon concrete holding tank. This tank has an overflow pipe sticking out of it. When the tank is full, we can use binoculars and see the water streaming out of that pipe.

The water in the tank runs down another buried water line to the bottom of the hill. There, it travels under the road, down the hill a bit more, over the creek and then is buried underground again where it meets up with the house water system. As you might imagine, with all of this vertical drop, we have great water pressure.

Weak Links & Dry Lines

The part of the pipe that crosses the creek is wrapped in insulation and heat tape, and this is encased in a large steel pipe. When winter brings freezing temperatures, this section is our weak link.

Although we had good household water pressure, we didn’t have abundant water. We measured the flow of the spring all those years ago and it was roughly 0.375 gallons per minute (gpm). We had a learning curve on water usage. At 540 gallons per day, running out of water was a fairly common occurrence in those first years.

Our second summer here, the spring dried up. We were so surprised. The spring returned that winter, but we decided to drill our first well, which gave 4 gallons per minute. We bought big black water-holding tanks and put them up on the hill behind the house. We rented a ditching machine and laid water line everywhere we thought we might need a faucet.

Pump It Up

The well-water system is separate from the house water system. Bob-O uses a small tracker with two 190 W PV modules to power the submersible well pump. We can pump that water to the black holding tanks for gardening and fire defense or to recharge the house tank. When we are not pumping water, we can flip two switches and the PV energy goes into the main house power system.

To refill our domestic water tanks, we connect a hose from the well-water outlet to an outside faucet on the house. After turning that faucet wide open we flip the breakers and start the pump. The pump has enough power to move water through the house pipes, across the creek, and up to the buried concrete tank. We set a timer and when it goes off, we check the overflow pipe using binoculars to know when the tank is full.

Conservation & Expansion

Two summers ago, the spring dried up again. Although it came back for two short months at the end of that winter, the water quit flowing early the next spring. This winter, the spring barely started again. Charging the house system with the solar pump has become routine—so much so that Bob-O buried a pipe under the driveway to protect the hose connected to the house.

We now have three wells. One was a real disappointment, coming in at only 2 gpm. Drilling for water is a gamble at best. We anted up two years ago and drilled another well (see “Home & Heart” in *HP162*). This one came in at 7 gpm, and that in a dry year. We were able to expand our irrigation water storage capacity to 5,500 gallons.

Every year seems drier than the last. Bob-O has noticed that the seasons seem to have shifted about two months. In the past,

the frost came at the end of September. Last year, it came at the end of November. Our historical last frost date is June 1. This year, I started the garden in March because of the warm, dry days.

We did get a little snow on the mountains around us from February into April. Not enough, and way too late to be the kind of mountain snow pack that recharges streams and springs. Although we live between two ski resorts (Mt. Shasta and Mt. Ashland), two years ago, neither one opened—there was not enough snow.

Because of the frugal nature of our water supplies, we use drippers and microsprinklers in our gardens. We have a one-pint-per-flush toilet, a front-loading washer, and a super-efficient dishwasher. And after 10 years of never using the bathtub, we replaced it with a shower stall.

We use battery-powered digital timers to water. A couple of times of forgetting what hose run was on—and waking up the next morning to empty water tanks—convinced us of the benefit of using timers. The other day Bob-O brought home a full trailer of organic straw bales for mulching and weed suppression. I'll be darned if I'll water weeds.

In years past, I've had to water my plants with dish-rinse water. I put buckets in the shower to catch the cold water before it warms. At times, I've had to choose which plants to let die in the garden as the water supply lessens. We can get our water usage down to a real minimum. That's a good thing, because it seems we'll need to if the drought

continues—or becomes the norm. Our creek is seasonal, and that season is shorter every year, so we only pump creek water in the early spring.

I've stood in the springtime garden watering plants and thought, "Look how rich I am—I turn on a faucet and clean water comes out. I don't have to walk several miles to lug it home. I don't have to boil it. I have enough to grow food." How many people will never know the sunny brilliance of water diamonds caught in the leaves of dinosaur kale as it is rinsed with the garden hose? We are rich, and we try not to waste that wealth.

In California this year, rice farmers can make more money selling their water allotment than growing the rice crop. California's Central Valley, where an amazing amount and variety of food is grown, is in its fourth year of drought. Food prices are going to rise. More and more food will be imported from other countries. This is the future. Water is a resource that needs to be protected and nurtured. We are rich with water here in the United States—let's spend it wisely.

This year, my garden has an international flair, with a focus on varieties that are well-adapted to hot, dry climates. I am growing Israeli melons, Palestinian tomatoes, Ethiopian kale, Texas watermelons, and several varieties of slow-bolt lettuces and spinach. If the plant came from a hot and/or dry climate, I bought the seeds. I try not to stay locked in on my plant choices. Adaptation of these varieties may be the key to successful growing in a hotter, drier climate.



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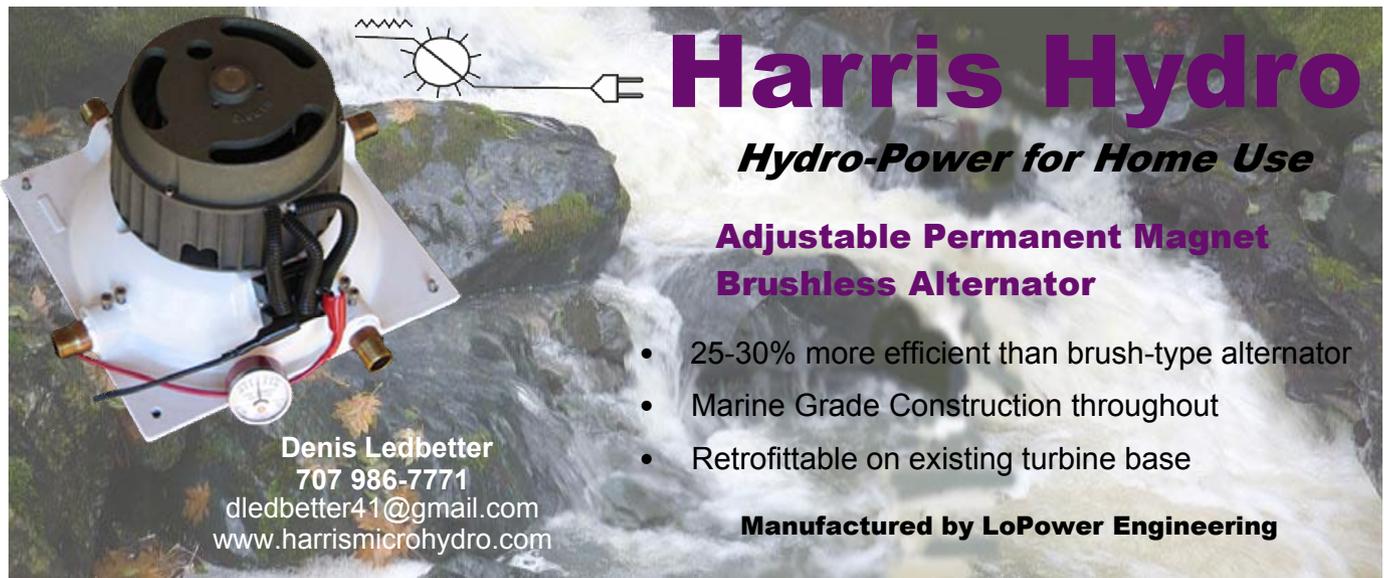
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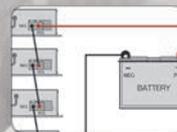
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Sizing Very Small PV Systems

Sharing solar technology with people who do not have electricity is a satisfying venture, and learning how to do it well helps us understand the basics of off-grid solar-electric system sizing. An example from my work in Costa Rica can help you grasp the process.

The three key design questions are:

- What is the electrical load?
- What PV array capacity is needed?
- What battery capacity is needed?

These three main parts of the system must be sized so that the load is well supplied, and the battery is regularly fully charged and never overdischarged. (A charge controller, which is not discussed here, would also be needed for this system to prevent the battery from being overcharged.) Finding that balance uses watt-hour math combined with some design experimentation and savvy.

Load. All off-grid PV system design starts with the load—how much energy is needed per day. Energy is measured in kilowatt-hours (kWh) in large home systems common in North America. In small developing-world systems, it's measured in watt-hours (Wh). The typical system we install includes three to five DC LED lights and a USB outlet converter for cell phone charging.

Calculating array capacity is based on:

- Daily energy needed
- Peak sun-hours on the site
- Modules available

Example Small System Loads

Load	Power (W)	Hours Per Day	Wh Per Day
Kitchen light	3	3	9
Living room light	3	2	6
Bedroom light	1	1	1
USB charger	2	1	2

Total Daily Load 18

In this design, we had several 20-watt modules available, and 4 peak sun-hours in the region. Using a basic formula (PV watts × peak sun-hours × 0.65 “reality factor,” which accounts for energy losses of an off-grid system and an unrealistic module rating system), we end up with 52 Wh per day from our 20 W module. This is almost three times the daily load and may seem excessive—but having this sort of headroom is wise with small systems, and accommodates some load growth.

Battery sizing considers:

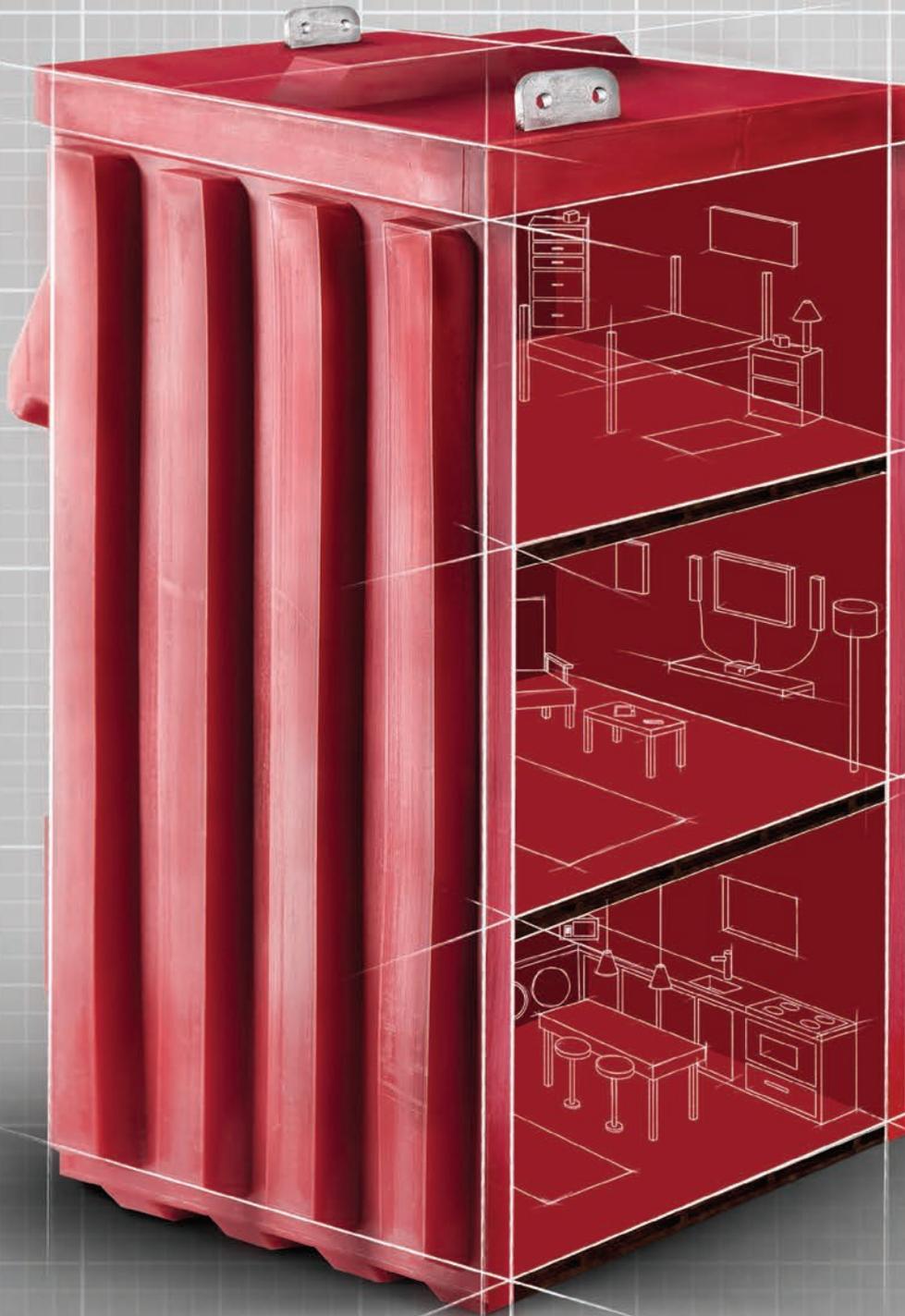
- Daily load
- Days without sun (days of autonomy)
- Recharge time with chosen PV module
- Batteries available

When we went battery shopping, we found a 12 Ah, 12 V battery, which means its energy capacity is 144 Wh. We routinely cut this number in half to give us the *usable* capacity, basing our design on an average 50% depth of discharge (DOD). This leaves us with 72 Wh of usable capacity. An 18 Wh daily load will only cycle the battery down about 12.5%. If we design based on a maximum of four days without sun, we are right at 50% DOD.

Also important is how long it will take to fully recharge the battery after four rainy days. With our “extra” PV charging capacity included in our 52 Wh per day, and assuming we continue to use the load at the full 18 Wh per day, it will take just over two days to catch up and fully recharge the battery (52 - 18 = 34 Wh extra per day; 72 ÷ 34 = 2.1 days). And this all assumes that the load doesn't grow, which is not always a safe assumption.

Finding the balance between the electrical load, solar generation, and battery capacity is a bit of math and a bit of art based on experience, and must take into consideration the real conditions at the site and product availability. Understanding the basic questions to ask will get you off to a good start for your own solar-electric system.

—Ian Woofenden



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