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OFF-GRID MEANS WORLD CLASS PERFORMANCE FROM CROWN BATTERY

Simplicity is Effective



I've just returned from another satisfying trip to the not-so-developed world of rural Costa Rica. My workshop group installed small solar-electric systems at the homes of four rural families. These simple systems will provide electricity for four to five LED lights and a USB port for cell-phone charging. I mentioned these systems to a North American solar colleague, and she said, "Small, like 1 kW?" No, a 1,000-watt rated PV system would be enormous compared to the 30- and 60-watt systems we installed last month.

A single PV module, a low-cost charge controller, some breakers, a USB converter, a 90 Wh battery, and a battery state-of-charge monitor, plus some wire, switches and a few lights can make a dramatic difference in the lives of people who live simply. No longer do they need to use candles or kerosene—or go without light—and at a cost of only several hundred dollars.

In the same week, our group donated four modern rocket stoves (see "REview: ACE 1, Ultra-Clean Biomass Cookstove" in *HP182*) to community facilities and homes in the area. These modestly priced but sophisticated devices burn small pieces of wood, corncobs, palm nuts, and other materials efficiently and with little particulate pollution. They replace cooking on open fires, which contribute to poor indoor air quality conditions in homes and deforestation.

Two things make these simple solutions work. One is the low energy needs of the families. Big-screen TVs, electric coffee makers, and trash compactors are not "essentials" in their homes. Gaining a bit of light, charging a cell phone, and cooking cleanly and efficiently are high priorities.

We used lights that draw 1 and 3 W in three of the systems, and 5 W lights in a system for an ecotourism farm. These small loads can be powered with a very small PV system. The rocket stoves we donated use about one-tenth of the wood required for open-fire cooking. They waste less heat, burn cleanly, and use waste wood.

I delight in the fact that my North American students get to see how these small and efficient technologies can improve lives in different cultural and socioeconomic schemes. I've watched many of them question their own lifestyles and consumption habits, and apply some of the principles we learned to their lives back home.

We can also use these and other technologies in our own "first-world" homes and lives. A 3 W LED light provides enough illumination for navigation and mood lighting, or even for reading if well-placed. My own off-grid home relies on a few dozen 5 or 6 W bulbs, and some 3-watters, to provide abundant light. The rocket stove we used in Costa Rica can be used as a camp stove (I was introduced to it while camping in Oregon); at home, we use it instead of our gas grill. This not only displaces fossil fuel usage, but uses up wood scraps from around the homestead, and is an educational eye-opener for city visitors on what efficient technology can do.

These are just two examples that might spark you to review your energy needs. Simplifying and reducing consumption make it easier and more cost-effective to use cleaner sources.

—Ian Woofenden, for the *Home Power* crew

Think About It...

"In character, in manner, in style, in all things, the supreme excellence is simplicity."

—Henry Wadsworth Longfellow

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Ian Woofenden

Seasoned energy-efficiency experts and off-gridders weigh in on the handiest and most efficient appliances they rely on at their remote homesteads.

30 **smart** inverters

Brian Lydic

Given the impacts PV systems can have on the grid, it makes sense that their inverters help ensure good, reliable power quality. Learn about the latest developments in smart inverter technology.

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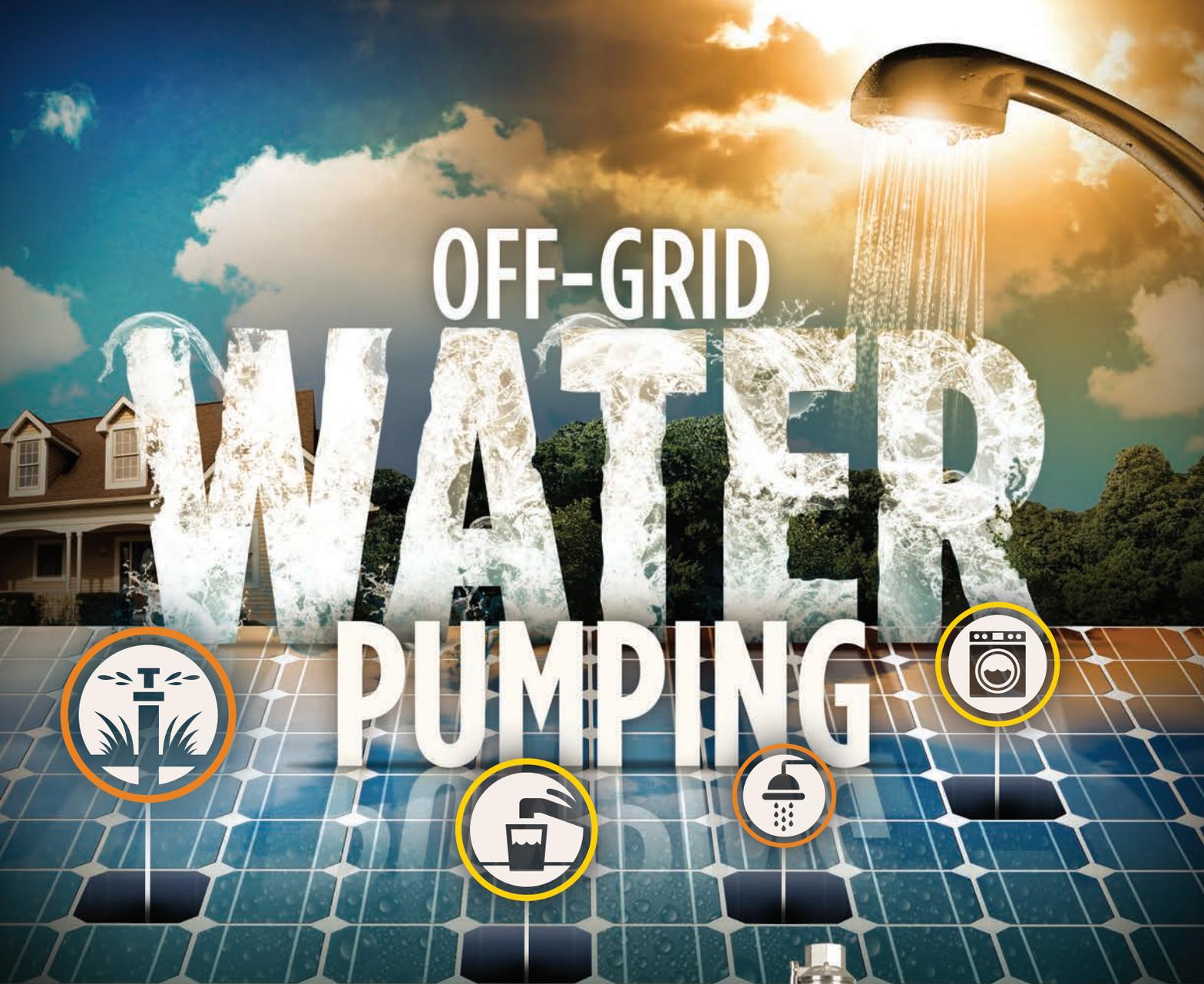


On the Cover

Home Power publisher Joe Schwartz with his new 16 kWh lithium-ion battery, which serves his off-grid, PV-powered cabin in the mountains of southern Oregon.

Photo by Shawn Schreiner.

Photos courtesy: Roy Rakobitsch, SMA



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 **Franklin Electric**

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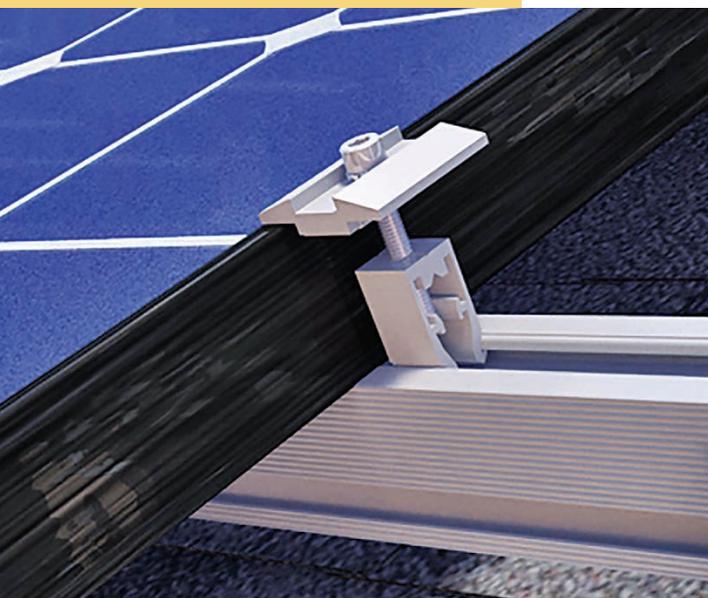
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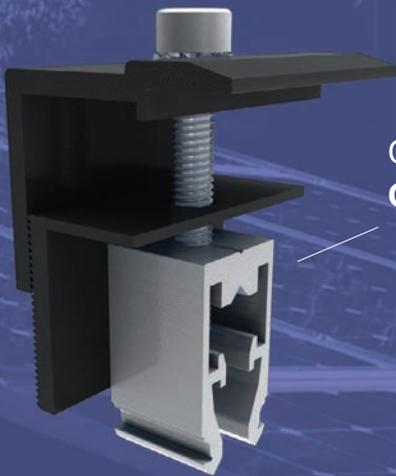
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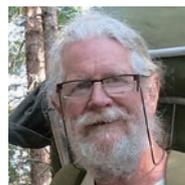
In 1977, **Windy Dankoff** started a business in New Mexico to supply wind power to off-grid homes. In 1980, he began to use PV systems for homes and well pumps. Eventually, his company, Dankoff

Solar Pumps, became a worldwide supplier. Windy credits his success to taking a whole-system approach to energy efficiency. He retired in 2005 and continues to write, teach, and explore.



Brian Mehalic is a NABCEP-certified PV professional, with experience designing, installing, servicing, and inspecting all types and sizes of PV systems. He also is a curriculum

developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.



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.



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.



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.



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.



Joe Schwartz is the publisher of *Home Power* and *SolarPro*. He attended Solar Energy International in 1995 and worked as a PV, wind, and hydro systems integrator prior to entering technical

publishing. Joe lives off-grid, and holds a Limited Renewable Energy Technician license in the state of Oregon.



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.



Brian Lydic started out in renewable energy in 2005 at a solar installation company in Ann Arbor, Michigan. He then joined Fronius, providing technical support, and tracking standards, regulatory, and inverter

market issues. Today, as Regulatory Engineer for IREC, he continues working with various stakeholders to increase access to sustainable energy.

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ABB

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ABB (abb.com) released its UNO-DM-PLUS-US residential PV inverter line, which is listed to UL1741-SA to comply with California's Rule 21 and Hawaii's Rule 14 for smart inverters. These batteryless grid-tied inverters offer dual MPPT inputs and are available in five capacities from 3.3 to 6.0 kW. Highlights include wireless communication via an integrated web server and a load manager, which is helpful for homes with smart appliances and systems designed to maximize PV energy self-consumption. Their CEC efficiency ranges from 96.5% to 97% at 240 VAC output. A NEMA 4X enclosure allows outdoor installation. These units can be installed with ABB's string-level rapid shutdown unit to comply with the 2014 NEC Article 690.12 requirements or with Tigo's TS4 optimizers, which meet 2017 requirements.

—Justine Sanchez



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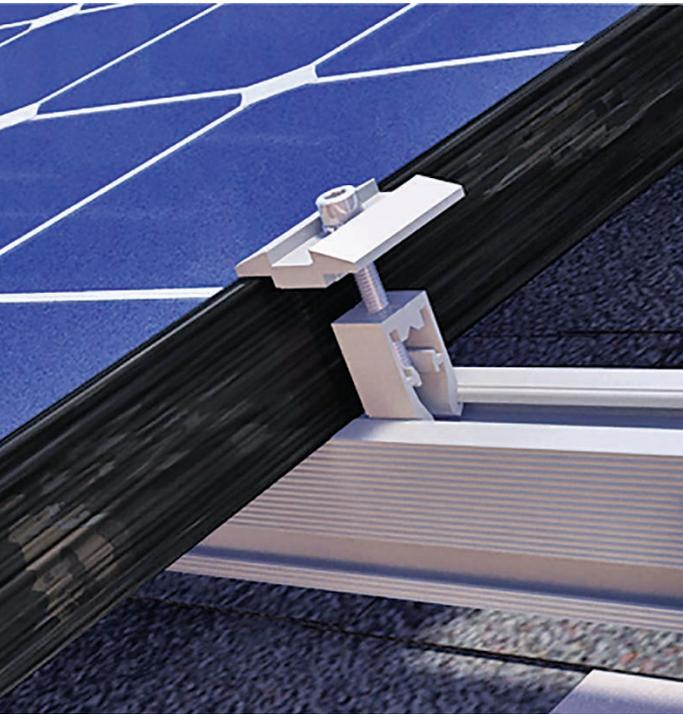
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Courtesy Quick Mount PV

Quick Mount PV

QRail

Quick Mount PV (quickmountpv.com) released QRail, a new rail-based rack for PV arrays. This product features QClick technology—in which module mid- and end-clamps click into place and stay upright, ready to receive a module—to expedite installation. The internal QSplice feature provides simultaneous electrical bonding and structural splicing of two rails without tools. QRail is available in light, standard, or heavy versions to accommodate various climate conditions and loading requirements. Available in mill or black finish, QRail comes in 168- or 208-inch lengths. These rails can be used with Quick Mount PV's waterproof mounts for various roof types or with other manufacturers' products. Quick Mount provides QDesign, a free online design tool that helps PV system designers determine array configuration options for the QRail system and generates a complete engineering report and a bill of materials.

—Justine Sanchez

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Clamps for Metal Roofing

Before purchasing metal roof clamps for PV arrays they must be tested on a sample of your metal roof panels. I had a new metal roof on my house and, for my rooftop-mounted PV array, decided to use clamps held in place by set screws. As the installer was setting the last clamp, he removed it and examined the roof metal “just in case.” Unfortunately, there were cracks in the metal under every set screw. We had to have the entire roof replaced and use a different rail mounting method (posts that fastened with screws through the roof, with rubber boots and lots of sealant).

Metal roofing panel quality varies, and you need to be sure your clamp vendor guarantees their clamps can be used with the panel make. Our clamp vendor replaced the roof at their cost and promised to remove our particular metal roof panel from their list of compatible products.

Our installer no longer uses that particular clamp and now has a list of metal roof panels that are not appropriate for use with seam clamps. If the roofing steel thickness is 26 gauge or less and has a wide seam profile, seam clamps are tested on a sample or in a low-consequence area of the roof, before being deployed. We’re happy to have worked with a quality installer and manufacturer who stood behind their work and products, but hope others can avoid the trouble we experienced.

Ron Watts • Anacortes, Washington

Courtesy Ron Watts



A PV Backup System for Power Outages

I wanted to share a quick “grid-down” experience with a system I have not seen mentioned in *Home Power*. The back-story is this: We have a two-year-old son with cystic fibrosis and live in a rural area prone to power outages. His medicines must be refrigerated, and he has a couple of medical devices that need to be used twice daily. When the power went out, our backup generators ran, but they were no fun!

We decided to purchase a large portable backup system—4 kW of PV modules with a 3 kW inverter and sixteen 110 Ah batteries. I am a bit of a nerd and have a tech background, and installed the system myself using the provided instructions.

When the grid is available on cloudy days and at night, the system uses it to keep the batteries maintained above a 90% state of charge. During sunny days, the array does that work. During grid outages, the system switches to the batteries, with no interruption to the circuits running through the inverter. I also installed a six-circuit transfer, which lets me control loads if needed, and a 120 VAC Grundfos well pump to provide a more secure water supply.

Now the story: During a huge windstorm on the East Coast, we had close to 80 mph gusts with 50 mph sustained—for two days. Trees didn’t stand a chance, and we quickly lost grid power. We were without utility electricity for three days, but the impacts were minimal because of our backup system. Psychologically, the peace of mind we have with a system like this is priceless. Knowing that we would be OK if the grid was down longer-term is a massive weight off our shoulders.

A system like this is not cheap, but quality never is! We may invest in an 8 kW system that can sell excess energy back to the grid. It is a great system for anyone who wants more energy security.

Dan Lewton • Southwest Virginia

23 Years Using Solar-Powered Hydrogen

In the summer of 2012, a rebuild—or “resurrection” as we like to call it—of a hydrogen and oxygen production plant was conducted. In 1994, this hydrogen plant, which uses PV energy to electrolyze water, was featured in *HP39*. After 16 years of reliable PV-powered hydrogen and oxygen production, in 2010 we shut down our home-sized hydrogen plant. The plant was offline for

about two years, due to operational problems with high cell voltage and cross-contamination of the hydrogen and oxygen output, which made them unsuitable for storage.

We wanted to get the plant back in service so we could have hydrogen available for cooking and oxygen for welding and cutting, our main applications. As a summer intern at H-Ion Solar, Nathan Miller took on the challenge of overhauling the hydrogen plant.

The first step was diagnosing the problem. We measured the voltage across each cell while the plant had been off for a considerable amount of time. Additional voltage measurements were taken once the plant was fired up. The cathodes were in excellent shape, but the separator boxes had cracked and split, and the anodes were severely corroded.

We installed replacement Spicer cell-packs into the cell containers. These second-generation packs improve on the previous model. The new model features an envelope around each electrode—one collects anode gas (oxygen) and one collects cathode gas (hydrogen). The cells received a new paint job, new Teflon O-rings, new gaskets (for the removable end-plate), and new stainless steel bolts. After replacing the electrodes and separators in four bad cells, and replacing the gas purifier catalysts, this plant is now in “standby” service, and can be used to generate oxygen and hydrogen.

The hydrogen plant requires a technically educated operator who can perform regular maintenance and day-to-day operational supervision. The plant has complex purification systems, for both hydrogen and oxygen output. The double-bubbler scrubbers have to be checked, filled with water, and drained. The water-removal filters have to be drained manually several times a week. And water must be added once or twice a week. Purity of produced gasses must be checked to assure storage safety.

New options are available for hydrogen production by electrolysis. We are now using our new Proton-OnSite PEM-electrolyzer, one of several gas chromatography H₂ carrier gas vendors. This type of electrolyzer is simpler to install and operate. Our new H₂ generator contains a palladium purification filter that is smaller and simpler than our old H₂-O₂ plant with H₂ and O₂ catalytic-purifier trains.

We are also doing a type of hydrogen net-metering using the PEM electrolyzer. When a hydrogen tank refill is needed, the small 300 cubic centimeter per minute PEM electrolyzer is started until the tank is full.

This may take several days, and our storage can provide several days' worth of H₂ for cooking and oxygen for welding.

We have used the hydrogen and oxygen for 23 years for: barbecuing, heating, welding and oxy-cutting, and briefly for making electricity in a fuel cell. We are unable to run the hydrogen heaters, except occasionally, due to inadequate seasonal storage.

Nathan Miller & Walt Pyle •
MIT and H-Ion Solar

Tribute

One of my best friends and longtime solar buddy, Levi Heinold, passed away in late February. As I continue to wrestle with this reality, I got to thinking about what he represented to anyone and everyone in his orbit.

I first met Levi at a PV class in Carbondale, Colorado, in 1992. *Home Power* founders Richard and Karen Perez were the guest instructors and I was there in a support role as the local solar business owner. Levi and I hit it off immediately (with some assistance from a 12-pack)!

Our friendship blossomed from there. As budding solar businessmen, we collaborated on projects over the next 25

years. We worked extremely hard, and shared countless experiences and stories. We climbed peaks, we camped, we played in the snow, and we partied. I will always consider him my brother.

Levi had a work ethic like no other. In his earlier days, he hiked both the Pacific Crest Trail and the Appalachian Trail. He built a reputation around a quality business without the use of a website or logos on vehicles—heck, I'm not sure he even had business cards! Everyone wanted Levi on the job because they could count on personalized service and a job well done.

Most of all, Levi built things and he fixed things. My standard description of Levi always included, "nothing scares him." He was a master plumber, a self-taught mechanic, and a problem solver. He had his NABCEP certification in PV and SDHW. Levi was practical, but never shied away from a challenge. A risk-taker, yet laid-back as well. He was one of the most solid people I have ever known.

It is with this in mind that I wanted to pay tribute to those who build. The awards, recognition, and yes, the money, generally stay upstream. But it is literally the people in the trenches who make this whole solar thing work.

And though I hung up my tool belt many years ago, I have always been able to count on my crew and guys like Levi to get after it in the field. Wind, rain, cold, snow, ice, mud, heat; through design changes and change orders—you name it, and these hardworking folks make it happen. And (usually) with smiles on their faces!

So Godspeed, Levi. You brought so much love, joy, laughter, and passion to this world. I am a better person having known you, and will forever work as hard as I can to continue your vision of a caring people and a sustainable planet.

Scott Ely, Sunsense Solar •
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Water Supply Backup

I recently bought my dream home in the woods of southern Ohio. The home is served delicious spring water that is 400 yards away and some 80 feet downhill. A submersible 240 VAC pump sits at the bottom of a 1,000-gallon cement tank, powered by a separate electrical service from the local utility. A second 120 VAC pump and small pressure tank in the house provide good pressure there.

The problem is that we get many power outages due to downed trees, and each power cut equals losing our water service to the house. A backup gasoline generator keeps the house loads powered during outages.

I'm researching backup power options for the well pump. A PV array is not an option due to the spring's location, which is at the bottom of a steeply wooded hill. Access to the spring is not easy; mechanical transport is not an option.

I was considering a battery backup solution with a trickle charge, which would keep the batteries topped off until the power goes out. But I'm having difficulty finding specifications that would accommodate a 240 VAC pump. An hour or two of backup would be great, and I would also like to add a generator to recharge the batteries during prolonged outages.

Tom Martin • Sugar Grove, New York

Battery backup for an hour or two may cost more than you think. I'm assuming your pump at the spring is rated at 1/2 hp, which equates to about 500 watts when running. Pumping for one hour would require 500 watt-hours (Wh). The battery bank and inverter reduce efficiency by about 30%, which means about 650 Wh would be required for an hour of pumping.

A lead-acid battery bank, both for longevity considerations and/or to deal with decreasing capacity in cold temperatures, would need a capacity of about 1,000 Wh (1 kWh) to serve this load. Batteries are traditionally rated in amp-hours (Ah). For example, a 24-volt battery bank would be rated at 1,000 Wh divided by 24 V, which equals

Courtesy www.framedrilling.com



It's easy to double your pressurized water storage for use during power outages by adding a second pressure tank.

about 42 Ah. The least expensive option in this case would be to purchase two 100 Ah, 12 V RV/marine flooded lead-acid batteries, at about \$300. The downside is that these batteries require regular maintenance. Sealed lead-acid batteries are maintenance-free, but would be about double the cost.

Because your pump runs on AC, you'd also need an inverter to supply AC from the DC batteries, and, if your inverter doesn't have 240 V output, a transformer to step 120 V up to 240 V to match the pump. You can expect to spend between \$1,000 and \$2,000 for this equipment.

Alternatively, you could replace the pump with a 120 VAC pump. You would also need wiring, safety devices, and weatherproof housing for the equipment, which may add another \$1,000. Depending on how the batteries are maintained and the number and length of outages, you may need to budget battery replacement in five to seven years.

You could also consider replacing the 240 V AC well pump with a lower-voltage DC pump made especially for PV or battery power. It will use about half the energy and eliminate the need for an inverter. With this pump, you could then use a single 12 V battery and, as you suggest, an inexpensive trickle charger. A variety of DC pumps are available, ranging from about \$100 for an RV-marine pump, to more than \$700 for a long-lasting, specialized pump made for PV power. You will still have a significant installation cost, likely more than \$2,000. DC pumps generally pump over longer periods of time. They may not last as long as a conventional AC pump, which runs only for short periods.

A simpler, low-tech approach would be to store water in a holding tank or cistern at the house. A tank is far less expensive than a battery backup system, and it is relatively maintenance-free, long-lasting, and reliable.

If you don't run your backup generator continuously during power failure, you may wish to extend your supply of pressurized water by replacing your pressure tank with a larger one. Or, keep it and add a second pressure tank to your system—your new capacity will be the sum of the two, and they need not be matched in size. The second tank can be installed anywhere on a main pressure line and won't require a second pressure switch. Even if you do nothing else, this will extend your water supply to weather most short-term outages.

Windy Dankoff • Founder (retired), Dankoff Solar Pumps

[Ed. note: Veteran solar installer Drake Chamberlin contacted the reader directly by phone. Their agreed-upon solution was to install a cistern for storing water at his house, which will get him through periods of utility outage. Tom is also considering a future PV system for his home.]

Cleaning PV Arrays

What is the most effective and safe method for cleaning a PV array? The company we bought our modules from suggested using only water to clean the modules to avoid scratching them.

We live in a desert mountain region of Mexico. A lot of dust and grime has accumulated on the array, and using water alone does not seem to be effective. Can a soft-bristle brush (like one used for washing cars) be used? What kind of detergent, if any, can be used, and how much?

Lamar Strickland • via email

I use a soft-bristle brush and plain water to clean my PV array. I do it early in the day, before the sun has a chance to heat the PV modules, which will evaporate the water and cause smearing.

I spray the array two or three times, letting the water soak into the grime and bird droppings for a bit, scrub (if necessary), and then rinse off the dirty water left after the scrubbing. Yes, a car-washing soft brush is good. If you want to use detergent, use a mild dish detergent.

If it rains regularly, PV arrays usually don't need washing (and even some visible grime won't affect output much). However, in arid areas and some agricultural areas, where farm machinery generates lots of dust, dirty PV modules can definitely reduce a system's overall performance.

Michael Welch • Home Power Senior Editor

Controller-Array Sizing

I had a question regarding Zeke Yewdall's comment about replacing 30-year-old batteries ("Ask the Experts" in *HP183*). He said that some charge controllers, such as MidNite Solar's, are current-sensing, and therefore can be purposely sized with an array that is larger than theoretically recommended.

I have an off-grid 1.9 kW PV array (ten 190 W Sanyo modules), and approximately 2 kW of 320 W modules in storage. I would like to add these extra modules to the array to increase PV production on cloudy days and keep my 760 Ah battery at a higher state of charge. Do I need to replace my charge controller?

Zack Gore • Ontario, Canada

Courtesy Zack Gore



While you don't necessarily need to replace your charge controller, you will need to add a second charge controller to accommodate your new modules and their string voltage. But first I would like to further explain the concept discussed in *HP183*. Oversizing a PV array can be done with some MPPT charge controllers that can regulate maximum output current. But what situations would warrant this?

For the majority of the winter, the weather may be poor and the sun low in the sky, with the location rarely receiving more than 50% full sun. In the summer, the days are much sunnier, and we don't need as large of an array. Doubling the array size, but not increasing the charge controller's size, could be effective in increasing the system's winter production. In the winter, when it's often less sunny, a smaller charge controller would generally not be a limiting factor. In the summer,

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the charge controller would limit the output amperage. This could eliminate the need for upsizing the charge controller, wiring, etc.

But you'll need to confirm with the manufacturer that the MPPT charge controller can limit output amperage and make sure the array does not exceed the charge controller's rated input current. For example, you can't put 60 A into a 30 A charge controller and have it limit the output to just 30 A. When array size is increased beyond a charge controller's traditional sizing, the array voltage, not its current, needs to be increased. The array's Voc maximum will need to remain less than the charge controller's maximum input voltage, too.

Regardless of the controller sizing, the array must consist of similar PV modules to use the same controller—at least the same Vmp for each string of modules. Mixing newer modules with the older ones will not work. Using multiple controllers allows different PV modules in the system, especially if there is a mix of 36-cell, 60-cell, 72-cell, or 96-cell modules, or different PV technologies (crystalline and amorphous, for example).

Zeke Yewdall • Ward, Colorado

Off-Grid System Troubles

We recently had an off-grid solar-electric system installed at our rural house, 2.5 hours west of Prince George, British Columbia, Canada. We had been running the home with a 3,000-watt Honda inverter generator. We have an electric fridge, water pump, TV, and LED lighting. Our "automatic" loads are the fridge and the pump.

We purchased a solar "package" that included twelve 340-watt Hanwha Q Cells PV modules, and a prebuilt, Magnum MS4448PAE inverter system with a solar charge controller. Our batteries are 24

used Surrette 2-KS-33PS lead-acid that were previously in service for eight months, according to our supplier. The system was installed in November 2017.

Our modules are only producing between 40 and 80 W each, even on sunny days. With fully charged batteries, we can only run loads for about 2.5 days. (However, when the batteries read at 100% SOC, the hydrometer says they are only at 1,220—and they have not come up. It takes more than 20 hours of running our 6.5 kW generator to fully charge the batteries. We paid more than \$25,000 for the system, and our fuel costs have tripled compared to when we were running only the generator.

Our installers have offered multiple reasons why we are having problems, including "no sun." But four of our neighbors have PV systems that work fine—in times of little sun, they run their generators about two hours a day, three days a week. Our installers have suggested we add another PV array to help charge the batteries. Our theory is that it's the batteries. What do you think?

Dan & Liv Kelly • Burns Lake, BC, Canada

Off-grid systems are by far the most difficult to plan because there are so many factors to account for, including the average brightness of the sun at your location (insolation), shading, sun angle in winter versus summer, and your daily energy usage. First, verify the system design. Did the installer perform both a site evaluation and a load evaluation before designing the system? These are both critical to sizing a successful off-grid system.

The installer should have looked up historical solar data for your area, and used a shading assessment. With that data, a good

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estimate of the site's solar potential is possible. From a solar insolation map, it appears that Burns Lake has a winter average of 1.0 to 1.5 full sun-hours. Without another RE source, some generator run time is necessary with so few sun-hours. Next, you should have completed a load evaluation spreadsheet to size your battery bank so that it ideally stays above 70% state of charge (SOC) for lead-acid batteries.

Although your battery bank can store about 84.8 kWh of energy, only half of that should be used, to avoid damaging the batteries from low SOC. That gives you 22.2 kWh of usable storage. Do the math to see whether your array—with its orientation and shading—can keep up with your usage and the battery losses.

Your PV charge controllers and your inverter/charger from the generator may not be programmed correctly. Be sure that the bulk, absorb, and float settings meet the battery manufacturer's specifications. The absorb phase is especially important and often neglected—it is timed for two to four hours and lets the system store the last 10% to 20% of incoming energy to bring the SOC to 100%. If your incoming PV or generator power isn't able to push the battery bank through the entire absorb cycle, chronic undercharging could result, which will eventually damage the battery bank.

An indication of this is your measurement of the specific gravity (1.22), which indicates about 70% to 80% SOC, when your battery monitor showed 100% SOC. Battery monitors are handy tools, but they don't account well for absorb-phase charging. Specific gravity is the only reading that is always correct for measuring actual SOC.

It's unlikely that either a bad battery bank or a miswired PV array is the cause of your problems, but it is possible. To check for this, look

at the watts reading on the charge controller. Are those low numbers what is showing on the display?

Ask the installer to bring an I-V curve analyzer to your site to check the output of each string of PV modules, and measure while also measuring both solar irradiance (how bright the sun is) and array temperature. If a PV analyzer is not available, you could use a digital voltmeter and clamp-on ammeter to compare each string in the array. The addition of an irradiance meter and infrared thermometer would give you even more detailed performance information from each string. Have them bring a battery load tester to track its performance under load, while timing the process and performing specific-gravity tests.

I suspect that you are simply using more energy than your PV system is producing during winter. If the battery bank is sized correctly for your loads, these problems should disappear in the summer, with more sun-hours.

I always avoid prepackaged off-grid systems, and instead design exactly for the customer's resources, loads, and budget. Off the grid, one size does not fit all, and I hope your system designer will make it right for you.

Dan Fink • Buckville Consulting

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Off-Grid

by Ian Woofenden,
with other off-grid guests

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Courtesy Roy Rakobitsch

Energy management is a key factor for successful off-grid living. I've been off-grid for more than 35 years, but this past year—2017—was my first with almost no generator use. I don't have a large PV array—just under 1.7 kW peak. My two modest wind generators are great contributors, complementing the PV production. But the third crucial factor in my off-grid success is wisely choosing and using appliances.

Seasoned off-gridder Roy Rakobitsch with his wind- and PV-powered minisplit heating system.

Heating & Cooling

Heating and/or cooling is the largest energy load in most North American homes. When the climate and site lend themselves to capturing free solar energy, passive solar design—coupled with a well-insulated and -sealed building envelope—is still the pinnacle of solar efficiency. If a wide-open solar window is inaccessible at the home site, building a small, superinsulated house is still critical to energy efficiency.

It's relatively easy to be off-grid if you have the budget for a large PV array and an auto-start generator—and if you don't mind using fossil fuels. But many of us try to minimize our wasteful and nonrenewable energy use for environmental and financial reasons, and because it makes our lives simpler and more peaceful. Achieving an off-grid lifestyle that leans primarily on clean energy sources takes attention to the details of appliance purchase, implementation, and management. Each off-grid task has different possible solutions, and every off-gridder has different approaches. In this article, we'll examine basic energy applications, and survey some longtime off-grid folks on their approaches.

A minisplit heat pump (indoor unit pictured below) can move three units of heat energy using one unit of electrical energy, making electric-powered space heating and cooling viable.



Courtesy Fujitsu

For off-grid homes, burning wood is a common backup or primary heat source. The greenest path here is using selectively harvested wood from your local woodlot and burning it in an efficient masonry heater or EPA-certified woodstove. Common advice had been that electricity shouldn't serve the heating need, but high-efficiency ductless minisplit heat pumps (MSHPs) are changing this. I recently had a 120 VAC MSHP installed at my off-grid home, though I can only use it in periods of good solar and wind system production. While it uses energy efficiently, it still consumes a lot of electricity—and I'm not willing to run a generator to power it. However, it has reduced my firewood usage substantially.

LEARN MORE: "Efficient Heating with Wood" by Stephen Hren in *HP159* • homepower.com/159.44

"Efficient Heating with Minisplit Heat Pumps" by Vaughan Woodruff in *HP180* • homepower.com/180.50

Heating Water

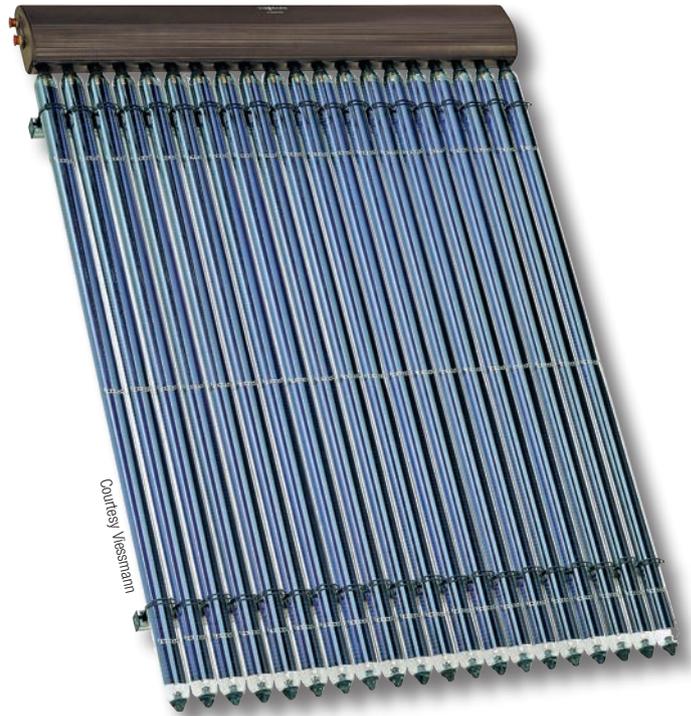
Heating water is often the second-largest household load. Some pioneering folks are heating water directly with a PV array, but not the main array, as that would put the battery bank at risk of overdischarging. Having a PV-direct-to-water-heater system gives all of the benefits, with none of the risk. This again requires an appropriate solar window and enough sun-hours to produce the hot water needed, and it may need a backup.

Other renewable water heating options are solar water heating (SWH) systems and wood. Boilers are a complex option, and heat exchangers within a firebox are simple, low-budget, and effective, but SWH systems are a natural fit for off-grid homes. I live with three water heating systems—one for the main house, one for an outdoor shower, and one for our hot tub. Direct solar thermal systems will likely not meet all of your water-heating needs (they meet about 75% of my needs), so backup may be needed. My home and hot tub systems are complemented with wood heat, and the home system has a propane on-demand backup heater (though it has been turned off for more than two years).

My wood-water heating system is a simple loop in the firebox with passive thermosyphon to a tank in the loft above. The tank also has an internal heat exchanger for my closed-loop-glycol SWH system.

LEARN MORE: "Off-Grid Water Heating" by Vaughan Woodruff & Ian Woofenden in *HP177* • homepower.com/177.50

"Mailbox: Heating Water with Wood, Off-Grid" in *HP179* • homepower.com/179.22



Courtesy: Viessmann

Above: Even with the cost of solar electricity at all-time lows, solar thermal collectors are a viable way to heat water off-grid.

Refrigeration

Refrigeration is usually the third largest household electrical load. It's crucial to buy efficient refrigerators and freezers that are not oversized. Some off-gridders use DC refrigeration to lower the load and eliminate the need for DC-to-AC energy conversion. Where renewable resources are tight in one season, some people lean on propane refrigeration, though many of us have eschewed this option by using high-efficiency electric units for decades.

Though mainstream refrigerators have become more efficient, units like this SunDanzer are superinsulated and available in either AC or DC configurations, making them ideal for an off-grid energy budget.



Courtesy: SunDanzer

LEARN MORE: "Choosing Your Off-Grid Refrigerator" by Dan Fink in *HP176* • homepower.com/176.44



Courtesy The Sun Oven Co.



Courtesy Aroma Housewares

Above: The hardest part of cooking with a solar oven is getting into the habit of using it.

Left: Induction cooktops waste less heat than resistance elements.

Cooking

Cooking is a heat-based activity, and making heat is a significant energy user. Electric ranges are unadvised for off-grid homes, though the advent of induction burners and cooktops has sometimes changed that. I use a single induction burner for much of the summer, when I usually have a surplus of solar electricity at lunch and dinnertime. Cooking with wood—from wood ranges to rocket stoves—is another renewable option. And solar cooking is an excellent possibility if you have the solar exposure and the mindset.

LEARN MORE: “Off-Grid Appliances: Ultra-Efficiency Required” by Ian Woofenden in *HP140* • homepower.com/140.106

“Inductee” by Kathleen Jarschke-Schultze in *HP157* • homepower.com/157.96

“REview: ACE 1, Ultra-Clean Biomass Stove” in Ian Woofenden in *HP182* • homepower.com/182.16

The Grundfos SQ Flex submersible pump is ideal for off-grid living as it can be powered by a variety of AC and DC voltages, and has a soft-start motor.



Courtesy Grundfos

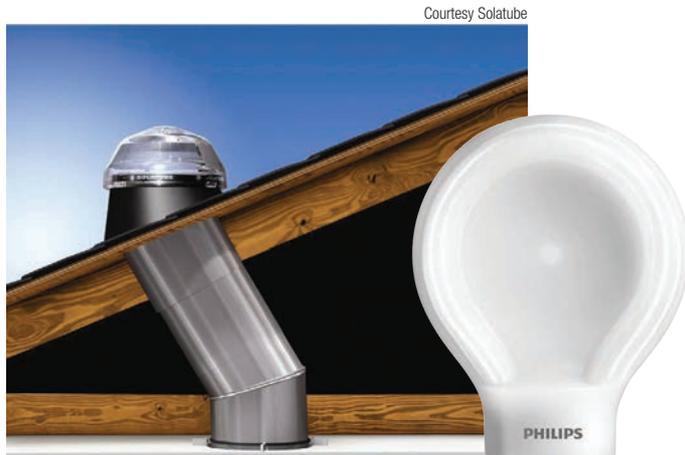
LEARN MORE: “Pumping Water with Sunshine” by Erik Lensch in *HP125* • homepower.com/125.74

“Solar-Powered Water Pumping” by Roy Butler in *HP164* • homepower.com/164.60

“Sizing a Solar Water-Pumping System” by Roy Butler in *HP164* • homepower.com/164.20

Lighting

Lighting is usually the first thing off-grid people want, and it can account for 15% to 25% of your electricity usage. In new homes today—on- and off-grid—going all-LED is the way. I recently replaced all of my off-grid homestead’s compact and tube fluorescents with LEDs, cutting my lighting load in half and doubling my light output—even though what I replaced was high efficiency in its day. With five LEDs (totaling 30 watts), my main room is brightly lit.



Courtesy Solatube

Courtesy Philips

The efficiency and reliability of LEDs (right) are perfect for off-grid lighting, but don’t overlook low-tech lighting solutions like daylighting from solar tubes and well-placed, high-performance windows.

LEARN MORE: “Efficient Home Lighting Choices” by Chris Calwell in *HP165* • homepower.com/165.34

Water Pumping

Water pumping and wells are very often part of the off-grid lifestyle. A few lucky folks have springs or other water sources well above the home site, so they can gravity-feed water for home and irrigation use. Most people must pump and pressurize from dug or drilled wells. A variety of pumping and storage options are available. If you go to conventional well businesses, they will likely set you up with a high-reliability pump—with relatively high energy use. Seek advice from renewable energy suppliers to get the highest-efficiency water pumping/pressurizing system available. Options include AC and DC pumps in various voltages and configurations. This load does not need to be huge for household use, but if you go conventional, it could be a problem.

Domestic Appliances

Domestic appliances such as washer, dryer, dishwasher, etc., are typically electrically run (though the dryer is likely to be gas-heated) in off-grid homes. Choosing ultra-high-efficiency AC models is the norm, though lower-tech options are widely used in simpler off-grid homes. Clotheslines outside, in my house loft, and above my shop’s wood heater mean I’ve never owned a dryer. Handwashing dishes with solar- or wood-heated water makes a dishwasher unnecessary. Many off-gridders prefer a simple lifestyle that doesn’t include the likes of trash compactors, plug-in coffee makers, and such.



Though modern appliances are getting more efficient, sometimes the low-tech, low-energy (and old-fashioned) way is also the most efficient.

© istockphoto.com/ AnikaSalsera

Modern portable electronics are often a more efficient solution than old-school components, and often provide a good excuse to upgrade.



Electronics

Electronics are another player in our modern energy lives. Choosing these carefully to avoid phantom loads (loads that draw energy, even while they’re not being used) and keeping the energy profile low are important. When we get some of our entertainment by working in the garden and walking in the woods, we may use less electricity to amuse ourselves. And when we live in community and have face-to-face interaction often, the desire for electronic connection may be diminished. Laptop computers instead of desktops will usually reduce the computing load substantially. Measuring total and phantom loads with a watt-meter in the electronics store is a good way to avoid buying something that will break your energy budget. Newer appliances keep getting more efficient, *if* you buy good quality. Don’t automatically believe the salesperson who says, “It’s energy efficient”—believe the watt-meter you bring to the store with you.

LEARN MORE: “Analyzing Your Electrical Loads” by Ian Woofenden in *HP156* • homepower.com/156.104

Transportation

Transportation can also be a very large load, and is typically relegated to fossil fuel. The amount of this energy usage depends on location, needs, and lifestyle. Some of us love bicycles and their simplicity, for their emission-free ride, and their ancillary health benefits. Electric bicycles—and larger EVs—can be an excellent complement to an off-grid lifestyle, as long as you plan for their energy consumption and the impact on your off-grid system.

Courtesy Chevy



LEARN MORE: “Pedal & Power: Electric Bicycles” by Ted Dillard in *HP172* • homepower.com/172.36

“Modern All-Electric Motorcycles” by Ted Dillard in *HP181* • homepower.com/181.30

“The Next Wave of Electric Vehicles” by Brad Berman in *HP180* • homepower.com/180.34

“Off-Grid EV Charging” by Steve Willey in *HP181* • homepower.com/181.17

Living off-grid in a cleaner and more economical way requires daily attention to your renewable energy resources, energy consumers, and energy use. Appropriate off-grid design starts with load analysis, and avoids addressing generating sources and complex RE gear until a solid load value is in hand. It’s upside-down to focus on the PV modules and wind generators before you do load analysis, since your load profile will determine the size of your system’s generating sources, battery storage, and wiring, electronics, and other components. While paying careful attention to load efficiency and efficacy is not the glamorous side of renewable energy technology, it’s the most important side. It’s what allows us to live off-grid comfortably and economically.

LEARN MORE: “Before You Go Off-Grid” by Allan Sindelar in *HP137* • homepower.com/137.100

Roy

Who: Roy Rakobitsch

Where: The Driftless Area, Wisconsin

Years off-grid: 16

Energy systems:

- **PV array:** 5.5 kW with two stacked OutBack FX3648 inverters
- **Wind turbine:** 13 ft. diameter axial flux Piggott/Otherpower homebrew on a 137 ft. tower
- **Battery:** Deka 48 V flooded lead-acid; 40 kWh capacity
- **Backup generator:** Diesel Listeroid 3 kW, with autostart. 15 gal./yr. fuel consumption

Motivations: It's fun and challenging (from an RE system designer's perspective)

Heating & cooling: Single Fujitsu 9RLS2H ductless MSHP. Kickapoo Stove Works wood heater when it's really cold.

Water pumping: Grundfos SQ flex with a CU200 controller and an underground pressure tank. This pump has soft-start and a helical rotor, which are much more efficient than a standard centrifugal submersible AC pump.

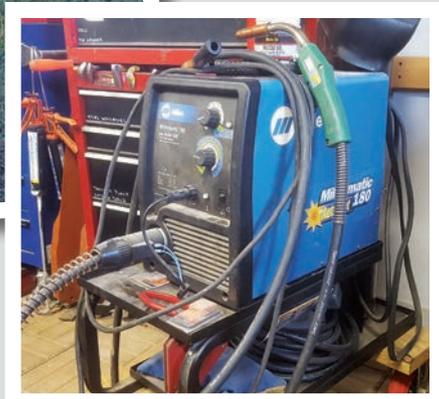
Water heating: Bosch AQ110HX on-demand propane heater (13 years old)

Refrigeration: Converted a 9-cubic-foot chest freezer to chest refrigerator with Johnson Controls A419 controller; 120 VAC

Freezer: Conventional 5-cubic-foot chest freezer



Courtesy Roy Rakobitsch (5)



Cooking: Conventional propane range

Other appliances: LG front-load washing machine; computers; Miller 240 VAC MIG welder, drill presses

Lighting: Almost all LED

Electronics: Lots of electronics test equipment, amateur radio gear, quite a few custom control systems

Transportation: Two compact cars that average about 40 mpg (Toyota Yaris hatchback and Honda Fit hatchback), standard combustion engine. Cummins diesel flatbed truck for work purposes and moving big heavy things.

Favorite energy-efficient loads:

- The minisplit—It is extremely efficient at making our living space more comfortable year-round. It cuts down tremendously on the wood we burn during the shoulder seasons and provides air conditioning for our 1,200-square-foot building all summer. Having air conditioning in an off-grid home is pretty nice. Average consumption when heating (it is less efficient than cooling) is between 4 and 5 kWh per day.
- The water pump—It uses only 700 W to pump water from 500 feet underground.



Allan

Who: Allan Sindelar

Where: Northern New Mexico

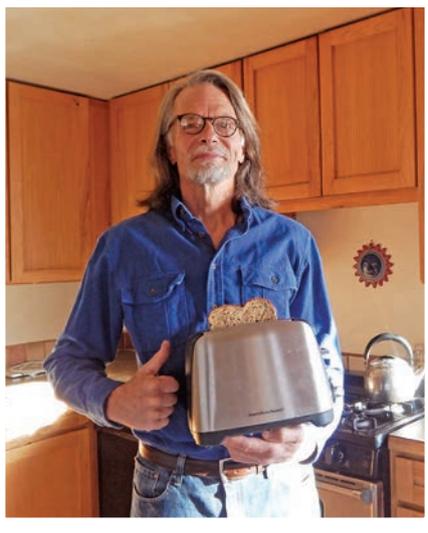
Years off-grid: 20

Energy systems:

- **PV array:** 1.584 kW; eighteen 88 W BP-590 modules (installed in 1997). Over their 21 years in operation, they have degraded to about 1.4 kW. Magnum MS4024 inverter and Mini Magnum panel with MidNite Classic 150 charge controller.
- **Battery:** 33.6 kWh industrial FLA (24 V, IBE, 1,400 Ah, about 5 years old)
- **Backup generator:** Generac Ecogen 6 kW generator; runs about 50 hours/year average, primarily to equalize batteries, as PV array alone is too small to do so.
- **Solar water heating:** Flat-plate collectors

Motivations: As a pre-solar-boom installer—to directly experience the modern homestead lifestyle and to walk my talk, which provides credibility. A 1.584 kW PV system served our family, which included my wife, my three children, and myself.

Heating: Multiple sources—main heat sources are an Avalon Mission woodstove and an older Slant-Fin propane boiler serving hydronic baseboard units (five zones with all DC pumps, circa 1999). A passive attached greenhouse. Two recycled circa-1982 4-by-8-foot flat-plate solar collectors mounted vertically on a south wall with a PV-direct pump, which feeds in-floor hydronic heat to a 480-square-foot family room on the north



Other appliances: Microwave, juicer, blender, food processor, toaster, waffle iron; shop with power tools

Lighting: Currently replacing most CFLs with LEDs

Electronics: Home theater, community WiFi, plus all the usual suspects of a web-connected family.

Transportation: 1984 Mercedes turbo-diesel converted to two-tank waste veggie oil (WVO) system, running on reclaimed sopaipilla and chile relleno oil from a Santa Fe restaurant

Favorite energy-efficient loads:

- LED Christmas lights. My front porch has a pair of strings that hasn't been deliberately turned off for 15+ years. Its energy use doesn't register on the TriMetric meter.
- A toaster. Harking back to "Toast, Pancakes, and Waffles," (*HP133*), it's the metaphor appliance for off-grid living: "Principle Three: Use energy in proportion to what's available."
- AC LED bulbs. LED bulbs are everything compact fluorescents promised to be 30 years ago—more efficient, cooler, and brighter, while also actually lasting as long as promised and leaving less toxic residue.

side of the home (untouched service since 2002). This system, which has no sensors or controls, provides a base level of heat to the family room floor to reduce use of the boiler.

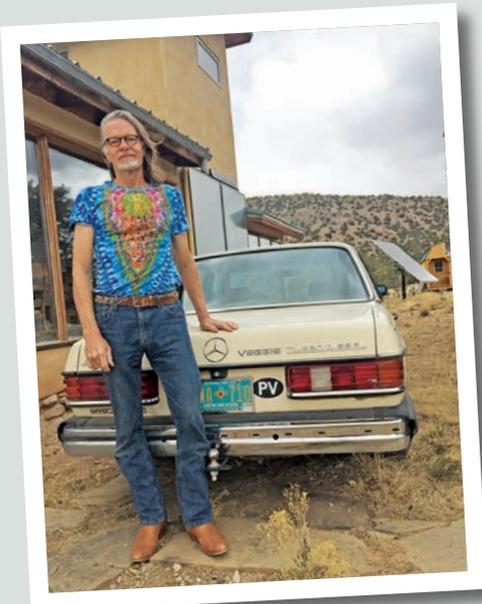
Water heating: Sidearm 105-gallon insulated tank with two internal heat exchange coils (one from solar collectors and one from propane boiler) with DHW zone priority from boiler. Two new solar collectors to be installed in the near future.

Refrigeration: 19 cu. ft. AC Kenmore refrigerator/freezer, bought in 2004

Cooking: Premiere Pro Series propane range



Courtesy Allan Sindelar (4)



E. H.

Who: E. H. Roy

Where: Northern New Hampshire

Years off-grid: 4 (full-time) in my current home; 11 (part-time, in a log cabin)

Energy systems:

- **PV array:** 440 W
- **Battery capacity:** 460 Ah at 100-hr. rate at 24 VDC
- **Backup generator:** Honda eu2000i, 2,000 W at 120 VAC; fuel consumption: 5–20 gal. per year

Motivations: Utility power is more than a mile away—I guess I like living in remote places. I also like living within one’s own electrical means. It makes you consider what you really need to live, which is much less than the average person in the United States. I enjoy not relying on climate-changing fuels for most of my electricity.

Heating: Wood heater (firewood harvested from my own woodlot)

Water heating: Water is heated on a woodstove in winter or on a gas camp stove in summer. Someday, I’ll have a wood cookstove and maybe an outdoor cookstove for summer. I do laundry in town when I am there for other reasons, but hope to buy a washing machine and use a clothesline for drying. I do not have “running” water—I harvest water in buckets from the nearby lake.

Refrigeration: SunDanzer chest freezer with thermostat to operate it as refrigerator. I used a very efficient (~1 kWh per day) 1953 Norge refrigerator the first year, but cut my electric energy use for refrigeration to about one-sixth of a kWh per day with the SunDanzer.

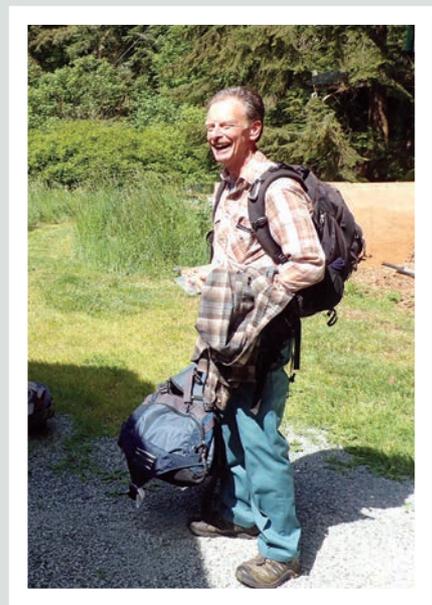
Cooking: Wood heater (winter); gas camp stove (summer)

Other appliances: Small transfer pump for shower; composting outhouse that is lit with a battery-powered LED controlled by a motion sensor

Lighting: LED lighting for most-used lights, CFLs for other lights

Electronics: Cellphone with charger, cell signal enhancer, laptop computer, Verizon Jet Pack for Internet, printer/scanner, small radio, CD/tape/tuner

Transportation: 2008 Toyota Yaris hatchback, best mileage 46 mpg—I use it like a truck. I also have a ¾-ton pickup for snowplowing and a diesel tractor for timber harvest. Recreational transportation is via bicycle or kayak. I would use a bicycle for more of my transportation needs if I was not on the local fire department—it’s hard to carry all the firefighting gear around on a bike and respond quickly to a fire call.



Courtesy E. H. Roy (5)



Favorite energy-efficient loads:

- The SunDanzer is my favorite because of its order-of-magnitude reduction in energy use over the old Norge, which itself uses less than most people’s refrigerators.
- At my even more remote log cabin that uses a small, battery-based PV system to power the lights, I needed two new batteries that were going to cost a couple hundred dollars each. Instead, I spent \$65 on a DC LED bulb and only had to buy one battery. Some folks would raise their eyebrows at spending \$65 on a lightbulb, but it saved me \$135—plus future maintenance and replacement of an additional battery.

Hugh & Jytte

Who: Hugh & Jytte Piggott

Where: Northwest Scotland

Years off-grid: 40-plus

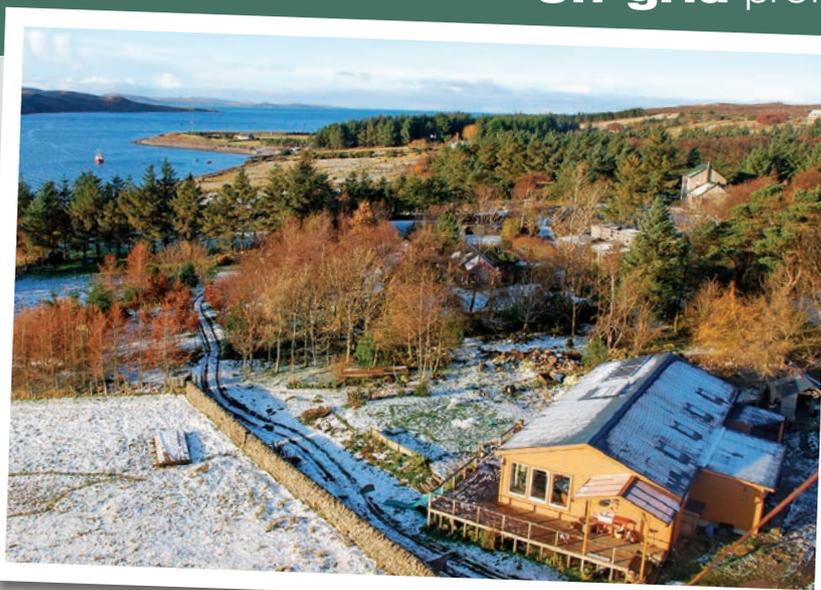
Energy systems:

- **PV arrays:** 2.32 kW total capacity—two 1,000 W arrays; 320 W array
- **Wind turbines:** 16-foot-diameter battery-charging turbine with resistance-heating diversion load in series; 12 ft. diameter, battery-charging turbine
- **Batteries:** 16 Rolls S530, 6 V, 400 Ah, for total of 800 Ah at 48 V
- **Backup generator:** 3 kW Pramac diesel, 100 hours per year run-time
- **Solar water heating:** Evacuated tube collectors

Motivation: We choose to live far from the grid and we simply enjoy making our own energy from sustainable sources.

Heating: Our house gets most of its heat from the sun shining in the windows and from surplus energy produced by our wind generators, which is routed to resistance heaters. We divert all surplus wind and solar to water heating. Surplus heat from the water tank is used for heating the house. When these sources are not sufficient, we use a condensing kerosene boiler to provide backup, burning about 100 gallons of kerosene per year.

Water heating: The RE system's charge controller diverts surplus wind and solar electricity to a 1,000 W water heater that



runs off a 48 V TriStar diversion controller. When this is operating and if additional heat is needed, it also triggers other AC heaters, which run off the inverter. Most times, there is enough energy to heat the house next door, as ours is already warm. An evacuated-tube thermal collector also contributes to water heating.

Refrigeration: Two standard AC refrigerators; two chest freezers

Cooking: We use some propane for the cooktop and oven, but mostly we use electricity for the single-burner induction hot plate, halogen oven, microwave, kettle, toaster, etc.

Other appliances: Food processor, vacuum cleaner, and workshop tools (including an arc welder).

Lighting: Mostly CFLs; some LEDs.

Electronics: Computers, audio-visual, Internet

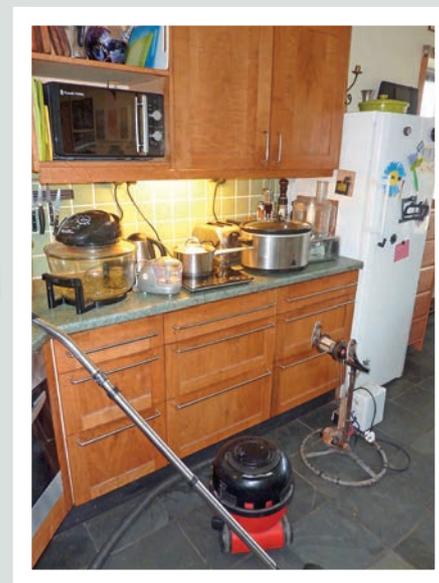
Transportation: Toro Workman MDE 48 V utility vehicle and a gasoline-powered quad bike.

Favorite energy-efficient loads:

- Halogen oven—It is an ideal size for our household. It heats up quickly and cooks the food with radiant heat and convection.
- 48 V Toro Workman utility vehicle—It is quiet, powerful, and can carry a 600-pound load with a passenger. We can charge it with excess power from our RE systems.
- Our superinsulated home—It is comfortable, and easy to heat. We enjoy views and heat gain through the large south-facing windows and the thermal-mass floor, which stores the sun's energy.



Courtesy Hugh & Jytte Piggott (4)



Ian

Who: Ian Woofenden

Where: Washington State's San Juan Islands

Years off-grid: 35-plus

Energy systems:

- **PV arrays:** Three, 1.57 kW total
- **Battery capacity:** Flooded lead-acid; 500 Ah at 100-hr. rate at 24 VDC
- **Backup generator:** 3 kW, 24 VDC generator
- **Solar water heating:** Flat-plate SWH systems combined with wood heat for domestic water and separate hot tub systems; evacuated-tube system for outdoor shower



Motivations for being off-grid: Independence, environmental concerns, original utility line extension costs

Heating: Wood, plus ductless MSHP when there's enough wind or sun energy

Water heating: Flat-plate solar thermal collectors and wood system, with propane backup (unused for the past two years)

Refrigeration: 1984 24 VDC Sun Frost fridge/freezer inside; SunDanzer and Steca freezers outside

Cooking: Wood, propane, induction hot plate, solar cookers, rocket stoves

Lighting: Almost entirely LED

Transportation: Bicycles, electric bicycles, buses, trains, and airplanes; 1954 dump truck; borrowed and rented gasoline vehicles as needed.

Favorite energy-efficient loads:

- The ductless MSHP uses most of my system's surplus energy fall to spring, and is dramatically reducing my wood usage.

- My 40 V Dewalt electric chainsaw allows me to use renewable energy to cut wood and do large carpentry cuts. And I can start working at daybreak without bothering the neighbors. The leaf blower that uses the same batteries is a wonderful trail and road-maintenance tool.
- LED lighting! LEDs have dramatically reduced my RE production needs.



Ian Woofenden (6)



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Get Smart - Advanced Inverters

by Brian Lydic



Hawaii's closed-system infrastructure (and excellent solar resource) means that variations in energy resources and demands need to be carefully balanced.

Distributed energy resources (DERs), such as grid-tied PV systems, offer tangible benefits to customers by reducing their utility bills, and to the utility by reducing use of grid energy at customer locations—but there are consequences when many systems export power into the grid. And in areas with lots of grid-tied systems, new grid-supporting products called **smart inverters** are becoming a necessity for protecting the grid and ensuring good power quality for all customers.

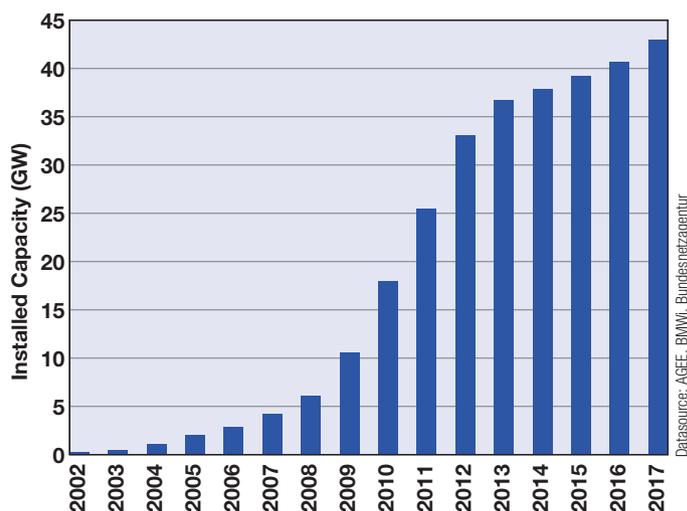
The Effects of DERs

Germany is one of the first countries that experienced having significant amounts of distributed PV and its resultant problems. Originally, grid-tied PV inverters were set to cease power production and trip offline under fairly narrow power-quality tolerances, which posed the threat of tripping many inverters offline and causing a large blackout. Since it was such a large portion of the nation's energy mix, a countrywide DER "retrofit"—new inverter settings and firmware updates—had to be applied. This allowed the systems to "ride through"

grid disturbances, rather than tripping offline. But the retrofit process was complicated, expensive, and time-consuming.

As California's DERs have become more prevalent, and to avoid a problem similar to Germany's, its investor-owned utilities (IOUs) and stakeholders began developing requirements for "smart" inverters through the Smart Inverter Working Group. This group convened to determine how Rule 21—California's technical requirements for interconnecting DERs to the grid—would be implemented. Phase 1 of the working group added the requirements noted in the "Rule 14

Net Solar Generation Capacity in Germany



The renewable generation capacity in Germany is high enough that cities experience times when peak production exceeds total national demand. That's impressive, but necessitates advanced system control.

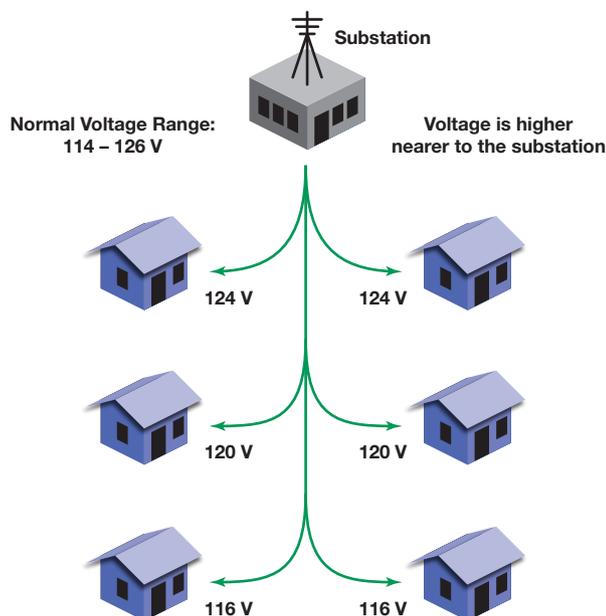


Courtesy worldfuturecouncil.org

& Rule 21 Inverter Default Settings" table. Since September 2017, any new grid-connected inverters in California must be smart inverters.

Hawaii has nearly 50,000 PV-powered residences (about one in three private rooftops) on Oahu alone. In late 2014, Hawaiian Electric began implementing ride-through. Like Germany, the response of inverters to grid disturbances was a major concern. Hawaii has even more of a challenge, however, since generation and load must be balanced on each island's independent electrical system. Starting in March 2018, Hawaiian Electric's Rule 14 (the technical requirements for interconnecting generators to the grid) requires smart inverters. While similar to California's 21, in addition to ride-through requirements, it also has frequency-watt (for frequency support) and volt-watt (for voltage support) function requirements.

Voltages in Normal Power Flow



Smart Inverter Functions

Smart inverters have been developed to not only ride through during brief fluctuations in power, but to also assist in raising or lowering grid voltage and help regulate frequency. While there are multiple grid-support functions available in each smart inverter, it is up to each state and/or utility to determine which functions will be required to be activated. Below is a breakdown of the available functions. Only one reactive power function (constant power factor or volt-var) may be turned on at a time. All others can run simultaneously.

Ride-Through Functions

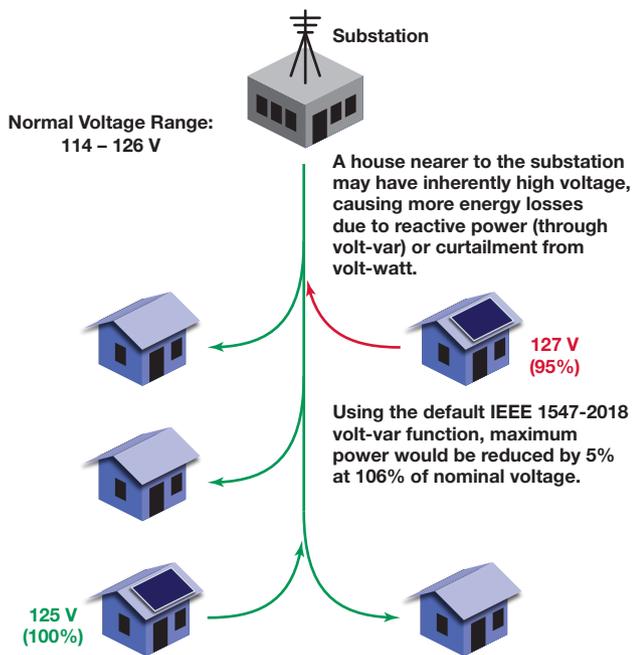
Voltage Ride-Through. The original tripping requirements for voltage and frequency in IEEE 1547-2003 were selected such that DERs would trip offline quickly and utilities wouldn't need to consider their effect much during grid disturbances. At low PV penetration, this worked fine for the utilities. But during a low-voltage disturbance, grid-tied PV systems can help keep voltage up, whereas tripping all PV systems offline in the area with the disturbance would cause voltage to drop further.

While frequency is generally the same throughout an electrical system, voltage will vary depending on location. The utilities have power quality requirements (generally upheld by public utility commissions) that constrain the delivered voltage. The normal range is +/- 5% of the nominal voltage. Faults on the transmission or distribution system (like a tree branch hitting a line) can cause voltage disturbances outside the normal range.

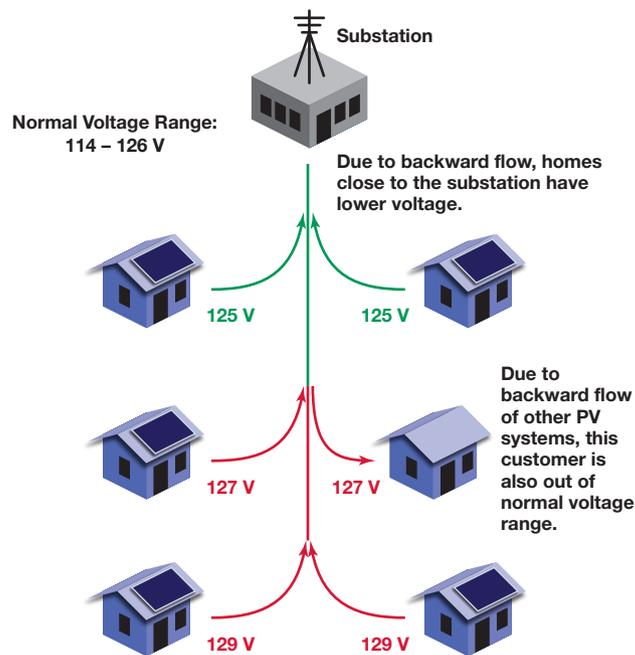
IEEE 1547-2003 required DERs to trip offline within a maximum of 2 seconds for voltages approaching dangerously high or low levels (outside +10% or -12%). Utilities in California have seen low and high voltages, sometimes caused by high air-conditioning loads depressing the voltage as their motors work harder due to an initial voltage disturbance. California, Hawaii, and IEEE 1547-2018 are increasing these trip limits to a maximum of 21 seconds.

Inverters have previously been allowed to trip well before any limits are reached. Smart inverters are designed for "riding through" low and high voltages. The inverter

Location Power Losses



Backward Power Flow



must remain connected to the grid through the duration of a voltage disturbance (unless the wider trip limits are reached). The ride-through times and trip times for smart inverters have been selected to enable them to stay online during most temporary disturbances. If the trip limits are reached, the inverter must stay offline for up to 5 minutes once normal voltage is restored. Given that some homes with grid-tied PV systems have had issues with inverters tripping offline due to existing poor voltage conditions, these new ride-through requirements can benefit owners by keeping their systems online more than previously.

Frequency Ride-Through. Frequency fluctuations can be caused by mismatched generation and loads. To keep the power system and customers' loads working correctly, frequency (in the United States) needs to stay near 60 hertz (Hz).

Due to requirements in the Institute of Electrical and Electronics Engineers' 1547-2003 standard (see "IEEE 1547" sidebar), inverters on the distribution system have been set to trip offline outside the frequency range of 59.3 to 60.5 Hz. While that was not a problem when DER penetration was small, it has become a liability as the percentage of DERs has grown. If frequency reached one of the trip limits, it would cause all DERs in the electrical system to trip offline, amplifying the problem. IEEE 1547-2018 updates the trip limit range to 56.5 to 62 Hz so DERs can stay online until the frequency is within normal limits. If the trip limits are reached, the inverter must stay offline for up to 5 minutes once normal frequency is restored.

IEEE 1547

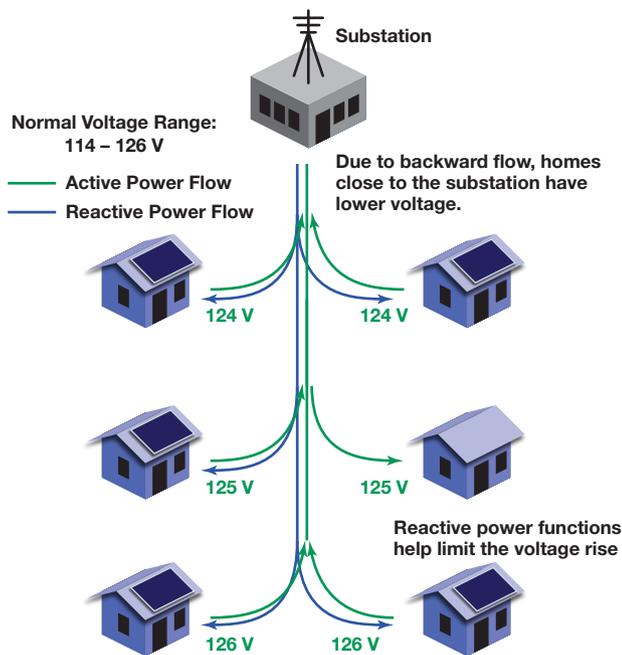
Utilities are taking notice of the smart inverter efforts. The nationally accepted standard for generator interconnection, Institute of Electrical and Electronics Engineers (IEEE) Standard 1547-2003, had limitations that kept it from fully supporting smart inverter functions, so IEEE began updating this document so any state or utility could require grid-supportive functionality. The document has expanded from 15 pages to almost 100, and will be published by mid-2018.

Following publication of its accompanying test protocols, utilities will likely begin to adopt its requirements. That could translate to changes in the interconnection requirements starting in late 2019 or 2020. Whether smart inverters will be used to their full capability is yet to be determined. IEEE 1547-2018 allows for flexibility in application of the functions, so requirements could still vary from utility to utility.

Voltage Control Functions

Constant Power Factor. Voltage responds to both active power (watts) and reactive power (var) flow. Absorbing reactive power decreases voltage, while injecting reactive power increases it. Inverters can use this to decrease the overall voltage rise caused by active power export. By absorbing a small amount of reactive power while exporting active power, voltage will be lower compared to producing only active power. The ratio of active power to total (apparent) power is called power factor—PF. When set to 1, all power is active. The lower the number, the more reactive power is absorbed or injected. Typical effective settings are down to 0.95 absorbing, but could be lower. IEEE 1547-2003 did not address PF capability, but most utilities required DER to operate above 0.95 without requiring a specific setting. Now, IEEE 1547-2018 requires a range of capability, down to 0.90, with the ability to set it.

Backward & Reactive Power Flow



Volt/Reactive Power (Volt-Var). While a constant absorbing power factor can limit voltage rise, it doesn't address the problem when voltage is too low. It also causes reactive power to flow any time the inverter is running. Utilities generally try to limit the amount of reactive power in the system since it causes losses in the wiring. Using a volt-var function instead of constant power factor can reduce reactive power flow when it's not needed by absorbing or injecting the right amount of vars (reactive power), depending on the voltage measured by the inverter. Unlike constant PF, the volt-var function will also correct for low voltage by injecting vars. If voltage is in the normal range while PV systems are operating at peak, but a cloud comes over and drops system output, voltage could drop as well. The volt-var function helps maintain it within the normal range. Only one reactive power function (constant power factor or volt-var) may be turned on at a time.

Volt-Watt. While reactive power can help lower the voltage, it may not always be enough. If voltage gets too far outside the normal range, curtailing active power may be required. Per IEEE 1547-2018, the volt-watt function would normally be set such that maximum active power starts to reduce above 106% of nominal voltage.

Just as voltage decreases farther away from a substation (due to wire loss), voltage also increases from an inverter when a system is exporting energy. Often, the customer's loads consume all of the PV system's power and no voltage rise occurs. However, during times of high generation and low loads, power may be exported to the grid. If many PV systems are exporting power at the same time, voltage could rise away from the substation, including at neighbors' homes that don't have PV systems. If there is too much uncontrolled voltage rise, power quality limits could be exceeded, possibly damaging consumer electronics.

Frequency, Voltage & Power

Frequency

Frequency is the sinusoidal oscillation in voltage on the grid. In North America, the grid oscillates at 60 cycles per second (or hertz; Hz) meaning that 60 times per second voltage rises from zero to its positive peak; back to zero and to its negative peak; then back to zero. Power output of the grid's spinning generators needs to be matched to the load drawn from them. If power output is too high compared to load, generator speed and frequency will rise. If power output is too low, they'll drop. Generators coupled through interconnected transmission and distribution networks all share the same frequency. In the continental United States, there are three separate interconnections—eastern (east of the Rockies); western (west of the Rockies); and Texas—which can have their own frequencies. For example, if the frequency is 61 Hz in Cleveland, it's also 61 Hz in Tampa.

Voltage

Voltage is the measurement of electrical potential (electrical "pressure") that causes work to be done when a load is placed in a circuit. Voltage is basically the same at any point that is connected by a conductor to another point without a load on the line. However, wires themselves aren't perfect conductors and act like a slight load, referred to as line impedance. Power traveling through a load causes voltage to drop, so voltage is always higher on a wire closer to the source of power than farther away.

Active power

Active power, measured in watts, is power that can produce work, like running a washing machine motor. Whenever the sinusoidal voltage and current waveforms are aligned (they cross zero at the same time), only active power is being utilized (if it's a load) or produced (if it's a generator). Energy is active power delivered over time, and measured in watt-hours (Wh) or more commonly kilowatt-hours (kWh; 1,000 Wh).

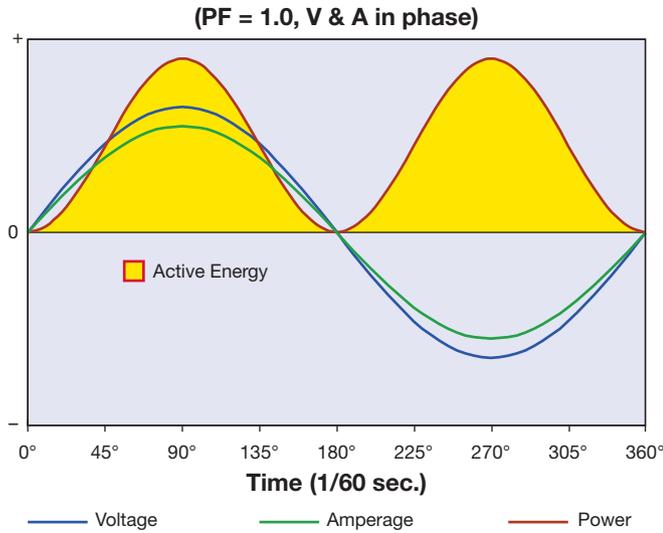
Reactive power

Reactive power, measured in vars, is just a shift in time of the current waveform relative to the voltage waveform—they don't cross zero at the same time. Reactive power is considered "absorbed" or "injected" dependent on whether the time shift is positive or negative; the words are just constructs to help define what the reactive power is doing. Reactive power doesn't cause any work to be done—it is stored and returned to the grid every half-cycle. The effect it has on voltage depends on the time shift. If the current waveform lags behind the voltage waveform, then voltage is lowered. If current leads voltage, voltage is raised. This is analogous to active power. When active power is absorbed (or consumed), voltage drops; when it's injected (exported), voltage rises. Since the current waveform can shift forward or backward in time without affecting the active power direction, reactive power can either be absorbed or injected regardless of the direction of active power flow.

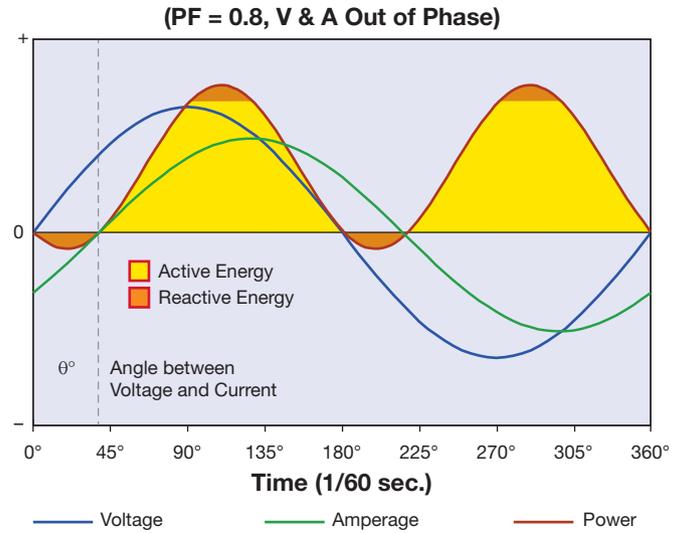
Apparent power

Apparent power is the vector sum of active and reactive power, measured in volt-amps (VA).

Active Power Flow



Active & Reactive Power Flow



Frequency Control Function

Frequency-Watt. Frequency-watt is a frequency regulation function. Since overfrequency conditions are caused by too much generation (such as in places like Hawaii that are operating on a smaller grid than the mainland), smart inverters will reduce their power output (curtail) as frequency increases to bring back balance. Since PV inverters are usually operating at full power under normal conditions (tracking the array’s maximum power point), they aren’t able to increase power in underfrequency conditions. However, storage systems can be called on to increase power output during underfrequency conditions, in addition to reducing power in overfrequency conditions.

Ramping Functions

Soft-Start Ramp Rate. Voltage fluctuations caused by high-capacity PV systems coming online or when many smaller systems start up simultaneously are concerns. A large grid disturbance (frequency or voltage) in the middle of the day could result in many systems tripping offline. Inverters wait five minutes after normal voltage and frequency is restored before turning back on. “Soft-start ramp rate” means power is increased smoothly on each inverter over several minutes to help keep voltage from spiking.

Rule 14 & Rule 21 Inverter Function Default Settings

Function	CA Rule 21	HI Rule 14
Voltage ride-through	On	On
Frequency ride-through	On	On
Constant power factor	Off	Off
Volt-var	On	On
Soft-start ramp rate	On	On
Normal ramp rate	On	On
Volt-watt	Not yet included	Off
Frequency-watt	Not yet included	On

Normal Ramp Rate. Normal ramp rate is also required by Rules 21 and 14. This function moderates rapid increases in power during the course of normal operation. In California and Hawaii, the default ramp setting is 100% of maximum active power per second, which means it is essentially turned off and keeps the function out of the way of power production. IEEE 1547-2018 does not require inverters to have a normal ramp rate function.

Ouch, That Smarts!

For all of their benefits to the grid, smart inverter functions are not without impact on the customer. Today’s electric bills only credit kilowatt-hours (kWh), which accrue from active power. Reactive power production, which can reduce active power production, isn’t compensated. Inverters have a rated power—the total of active and reactive power—that cannot be exceeded. Thus, if the inverter is operating at its limit, any reactive power demands will reduce active power capability. When operating at a lower active power, there’s usually enough “headroom” below the inverter’s power rating to provide reactive power while still operating the PV array at maximum power. Reactive power requirements typically cause “clipping” at the top of the typical PV system’s power production curve, introducing some energy production losses. For example, a 0.95 PF setting will limit active power generation to 95% of the inverter rating. PV systems are often oversized on the DC capacity compared to inverter AC output power capacity (known as the DC-to-AC ratio). Typical DC-to-AC ratios are 120% or higher. When a PV array is at high output, it will be limited by the inverter’s AC active power limit, also resulting in clipping. Given that a constant PF of less than 1 can reduce inverter AC active power, this effectively increases the ratio and increases clipping. System designers should be aware of the utility’s reactive power requirements for interconnection to assess this potential loss. Programs that estimate a PV system’s energy production can usually account for a constant PF so that the system can be

sized correctly. Using a larger inverter, if possible, can alleviate the production loss effects of reactive power.

Frequency-watt and volt-watt functions also impact the number of kWh produced by curtailing active power, although they aren't likely to be triggered very often. And while the normal ramp rate is turned off (i.e., set to 100%) for grid-tied PV installations in California and Hawaii, it could have large production impacts if the utility required it to be set below 100% per second. Simulations done by the National Renewable Energy Laboratory on two distribution circuits in Hawaii found that, at higher PV penetration levels, the majority of customers with grid-tied systems would have less than 1% yearly loss from the impacts of volt-var and volt-watt functions combined. However, likely due to the location variability of voltage, some customers could experience a 5% or more loss in their PV systems' production. Customers who have PV systems with smart inverter functions turned on will want to take a closer look to ensure energy production isn't being unduly affected. If major energy losses are suspected (i.e., greater than 1%), the RE installer and utility should be contacted to pinpoint the problem and determine if functional settings need to be adjusted—or if something else is to blame.

It is challenging to track how much production is lost, since the inverter doesn't necessarily know how much power was available from the PV array unless it was operating at the



Smart microinverters from Enphase Energy can provide estimates of energy lost to curtailment from export limiting and can apply voltage rise compensation, which avoids excess reactive power production (due to volt-var) or active power curtailment (due to volt-watt). Soon, these inverters will also be capable of reporting energy loss estimates for commanded curtailment, volt-var, volt-watt, and frequency-watt.

SMA's Sunny Boy line of inverters was among the first to receive UL1741 Supplement A certification for California's Rule 21.

maximum power point. When curtailment occurs, the power point tracking reduces the power coming from the array so it's no longer at maximum. Customers and installers may prefer inverters with a monitoring system that can track when regulation functions are triggered or how many var-hours (a measure of the reactive power produced) accumulate.

California's Rule 21 does not currently require frequency-watt or volt-watt to be activated, but likely will within the next year or so. Likewise, the volt-var function used now doesn't reduce active power or affect energy production, but that feature is likely to be added in the near future (which will align California with Hawaii and IEEE 1547-2018). Discussions and developments are ongoing about how a customer can or should be protected against energy production losses due to smart inverter requirements. How to track those losses, how customers can file complaints, and how they can be compensated for losses are all questions that are still awaiting answers from PUCs.

Getting Smarter with Communications

The smart inverter functionality required so far is autonomous, meaning that the inverter itself determines what to do based on parameters that are set. In the future, utilities may monitor PV systems, prescribing different operational parameters at different times. Data communications channels could be used for this purpose, but most utilities don't have the means to communicate with many distributed inverters. While IEEE 1547-2018 outlines standardized communications and control requirements for inverters and DERs in general, it still allows for three different communications protocols (the data "languages").



There's no nationwide consensus on which protocol to use or how exactly to build a communications network to the inverters, though California has chosen IEEE 2030.5 as its standard data protocol. The Internet could be used as one option for transmitting data, or a dedicated network could be created to reach into the distribution system. "Aggregation" companies could act as an intermediary between utilities and grid-tied PV systems. Regardless of how it's accomplished, there are plenty of security concerns to address given that these systems interact with the grid and could possibly raise the potential for cyber attacks. Many smart inverters already include control capabilities that may only be used in specialized circumstances, like in pilot programs or microgrids.

Smart Inverters of Today & Tomorrow

Due to California and Hawaii's smart inverter requirements now in effect, many modern residential PV inverters have the required functionalities. Utilities in other states such as Illinois, Massachusetts, and Pennsylvania are also starting

to require ride-through and/or smart inverters. See "Next-Generation Grid-Tied Inverters" in *HP183* for tables of inverters that are Rule 21-compliant. Updated listings of certified equipment for California and Hawaii are available at gosolarcalifornia.org (look for UL1741 Supplement A certification) and hawaiianelectric.com.



web extras

"Next-Generation Grid-Tied Inverters" by Justine Sanchez in *HP183* • homepower.com/183.26

"Power Factor: Back Page Basics" by Ian Woofenden in *HP150* • homepower.com/150.120



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Living with Lithium-Ion Energy Storage

by Joe Schwartz



Insights on Integration, Operation & Performance

This article details my experience integrating lithium-ion (Li-ion or LI) energy storage into my off-grid homestead's energy system, and includes design and installation considerations, plus initial performance and operation insights.

Ben Root

Right: The original PV system consisted of two 1,050 W PV arrays on pole mounts and an additional 1,308 W on the power shed's roof.

Below right: An additional 3,450 W of PV capacity were recently added on the shop roof, for a system total of 6,858 W.



Joe Schwartz (2)

Without really thinking about it, my partner Emily and I have surrounded ourselves with lithium-ion (LI) batteries at our off-grid cabin. My sports watch and Bluetooth audio speaker use LI energy storage. The Apple devices strewn about—laptop, tablet, smartphone, and wireless ear buds—all run on LIs when disconnected from AC power. The upright and handheld vacuums both use them. Out in the shop, a half-dozen cordless hand tools share a common LI battery platform. The wireless weather-station sensors and shop alarm system incorporate LI technology. I never made a conscious decision to purchase these products based on their battery technology, but I am benefiting from and rely on the high power density and long cycle life that LI batteries provide.

LI use in home-scale energy storage systems (ESSs) is a relatively new application. Like a lot of renewable energy (RE) enthusiasts, I'd followed the LI ESS development for home-scale systems and researched how the products integrate with other RE system components. After 15 years of living off-grid with lead acid (LA) batteries, I had a growing curiosity about not only how LI technology might influence system design, but, more importantly, how it might change the way we manage energy generation and use in off-grid systems.

In early January 2018, I installed Blue Planet Energy's Blue Ion 2.0 16 kWh ESS at my off-grid property. Because LI installations are still uncommon in residential energy systems, I invited some local installers—Bruce Fiero and his daughter Allona from Willpower Electric, and Shawn Schreiner and Shawn Franks from True South Solar—to check out the installation. I was fortunate to also have Kyle Bolger and Jody Powell from Blue Planet Energy on site on installation day.

The Lay of the Land

Our 50-acre off-grid property is at 4,600 feet elevation in southwestern Oregon, about a dozen miles outside of Ashland. With hot, dry summers and a little less than 20 inches of annual precipitation, southern Oregon has a Mediterranean climate. Temperatures on the property range from triple digits in the summer to single digits in the winter, when the snow can pile up for several months. The site has wide-open, nearly shade-free solar access in a region with an annual average of 198 days of sunshine (4.9 average daily peak sun-hours). Even during periods of unsettled weather, we rarely experience multiday runs without at least some partial sun.

The property has slowly evolved from a simple retreat—a camp trailer, a few PV modules, and a satellite Internet dish—to a rustic homestead with a small organic farm that Emily and I began to develop in 2015. The site's electrical loads have been variable, but always increasing, during the 15 years we've been on the land. Our daily energy requirement ranges from 5 kWh to more than 20 kWh depending on the season. The base electrical load includes a well pump, lighting, household appliances, home electronics, Internet networking components, and the power tools we drag out during construction phases. We use an induction cooktop,



The balance-of-system components now consist of the original OutBack Power 3,600 W inverters and 60 A charge controllers (left wall) and the new Morningstar 600 V charge controller (right wall).

microwave, and outdoor propane grill for most of our cooking. Water heating is either electric or propane, and space heating is primarily by wood, but we also supplement with electricity and propane. Our highest period of energy use is during the long, hot days of summer when we pump water to our drip-irrigated gardens.

In 2005, I designed and installed the homestead's core power system, which included two pole mounts each with six 175-watt Sharp PV modules (2.1 kW total); two OutBack Power VFX3648 inverter/chargers, a balancing transformer, and overcurrent devices mounted on an OutBack PS2 power panel; and two OutBack MX60 charge controllers. All of this equipment has been durable and reliable—it is still in use. I was an early adopter of using AGM batteries in an off-grid system. The original battery bank was eight 6 V, 390 Ah Discover AGM batteries (18.7 kWh total rated capacity) that lasted 11 years. We tended to be conservative with how deeply we discharged the battery bank. A typical overnight depth of discharge (DOD) was 15% to 20%, and we would take the bank down to about 50% during periods of stormy weather.

This system ran largely unchanged for about a decade, but has been expanded over the last few years to meet the growing energy requirements of the farm. In 2016, I reconfigured the pole-mounted arrays to share an MX60 controller and added four 327-watt SunPower PV modules (1.3 kW) on the power room roof, regulated by the second MX60. Our friends at Haase Energy Systems installed a 14 kW Kohler 14RESA propane backup generator in the fall of 2017.

We installed the Blue Ion 2.0 ESS in January 2018, and in March, True South Solar installed a new PV array of ten 345-watt SunPower modules (3.45 kW total) on the roof of an agricultural building located 320 feet from the power room. The array is configured as two, five-module series strings (287 Vmp @ STC). Output power is processed and stepped down to 48 VDC nominal by a Morningstar TriStar 600 V charge controller. Our PV capacity is now 6.85 kW.

The original AGM battery bank provided excellent value and was in service for more than a decade. In hindsight, though, we operated the battery bank longer than we should have. During the last year or so, the voltage would crash and

we'd operate the system at voltages as low as 44 V on some mornings. The bank eventually failed in an uncommon and unsettling fashion. While I wasn't on site to witness the failure, my diagnosis is that a short developed in one of the cells, which resulted in the rest of the bank discharging into the failed battery. The failure mode was exacerbated by an unregulated charging scenario in which the charge controllers did not reach regulation voltage and continued to dump power into the failing bank until the sun was off the arrays. The day of the meltdown, I came home to a system shut down (due to low voltage) and deformed battery cases, which were still hot to the touch. As designed, the sealed batteries outgassed to reduce the internal pressure buildup. The result was condensed electrolyte in the battery enclosure, and in nearby conduit and a wire trough. While no other equipment was damaged, the experience left me with a heightened respect for and awareness of the energy stored in battery-based systems.



The new Blue Ion 2.0 ESS lithium-ion battery consists of eight 48 V, 2 kWh battery modules.

Ben Root (2)

Product Overview & System Integration Considerations

Blue Planet Energy's storage systems are compatible with grid-tied and off-grid applications, but the company is primarily focused on the off-grid market. Our 16 kWh of battery capacity is housed in a single cabinet (8 and 12 kWh versions are also available; multiple cabinets can be configured in parallel for as much as 450 kWh). Our system's nominal voltage is 48 VDC, which is the standard for most new home-scale off-grid systems. The Blue Ion 2.0 ESS we installed is built only for 48 VDC systems; however, other vendors manufacture LI systems that operate at different voltages. Blue Planet Energy offers its system through a U.S. network of certified dealers.

Battery modules and BMU. The system integrates olivine-type lithium iron phosphate (LiFePO₄) battery modules manufactured by Murata (formerly Sony). These are more thermally stable than cobalt-based LI chemistries. The 16 kWh Blue Ion 2.0 system has eight battery modules, each with 224 individual 3.45 V, 9.375 Wh cells. Each battery module has a removable safety plug, to be installed when the system is completed. Until the plug is inserted, the battery module terminals are touch-safe and present no shock hazard.

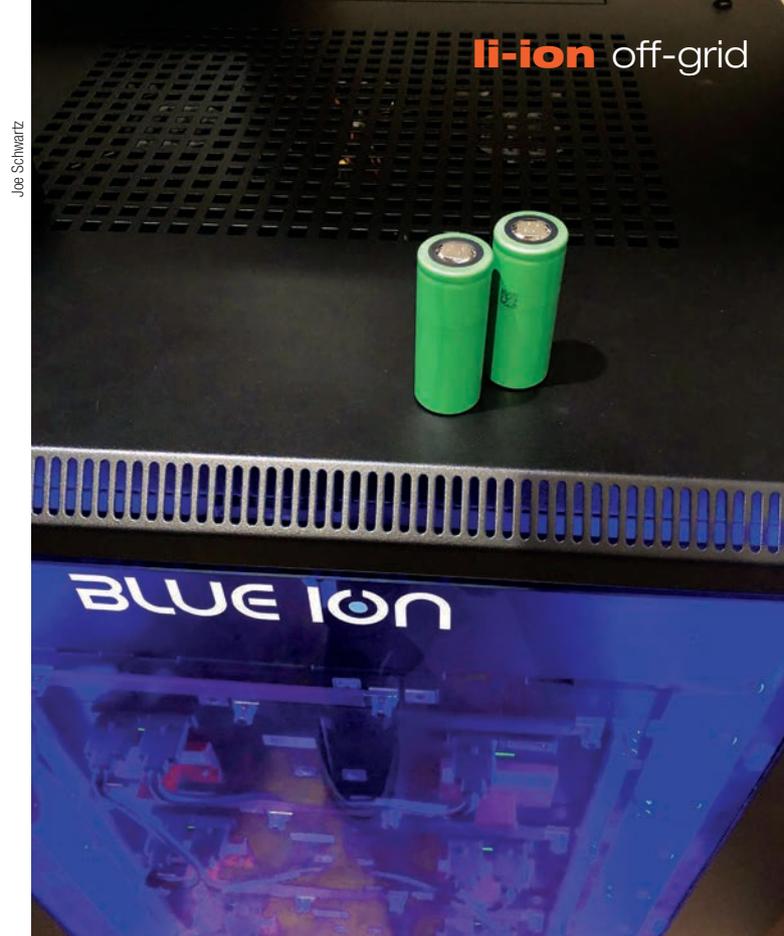
Each battery module balances charging between cells and reports cell-level data including voltage, current, and temperature, to a battery management unit (BMU) located beneath the top of the cabinet. The BMU has protective functions that, based on the measured operational data, can control and, if necessary, shut down the battery modules due to temporary conditions, including when temperatures are over or under specification, as well as permanent battery failures, such as a capacity percentage that no longer meets the required specification. The BMU draws 5 W for 120 Wh per day.

Current, voltage, and power. Under its ETL listing to UL9540, the Blue Ion 2.0 BMU is approved for continuous operation at charge and discharge currents up to 160 A continuous; 200 A for 30 minutes; and 220 A for 5 minutes. The product includes

Inside the rear of the cabinet is the battery management unit: the brains of the Li-ion battery.



Ben Root



Joe Schwartz

Each of the eight 48 V battery modules contains 224 individual 3.45 V, 9.375 Wh cells.

a factory-installed 250 A DC disconnect breaker. The Blue Ion 2.0 integrates with common 48 VDC power electronics, including inverters and charge controllers. Its actual voltage range is 44 to 56 VDC depending on battery state of charge (SOC). These specifications make a single-cabinet Blue Ion 2.0 unit a good fit for systems with array capacities and inverter/charger systems of about 8 kW. My system has 6.8 kW of PV capacity and 7.2 kW of inverter/charger capacity.

Cycle life and storage capacity. A battery's cycle life impacts its lifetime cost as well as the system's design. Generally speaking, measured battery cycles are cumulative—a 100% depth of discharge (DOD) is measured as one cycle; two 50% DODs would also be measured as one cycle. For lead-acid batteries, lower DODs result in longer cycle life. For example, a high-quality industrial LA battery might have a specified cycle life of 6,000 cycles at a 30% DOD versus 2,000 cycles at an 80% DOD. Accordingly, system designers need to balance a battery's capital cost, design DOD, and rated cycle life to determine the lifetime cost of particular equipment and designs. A general rule has been to design off-grid LA battery systems for a 20% to 30% overnight DOD and a maximum of 50% to 60% DOD when RE charging resources are limited. Individual designers may choose to be more conservative or more aggressive with their DOD designs.

The operational cycle life of LI batteries is not meaningfully impacted by DOD, and they are considered to have a usable capacity near 100%. Deep discharges, even up to 100%, will not



Ben Root (2)

Left: Allona Fiero of Willpower Electric carries a 59.5-pound LI battery module with a usable rated capacity of 2 kWh.

Right: Temperatures in the power room are monitored and have never dropped below 41°F or exceeded 88°F.



damage the battery or result in a permanent loss of capacity. (However, discharging a LI battery to 100% would shut down the power system.) The Blue Ion 2.0 specifies a cycle life of 8,000 cycles at 100% DOD. The cycle rating works out to just under 22 years (8,000 cycles divided by 365 days). This available capacity allows off-grid designers to consider days of autonomy and array-to-storage capacity ratios from a new perspective.

Efficiency. Optimizing an RE system's efficiency—whether it's considering a PV module or inverter's conversion efficiency or minimizing power loss in transmission conductors—is part of good system design, especially for off-grid systems. With the introduction of LI ESS products, the efficiency of energy-storage systems is another design variable to consider. No batteries are 100% efficient during charging and discharging, and their charge efficiencies are typically nonlinear. For example, a new LA battery is generally considered to have an average round-trip charge/discharge efficiency of about 85%. Its efficiency will be higher at a lower SOC and a lower rate of charge. But because an LA battery's efficiency is nonlinear, it may have an average efficiency of more than 90% up to about 85% SOC, and closer to 60% at higher SOC as its impedance increases.

LI battery types have higher round-trip efficiencies than LA batteries. The BMU is often the limiting factor in how fast a LI battery can be charged. The Blue Ion 2.0 specifies a base round-trip efficiency of 95% at full rated power. My new 16 kWh system and 160 A-rated BMU are specified to operate at a round-trip efficiency of 98% at 30% of rated power.

Environmental requirements. Most battery types used in RE systems need to be protected from freezing. The Blue Ion 2.0's LFP cells will be seriously damaged if they're charged at temperatures below 32°F, although the product can safely discharge to run loads at temperatures down to -4°F. While the product's BMU will not allow the battery modules to charge at 32°F (or lower), the manufacturer recommends that the product not be installed in a location that's exposed to

temperatures below 32°F. Ideally, the unit should be installed in a space that's conditioned enough to keep plumbing from freezing. My system is installed in a well-insulated power room that also houses the water system's pressure pump. I use a recording thermometer to monitor the room's temperature. The well-insulated building retains the waste heat from the PV system's power electronics, and has never fallen below 41°F. On the flip side, temperatures higher than 113°F decrease the life expectancy of almost all battery types used in RE applications and should be avoided. Our power room's insulated slab floor moderates temperature extremes in the building and indoor temperatures above 80°F are rare. During triple-digit days in the summer, we close window blinds during the day and open windows at night to cool the building.

Warranty. The Blue Ion 2.0 system is covered by a 15-year or 8,000-cycle at 100% DOD performance warranty and a 10-year product warranty. The performance warranty specifies 70% remaining capacity (11.2 kWh, in the case of my 16 kWh-rated system) of the product's rated storage at the time of commissioning. If the capacity falls below 70% while the product is under warranty, the manufacturer guarantees full replacement of the product's original rated energy-storage capacity.

Cost. Like other solar products and services, the Blue Ion 2.0's system's cost varies depending on the installation region and sales channel. Average retail pricing for the systems are currently \$10,788 for the 8 kWh model; \$13,989 for the 12 kWh model; and \$17,191 for the 16 kWh model. For my system, the cost works out to \$1,074 per kWh of storage.

According to my research online, the capital or initial cost per rated kWh of energy storage for residential-scale RE systems ranges from about \$150 per kWh to \$1,200 per kWh. While capital cost is an important consideration when investing in any RE equipment, its lifetime cost and the levelized cost of energy (LCOE; the net present value of the unit-cost of energy over the lifetime of a generating asset) are additional ways to determine the value of ESS equipment over its lifetime. System owners should consider both the capital cost and lifetime cost, and how usable storage capacity, depth of discharge, cycle life, power conversion efficiency, and avoided generator fuel costs impact the cost, and value, of the investment over time.

Step-by-Step Installation

The Blue Ion 2.0 ESS shipped on two pallets—one with eight battery modules, the other with the battery cabinet—to our studio in town. I loaded the batteries into my truck by hand, and used a hand truck and ramp to load the cabinet. Once the equipment and installation crew were on site, we got to work.

Pre-installation modifications. We needed to ready the existing power system for the installation. We opened the overcurrent protection breakers for each of the charging sources, which include the PV arrays and the generator, and the two DC breakers that are located between the battery and the inverter/chargers. With the system de-energized, we could safely disconnect and remove the eight L-16 lead-acid batteries and their plywood enclosure.

The Blue Ion 2.0 cabinet has wheels, allowing it to be rotated for accessing components from the rear to install the battery modules, land the battery-to-inverter and equipment ground conductor terminations, and make networking connections before rolling the cabinet into place. With this design, the Blue Ion 2.0 system is commonly installed with a short length of open-air battery cabling, rather than rigid conduit. The 4/0 AWG battery-to-inverter cabling had previously been routed through 2-inch EMT conduit and an LB conduit fitting. I removed this conduit and installed a 2-inch box connector, nut, and bushing to provide strain relief for battery cabling where it exits the DC wire trough. Due to the enclosure's compactness (39" H × 24" W × 24" D), I was able to shorten the existing positive battery cabling by a few feet. I also terminated a 6 AWG equipment ground conductor at an existing busbar in the wire trough. This would later be connected to an equipment ground lug in the cabinet.

Cabinet preparation. After the system modifications were finished, we prepped the cabinet for the battery modules. We removed the cabinet's glass front door, and side and rear panels, which provided access to all four sides of the enclosure. We temporarily positioned the cabinet in a location that allowed sufficient clearance to existing equipment and disconnects, and then determined the best location for the battery-to-inverter cables to enter the cabinet. The cabinet is not manufactured with knockouts, so I used a step bit and stud-driven hole-punch to create two holes. I fit these with plastic wire glands that came with the cabinet. The connectors provide strain relief and protect the cables from abrasion where they enter the cabinet.

Battery mounting. The 16 kWh Blue Ion 2.0 ESS includes eight individual 2 kWh battery modules. Each module, which weighs 59.5 pounds, can be easily moved and positioned by a single installer.

Prior to installing the battery modules, we removed the enclosure's two front support plates and the middle support bracket. The battery modules were installed in pairs, side by side. After we slid the first two modules in place, we secured the back end of each module to the cabinet's back support plate with four M4 (4 mm metric)

Penetrations for the battery-to-inverter cables were punched into the right side of the cabinet.



Ben Root (3)

Cables were threaded through the cabinet penetrations before crimping on the ring lugs.



Kyle Bolger slides the battery modules into the cabinet—four sit on the lower shelf and four on the upper.





Battery modules are held in place by support plates that are secured to the cabinet and each module. Horizontal busbars are installed before the final fasteners are inserted into the support plates.

With the rear panel of the cabinet removed, modules were secured to the rear support plates.



Ben Root (2)

cap screws. Batteries No. 3 and No. 4 sit directly on top of batteries No. 1 and No. 2. The middle support bracket carries the weight of the top four battery modules (battery Nos. 5, 6, 7, and 8). The battery and cabinet mounting holes, and threaded battery terminals that secure the system's electrical busbars, have tight tolerances. We used a screwdriver to gently position and align the various mounting holes to accept their respective fasteners.

Battery parallel electrical connections. With the individual modules in place, it was time to make the parallel connections between each battery. Positive busbars create an electrical path between the battery modules' positive terminals; negative busbars create an electrical path between the negative terminals. The resulting configuration connects the eight individual 2 kWh, 48 VDC nominal battery modules into a battery bank rated at 16 kWh and 48 VDC nominal.

The Blue Ion 2.0 uses horizontal busbars to electrically connect each side-by-side pair of batteries (battery 1-to-2, 3-to-4, and so on) and vertical busbars to connect the four pairs together. To facilitate easier alignment of the various mounting holes and fasteners, the horizontal electrical busbars are installed before the final fasteners are inserted through the cabinet's front support plates and tightened down.

The battery module's threaded electrical terminals are aluminum and the fasteners used to secure the busbars are stainless steel screws, so it's imperative to use an anti-seize thread lubricant to avoid galling, which can damage the threaded terminal. We dabbed the screws with anti-seize and secured the horizontal busbars with M6 screws, lock washers, and flat washers. With the horizontal busbars in place, we secured the cabinet's two front support plates and then installed the vertical busbars.

The final electrical connections on the front of the unit connect the paralleled battery modules to the system's BMU. We terminated factory-installed 2/0 AWG cables at their respective busbars. The positive cable connects to the top terminal of the positive vertical busbar and the negative cable connects to the bottom terminal of the negative vertical busbar with an M6 screw, lock washer, and flat washer.

Battery communication cabling and addressing. Because LI energy-storage systems are typically made up of hundreds or thousands of individual cells, accurate component measurement and charging is imperative. Each of the battery modules communicates with the system's BMU via a communication cable network. Each battery module has two communication ports. We installed the communication cables in a daisy-chain (series) configuration, starting with the lower right hand battery, which is also connected to the system's BMU.

The BMU maps each battery module by its dedicated address, which is set by adjusting a rotary configuration switch on each battery with a small, flathead jeweler's screwdriver. The lower right battery (battery No. 1) is configured as 0 on the rotary switch. The battery to its left (battery No. 2) is configured as 1, and so on for the remaining six batteries in the enclosure.



After the modules were positioned and secured, Willpower Electric's Bruce Fiero tightened busbars and terminated the main cables that connect to the BMU.

Battery to DC bus connection. The DC power output of the Blue Ion 2.0's BMU is factory-terminated at positive and negative bus terminals that are accessible from the back of the cabinet. As pointed out in the product manual, it may be necessary to pass the battery-to-inverter cables through the cabinet's wire glands before installing the power conductors' crimp ring lugs. This was definitely the case for my system's existing 4/0 AWG cables. Once we routed the cables into the cabinet, I crimped on new 4/0 ring terminals and landed the cables on their respective positive and negative bus terminals. I also landed the 6 AWG equipment ground conductor I had prepped earlier in the installation process.

Monitoring-equipment installation. The Blue Ion 2.0 system integrates a preconfigured eGauge monitoring system. The eGauge components include an energy meter and two current transformers (CTs) that are used to measure AC Leg 1 and AC Leg 2 current in my split-phase 120/240 VAC power system. Optional CTs, both AC and DC, are available to measure additional circuits, such as specific AC loads and charging sources like PV arrays or a backup generator.

We added a ganged 20 A breaker to the AC side of the existing OutBack power panel to provide power to the eGauge energy meter, and clipped a split-core CT around the inverter's AC Leg 1 and AC Leg 2 output conductors. Ethernet cabling is run between the eGauge energy meter and the local area network (LAN) Ethernet switch, and between the BMU and the LAN switch. These two connections allow the battery and eGauge systems to interact over the LAN and, in turn, make the processed system data available over the Internet, as well as over the LAN.

System commissioning. We rolled the cabinet into place, locked the wheels, and dropped the four threaded cabinet legs until they made firm contact with the floor. The unit's adjustable legs allow for some slight leveling if the floor surface is uneven. We then verified that the factory-integrated 250 A DC breaker was in the "off" position before using a voltmeter to check that each battery module's voltage was within ± 0.5 VDC (highest measurement and lowest measurement). This measurement is taken between the battery negative terminal and the inside of the recessed right side of the battery disconnect plug. The voltage of each module measured a precise 52.3 VDC.

The communication cables for each module are daisy-chained to the BMU; each module was assigned a digital address via rotary switches.





Two CTs and the eGauge energy monitor, installed in a wire trough, measure output on the main inverter AC lines and communicate via the site's local area network.

With the orange safety plugs installed, the battery system is energized. Engaging a rocker switch on the BMU initiates a 10-second diagnostic and battery module-mapping startup routine.



Ben Root (2)

At this point, we were ready to energize the Blue Ion 2.0 system, which consisted of inserting a battery safety plug into each module, completing its circuit. With battery modules energized, we locked the front cabinet door to prevent unauthorized access. Next, we turned one of two rocker switches located on the back of the BMU to the “On” position. Holding the “Start” rocker switch for 10 seconds initiated a first-time startup procedure in which the BMU ran several diagnostic routines, and mapped and registered the addresses of the individual battery modules.

While leaving all AC and DC charging sources and AC loads disconnected, we turned on the Blue Ion 2.0's integrated DC breaker and the pair of 175 A DC breakers in the DC panel of the OutBack Power system. Next, we turned on the inverters, flipped the 20 A ganged breaker to power up the eGauge monitoring system, and turned on a single AC breaker to power up the circuit for the power room's LAN and satellite Internet modem. This allowed us to confirm that both the BMU and eGauge monitoring systems were networked and functioning as intended.

With the ESS and inverters running, we turned our attention to adjusting charge setpoints on the inverter/chargers and charge controllers. The Blue Ion 2.0 controls all charging below a programmable setpoint, typically set at 55.2 VDC. The system is not designed to regulate charging sources once the ESS has reached 100% SOC; the system's existing charge controllers regulate the PV array's output once the ESS is fully charged.

Because the Blue Ion 2.0 is responsible for balancing charging between individual battery modules and cells, some of the charge controller functionality typically used to charge lead-acid batteries, such as multistage bulk, absorb, and float charging algorithms and temperature compensation, are not used. We programmed each of the two OutBack MX60 charge controllers with the following settings: 55.2 VDC bulk, 55.2 VDC float, and 0.1-hour absorb time. I used Morningstar's MSView PC software to program the TriStar 600 V to the same charge setpoints as the MX60s. After configuring the setpoints on each of the controllers, we turned on the PV input breaker for each respective controller and began charging the ESS.

We also adjusted the battery charger setpoints on each of the OutBack inverter/chargers to properly regulate the charging from the 14 kW Kohler backup generator. We set the battery charger absorb voltage to 55.2 VDC, the absorb time at 0.1 hour, the float voltage at 55.2 VDC, the float time at 0.0 hours, and the refloat voltage at 48 VDC. Temperature compensation was disabled or unplugged on each of the power conversion components.

The final installation step included registering the system via Blue Planet Energy's Dealer Portal. Once the system is registered, if you're the system installer, you'll be able to view its data. If you're the system owner, you can access system data via a separate Project Owner account.

Right: This eGauge screenshot shows daily state-of-charge (SOC) data for the first three months of the system's operation. As of this writing, the lowest SOC has been 15%.



Below: The Blue Ion 2.0 system has both web-based and app-based monitoring interfaces. These app screen-captures show battery SOC information (left); weekly cycling (center); and a polar chart of 24-hour energy usage (right).

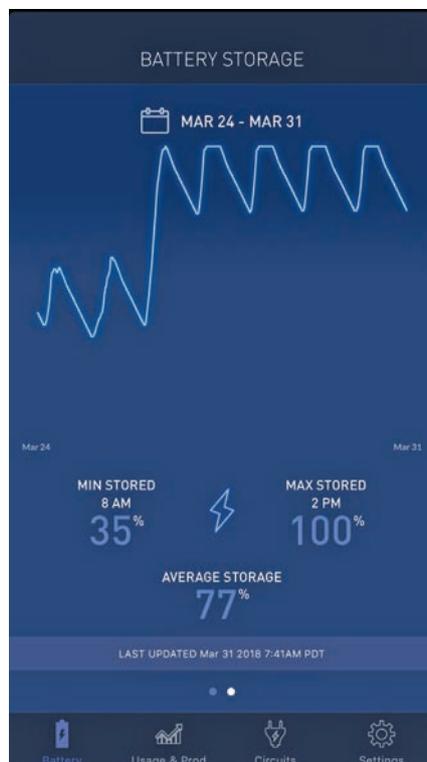
Initial Operation & Performance Insights

At this time of writing, we've been living with the Blue Ion 2.0 for a little more than three months—we're at the beginning of our experience with a product that carries a 15-year, 8,000-cycle warranty. Even though almost all of my operational experience with the product lies ahead of me, I have some initial insights to share.

Monitoring interfaces. Because we spend some of our time at our studio in town, online access to our system data is especially important. Prior to the Blue Ion 2.0 installation, I used OutBack Power's OpticsRE software to check battery voltage and system charging remotely, and could remotely

start the backup generator if we ever needed to using this platform.

Adding the Blue Planet Energy and eGauge monitoring has provided new visibility into our off-grid system. I typically use the Blue Planet interface for quick system status reports. Less frequently, I do a deep dive into the eGauge data. The Blue Planet monitoring includes a web-based interface that's linked to the system owner's account, and an Apple iOS app. The app's initial view displays battery SOC information that includes: the time until the battery is full, at the current charge rate; a battery SOC graph; the kWh needed to fill the battery to 100%; the total charging power of the site's inputs; and the



Joe Schwartz (4)

cumulative number of battery cycles. Additional app displays include daily, weekly, and monthly data for minimum, maximum, and average battery SOC. If additional CTs are installed on individual charging sources or load circuits, this information is also available online. The app includes a unique circular 24-hour energy usage graph that also indicates sunrise and sunset markers for the current day. It's an interesting way to view the system's daily energy consumption cycle.

Behavioral modifications. While I'm always keen to dive into solar product data sheets, manuals, and research papers, one of the most interesting things about my recent venture into home-scale LI energy storage isn't technical, it's behavioral. After the installation, it quickly became apparent to me that 15 years, the length of time I've been developing my off-grid homestead, is plenty of time to ingrain some serious behaviors related to living with batteries.

I'm what most folks consider a conservative off-grid battery user. To maximize battery service life, my approach has been to take it easy, limiting daily cycling to 15% to 20% DOD; avoiding excessive deep-cycling during inclement weather; and having an array that is oversized compared to the battery capacity so the system reaches full SOC almost daily and spends a high percentage of its time in float mode.

Since we've installed the Blue Ion 2.0 LI system, I'm gradually becoming more comfortable with DODs that I never

would have considered in the past. Another shift is being comfortable operating the system at lower SOC ranges—I can go to bed with the battery at 40% SOC and not have my heart race when I wake up in the morning and see it at 15% SOC. Our energy-use patterns are starting to shift, too. We're getting into the habit of using electric cooking appliances and electric point-of-use water heating after dark or in the morning when the sun's not yet on the arrays. And we're increasingly confident that the current power system could support electric heating and cooling using an efficient minisplit heat pump, which will reduce our wood-heating load.

In off-grid systems, perhaps the biggest upside offered by additional usable energy storage capacity, regardless of the battery technology, is the opportunity to minimize backup generator run time and fossil fuel use. Having access to the full capacity of the LI battery has already had a big impact on if and when we run the generator. With the addition of the new array, I think we can nearly be generator-free. We're becoming more patient and waiting longer for the next patch of sun.



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Residential Rooftop Access

by Brian Mehalic

The 2018 *International Residential Code* and *International Fire Code* (the *IRC* and *IFC*, two of the *I-Codes*) have been published, and PV system designers and installers should be champing at the bit for their local authorities having jurisdiction (AHJs) to adopt them, as there are significant beneficial changes regarding firefighter access requirements for residential rooftop PV systems. (View the *I-Codes* online at codes.iccsafe.org.)

Like the *National Electrical Code (NEC)*, the *I-Codes* are updated on a three-year cycle. They first substantively addressed PV system installation requirements in the 2012 editions. Currently, the *I-Codes* detail requirements for marking PV systems, particularly for labeling rapid shutdown systems. These requirements match those of the 2017 *NEC*. The labeling provides crucial information for first responders and firefighters. The *IRC* also addresses PV equipment listings, roof and wind loading, fire classification, roof penetrations, and building-integrated PV.

The 2012 and 2015 *I-Codes* editions contained many detailed requirements regarding the installation of the electrical equipment associated with PV systems—but the language was not always consistent with the *NEC*. The 2018 *IFC* and *IRC* defer to the *NEC*, stating that the “electrical portion of solar PV systems shall be installed in accordance with NFPA 70” (*IFC* 1204.1 and *IRC* 324.3).

Access & Pathways

Regarding residential rooftop PV systems, the *I-Codes*’ primary focus is to ensure safe and adequate access—and egress—so that fire-fighting operations are not interrupted or hindered. This is accomplished through requirements for:

- Access for inspection
- Pathways with structural support and minimal obstructions (including conduit, vents, and other equipment) that are capable of supporting firefighters
- Adequate spacing for ventilation opportunities
- Roof egress

The access and pathway requirements, found in *IRC* Section R324.6 and *IFC* Section 1204.2, apply to “Residential Group R-3” occupancies with roof pitches greater than 2:12, defined in Section 310.4 of the *International Building Code (IBC)*. These include one- and two-family dwellings; care facilities with accommodations for five or fewer people; congregate

living facilities with 16 or fewer nontransient occupants (such as convents, dormitories, fraternities/sororities, and monasteries); boarding houses with 10 or fewer transient occupants; and transient lodging houses with five or fewer guest rooms and 10 or fewer occupants. Note that *IFC* Section 1204.2.1 also defers to the *IRC*, stating that the *IFC* rules do not apply to Group R-3 buildings constructed in accordance with the *IRC* (the requirements in the two *I-Codes* being essentially the same).

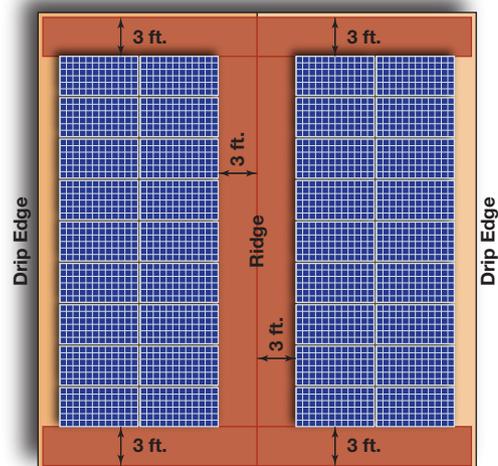
The Old...

Many PV system designers and installers are familiar with the more stringent access requirements in earlier editions of the *I-Codes*. These requirements ate into precious rooftop area, the lack of which is often a limiting factor in a PV system’s size. These restrictions called for:

- 36-inch-wide pathways from the ridge to the drip edge, along both edges of the roof surface
- Array setbacks at least 36 inches from the ridge
- At least 18 inches of space on either side of a hip or valley

But the requirement that very much limited potential system size was the one that specified each roof surface with PV had to be treated independently, so the pathways had to be provided for every individual roof surface with PV mounted on it.

2015 Access & Egress Requirements



3 ft. access on both sides of array, from drip edge to ridge

3 ft. access above array to ridge

...& the New

Pathways. While the 2018 *I-Codes* still require two 36-inch-wide pathways from the lowest roof (drip) edge to the ridge (*IRC* R324.6.1; *IFC* 1204.2.1.1), they must be on **separate** roof planes, and:

- One must be on the street or driveway side of the roof
- One must be on the same roof plane as each PV array, on an adjacent plane, or straddling the roof with PV and an adjacent roof (such as on either side of a valley)

Ridge setbacks depend on how much of the roof is covered with PV modules, and whether or not the building has an automatic sprinkler system installed. A minimum 18-inch-wide pathway is required on either side of the ridge if the PV array covers **less than or equal to**:

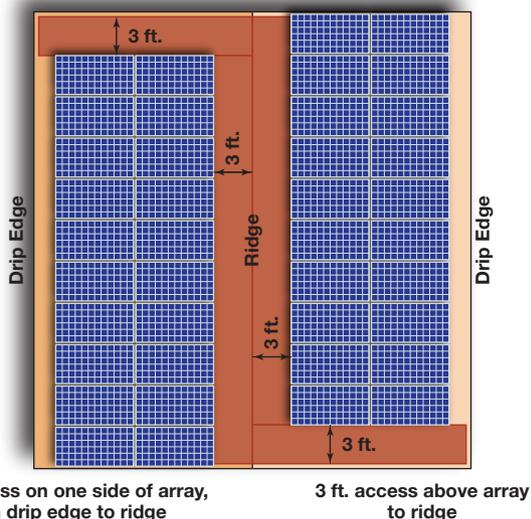
- 33% of the total roof area in the building plan view
- 66% of the total roof area in the building plan view and the dwelling has an automatic sprinkler system

A minimum pathway of 36 inches is required on either side of the ridge if the PV array covers **more than**:

- 33% of the total roof area in the building plan view
- 66% of the total roof area in the building plan view and the dwelling has an automatic sprinkler system

In many cases, this means that the access pathway plan will not have to change even if there are PV modules on more than one roof surface (the percent of coverage still applies). A house with a single ridge line running parallel to the street (and no automatic sprinkler system) could have a PV array on both sides of the roof, covering 75% of the total roof area, and only need two 36-inch-wide access pathways between the ridge and

2018 Access & Egress Requirements



IFC Section 1204.3 provides an exception that extends Group R-3 residential requirements to non-Group R-3 buildings when the roof configuration is similar.

drip edge (one on each surface) and 36-inch setbacks on either side of the ridge. Essentially, this would be a gain of $[36 \text{ in.} \times (\text{the length from the drip edge to the ridge minus } 36 \text{ in.}) \times 2]$, which could be several hundred square feet.

If there are emergency escape or rescue openings on the building, PV modules cannot be placed on the roof portion below them and a minimum path of 36 inches to the escape/opening must be maintained (*IRC* 324.6.2.2; *IFC* 1204.2.2). All pathways must be capable of supporting the weight of firefighters and have minimal obstructions—in some cases, overhangs may not meet this requirement.

Exceptions

Two primary exceptions to access pathway requirements are found in the *I-Codes*. The first, in cases where rooftop operations will not be used, gives local fire code officials the authority to render access pathways or spacing unnecessary. These decisions may occur on a case-by-case basis, based on the particular building in question, or the exception may be applied generally, as there are numerous jurisdictions across the country where vertical ventilation and/or rooftop firefighting operations are not, and will not, be used. As always, consult with the local AHJ and fire officials before designing or installing a PV system.

The other exception applies to detached, nonhabitable structures that serve Group R-3 buildings. As defined in the *IBC*, these structures include detached garages, parking shade structures, carports, solar trellises, and the like. They are exempt from the access requirements.

IFC Section 1204.3 provides an additional exception that allows fire officials to extend the Group R-3 residential requirements to non-Group R-3 buildings when the roof configuration is similar to that of an R-3 building. This could apply to an office park (Group B), some medical buildings (Group B or I), some educational facilities (Group E), and even some churches (Group A) that resemble residential construction, and are probably best treated as such with regard to access and pathways.



Getting Charged Up

with Homestead Tools

by Kathleen Jarschke-Schultze

My husband Bob-O and I both like tools, and I like gadgets. We consider a good tool to be a wise investment. When Bob-O found several reasons for buying a battery-powered electric chainsaw, one thing led to another—now, we have the beginnings of an arsenal of cordless tools.

Years ago, I gave up on my gasoline-powered minitiller. When I could start it, it was a great tool for tilling raised garden beds and spot-tilling amendments into the soil. But every spring, before I could use it, it would require visiting the small engine repair shop to have the spark plug changed and engine cleaned. Even though I diligently drained the gas before wintering the tiller, I never could skip its spring cleaning. It was just a fickle small engine.

Then gardener (and solar dude) Bill Battagin told me how he had traded his gas minitiller for a corded, electric model. One of the things he warned me about was that I would rapidly learn the importance of cord control. Thankfully, all three of my gardens are within reach of an extension cord. But Bill was right; cord manipulation is paramount—it must be kept away from the spinning tines. My Mantis electric minitiller has performed beautifully. I plug it in, turn it on, and it runs, wherever I need it. The tiller is mostly used in the spring for prepping the various garden beds. This tool has saved me time, frustration, and money—and reduced our use of fossil fuels.

When we bought and assembled our wood-fired Snorkel hot tub (“Home & Heart” in *HP136*), we vowed to never spend money on wood to heat the tub. We buy or barter for our firewood, getting our favorite—cut and split madrone. But the Snorkel likes a hot, fast fire, so smaller limbs and branches work fine. Our native juniper trees often drop a limb or just fall over and die—they are not long-lived. We clean up the deadwood, cutting the usable limbs and sticks in small lengths for the hot tub and piling the smaller brushy parts for burning. I really enjoy the smell of a juniper fire; it’s like forest incense.

After last year’s stormy winter there were quite a few downed junipers for us to harvest. Halfway through cleaning up a small fallen tree, Bob-O’s chainsaw gave it up. Now Bob-O



was once a tree feller—he knows how to maintain a saw. Truth is, this saw just wore out. It could have been brought back to life, but only with a lot of parts, cussing, and time. Bob-O had discussed battery-powered chainsaws with our friend Lance Barker at the last Solar Pioneers Party. Lance had been using one for a while and he was pleased with its performance. We read online reviews, but having the recommendation of a trusted, knowledgeable friend is pure gold. Bob-O called Lance and ran through all the questions he had.

Because of potential drought conditions for this summer, Bob-O has been concentrating on clearing low brush and limbs near our home and outbuildings. We want to have a large fire-defensible space around our buildings. All the wood big enough to be burned in the hot tub’s wood heater is stacked to dry. The small brush is piled for burning when it rains or to run through the chipper/shredder.

With the large amount of brush removal needed this spring, Bob-O chose the GreenWorks 40-volt 16-inch chainsaw. The unit still uses bar-and-chain lubricant but gets its power from a rechargeable 40 V, 146 watt-hour lithium-ion battery. We opted for a charger and two 40 V batteries. Two charged batteries will get you through a job when one might not.

Having dipped a toe into the world of electric tools, Bob-O decided to take the full plunge, buying a cordless

8-inch pole saw and a string trimmer which use the same batteries. GreenWorks has more than 25 products that use this size of battery (and similar tools using 24, 60, and 80 V batteries). Of course, we don't need every tool they sell.

I tried out the string trimmer on the tall dry grass along one garden fence. It worked quite well. Feeling empowered, I used it to trim the dead stalks of lavender sticking up from the rounded green foliage along the road beside the main garden. It only took me 25 minutes to do what would have taken me three or four hours with a pair of hand shears. I was hooked.

We often use our electric farm cart Evie ("Home & Heart" in HP163) to ferry wood around our homestead and deal with downed trees. While Bob-O uses the electric chainsaw to clean the smaller limbs and twigs from a downed tree, I gather them into a burn pile. This leaves the area around the tree clear for Bob-O to cut it into stove lengths or rounds for later splitting. We load up Evie's steel bed with wood and bring it home to stack.

The "chainsaw-on-a-stick," as Bob-O calls the pole saw, has been tremendous for pruning low-hanging branches and removing fuel ladder from our trees. After the limb falls, it gets the same treatment, and ends up in a wood rick.



Courtesy GreenWorks

So far, no job we have accomplished with the new electric tools has depleted the batteries more than 50%. Since they are lithium-ion batteries, however, they do not retain a charge memory, so we don't have to run them out completely before recharging them.

The features we like best are the mobility (no cords!) and immediacy of startup. There's no gasoline, two-cycle oil, noise, nor carburetors. The tools are ready when we are. The frosting on the cake is that we have reduced our use of fossil fuels and now run our new tools with renewably produced electricity. It's going to be a great spring.



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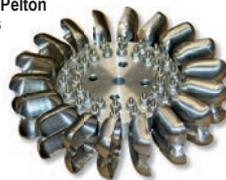
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It's All About the Load

When discussing renewable energy (RE) with students, clients, readers, friends, and family, it's very common for the conversation to focus on RE generation sources like sunshine, wind, falling water, biomass, etc. and the technologies, such as photovoltaic (PV) modules, wind generators, and hydro turbines.

While the technologies are interesting—what's next, how much they cost, and how they work—what should drive the design of any energy system are the *loads*. When a client asks how much a PV system will cost, I don't ask about the square footage of the house, how many people live there, or even how much sun they have. I ask them how much energy their home's loads use, which determines an RE system's design. This logical starting point is too often bypassed as we get excited about the glamorous generating technologies.

To understand loads, some basic electrical terminology literacy is helpful. "Watt-hours" (Wh) measure electrical energy generation and usage; 1,000 Wh equal 1 kilowatt-hour (kWh), which is the measurement we use in our homes, pay the utility for, generate with our RE systems, store in batteries if desired, and send back to the utility when our RE systems provide surpluses.

On-grid folks can usually pull out a recent utility bill to determine these numbers for their electrical energy usage, and, if they are on the fossil-fuel grid, for their monthly natural gas or propane consumption. Off-gridders have a bit harder task, though modern metering tools can provide excellent information. But if we don't have metering or if we're trying to plan for a future home, a load spreadsheet,



Measure your loads with a kW/kWh meter.

Ben Root

Example Load Analysis

Load	Qty. x	Watts x	Hrs. / Day x	Days / Wk. ÷ 7 =	Avg. Daily Wh
Refrigerator	1	507	3	7	1,521
Fans	2	100	8	5	1,143
Computers	2	80	8	5	914
Wireless router	1	15	24	7	360
Printer	1	200	0.5	5	71
Lights	8	25	6	7	1,200
Clothes washer	1	320	1	2	91
Total Power		1,602		Total Energy	5,300

on which the wattage and daily duration of each load is recorded, is necessary.

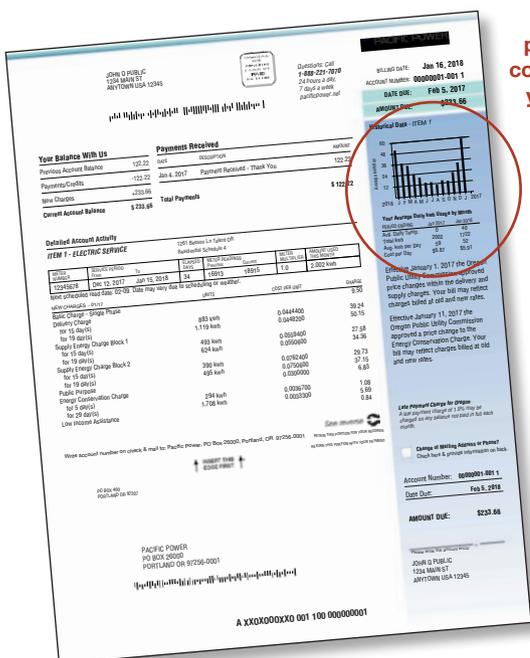
Handy tools for this analysis include watt/watt-hour meters like the Kill-A-Watt brand; hard-wired utility-type meters; and the utility's existing kWh meter. Each is used to measure the instantaneous wattage or the cumulative kilowatt-hours of individual loads, specific circuits, or your whole house. See "Using Energy Wisely Off-Grid" (in this issue) for more information and examples of off-grid loads.

Loads for a residence in the planning stages require estimation. Since you cannot measure the wattage of electrical appliances and loads that aren't purchased yet, you need to research their energy requirements and estimate the daily usage of each to arrive at the total anticipated loads. This is something a skilled RE installer can help with.

Understanding electrical loads and how they are measured is the right first step toward using RE in your home. Wrap your brain around the terms and then do the sleuthing to find out how much you use in your home. You'll be the life of a nerd party with this knowledge and better prepared for purchasing an RE system.

—Ian Woofenden

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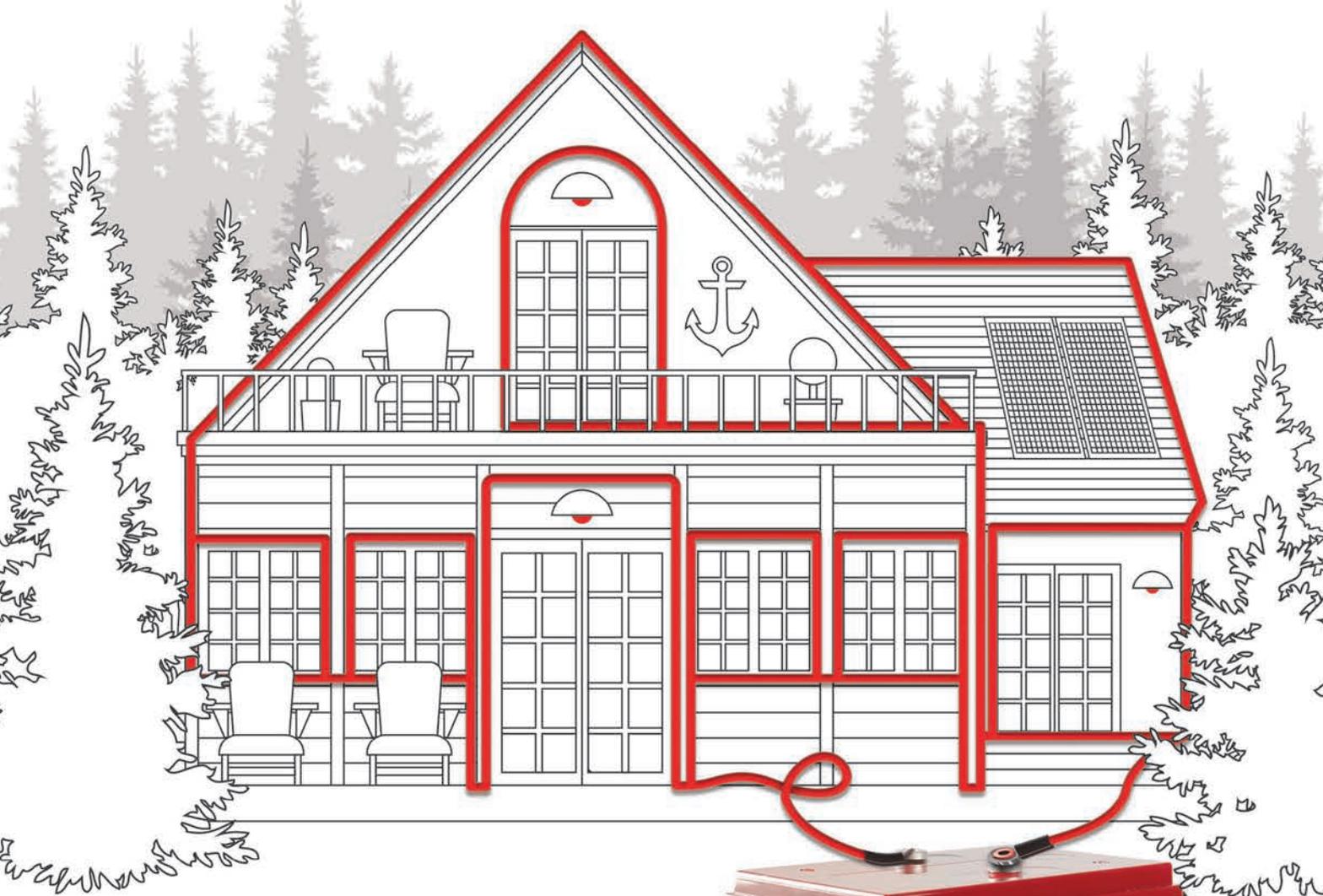
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