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Mar. & Apr. 2017, Issue 178
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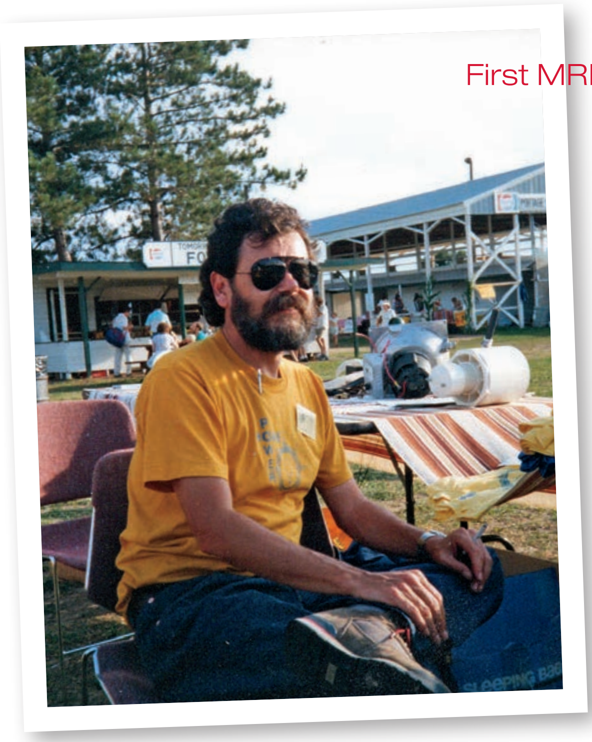
Our Founding Visionaries

In 1987, something amazing happened to many of us who lived off-grid—*Home Power #1* arrived in our mailboxes, unannounced. After years of sporadic contact with a few gurus and even fewer end users, we had a direct link to hundreds—and soon, thousands—of renewable energy users, promoters, manufacturers, and experts. This connection, which we all take for granted in this era of widespread Internet access, was remarkable. It was awesome and mind-blowing—it changed our lives. And it was because of the vision, hard work, investment, and dedication of Richard and Karen Perez.

Richard was born in Bedford, England, in 1945. His father, Guillermo, a United States Army Air Corps pilot, met his mother Grace at a USO dance in nearby Thurleigh. Like many children from military families, Richard moved frequently during his early childhood. He resided in San Antonio and Galveston, Texas; Tehran, Iran; and Wichita, Kansas; before a long stretch in Portsmouth, New Hampshire, where he graduated from high school in 1964. While in Portsmouth, Richard was on the debate team that won the state championship. He also built a computer that played tic-tac-toe and won first place in his high school's science fair. This was the start of Richard's lifelong fascination with rhetoric, computers, and electronics.

"Small Bear" & Richard

Richard always embraced the alternative, and more often than not was absolutely convinced that he was right. As a young man, this heady combination led him on a journey that included deep dives into books such as Aldous Huxley's *The Doors of Perception*; and stints at Cleveland, Ohio's Case Institute of Technology and the freewheeling Goddard College in Montpelier, Vermont. He was active in the voters' rights efforts of the 1960s, where he subjected himself to multiple arrests for civil disobedience while speaking out for equal access and treatment at the ballot box.



First MREF, 1990

Solar Pioneers

It's no surprise that Richard landed in San Francisco in 1967, where he joined in the "Human Be-In" gathering in Golden Gate Park and the Summer of Love that followed. He got down to free Grateful Dead and Jefferson Airplane shows, living in the city's Haight-Ashbury district, and eventually met his future wife Karen during a friendly hashish exchange (as the story goes, Karen was selling).

In 1971, Richard and Karen moved from the Bay Area to their off-grid homestead in remote southern Oregon. Their home on Agate Flat was later nicknamed Funky Mountain Institute, in a friendly comparison to the think tank of another visionary couple in the energy world. Richard and Karen's love of the Dead's music was a driving force in their initial quest for electricity—to run a cassette tape player. Richard gradually developed a solar-electric system, and then began helping others in their remote neighborhood use the new PV technology that we now take for granted.

After developing that small local business, Richard and Karen made a decision that has affected so many people and advanced the industry in innumerable ways. Instead of just serving their local area with RE advice, equipment, and service, they started the magazine that you're reading—so far, 178 issues packed with personal and technical experience and information about renewable energy and sustainability.

First SEER Fair, 1990

First MREF, 1990

It started out with a single Mac computer—shared by three people—with no hard drive and a 400K floppy drive. Early members of the *Home Power* crew remember publishing the magazine from the bush via solar electricity and radio-telephone modem at 300 baud. There was no bathroom, indoor shower, or laundry, just an outhouse—they had their priorities. As technology and the industry advanced, the business advanced, with a growing crew and a much wider audience. Later this year, *Home Power* will celebrate its thirtieth anniversary, a testament to a successful mission, crew, founders, and most importantly, our readers.

Always Talking Tech

With the Crew, Circa 2002

Richard left his body behind on January 13, 2017, twenty-six months after the passing of his beloved partner Karen. His passing was peaceful and supported by family and friends at his 46-year home on Agate Flat. Richard's vision of changing the way people make and use energy, "one rooftop at a time," has helped thousands and thousands of people to re-evaluate their energy lifestyles and make changes that have improved the planet and the spirit of our world.

And we'll just keep on truckin' on…

—The *Home Power* crew

Think About It…

"Sometimes, the light's all shining on me; other times, I can barely see. Lately, it occurs to me what a long, strange trip it's been…"

—"Truckin'" by the Grateful Dead, lyrics by Robert Hunter

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On the Cover

Pika Energy President Ben Polito field-tests a T701 wind turbine.

Photo courtesy Pika Energy

Photos: Courtesy Pika Energy; Sean Chastain; Jerry & Sally Bowker

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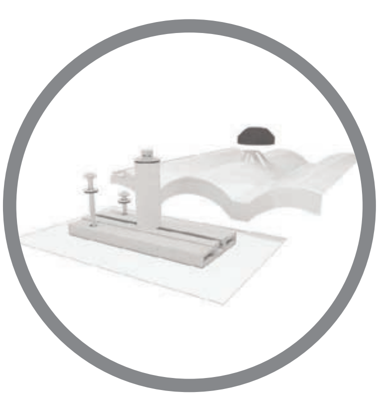

W Tile Mount

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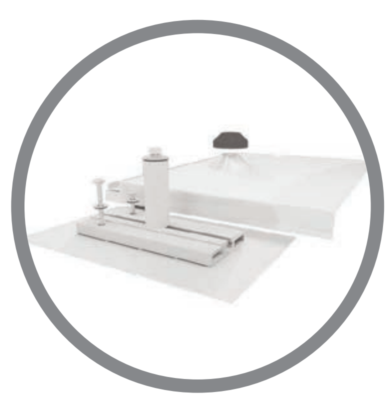

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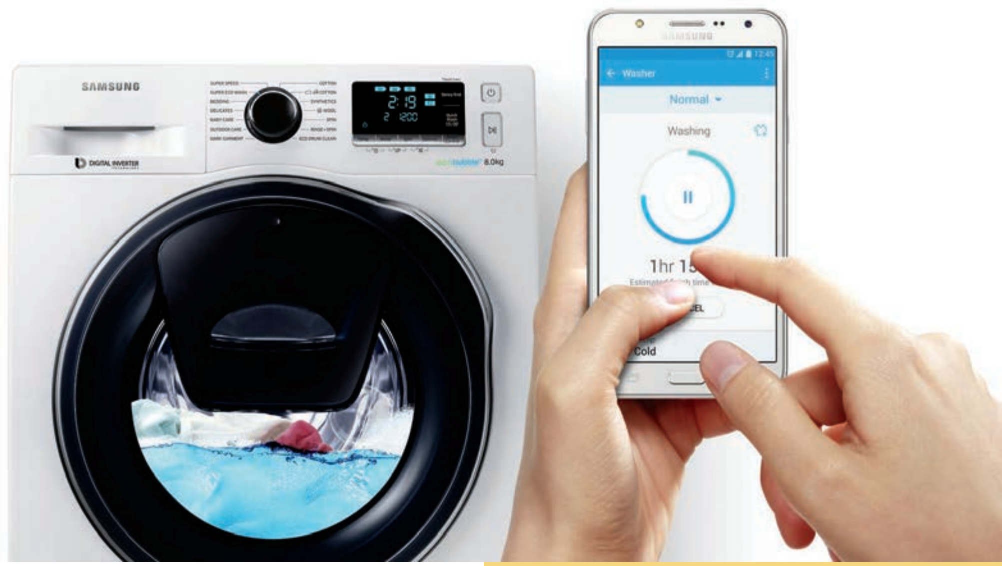

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Photos: Courtesy Samsung; Petzl; Fronius

This is where your investment in Solar & Wind Power Equipment pays off.

Crown Battery's proven array of Renewable Energy Deep Cycle Batteries. Unlike some deep cycle battery manufacturers who lump a few of their industrial products into a group and call it their RE line, Crown Battery evaluated the marketplace needs and re-engineered an entire line of 2-, 6- and 12-volt batteries to fit contemporary solar and wind power systems.

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Jerry Bowker grew up on a Wisconsin dairy farm, where he formed a love of natural plants. His education focused on botany, and then art, and he worked as a gardener/landscaper. Now in retirement, he works intensely on his own vegetables, flowers, and orchard, plus is devoted to woodlot management and making firewood.

Sally Bowker's education was in sociology and library science, but she returned to school in art and has been an artist ever since. Retired from her job as visual resources librarian and adjunct instructor in a college art department, she works in photography and textiles, with the natural world around her as her subject (sallybowker.com).

Sean Chastain is a project manager at Yes Solar Solutions of Cary, NC. A graduate of North Carolina State University, he holds a NABCEP certification for PV installation and has completed PV courses through Solar Energy International, Imagine Solar, Tesla, and the Solar Center at NCSU. Sean is a U.S. Army Veteran and served in Operation Enduring Freedom in Afghanistan.

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.

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

Christopher Freitas has been working in the PV industry since 1986, and lives with solar and microhydro power systems. Currently, he is the CTO of the Australian startup Redback Technologies, which offers advanced PV energy-storage hardware and cloud-based system management software.

Hugh Piggott lives off-grid on the northwest coast of Scotland. He builds small wind turbines, writes books about how to do so, and has taught construction courses around the world. Hugh also installs hydro and PV systems, and writes about off-grid renewable energy systems.

Robert Preus, PE, is Technical Lead for Distributed Wind at NREL. He founded Advanced Renewable Technology, which provided training, engineering, and certification support for small wind manufacturers. With 28 years of experience in wind energy, he has led the successful development of 2.5 kW to 300 kW wind generators. He also co-chaired the group that wrote a section for small wind in the *NEC*. In 2010, he received the Small Wind Advocate award.

Carol Weis is a IREC-certified Master PV Trainer and NABCEP PV Installer. Carol was a lead member of SEI's PV technical team for 15 years, and now primarily focuses on helping other solar training programs establish themselves throughout world. Carol has advocated for inclusion of women in the energy sector by teaching all-womens' classes since 1999.

Robert Wills, PE, has worked in renewable energy since 1982. He is president of Intergrid LLC, a consulting engineering company. Rob represents the American Wind Energy Association on the *National Electrical Code* and helped write Article 694, "Wind Energy Systems."

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, and lecturing, teaching, and consulting with homeowners.

Vaughan Woodruff owns Insource Renewables, a solar contracting firm in Pittsfield, Maine. His firm, along with Assured Solar Energy, was selected to run the Solarize Freeport campaign. He is a NABCEP Certified PV Technical Sales professional, a NABCEP Certified Solar Heating Installer, and an instructor for Solar Energy International.

Contact Our Contributors

Home Power works with a wide array of subject-matter experts and contributors. To get a message to one of them, locate their profile page in our Experts Directory at **homepower.com/experts**, then click on the Contact link.

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Petzl's Volt Wind LT Harness

A climbing harness is a crucial piece of equipment for wind-electric system installation and maintenance. Its first function is keeping the climber safely on the tower. One hundred percent attachment is the rule, and having a safe harness that fits is vital. Harnesses also provide comfortable positioning and seating, and places to attach tools and other gear.

In more than 30 years of climbing, I've witnessed a dramatic evolution in my personal harnesses. My first harness was tied out of manila rope. It wasn't comfortable, but it was cheap and got me into the air. Later, I bought a basic tree-climbing harness, with a waist belt and a simple butt strap. But it, like the even simpler lineman's belt, is far from safe. Without full leg straps and chest harness, a climber can fall out of a harness.

Eventually, I ended up with climbing harnesses used in the cell tower industry. These are fully equipped with chest straps and multiple attachment points—everything you need—but they are quite heavy. While this sturdiness gives a feeling of security, after a long day of climbing, it wears you out to haul this much weight up and down a tower.

Courtesy Petzl (2)


Ian Woofenden

Enter Petzl's Volt Wind LT harness. Used with the optional seat, it has most everything I could dream of in a harness. This full-protection harness is light and comfortable, with multiple attachment points. All of its buckles are easy and quick to operate, while not being prone to accidental opening. You don't have to step through the leg straps (as you do in some harnesses)—you just put the harness on like a jacket and then connect the leg, waist, and chest attachments.

With the separate seat permanently attached, it's a versatile harness that allows rappelling and use with fall-arrest devices. It accommodates a wide variety of climbing and positioning techniques. Though it was designed for utility-scale wind climbers, it's excellent for home-scale tower climbing as well. It's going to be hard for me to use anything different after experiencing this harness's convenience, comfort, and utility.

Petzl has been making great climbing gear for years, and some of it has been in use in the wind industry before. This harness is an excellent addition to its product line, and would be a valued part of any wind energy climber's gear.

—Ian Woofenden

The Future of Net Metering

Great article on net metering in *HP177*! As a longtime solar installer in southern Arizona, I've been closely following solar politics here, and strongly encouraging pro-solar folks to make their voices heard in support of net metering.

Unfortunately, our elected Arizona Corporation Commission voted four to one in December 2016 to end net metering as we know it. Rooftop PV customers will receive full retail-rate benefits from electricity that their systems produce and use immediately, but any energy exported to the grid will be credited at a lower-than-retail rate. Initially, this rate will be based on the price of utility-scale solar plants; it's expected to be about 70% of current retail rates, and will step down each year.

Under the new scheme—to be implemented later in 2017, after specific hearings for each utility—new customers will be able to lock in this export rate for 10 years. Current customers will grandfathered into net metering for 20 years from the time they connected to the grid.

It's going to be an interesting new world for solar installers here in Arizona, and wherever else net metering is rolled back. Our company has been looking at how we can be more efficient—and we'll need to be, since I estimate we'll have to cut our installed cost by as much as 15% each year if we want to keep simple system payback to less than 10 years.

On the other hand, we're excited about the long-term promise of storage and energy-management technologies. Unfortunately, it is in no way a cost-effective solution today, because our retail electricity rates in Arizona are only $0.09 to $0.14 per kWh. Currently, energy storage is significantly more expensive than the difference between retail rates and export rates. But if storage costs drop to 25% to 50% of current levels, it'll be a whole new world.

Beyond understanding the details of how to install storage systems, I think PV installers will need to up their game with energy modeling, load control, and other building management technologies. With no banking of energy credits, and a differing rate for imports and exports, it's much more difficult to estimate a PV system's financial performance than the simple calculations currently required for net-metered systems. We'll have to obtain detailed energy-use data for clients, and predict each energy flow on a second-by-second basis, since maximum benefit will be when customers use as much energy as possible as it's generated.

We're going to need to offer real energy solutions that are easy for the consumer to understand and implement. For better or worse, consumers will have to accept more uncertainty regarding the financial payback for their systems, since their specific energy-use patterns will affect how much energy is sent to the grid at a reduced compensation level.

As we move into a new energy policy era in Arizona, I believe rooftop PV systems will still be an important part of Arizona's energy mix. If you're in a state considering changes to net metering, it's critical that solar supporters gain a better understanding of the issues, show up at hearings, write letters, and support organizations that are fighting for net metering around the country. We've got to all work together to make sure solar energy has a bright future.

Louis Woofenden •
Net Zero Solar, Tucson, Arizona

Experimental Battery Management

I've been living off-grid since 2001, and have a substantial tech background, including electrical engineering studies plus software engineering. I've implemented some modifications to my PV system to increase battery life, such as a battery heating system—it's 13°F outside right now; my batteries are a balmy 71°—plus battery caps to limit electrolyte lost in gassing. I'm now working on a bank-switching system.

I'm wondering if there's a methodology for creating a curve based on electrolyte specific-gravity readings over say, six months, and extrapolating that with nonlinear degeneration rate to predict how long batteries will last. I'd like to be able to assess my bank-switching system and see early on if it is on track for the expected gains in battery life. From a layperson's perspective, it seems that batteries only have so many metaphorical "heartbeats"—their capacity of charge/discharge cycles. In my case, it is a precious 3,000, assuming a depth of discharge (DoD) of less than 20% at 80°F. Since every day is essentially a new charge cycle, that works out to about 8.2 years.

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What's best for Arizonans—rooftop PV power or fossil-fueled power like Arizona Public Service's Cholla coal-fired power plant?

Courtesy Louis Woofenden
Courtesy PDTillman


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continued from page 14

Look at the manufacturer's spec sheets. For $8,000 of batteries, so few cycles simply won't do. Although I climbed outside of the box and came up with an approach, I don't want to wait years to know if it is going to work.

My battery storage was designed on the high side, with an 1,110 amp-hour system for a daily usage of 70 amp-hours. In other words, a DoD of about 6%. Averaging over the year, usage is probably more like 10% per day. Maybe that bumps cycle life to 3,500, but the graph I have does not extend far enough to say. At that rate, let's assume a battery life of 10 years. Yay. Spoiler: Your average DoD (not counting winter high-demand days) needs to realistically be less than 12% for this strategy to work.

Why not break those three strings into three banks? Yes, it's a bad idea to have three strings, anyway. The bank still would have a cycle life of 3,000, even if each resultant 370 Ah string is drawn down to 18% DoD. The 3 at 10% won't happen because I will combine banks for days when higher capacity is needed. With my setup, I can switch and combine these banks on the fly without shutting down the system! I don't have to worry about inductive in-rush currents of the inverter/charger damaging the switches! I don't have to abuse the inverter/charger with frequent on-offs! This also permits regular de facto float charging of the idling batteries to avoid stratification.

Now, each bank is only seeing about 140 charge cycles per year (assuming 20 when banks are combined together). In other words, the life of the batteries has been more than doubled by making the "heartbeats" farther apart. Instead of 8.2, I can expect 21.4—for the cost of a $1,000 upgrade. If it works out, this could be kind of a big deal. Hence, the need to assess battery aging scientifically with a few months' worth of data.

I know a battery sitting on a shelf and regularly floated is going to last longer than one that is using up charge cycles. If the battery is used one-third of the year, will it last three times as long? Probably not, but maybe more than two times. I suspect there are some gurus who can weigh in and say exactly how much longer, but have they *done* it? Also, have they done it in combination with equivalent other tweaks? Anyway, I suspect people would be interested at least in a possible way to get 20+ years out of some L-16 batteries, and what that might look like.

As a side note, I looked into nickel-iron (NiFe) batteries before buying these. What I ran into was disingenuous. More than one salesperson tried to sell me battery capacity at 50% DoD for NiFe and equate that to storage for regular L-16s at 10% DoD—not an apples-to-apples comparison. Although some say that the DoD does not impact lifespan of NiFe, my research with the manufacturer's own documents says otherwise. Based on the manufacturer's own spec sheets, I found that it would cost five times more than a properly sized L-16 system, and last about two times as long. (And it would weigh several times more—likely needing a customized shed to handle the weight.) So if I can get L-16s to last about 20 years—even if I have to enlarge the system storage with a third string—best I can tell, I'll still be ahead.

Rick Warner • via e-mail

Courtesy Steve Johnston

These BioWIN wood pellet-fired boilers provide water and space heating with less maintenance than a firewood burner.

Using Wood Pellet Boilers

Your article about off-grid water heating in *HP177* was very thorough but failed to mention wood pellet boilers as a possibility for wood-fired water heating. Many of your readers are the pioneering type who may enjoy cutting, splitting, stacking, storing, and feeding firewood into a stove or boiler, but some of us do not have the access to a wood lot or the time for handling firewood, or may be physically incapable of doing that work.

I have an integrated heating system that uses a 600-gallon tank as pictured in your article. One of the heat exchangers is connected to a BioWIN pellet-fired boiler, and the others to a domestic hot water, a solar hot water, and a radiant heating system. By connecting to a large tank, the boiler burns with incredible efficiency (>90%). It puts out very low levels of particulates, so it can be used in cities that restrict wood burning. It also requires very little maintenance—about two hours per year—and runs automatically, like a propane boiler. It has an automatic feeding system, so it does not require constant fire-tending. For older folks, a big plus is bulk delivery of pellets, available in many parts of the country, so even handling the bags of pellets is eliminated.

In short, it uses a renewable fuel source, has low maintenance, high efficiency, and automatic functioning—qualities that are hard to beat in a water-heating system. The only drawback is the boiler's high initial cost.

Steve Johnston • Sweet Home, Oregon

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Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Heating Choices

I am designing a grid-tied, energy-efficient home in the Sierra Foothills of California. I plan to put a solar-electric system on the ample south-facing roof and install radiant heat in the concrete slab for space heating. I am considering hydronic or electric resistance heat. Do you have any suggestions for which approach might be best?

Grant Krueger • via email

As with any heating project, the solution depends on the size and construction of your building, and on the climate. For example, if you want a radiant solution for a highly efficient home that requires little supplemental heating, an electric-resistance hydronic heat source—such as a dedicated water heater or an electric boiler—might be the easiest and most practical solution. Another option for using electric-resistance radiant heat is the use of electric towel warmers or heat mats that can be installed under a compatible floor finish, such as ceramic tile. These approaches are typically used in spaces like bathrooms that have a small heating load.

If you want that radiant heat for a large home at higher elevations where there may be more significant heating loads, a ground-source heat pump (sometimes called "geothermal") coupled with a hydronic distribution system may be most appropriate. For a location with moderate heating demands, an air-to-water heat pump might be a good solution. This technology hasn't yet seen the advances experienced by air-to-air heat pumps, but there are some products on the market you could investigate. Examples of available models include the Daikin Altherma and the Chiltrix.

The benefit of heating with a heat pump rather than using electric resistance heaters is that they produce 2.5 to 5 times the heat output per amount of electricity consumed. If your plan is to use net-metering credits that accrue from your PV system during the nonheating season to offset the heating system's electricity use in the winter, you'll be dollars ahead with this approach, as the required PV system will be much smaller.

Consider the style of radiant system you might use. Especially in moderate climates, a radiant floor may not be the best fit for a high-efficiency home. Instead, panel radiators, radiant walls, or radiant ceilings might be better matches. See John Siegenthaler's article in *HP152* for more details on radiant options (homepower.com/152.50).

You may want to forgo radiant heating altogether. With advances in air-to-air heat pump technology, you may find that a minisplit heat pump provides the best savings for your renewable energy dollar.

Courtesy Daikin

When it comes to heating water, an air-to-water heat pump is more efficient than an electrical resistance water heater.

These are forced-air, single-duct units and provide a different type of heating comfort, but they are quite versatile and can also provide air conditioning should it be required.

Whatever route you take, be sure to insulate and seal the building well. It will maximize your renewable energy investment.

Vaughan Woodruff • Insource Renewables

Matching Hydro Runner & Alternator

I'm designing a microhydro system using a Fisher & Paykel washing machine motor converted to operate as an alternator. The alternator has a 250-millimeter diameter and the magnets are on the outer edge of the alternator. Since a Pelton wheel's force occurs at the outside of the wheel (via the buckets), should the wheel be the same size as the alternator? If the Pelton wheel was larger, should it have a more efficient drive force on the smaller-diameter alternator? If so, what is the optimum ratio of the wheel-to-alternator diameter?

Grant Keeley • via e-mail

There is no direct relationship between motor diameter and turbine runner diameter, but there are several important factors that must be considered to optimize the turbine.

After factoring in losses in the pipe, we can estimate the net head, or pressure, which determines the velocity of the water striking the runner. As head increases, velocity increases. Quadrupling the head, for example, results in doubling the velocity. The Pelton buckets will capture the most energy if they run at just under half the velocity of the water jet. This, in turn, determines the revolutions per minute (rpm) at which you will get the most output, based purely on water pressure and runner circumference. For example, 100 feet of head (43 psi) on a 9-inch-diameter Pelton runner will hit the runner's sweet spot between 800 and 900 rpm. The peak is fairly flat, so there is no need to be precise.

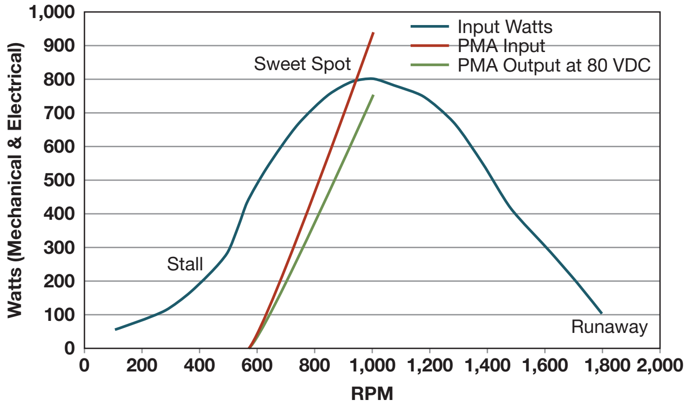
In theory,
rpm = {[square root (head, in feet)] ÷ diameter, in inches} × 920

In reality, due to friction losses, the peak performance will be somewhat lower.

Design the motor/alternator to generate the expected power at this rpm. If the power converted is too low at the critical speed, it will overspeed; if you try to produce more power than the turbine can give, you will stall it, and run below the optimal rpm. These deviations can be observed from the spray pattern coming off the runner.

Your biggest design decision is choosing a motor winding that can deliver the power you expect at the voltage you plan to use, and at the rpm the site requires. A Fisher & Paykel "Smart Drive" motor has many coils that can be rewired in series or parallel to tweak the output in relation to voltage and rpm. You can do this yourself, or buy a modified Smart Drive stator from PowerSpout (powerspout.com). The company also provides a free, downloadable design guide (bit.ly/S-DriveDesign). The output voltage will depend on this stator winding, and it will increase in proportion to the rpm. The turbine's voltage on load must match the battery's voltage on charge when the turbine runs at an rpm close to the sweet spot. Bear in mind that the load current reduces the motor/alternator's voltage (by up to 43% at maximum power), so figuring out the best stator to use may take several steps of calculation.

continued on page 20



Source: EcoInnovation Smart Drive Application Manual

continued from page 18

Even with a well-chosen stator, it's unlikely that this will achieve the rpm you're aiming for, but it may be close enough to meet your needs. If you want to increase the rpm, adjust the magnet rotor so that it induces less voltage at a given speed. Turbine speed will rise accordingly.

You can also use an MPPT controller (designed for PV systems) to fine-tune the hydro turbine's rpm. This is ideal for use with variable-flow sites at which the pressure or the voltage changes a lot due to long pipes and long wire runs. Choose an operating voltage that is above the battery voltage, but bear in mind that there is a big difference between this voltage and the runaway "open-circuit" voltage that can occur when no power is being used. Open-circuit voltage may be three times higher and—if the system isn't properly designed—may destroy your controller.

Building a home-scale microhydro system is very satisfying, and it can contribute a lot of energy. You will need to be smart and resourceful to create a good intake and install pipes, wires, and the electrical system. Building your own turbine is doable, but there are small companies that can help you with friendly advice and provide a turbine package that is sure to work properly on your site. Several of them advertise in *Home Power.* Good luck with your project.

Hugh Piggott • Scoraig, Scotland

Wind Turbine Tower Grounding

A wind turbine installer I recently spoke to claims that the connection between the equipment and tower grounds is unnecessary and dangerous. I disagree, but don't have the code or research to back up my opinion.

Mark S. Mayhew • NYSERDA

The *NEC* is clear—you have to follow code, or convince your inspector otherwise (which is unlikely).There is a safety reason for bonding the tower ground. A case in point: Years ago, a Skystream was wired improperly at the nacelle and the four connections (two line, neutral, and ground) were all off by one position. There was no separate bond at the tower base to the equipment grounding system. The result was that the tower was "live" when the turbine was first energized. An installer happening to put a large wrench on a tower bolt would have been at risk for a deadly shock.

Uninspectable ground connections at the tower top, and the possibility of a live connection to tower ground via loose wire or perhaps alternator failure pose safety hazards. For this reason, requirements were written into *National Electrical Code's (NEC)*

Article 694 that specify an inspectable ground to the tower. This requirement echoes the general requirements on grounding in the *NEC*: all exposed metal must be grounded. While there are some exceptions—rotors, tails, and guy wire, for example—the relevant 2017 *NEC* sections are 690.40 (A), (2), (3) and (4):

694.40 Equipment Grounding and Bonding.

(A) General. Exposed non–current-carrying metal parts of towers, turbine nacelles, other equipment, and conductor enclosures shall be grounded and bonded to the premises grounding and bonding system. Attached metal parts, such as turbine blades and tails that are not likely to become energized, shall not be required to be grounded or bonded.

(2) Bonding Conductor. Equipment grounding conductors or supply-side bonding jumpers, as applicable, shall be required between turbines, towers, and the premises grounding system.

(3) Tower Connections. Equipment grounding, bonding, and grounding electrode conductors, where used, shall be connected to metallic towers using listed means. All mechanical elements used to terminate these conductors shall be accessible.

(4) Guy Wires. Guy wires used to support turbine towers shall not be required to be connected to an equipment grounding conductor or to comply with the requirements of 250.110.

However, there is controversy about tower-to-premises bonding and, similarly, array-to-premises bonding for PV systems. The counterargument is that a lightning strike at the tower or array will cause a ground bounce at the premises through the connected equipment-ground bond, potentially damaging equipment and posing a shock hazard.

I believe that this conjecture is unproven, theoretically and practically. The inductance of the equipment ground from tower to premises is actually significant, and it probably mitigates the coupling effect. There is no doubt in my mind that the personnel safety achieved by bonding towers to premises outweighs the lightning-coupling argument. The thought that an alternator insulation breakdown could result in a live tower is unacceptable.

Dr. Robert H. Wills, PE • Intergrid

I agree. If you do not connect, then you are trying to isolate. Isolating the turbine machinery ground and the tower from each other in a lightning strike is not viable, and could create just enough voltage difference to cause extensive damage. The main function of surge or lightning arrestors is to limit the voltage difference, which prevents blowing holes in the insulation, while draining energy to ground before the voltage spike reaches any sensitive equipment.

Robert W. Preus, PE • NREL

write to:

asktheexperts@homepower.com

Published letters are edited for content and length. Due to mail volume, we regret that unpublished letters may not receive a reply.

Wind-Electric History & Home-Scale System Design

by Hugh Piggott & Ian Woofenden

Utility-scale wind turbines have overtaken nuclear energy in global power-generating capacity, and outstripped solar by more than three to one in electrical energy production. The technology is mature, growing fast, and producing cheap electricity. Home-scale wind energy is less mature, and often doesn't compete with solar as well.

This article will help you understand what small wind turbines can do, and what engineering approaches work best. Globally, small wind turbines represent less than 1% of the total wind-generating capacity, but they do have their place when properly sited and installed.

Design Evolution

Wind turbines convert wind power to mechanical power. The earliest applications were windmills that performed essential tasks like grinding grain and pumping water. At first these were "panemones," vertical shafts driven by crude sails that were blown downwind on one side and made their way back upwind on the other side of a central shaft. Next there was a huge technical breakthrough, and the sails were mounted on a horizontal shaft so that they worked by lift instead of drag, sailing across the wind instead of being carried before it. This meant that they could work all the time throughout the revolution of the shaft, with improved efficiency.

Nineteenth-century water-pumping windmills in the United States were designed to produce as much torque as possible at lower wind speeds, using many blades. This technology was enormously successful, with millions of units installed. It is not surprising, then, that the first electricity-producing windmill, built in 1888 by Charles F. Brush, was of the same design. The resulting machine was enormously heavy, with 144 blades and 1,800 square feet of surface area.

Although the turbine operated successfully for 20 years and supplied his home with electricity, it was an unwieldy and inefficient machine. A more-efficient turbine uses high rotational speed, not high torque. Fewer blades, moving

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Courtesy Pika Energy

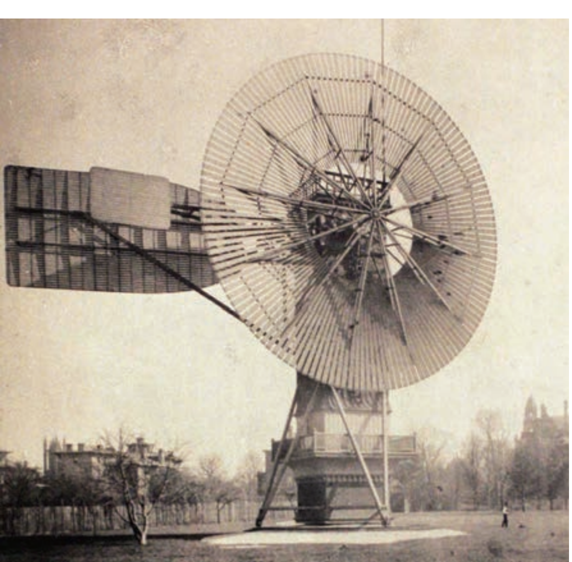
faster, can capture more of the available energy in the wind. European windmills with four sails had the advantage over multiblade ones, and by 1918 there were more than 100 windmills of that classic type supplying electricity to Danish utilities.

The early 20th century saw the birth of the aeronautical industry, and with the knowledge to fine-tune the lift-to-drag ratio it became possible to capture the wind with only two or three blades, moving fast across the wind. This rotor type is more efficient than high-torque ones because it does not generate as much of an energy-wasting swirling wake. Tens of thousands of "propeller-type" two- and three-bladed wind generators brought electricity to ranches across the Midwest plains in the 1920s. Modern wind turbines are similar, but with blades more slender in relation to their ever-increasing length. This has proven to be the most successful blade design.

With the expansion of the electricity grid and the low cost of fossil fuels, wind energy development proceeded in fits and starts. Plenty of variants were discovered and rediscovered, including the vertical-axis type. In 1924, a Finnish inventor, Sigurd Johannes Savonius, popularized a variant with two offset half cylinders. Very slow and inefficient, its main appeal is its simplicity.

In 1931, a French engineer, Georges Jean Marie Darrieus, patented a high-speed vertical-axis turbine with slender blades that has been the darling of university engineers ever since. It has many inherent challenges they can try to deal with. It is not self-starting, nor is there any simple way to control its speed when running. Vertical-axis designs remain popular in spite of failing to achieve commercial success over a long period. It often appears that enthusiasts are unable or unwilling to learn from past failures of the genre.

From time to time, the "ducted" turbine is hailed as a new discovery, intended to funnel the wind into an aperture where it can be processed by a turbine. These projects fail to produce cost-effective turbines because the wind simply makes its



Public Domain

Left: The world's first automatically operated wind turbine was built in 1888 by Charles F. Brush. It was 60 feet tall with a diameter of 56 feet, weighed 80,000 pounds, and had a 12 kW generator.

Right: Two wrongs don't make a right. Here, a Savonius rotor is placed at the center of a Darrieus to make it self-starting. But Darrieus turbines are inefficient and structurally flawed.

Courtesy Fred Hsu

Courtesy Bergey Wind Power

For overspeed protection, Bergey's Excel 10 kW turbine features a pivoting tail and flexible blades, which twist to allow furling under excessive wind load.

way around the structure. Unlike water, it is impractical to trap the wind and concentrate its energy. Another folly is the building-integrated turbine, which is installed on a rooftop or built into a hole in a wall. Winds around buildings are generally inadequate in speed, and are turbulent. If the turbine actually does run, it generates considerable noise and vibration within the building.

The search continues for an improved wind-energy converter, but the most important thing to know about using wind turbines is that they need wind. Just as you would not mount a solar-electric array in the shade, a small wind turbine cannot be viable unless it is prominently exposed to the wind resources, on a site that has few to no obstructions.

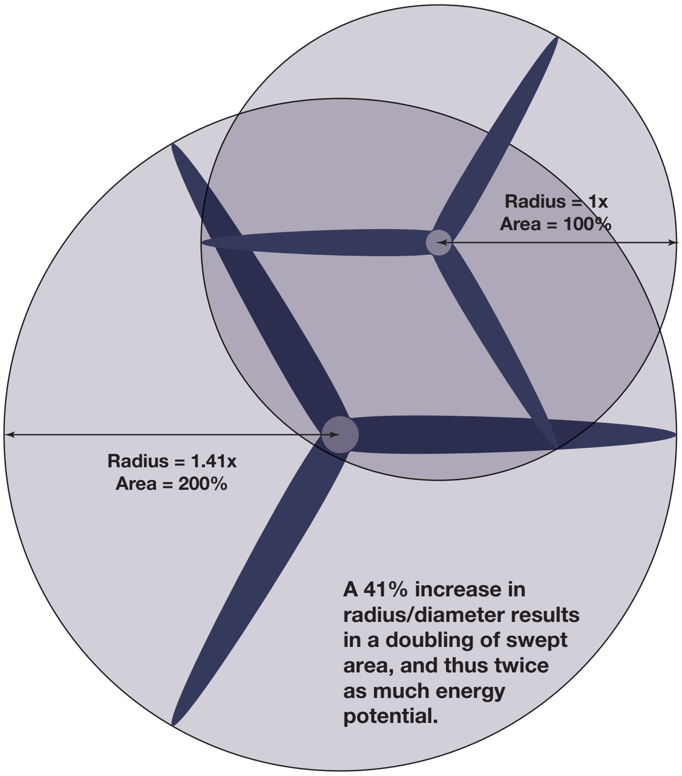
Larger Collectors

The rotor blades of a wind turbine are the engine. The wind is the fuel. The amount of energy it can capture depends directly on the rotor's diameter. Increasing the diameter makes a big difference, because the energy captured is determined by the area of the circle inscribed, and this is figured by the radius, squared. Doubling the area is a sure way to double the turbine's energy capture. (See the AEO table in the "Wind Reality Check" sidebar.)

The number of blades is less important. If three blades can produce 1 kilowatt, it does not follow that six blades can produce 2 kilowatts. A properly designed turbine will capture almost all the power that can realistically be captured. Wind turbine blades rotate several times faster than the wind speed. If there are fewer blades, they simply need to move faster to cover the ground. The higher airspeed generates more lift force per blade, which compensates for having fewer blades.

For example, two-bladed turbines run at higher rpm than three-bladed ones—an advantage for electricity production as it allows for a lighter-weight, less-expensive generator. Some downsides are that the blades will be slightly noisier, and the tips may become eroded over time. And the two blades switch rapidly between horizontal and vertical alignment, causing a jerky motion when the turbine yaws to face a changing wind direction. This can shake the machine and tower, leading to extra wear. Many observers also agree that a three-bladed turbine is easier on the eye. More than three blades is less common, as they add to the cost and weight without any particular benefit.

Swept Area is Key



This Renewtech turbine is a tailless upwind turbine that uses electronics to yaw. Larger turbines are often better at obtaining both efficiency and durability, but that can challenge the budget of a homeowner.

Courtesy Renewtech

Governing

If a site has enough wind to produce useful wind energy, the wind will sometimes gust at much higher speeds, which challenge the turbine's survival. Turbines must include an automatic protective governing system to limit blade speed and power. Otherwise, the generator will be overloaded and burn out, or the blades will overspeed and possibly break. Coping with high winds is just as important as working well in useful wind speeds, or the wind turbine won't last long.

The "furling tail" is a simple, popular governing system. When the wind is below the speed for maximum power, the tail steers the machine to face the wind directly. In higher wind speeds, the tail folds partially or completely, allowing the turbine's rotor to yaw sideways and present a smaller profile to the wind, catching a smaller proportion of the increasingly strong wind. The system uses few moving parts and there's little to go wrong—but the drawback is that the yawing motion is slow, so the governing action is delayed and imprecise. In high winds, a good furling system needs to keep the turbine safe, protecting it against sudden gusts, resulting in an average output that is often quite low. This is of less concern in an off-grid situation, as the battery is likely to be already fully charged at this time, but it can represent a missed energy-harvesting opportunity for grid-tied systems.

A more precise method of controlling turbine speed and power automatically adjusts the pitch of the blades to fine-tune the lift force. Pitch-controlled turbines have a steadier speed and output than tail-furling turbines, but this comes at the cost of a more expensive and complex governor, with moving parts and springs that can wear or break.

Some modern wind turbines rely instead on stalling the blades. The generator acts as a dynamic brake, using an electrical load to limit the blades' speed. The blades perform less well when turning slowly in relation to the wind speed, so this method limits the power without extra mechanical parts. Sometimes, a backup braking system is needed for safety in stormy conditions, when the wind is fast enough to overcome the electrical load.

A machine's "power curve" is a good representation of how well it governs in high winds. Wind energy continues to increase cubically as wind speed increases, and a method of protecting the turbine in powerful and damaging winds needs to be available.

System Configurations

Though the distinctions can get muddy at times, it's useful to have some basic terms and system configurations in mind as you consider wind electricity for your home or small business. These four system types cover the major ground, with some variations possible:

- **Off-grid systems without batteries** are unusual. They include systems that do direct heating or pumping, as well as wind-assisted hybrid fuel-fired "minigrid" systems.
- **Off-grid with batteries** is the most common off-grid configuration, with the batteries receiving charge from wind, PV, hydro, or a generator.
- **On-grid with batteries** allows grid interconnection and "selling" of surplus electricity for credit or cash, plus utility outage protection through battery storage.
- **On-grid without batteries** does not give outage protection, but is perhaps the most-efficient way to use wind electricity. Interconnection with the grid may be via an inverter or via an induction generator. Energy not used at any given moment is sent back to the grid under a net-metering or intertie agreement.

This Pika Energy turbine is a classic three-bladed, tail-yawing, upwind turbine.

Courtesy Pika Energy

Alternator & Controls

Most small wind turbines use permanent-magnet (PM) alternators to produce an AC output that varies with rotational speed. Very powerful magnets are used, and sophisticated power electronics are needed to deal with the wild AC that they produce. Compared with conventional generators that need to feed current to rotating coils to create a magnetic field, the efficiency is higher, and there are fewer moving parts to fail.

The "wild AC" from a PM alternator is rectified into DC. Turbine voltage and speed are determined by what it is connected to. The simplest electrical configuration is to hook this DC output directly to a battery. The battery acts like an anchor to the rising voltage by drawing current that matches what the wind has to offer. Unlike PV modules, which can be safely disconnected when the battery has had sufficient charge, a wind turbine must be kept connected to a load all the time or it will overspeed and produce excessive voltage. Surplus energy must be diverted into a suitable heater (also known as a diversion load or dump load). A diversion controller must be used to regulate the battery's voltage. However, this is not a fail-safe strategy—the *National Electrical Code* requires a "second independent means" of diversion as a backup to keep the battery from overcharging.

Some small wind turbines can be connected to the grid without batteries. A batteryless grid-tied inverter converts DC from the turbine's rectifier to standard AC power—and this can be fed back into the grid. In the past, the power was generated by induction motors "backfeeding" power, but this restricted the blades to a fixed rpm. Modern PV inverters have opened the door to using DC rectified from the wild AC from turbines instead, but at several hundred volts DC rather than at battery voltage. The higher voltage means considerable cost savings on long wire runs. Just as with maximum power point tracking (MPPT) of PV arrays, it's advantageous to tweak a wind turbine's operating voltage to optimize blade speeds for different wind speeds. The MPPT algorithm in a batteryless grid-tied PV inverter will not work to optimize a wind turbine, because the wind changes too rapidly, and the turbine also has inertia. So inverter software has to be modified to produce a "wind inverter" that's programmed with a "curve" that tells it the best DC operating voltage for that turbine at any particular level of power output.

A wind inverter also needs to be protected against overvoltage from the wind turbine. When running unloaded, the "open-circuit" voltage rises much higher than in a PV system. Overvoltage protection devices from inverter suppliers or from wind turbine manufacturers are essentially diversion-load controllers that dump excess wind energy into resistance heaters when the grid-tied inverter cannot use it, such as during a utility outage.

Turbine Manufacturers

Bergey Wind Power • bergey.com

Dakota Turbines • dakotaturbines.com

Eocycle • eocycle.com

Ghrepower • ghrepower.com

Kestrel • kestrelwind.co.za

Kingspan Environmental • kingspanenviro.com

Lely Aircon • lelyaircon.com

Northern Power Systems • northernpower.com

Osiris Energy • osirisenergy.com

Pika Energy • pika-energy.com

Primus Wind Power • primuswindpower.com

Renewtech • renewtechllc.com

Sonkyo Energy • usa.windspot.es

Sumec • en.sumec.com

Weaver Wind Energy • weaverwindenergy.com

Xzeres Wind • xzeres.com

Certifying Bodies

Small Wind Certification Council • smallwindcertification.org

Interstate Turbine Advisory Council • bit.ly/ItacList

Intertek Wind Certification Program • intertek.com/wind/directory/tested-certified-sumec-wind-turbines/

Even stand-alone battery systems (with no grid connection) can benefit from using higher-voltage turbines and MPPT controllers adapted for wind-electric systems. Another popular configuration for larger systems is to use AC-coupling. This means using a grid-tied wind inverter to connect your turbine to the AC service panel (which is also connected to a battery-based inverter). If the turbine produces more energy than is required by the loads, the battery inverter can use the surplus to charge the battery.

Total System

While the wind turbine is the primary component, a wind turbine without the rest of the system cannot generate any electricity. A complete home-scale wind-electric system includes these components:

- Wind turbine
- Tower, with turbine adaptor, foundation(s), and (possibly) guy wires
- Wire runs (down tower, and from tower to power center)
- Electronics associated specifically with the turbine model
- Charge controller (for battery-based systems) and, possibly, a diversion load
- Batteries (for battery-based systems)
- Inverter
- Metering and monitoring
- Utility interconnection equipment (for grid-tied systems)

Find out up front what it takes to make a complete system before becoming entranced with a specific wind turbine and its price. If possible, buy your complete system from one supplier. Buying from a single experienced supplier has an advantage—if or when you have issues with the system's design, installation, or use, there's one company to turn to for help.

There are many wind turbines on the market—make sure they are well-matched for the intended job. In addition, be mindful about getting all of the components necessary for a functional system—and make sure they will work well together. It is too common in our industry to hear of people getting a "bargain" on a wind turbine, only to find out that it does not have all the components needed for a working system, and that functional and *Code*-compliant parts are hard to find.

Wind Turbine Specs & Choices

This article does not make recommendations of specific turbines or manufacturers, though you can see a list of manufacturer websites in the sidebar. When you are looking at wind turbines, there are some key specifications that you should understand and scrutinize. If you don't find this information readily available, *ask* until you get it or remove it from your consideration list.

The manufacturer's website is a good first source of information. Read through the content thoroughly, including the fine print. Independent opinions are also important, so check out third-party test reports and customer experiences that may have been shared online. It's important to know what problems previous customers may have had, and equally important to learn how the manufacturers responded to these issues.

Courtesy Kingspan Environmental

The Kingspan Environmental KW6, 6 kW turbine is a downwind turbine. Speed control is provided by a unique pitch-control system that relies on a string and two hinges at the blade root.

Find out how many years the company has been in business. This may tell you about the reliability of the machines and the company behind them, as well as capability of keeping wind turbines and a business support structure alive.

Determine how long a specific model has been in production, which may indicate the machine's level of development and its reliability.

Warranty is an important factor in choosing a machine because it protects you in the case of failure due to design and workmanship, and because it may indicate the manufacturer's confidence in the machine. Read the fine print to be clear on what is and is not covered. Usually parts are covered, but not repair or replacement labor.

Rotor swept area is the collection size of a wind generator—the basis of the quantity of energy it can capture. No other turbine specification has more to do with a wind generator's production—not its rated output, weight, alternator design, or number of blades.

Rotor diameter is another way to indicate the swept area, but it's deceptive because area is proportional to the square of the *radius* (which is half of the diameter).

Tower-top weight may provide you with some indication of a machine's robustness, since heavier machines may be more durable. The weight may also be important to know for choosing a tower.

Certification lends credibility to a turbine, showing that it has gone through a standardized testing process that documented the performance or ability to survive sustained high winds. Without the discipline of independent testing, manufacturers are prone to inflate predictions of energy output. Some manufacturers choose to avoid the expense and time of certification, and certification is not a direct measure of longevity in the field, which is more important than peak performance, and even energy output estimates.

The following organizations have been qualified by the Small Wind Certification Council: High Plains Small Wind Test Center; National Renewable Energy Laboratory; UL/WTAMU Advanced Wind Turbine Test Facility; Windward Engineering; and The Wind Energy Institute of Canada.

Rated power at 11 meters per second (m/s, 25 mph) is a standardized power rating that may be handy for comparison, but is not particularly useful beyond that, and can be deceptive.

Rated AEO (annual energy output) at 5 m/s (11 mph) average wind speed is a standardized energy rating, and can be cautiously used to compare turbines—but won't relate to your site unless you also happen to have a 5 m/s average wind speed.

Estimated AEO at 8 through 14 mph average wind speed is predicted energy production at wind speeds most common at residential sites. (Wind speeds of 14 mph and above are rare.) These are important specs because they relate to your specific site. Find out where these numbers come from for any machine you are looking at, and try to confirm them via multiple sources. The only energy production numbers worth dwelling on are the predicted energy for your site's average wind speed. This specification also demonstrates the need for good average wind-speed measurement or calculations for your site.

Rpm at rated power identifies the turbine's rotational speed and is a useful comparative number between machines of about the same rotor diameter. In general, lower rpm turbines are longer-lived, with less wear and tear and lower noise levels.

Governing system specifies the method of controlling overspeed, a crucial design factor for all turbines. High winds pack a punch that needs to be avoided—not absorbed. Without a reliable governing system, your turbine will sooner or later break—with it, it will continue to make energy during and after high-wind events.

Wind Reality Check

How do we compare the value of wind turbines on the market? Should we look at the power output relative to cost? It's easy to arrive at a figure for watts per dollar, but this is very wrong. You are not buying power (watts), but energy (kWh). How can you tell how many kWh of energy the turbine will produce each year? This will depend on the wind turbine's size and on the average wind speed at your site. Estimate how many years a turbine will last, as this will affect the total kWh that you may get for your investment.

Manufacturers sometimes publish estimates of annual energy output (AEO) for their turbines under given conditions (mean wind speed), but treat these figures with caution unless they have been verified by an independent testing agency or reliable user experience. Sometimes they have been derived from testing in a wind tunnel (which can give very misleading results) or they are simply estimated, based on an overly optimistic approach to the evidence.

Realistic Annual Energy Output (kWh)

Avg. Wind Speed (mph)	Swept Area, in Diameter (Ft.)			
	8	10	15	20
8	541	845	1,901	3,379
10	1,056	1,650	3,713	6,600
12	1,825	2,851	6,415	11,405


Courtesy Bergey Wind Power

Wind power may seem like an easy solution, but adopters need to be ready for the logistics, infrastructure, and costs of both installation and maintenance.

Governing wind speed is the speed at which a machine is fully governed—protected from high winds and the overspeed conditions they can cause. A low governing wind speed is more likely to indicate a long-lasting machine. The "lost" energy of not capturing high winds is minor because high winds are a very small fraction of the wind energy distribution curve.

Cost typically includes turbine and controls, but look carefully at exactly what is included in each package—and what else you will need to make a complete system (review the "Total System" list).

web extras

"2015 Wind Turbine Buyer's Guide" by Ian Woofenden & Roy Butler in *HP167* • **homepower.com/167.50**

"Ask the Experts: Measuring Wind Energy Potential with an Anemometer" by Brent Summerville in *HP175* • **homepower.com/175.26**

"Wind Energy Physics" by David Laino in *HP161* • **homepower.com/161.70**

"How a Wind Turbine Works" by Ian Woofenden in *HP148* • **homepower.com/148.46**

"Back Page Basics: Understanding Wind Speed" by Ian Woofenden in *HP173* • **homepower.com/173.68**

"Wind Power Curves" by Ian Woofenden in *HP127* • **homepower.com/127.92**

Make a Sensible Purchase

Those with solid experience in the wind business look at "new" inventions that constantly reappear in the media and on the Internet, and shake their heads. Wind is a diffuse and elusive source of energy that can work well in very specific conditions. Most notably, you need winds that are strong and steady. To find them, you will have to put your turbine well above any obstacles in an open landscape.

Be realistic about size (see the "Wind Reality Check" sidebar). Choose a reliable, efficient design. This usually means a three-bladed horizontal-axis turbine—after a hundred years of trial and error, this design has been the most successful. New inventions that claim to work where there is very little wind are simply toys. If you expect them to defy the laws of physics and produce useful amounts of energy, get ready for disappointment.

Small wind turbines have many handicaps in comparison to the huge ones that are becoming commonplace. They do not have access to the strong, steady winds that are available up high where utility-scale machines run. Unlike PV systems, which can be scaled, wind turbines have an economy of scale. What small wind turbines do have in their favor is that they produce energy locally—at the site—and are useful on a residential scale. They also produce energy that complements solar-electric systems. It's unlikely that they will provide competitively priced electricity other than in an off-grid situation. But for those of us who take pleasure in producing our own energy, they can be very satisfying.

AN OFF-GRID EDUCATION

by Ian Woofenden, with Sally & Jerry Bowker

All photos courtesy Sally & Jerry Bowker

In 2009, when Sally and Jerry Bowker retired to their property in Bayfield County, Wisconsin, living off-grid was not new to them. In the 1970s and early '80s, they lived without electricity on a 100-acre homestead in western Wisconsin. Although they'd subsequently lived in a conventionally powered home, upon retiring, they wanted to build an off-grid home in the woods of northern Wisconsin. In 2004, they found 10 wooded acres near the south shore of Lake Superior. In 2007, they built a small studio there, along with a small PV system, and made plans to build an off-grid home.

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Most of Bayfield County is public forestlands, and these extensive natural areas are great for recreation. Jerry and Sally help maintain the Apostle Islands National Lakeshore mainland trail that runs close to their homestead. Many people living in the area understand that they are an element of nature that needs to find its harmonious path within the larger natural system. This cultural mindset, as well as the area's natural beauty, was the couple's primary attraction to the region.

Sally is an art photographer, focusing on nature. Jerry also has an art background, and enjoys applying his aesthetic sense to the areas around their homestead. Ecologist Aldo Leopold was an early inspiration for merging the natural world with his intellectual life as an environmental philosopher and professor at the University of Wisconsin.

Using local materials can reduce a home's embodied energy. Wood flooring was locally sourced, and even the plywood for sheathing and subflooring came from mills only a couple of hours away.

Thoughtful Design

Sally took on the home's design, working with designer-architect Kristine Recker and studying Christopher Alexander's *A Pattern Language*, which was based on the idea that "people should design for themselves their own houses..."

The house fits the couple's specific pattern of living, with the kitchen and the wood heater in the center of the house. The main rooms are multiuse and sized to accommodate 95% of their everyday activities. For example, the sunroom also serves as a library and guest bedroom, with bookshelves on three sides and a sofa bed. It also is an art studio, with a loom and weaving supplies. Its deep windowsills are used for growing flats of seedlings in the spring. The center room is a gathering space, with chairs by the wood heater, pet beds, and a table for dining or projects. Here, a window seat holds bedding for the guest bed. Their home office, with desk and files and computer, is also here. The computer and a photo printer form a studio for photography work in this space. The PV balance-of-system equipment, along with a freezer, a washer-dryer, utility sink, and toilet occupy the utility room. The entry to the crawl space is here as well. The crawl space holds the water pressure tank, the PV system's batteries, home canning storage, and is used as a root cellar for garden crops.

The 1,200 square-foot home's longer axis was oriented to take advantage of winter solar gain, with well-sized windows to the south and west admitting solar gain and reducing the home's reliance on wood heat. Adequate overhangs shade the windows in summer. The home's builder, Jim Steffenson of Steffenson Carpentry, had built his own passive solar, off-grid home. Jim and solar-electric installer Kurt Nelson of SOLutions in Cornucopia, Wisconsin, coordinated plans for reducing the building's ecological and energy footprint, and incorporating the solar electrical requirements during the home's construction.

To provide ample insulation for the northern home, the walls are double-stud construction. The 9.5-inch-thick walls were filled with blown-in cellulose insulation, resulting in an R-value of about 33.

The wood heater is fueled only until late morning, when the sun-tempered house then starts gaining heat from the winter sun through the southern windows.

System Evolution

Although only a mile from the closest utility line, it would have cost about $12,000 to bring in utility electricity that is largely (60%) coal-fueled. Both Jerry and Sally felt using solar electricity was far more environmentally responsible, but neither of them was really interested in the technical aspects of designing or installing a system. In 2007, Kurt designed a 440 W PV system—four 110 W modules and four 370 Ah flooded batteries—to provide energy for constructing the studio. A 10- by 10-foot gambrel-roof utility shed housed the balance-of-system equipment and batteries, with the PV modules mounted on the lower portion of its roof. This small system provided their first practical experience of using solar electricity and, along with a generator, some of the electricity needed for the home's construction.

In 2009, when construction of the house began, a pole-mounted array was installed, with six new 110 W modules added to the original four. The battery bank grew to eight 370 Ah L-16s. In 2014, two 310 W modules were added (and two 110 W modules removed, see "Adding PV" sidebar). Most recently in 2016, two more 310 W PV modules were added—the winters are increasingly cloudy and generator use had been growing. This brought the total array capacity to 2.12 kW.

Located near the south shore of Lake Superior, the late fall and early winter months are often cloudy and windy. A nearby off-grid household is both solar- and wind-powered—the two renewable energy sources mesh well, providing consistent energy. However, the Bowkers had already invested as much money as they felt they could on an electrical system.

The array was sited in a south-sloping meadow that is also Jerry's garden. There was discussion about how many of the surrounding trees needed to be thinned, especially some spruce and firs at the southern end of the meadow. However, Jerry and Sally refused to cut them, though they knew that keeping them would affect the array's production to some extent. Trees are very important to the couple, and marginally reduced array output is a trade-off they are comfortable with.

Though traditional country style, the home's design takes advantage of some passive solar heating.

A Danby refrigerator (no freezer) joins a host of energy-efficient appliances.

The studio has its own electrical distribution panel, and the utility room in the house has another electric panel, plus the inverter, and other PV balance-of-system components, where the system metering can be easily viewed. The batteries are located in the insulated crawl space under the house, where they are buffered from temperature extremes. The batteries are vented to the outdoors via a schedule 40 PVC with a Zephyr power vent driven and controlled by the OutBack MX-60 charge controller. Wheeled stools make it easy to get around that space and check on battery water, connections, and cleanliness. The generator is located in a woodshed, about 50 feet from the house, which keeps the noise at a distance, but line losses from the wire run acceptable.

Adding to an Off-Grid System

Located in northern Wisconsin, the Bowkers' property averages about 4.5 peak sun-hours a day. This average, however, actually translates into about 6 hours per day during the prime summer months, and as little as 2 hours per day during the winter months. Most off-grid PV systems are sized a little larger than what the average peak sun-hours would dictate, but somewhat less than what the low winter months might demand. Thus, a backup power source (typically, a fossil-fuel generator) is used.

Using a generator occasionally to supplement PV production will increase the life of the system's battery. However, if you are running your generator more than several hours a week during periods of low solar production (for example, winter in Wisconsin), you may want to add capacity to your PV array. If you're running a generator at all to top off batteries during the longer days of summer, you should definitely consider a bigger array.

Adding PV modules to meet demands during low production periods will likely result in overproduction during the sunnier seasons. While this is not a problem from a system perspective, it's a good idea to find ways to use this extra energy. During periods of ample sunshine, excess energy can be automatically diverted to heating domestic water. Other diversion loads may also fit your needs, but loads like space heating and lighting are usually poor choices since they are typically used more during non-sunny periods. And while excess summer sun might power a high-efficiency window air conditioner, operating it at night will quickly consume stored energy. Properly designed automation of diversion loads may make full use of excess production without user involvement, while helping eliminate any chance of "operator error" (i.e., battery abuse).

Adding to an existing PV array may be easier and less costly than you might think. For example, the existing wiring and charge controller might accommodate a larger array by increasing array voltage rather than array amperage (adding more modules in series rather than in parallel).

Almost all modern charge controllers with maximum power point tracking (MPPT) will accept an array voltage that's higher than the battery bank's voltage. If your system doesn't yet incorporate such an MPPT charge controller, upgrading to one will itself increase production during those cold winter months by better matching array output to battery voltage.

More daily energy coming in means fewer deep battery discharges. A larger PV array relative to battery size will almost always translate into a healthier and longer-lived battery, in addition to reduced generator run-time.

How the Bowkers Grew Their System

The Bowkers' original system was four Mitsubishi 110 W modules for 440 W DC and a 220 Ah, 24 V battery bank. The inverter was sized to power the tools used to build Sally's studio, but it and the charge controller were also sized to serve their future, energy-efficient home.

The initial four modules were attached to the existing shed that temporarily housed the balance-of-system components. Since the PV wire length to the controller was negligible, the array was wired at 24 V nominal—two parallel strings, with each string composed of two, 36-cell modules in series.

When the Bowkers finished Sally's studio and began phase two of their plans—building their off-grid home—the array size was increased and relocated to a top-of-pole mount. This array—a total of 10 Mitsubishi modules, for 1.1 kW DC—was wired to the more-distant house as two parallel strings, each with five modules in series. This is the maximum number of these modules that can be used in series to avoid exceeding the OutBack MX-60 charge controller's 150 V maximum rating. During cold periods, the array could reach an open-circuit voltage (Voc) of 130 VDC, and having a sixth module in the string would have pushed the Voc over the 150 V max.

With the space to handle 15, 110 W modules, the rack was sized with expansion in mind. Eventually, the need to increase the array size became apparent due to excessive generator run-time during marginal solar periods. By then, the Mitsubishi 110 W, 36-cell modules were no longer available. Instead, two 72-cell Canadian Solar 310 W modules were chosen. The array was reconfigured into two strings of four Mitsubishi modules and a new string of two Canadian Solar modules. (One of the original modules had failed, and the ninth original module was pulled from the array and retained as a spare). Each parallel string of PV modules in the Bowkers' array contains 144 cells in series, making the maximum power point voltage (Vmp) of all series strings similar.

In late 2016, the 1.5 kW array received another string of two 310 W, 72-cell modules, for a total of 2,120 W, further reducing the Bowkers' generator reliance. The lower cost and high value of today's PV modules makes such PV array additions affordable. The idea was to be able to expand an existing system without much tinkering with the balance-of-system equipment. The same home-run wiring to the house and the same charge controller were used as additional PV modules were installed. However, the combiner box was upgraded to a MidNite Solar MNPV6, which has more circuits.

—Kurt Nelson

The PV array grew incrementally. Here, Jerry gardens beneath the pole mount prior to the most recent addition of modules.

Maintenance & Operation

The Bowkers have learned to maintain and troubleshoot their system, which makes it easier on Kurt, the solar electrician. "I do routine maintenance for the batteries, array, and generator," says Jerry. "Once a month, I check the batteries' electrolyte levels. Usually they don't need a distilled water top-off, but when we're using the generator a lot, I check them more than once a month. We live in the snow belt, and when there is any snow cover on the arrays in the morning, I sweep them off—unless it is still snowing. The generator gets normal engine maintenance of regular oil changes. We adjust the array's tilt angle seasonally, around the equinoxes."

The home's appliances are propane and electric, and include a Whirlpool Duet washer and propane-heated dryer. A kitchen range, a Bosch on-demand water heater, and an Empire wall heater also run on propane. With the most recent expansion of the PV array, they also added a diversion load of a tempering tank preheating their water to the on-demand heater.

The refrigerator is a Danby electric model, without a freezer compartment. A high-efficiency SunDanzer DC freezer lives in the utility room. The Bowkers do not have a dishwasher or a microwave, but use a coffee maker, hair dryer, TV, laptop computer, printer, DC ceiling fans, and lots of electrical tools, such as table saws, drills, and sanders for house projects.

Wood is the primary heat source, with a centrally located wood heater. A propane wall heater provides backup when the house is unoccupied (and because homeowners' insurance required it). Access to trees and Jerry's love of making firewood allows him to "pay the heating bill" and maintain their woods at the same time.

The PV system's modest size and seasonal sunshine mean that Sally and Jerry have to be acutely aware of their electricity consumption. "We check our battery state of charge several times a day, and don't let it get below 70% before using the generator to recharge. We also check the weather reports to see when sunshine is forecast. Being aware of the system becomes an interesting part of our day," says Sally.

A propane wall heater provides backup heating when solar gain is minimal and the wood heater is not in operation.

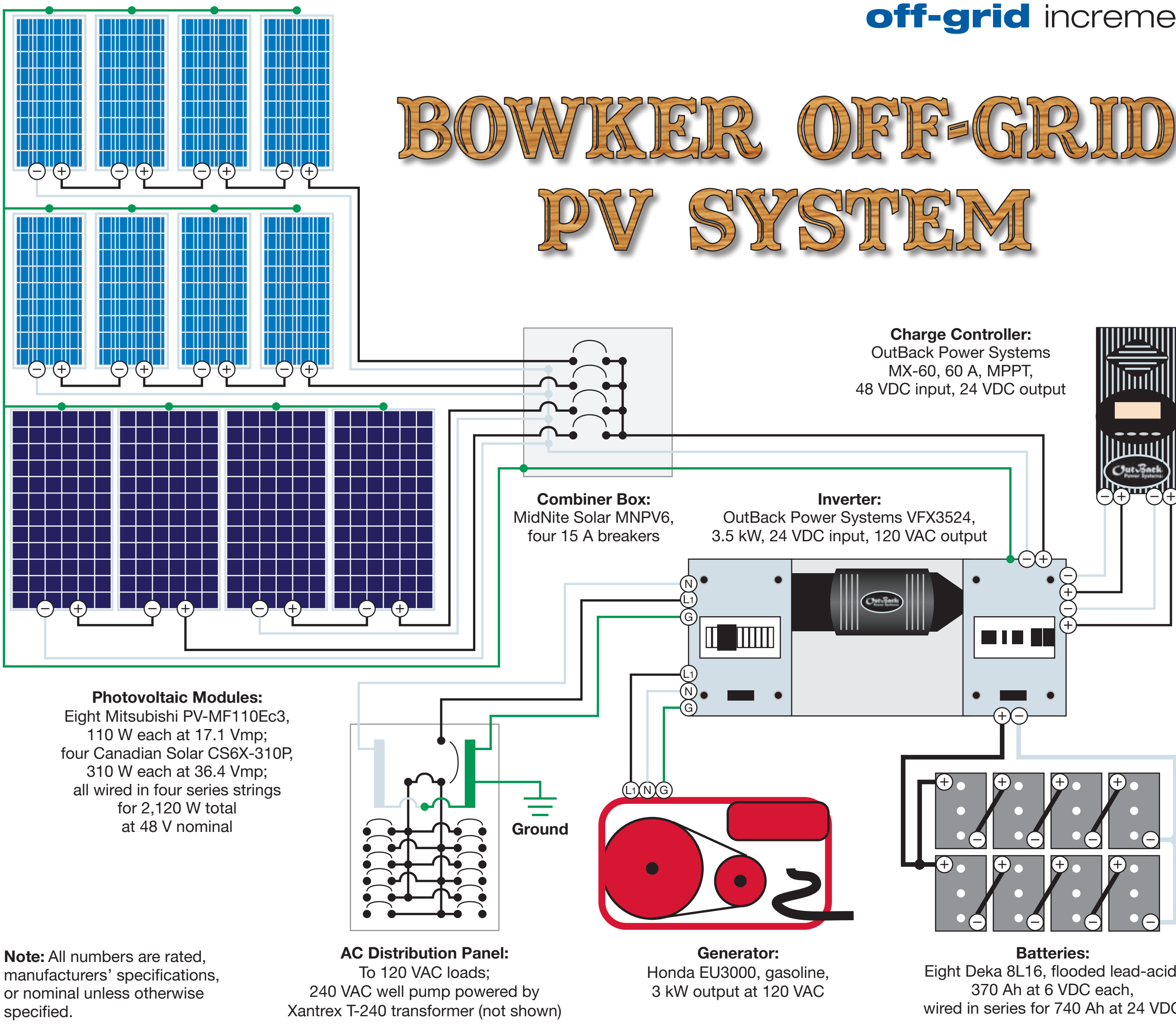
If company is coming after dark, the porch lights go on about two minutes before they're expected and then are off until the guests are leaving. Laundry and vacuuming are sunny-day activities. Like many off-gridders, when the sun shines, the couple finds ways to use the energy. "If I feel I must do a load of laundry or vacuum on a cloudy day and the batteries are quite high (above 85%), I will sneak in a load or do a quick vacuum run over the rug. It feels like that—sneaking. But we are very pleased with our system, and with how matter-of-factly it works for us."

A SunDanzer DC freezer in the utility room provides efficient food storage.

A Whirlpool Duet horizontal-axis washer and propane-fired dryer make efficient work of laundry with less load on the batteries.

A Bosch propane on-demand water heater serves the home.

BOWKER OFF-GRID PV SYSTEM



Tech Specs

Overview

Project name: Bowker residence

System type: Off-grid solar-electric

Installer: SOLutions

Date commissioned: 2007, 2009, 2014, and 2016

Location: Bayfield County, Wisconsin

Latitude: 46.9°N

Solar resource: 4.5 average daily peak sun-hours

ASHRAE lowest expect ambient temperature: -11.2°F

Average high summer temperature: 77°F

Average monthly production: 180 AC kWh (estimated)

Photovoltaic System

Modules: 8 Mitsubishi PV-MF110Ec3 modules, 110 W STC, 17.1 Vmp, 6.43 Imp, 21.2 Voc, 7.16 Isc; and 4 Canadian Solar CS6X-310P modules, 310 W STC, 36.4 Vmp, 8.52 Imp, 44.9 Voc, 9.08 Isc

Array: Four series strings: two 4-module series strings and two 2-module strings, 2,120 W STC total

Array combiner box: MidNite Solar MNPV6 with 15 A breakers

Array disconnect: OutBack 40 A breaker

Array installation: Direct Power & Water top-of-pole mount; tilt adjusted seasonally

Energy Storage

Batteries: 8 Deka 8L-16, 6 VDC nominal, 370 Ah at 20-hour rate, flooded lead-acid

Battery bank: 24 VDC nominal, 740 Ah total

Battery/inverter disconnect: 250 A breaker

Balance of System

Charge controller: OutBack Power MX60, 60 A, MPPT, 48 VDC nominal input voltage, 24 VDC nominal output voltage

Inverter: OutBack Power VFX3524, 24 VDC nominal input, 120 VAC output

System performance metering: Bogart TriMetric

Left: The OutBack VFX3524 inverter and balance-of-system components.

Right: The eight Deka L-16s provide 740 Ah at 24 VDC.

Lessons

Sally and Jerry love having renewable electricity, and believe that RE needs to become the common form of household energy. “We’re still amazed that it comes directly from the sun right above our house,” says Sally.

Their system has been reliable, but their installer Kurt checks in with them periodically. Sometimes their feedback means something more to him. Then he comes and adjusts, or makes recommendations. “Our experience in off-grid living,” says Jerry, “has made us feel strongly that off-grid solar is a viable option for non-technical people, if they have assistance available.”

System designer Kurt Nelson (left) with Sally and Jerry under the array.

Installing EMT

Tips, Tricks & Techniques

Story & photos by Sean Chastain

Just thinking about working with electrical metallic tubing (EMT) conduit can bring a shudder from a seasoned installer. It's a steel tube that must be accurately bent to fit equipment, carefully routed to avoid obstacles, and, maybe worst of all, requires math to do so. The good news is, with a little guidance, you can make your EMT experience better. Knowing how to install EMT can set your work apart from others. EMT will not only make your installation look clean and professional, but it can cut down on material cost and installation time.

Advantages of EMT

EMT conduit is a popular choice among electricians—it is lightweight, durable, inexpensive, and can be bent to fit almost any application. Correctly installed EMT provides evenly rounded sweeps and straight lines that produce a tidy appearance. For PV array wiring on a building, EMT provides the required metal raceway for source or output circuits and can be used outdoors with the appropriate fittings.

Assessing Your Conduit Run

Before you begin a conduit run, examine your working space and develop a plan. Consider where the start and end points are and the easiest way to get there, while keeping aesthetics in mind. Skirting around obstacles may require implementing a special bend. Once you determine the best route, it's time to execute.

Know Your Bender

A quality conduit bender is essential for performing electrical work. Like any tool, you must be familiar with what it is capable of.

1) Toe: The toe is the front of the bender, the end with the arrow.

2) Arrow: Used to make standard 90° bends, offsets, and the return bends of a saddle.

3) Rim notches: Used to make saddle bends of varying degrees.

4) Star: Used to make 90° back bends.

5) Angle marks: Denotes the bend angle of the conduit.

6) Heel: The back of the bender where foot pressure is placed.

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web extras

For the basics of conduit types, planning, and routing, see Sean Chastain's article, "Clean Conduit Installation" at **homepower.com/176.52**

On-the-ground 90° radius bends are the easiest to make. Line up the arrow on your mark (subtracting appropriate take-up); apply firm pressure with your foot on the bender's heel; pull the handle with smooth, even pressure; use the sight mark for the final angle, taking care not to overbend.

Bending Methods

On the ground. Most bends will be with the conduit lying on the ground and the bender handle pointing up. This allows the rotation of the bender to do the majority of the work, with steady foot pressure and slight downward force on the handle.

In the air. Some bends are best made in the air, with the handle of the bender planted on the ground. The conduit is pulled down near the body until the desired angle is reached. In-the-air bending is used mostly when additional bends in the conduit, such as offsets or smaller bends, are necessary. Being able to inspect the conduit from above allows the installer to easily see angle marks for more accurate bends and, in the case of an offset, ensure the second bend is in line with the first.

For easier and cleaner-looking installations, plan box placement to accommodate straight conduit runs and adequate space for EMT bends.

EMT Toolbox

To make accurate, consistent bends, a few tools can help you do the job right.

- A bender appropriate for the size conduit you are using
- A tape measure
- A small magnetic level or conduit level
- Safety glasses
- Well-fitting gloves
- A cutting tool such as a steel pipe cutter, hacksaw, reciprocating saw, or band saw
- Slip-joint pliers, to tighten fittings
- A reaming tool to clean burrs from a cut edge
- A marking tool, such as a highlighter, pencil, crayon, chalk, or dry-erase marker

In-the-air bends allow sighting conduit along the bender handle, which helps to align multiple bends on the same plane without doglegs.

Common Bends

Although there are dozens of bends that can be made in EMT, the most common are 90°, offsets, and saddles. Nearly all others can be made using some variation of these bends.

90° Bends

The most common bend, and possibly the easiest, is a 90° bend. While easy, there are some things to understand to make it easier. This is where your math lesson begins—with simple subtraction.

Before making any bend, you must understand its "take-up," also known as the deduct. When the end route of your conduit is determined, the take-up must be subtracted before marking your conduit to give you a reference point for the bend. The take-up is determined by the bender radius. As the conduit is bent, the mark made is pulled up and around the bender, essentially decreasing the horizontal length from the measured end. This can easily be accounted for by the take-up, where the radius of the bender makes the measurement an even number and bends your conduit without kinking.

For example, say you want to make a 90° bend in 3/4-inch EMT. To clear a box on the wall, the bend must be made so, after the bend, your conduit is 36 inches below the starting point. The take-up for a 90° bend in 3/4-inch EMT is 6 inches. If the bottom of your bend needs to be 36 inches below the fitting, you must place the arrow/line of the bender on the 30-inch mark. The resulting bend will be exactly 36 inches down, clearing the obstacle on the wall.

Once the distance is measured and take-up accounted for, place the arrow of the bender on your mark, with the toe of the bender facing the measured end. Apply firm foot pressure. The conduit will begin to move up, at which time you can begin placing some pressure on the handle. Remember that the majority of pressure should come from your foot. When it appears the conduit is near 90°, relieve pressure and check the angle with your level. It may be necessary to add a little more pressure to the bend to get it just right. Go slow, and check often—it is easier to bend little by little than to correct an overbend! When bending a 90°, do not allow the heel to touch the conduit. If it does, the bend will be greater than 90° and must be corrected.

Ninety-degree backbend. If bending conduit near the end of the EMT stick, there may not be enough conduit in contact with the ground to allow a proper bend. In this case, turn the bender around so the heel faces your measured end—this allows you to accomplish the 90° bend via a "backbend." Measure the distance you want your bend to be but, in this case, do not subtract the take-up distance. Place the "star" of the bender on your mark, which will give you the correct bend.

Take-Up for a 90° Conduit Bend

Conduit Size with Standard Bender	Take-Up
1/2 in.	5 in.
3/4 in.	6 in.
1 in.	8 in.

Ninety-degree sweeps near the end of the conduit need to be created as backbends. These two examples also have extra offset bends.

When EMT Isn't the Best Choice

Although versatile, sometimes EMT may not be the best choice of raceway. Here are some situations in which it might be better to consider another type of conduit:

- If several turns or tight turns must be made that exceed the bending radius of the EMT size.
- If conduit needs to be installed in a location where physical damage is likely—such as in an auto repair facility, at a truck stop, near heavy moving equipment, or in a storage unit—consider using rigid metal conduit (RMC) to protect wires.
- When burying conduit or in extremely wet areas, PVC is a better choice, as it is more resistant to moisture.
- If the installation is on a structure with dissimilar metals, such as bronze, copper, brass, martensitic steel, or austenitic steel, galvanic action becomes an issue when in contact with EMT.

Offset Bends

An offset bend is used to continue the same general path of conduit, but shifts the conduit to avoid obstacles. Essentially, it is two bends—one bend to change the angle of the conduit and another bend at the same angle, but in the opposite direction, to bring your conduit parallel to the original direction of travel.

Offset bends are made using a multiplier, which gives the correct distance between the two bends in the offset so the conduit arrives at the correct level. The most common bend is 30°, simply because the multiplier is an even 2—and easy math is the best math.

If you are working with EMT frequently, consider memorizing common multipliers for 10°, 22.5°, 30°, 45°, and 60° offset bends. Many benders have the offset multipliers stamped on the bender opposite of the common angles, but knowing these numbers when laying out conduit can make the process faster.

Measure the desired distance of your offset. This distance will be from the center of the current conduit to the center of the desired conduit route. If the EMT must raise 8 inches to avoid an obstacle, multiply 8 by the desired multiplier. For a simple example, we will make 30° bends, thus using a multiplier of 2. This means the distance between the first bend and second bend is 16 inches. After the conduit is bent, the resulting distance is 8 inches of lateral offset. A 60° bend would require a multiplier of 1.2, giving a distance between bends of 9.6 inches.

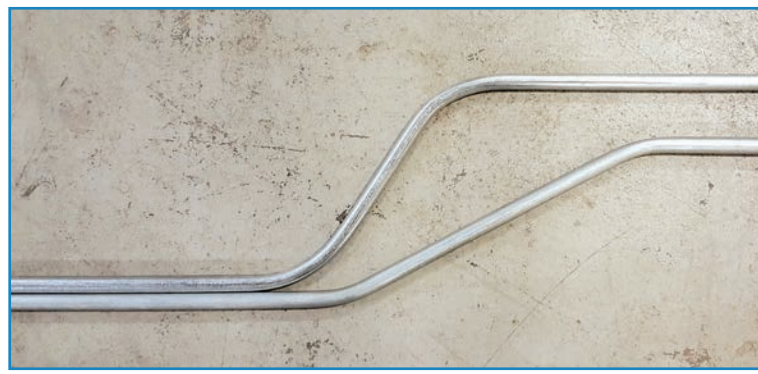
A low-angle bend requires further distance to give you the correct offset, while a high angle and sharper turn makes the correct offset closer. However, reducing the angles and number of bends can keep your 360° rule in check and make wire pulling easier. A good rule is big angles for large offsets, small angles for small offsets.

Bending an offset is typically done by making the first bend on the ground and the second in the air. Using the example above, we will make an 8-inch offset at 30°. Our first bend will be made 36 inches from a coupler. Using the 30° multiplier, we found the offset distance to be 16 inches from bend to bend. Make a mark at 36 inches for the first bend, and then measure 16 inches from that for the second bend (52 inches from the measured end). With the arrow on the 36-inch mark, we make our first 30° bend. With the conduit still in the bender, slide it forward to the next mark and perform an in-the-air bend until 30° is reached.

Multipliers for Offset Bends

Angle	Multiplier
10°	6.0
22.5°	2.6
30°	2.0
45°	1.4
60°	1.2

For this offset, the first mark is aligned with the notch and a 45° bend is completed. The bender is then slid to the second mark for the return bend.



Comparison of a 60° offset (top) and a 30° offset (bottom) shows the difference on the overall length and the effect on the 360° rule.

Offset bends are often used to bring conduit from a box knockout and make it flush with the wall plane.

360° Rule

Having too many bends not only makes pulling wire more difficult by adding friction, but increases the chance of damaging the wire. The *National Electrical Code (NEC)* requirements limit the number of bends in a conduit run to 360°. If conduit bends exceed 360°, a conduit body or junction box must be installed to provide a pull-point for wire. When bending offsets, or saddles, use a smaller angle when possible to prevent exceeding the 360° rule.

Saddle Bends

Saddle bends are used to clear an obstruction so the conduit can continue along its path. The saddle bend is commonly viewed as the most difficult bend to make, particularly because the bends are close together and a dogleg in any bend will cause the conduit to change direction.

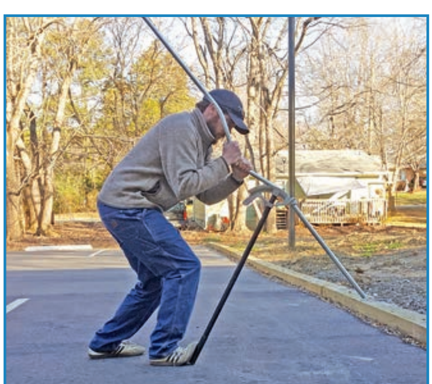
Three-point saddle bends are most common when there is a small obstruction, such as a perpendicular pipe or conduit, to clear. This is where more math comes in.

1. Measure the distance to the center of the obstacle from your starting point.
2. Measure the height of the obstacle to clear it, then factor in 1/2 to 1 inch of clearance past the obstacle.
3. Determine the angle of the center bend. Most commonly, bends are made at 45° and 60° center bends. Some benders only have a notch at 45°, which will limit your saddles to this angle. Also keep in mind that a 45° center-bend saddle equals 90° after return bends are made; 120° for a 60° saddle. The 360° rule always applies!

The mark for the center bend of a saddle bend is aligned with the saddle rim notch mark.

Return angle marks are aligned with the arrow using a backbend. The conduit's center bend should be in front of you and pointing down toward the ground (not up in the air).

The middle bend of a saddle is performed first.



The return angle bends (half the angle of the center bend) are then performed.

4. Using the "Three-Point Saddle Bends" table, determine the distance to mark your conduit.

   Measured Distance to Obstruction Center + Shrink = Center Mark

5. From your center mark, measure and mark in both directions the appropriate distance in each direction based on the table. You will now have three marks.
6. Line up the center mark with the appropriate saddle rim notch on the conduit bender and bend the conduit to that angle. Ensure the rim notch remains on the center mark and be careful to get the angle correct to keep your saddle even. Do not remove the conduit after bending.
7. Flip the bender over to prepare for an in-the-air bend. Slide the conduit back toward your body until the return angle mark is on the arrow. Line up the conduit so your

Three-Point Saddle Bends

Clearance (In.)	45° Center Bend		60° Center Bend	
	Distance to Center Point (In.)	Shrink (In.)	Distance to Center Point (in.)	Shrink (in.)
1	2.5	3/16	2.0	1/4
2	5.0	3/8	4.0	1/2
3	7.5	9/16	6.0	3/4
4	10.0	3/4	8.0	1
5	12.5	15/16	10.0	1 1/4
6	15.0	1 1/8	12.0	1 1/2

A saddle bend (here, a center 45° and two 22.5° bends) clears an obstacle, then returns to the original path.

center angle is pointing down. Once aligned, make a bend to half of the center bend angle.

8. Remove the conduit from the bender. Turn your bender 180°, toe for heel, and place the arrow on the third mark to perform another air bend. Again, with the center angle pointing down, bend the conduit to half of the center bend angle. This is a repeat of the second bend performed from the other side.
9. Lay the finished product on level ground. If the conduit lies flat without bowing up and in a straight line through the saddle, you have a finished product! Some adjustments may be done to correct minor issues; however, it is difficult to correct overbending, bowing, and doglegs.

For example, 45 inches from a coupler, a 3-inch PVC pipe runs perpendicular to your conduit. Your conduit bender only has one rim notch at 45°. Height is 4 inches to allow proper clearance of the pipe. From the table, the shrink is determined to be 3/4 inches and the distance to center 10 inches.

Measured Distance to Obstruction Center + Shrink = Center Mark

45 + 3/4 = 45 3/4 to Center Mark

Once you make the center mark, measure on each side 10 inches for return angle marks. You will have three marks on the conduit at 35 3/4, 45 3/4, and 55 3/4 inches.

Now follow the instructions from step No. 6 and make the appropriate bends.

Again—Which End?

It is important to be sure you are bending conduit in the correct direction. When bending from the arrow, you must bend the conduit so the toe of the bender points toward the end your tape measure was hooked to and take-up is used. For a backbend, the heel of the bender will face the measured end and take-up is not accounted for.

Tricks of the Trade

- Use the correct bender for the conduit size
- Use steady, even pressure to roll the conduit around the bender. No jerky motion!
- Make sure the conduit and bender are steady and stable before bending. Sliding can cause uneven bends, crooked bends, or doglegs, and possible injury.
- Conduit tends to relax when pressure is taken off the bender, so it may be necessary to bend slightly beyond the desired angle. Try bending it to the desired angle, then remove the pressure to assess the angle. If needed, you can bend slightly more to achieve the correct angle.
- A highlighter, pencil, chalk, crayon, or dry-erase marker can be used to mark the EMT and can then be wiped off after the bends are made.
- Many installers choose to make bends without measuring the precise bend locations, instead opting to leave excess conduit that can be cut to the necessary length. This is always an option and, for difficult bends in tight spaces, is recommended.
- When making bends in the air, the handle must be kept steady by bracing the end of the handle with your foot.
- Conduit must be kept close to the body when pulling it down for bends in the air.
- Don't pull on the EMT far away from the bender! This will cause the long section of the pipe to have a slight bow that is nearly impossible to correct.

Choosing the Right Fitting

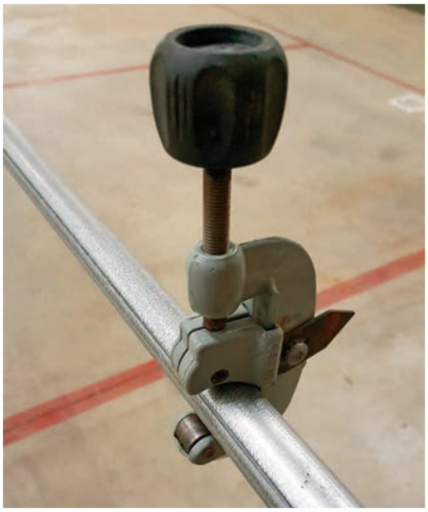
There are three common types of fittings for EMT: set screw, compression, and rain-tight compression.

Set screw. For indoor applications where moisture is not a factor, set-screw fittings are most common. EMT easily slides into the connector, then the set-screw is tightened to secure the conduit and complete a good bond to ground.

When installing set-screw fittings, ensure that the EMT is pushed completely into the fitting until it hits the lip, in the center for couplers and near the threads for connectors. The set screw should be unscrewed just enough to allow the conduit to pass through without blocking it. Once the conduit is fully seated inside the fitting, tighten the screw to manufacturer specifications.

Compression. Compression fittings are also used for conduit installed indoors. A compression fitting uses a split compression ring to secure the EMT as it is tightened onto the body of the fitting. The ring is more secure than a typical set screw and also provides ground bonding. Standard versions of these fittings are not UL-listed as rain-tight, contrary to some debate, and should not be used in outdoor locations.

Left to right: A set-screw fitting, compression fitting, and rain-tight compression fitting.



A pipe cutter is an easy and safe tool to use for creating clean cuts.

Making bends first, then marking conduit for cutting, is more fail-safe than relying on exact math.

To install a compression fitting, loosen the fitting enough to ensure the compression ring is open. Push the fitting straight onto the conduit until it reaches the lip. Often, the split compression ring may be turned inside the fitting and can block the EMT from moving all the way in. It may be necessary to loosen the fitting all the way, slide the nut and the compression ring onto the EMT, and then push it into the fitting. Once it is in, tighten the fitting with appropriately sized slip-joint pliers. Using a second pair of pliers, hold the body of the fitting while you turn the nut to ensure it is tight.

Rain-tight. For outdoor applications, rain-tight compression fittings are required. These work similarly to standard compression fittings but also include a gasket to prevent moisture from entering the conduit. Typically, rain-tight fittings are blue or green, indicating they are intended for outdoor use. Connectors come with a rubber gasket between the body and lock ring, which is used to seal the knockout from moisture. Although they are called rain-tight, these are not waterproof and the EMT is still considered a wet environment when installed outside. Wire must be chosen that is rated as such (for example, THWN).

Installing rain-tight fittings is similar to installing compression fittings. However, there are other rings inside the fitting that make installation difficult. It is best to disassemble the fitting, slide it onto the EMT, and then push the pipe into the fitting. In order, the fitting consists of the nut, the split compression ring, a thin metal separation ring, and a gasket. When tightening a connector, be sure the rubber gasket is not overtightened—otherwise, it may separate from the connector and allow water into the knockout.

While not a common fitting for typical installations, NEMA 6 fittings are available that prevent any moisture from entering the conduit and are rated for use in areas that have prolonged moisture exposure. In such cases, using another type of conduit is recommended, as constant contact with moisture can degrade EMT over time.

Cutting EMT

To make cuts in EMT, several tools are available. A conduit-specific pipe cutter is the best choice, as it cleanly cuts the EMT and rarely requires additional pipe reaming. A metal hacksaw may be used as well, although this requires a sharp blade and a little elbow grease. A reciprocating saw, which most installers own, is perhaps the most common method but also the most dangerous. When cutting with one, ensure the proper metal blade is used, the conduit is secure, and the saw is held in such a way that no one will be injured if the blade bounces or breaks through the conduit.

Once the cut is made, the pipe should be deburred so the pipe fits property into the fitting. More importantly, deburring prevents damage to wire during the wire pull. A handheld pipe reamer or a drill attachment can be used for this task.

Conduit bending is an important part of installing renewable energy systems, and doing the job right takes a little practice. Using these common bends and installation techniques can elevate a project to the next level.

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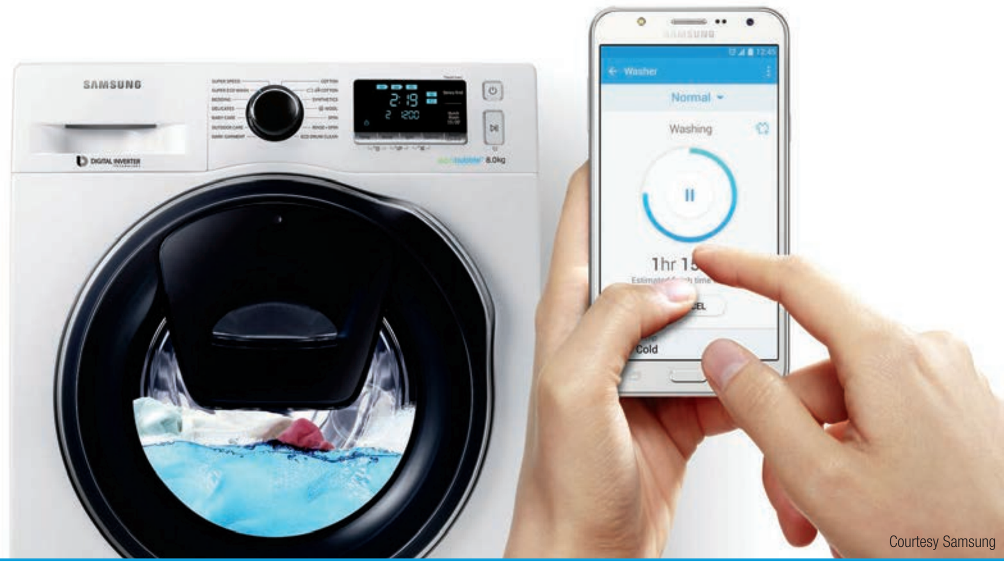
MAXIMIZING Solar Self-Consumption

Using Your PV-Generated Energy On-Site

by Carol Weis & Christopher Freitas



Courtesy Samsung

Some modern appliances can be programmed or controlled remotely to operate when there is PV-made electricity, thus increasing self-consumption.

A PV "self-consumption" (SC) system maximizes the use of solar array-produced electricity on-site and minimizes using electricity from the utility grid. Loads are managed so they run during prime solar-production hours and, optionally, the PV-generated electricity can be stored for later use.

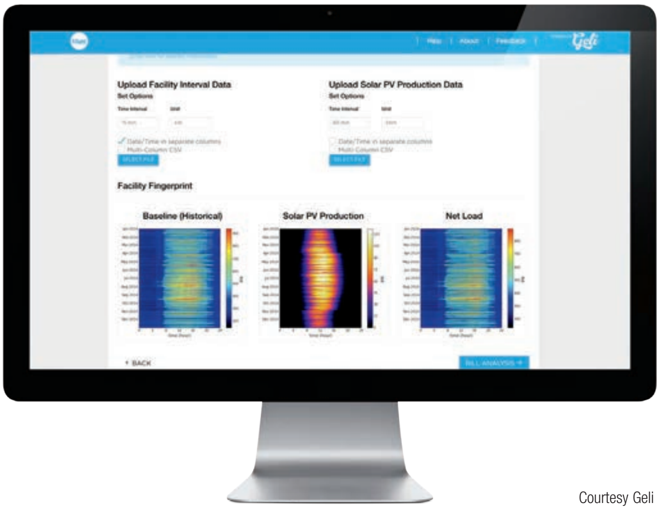
An SC PV system, however, is different from a net-metered PV system. In a net-metered system, excess PV-generated electricity is sent back onto the grid and credited, kilowatt-hour by kilowatt-hour, to the user's account at the utility's retail rate on a 1-for-1 basis. In net-metered systems, loads do not need to be coordinated with the PV system's production. In SC PV systems, as much as possible, loads are coordinated with the system's production.

In reality, any PV system that has loads on during the day when the PV modules are producing energy has some "self-consumption." In some areas, recent regional policy and regulation changes to net metering have made it more advantageous to maximize self-consumption. Some motivations include:

True solar energy use. To address climate change, home and business owners can make conscientious choices about the type of fuel powering their loads. Most utilities are producing electricity with fossil fuels that net-metered homes use when their loads exceed the PV production, and at night. If you're striving to not use fossil fuels and be truly solar-powered, then you need to implement SC PV strategies in which the PV-generated electricity is consumed directly during the day or stored on-site for later use.

Non-net-metering utilities. Some utilities have not adopted net metering or are ending their net-metering policies. Although these utilities may allow export, the PV electricity

Whole-house monitoring and management systems, like this one from Geli, can track energy production, use, storage, and patterns to maximize self-consumption.



Courtesy Geli

sent to the utility is credited at a lower wholesale rate, while the utility energy used by the consumer is charged at a higher retail rate. Increasing the SC of PV systems reduces the amount of higher-priced utility energy that is consumed.

Zero export restrictions. Some utilities have restricted exporting electricity from PV systems to the grid. If you live in such an area and if the utility rates are high, having an SC PV system can reduce the amount of utility electricity you'll need to purchase and can reduce your utility bills substantially.

SC Strategies

Here are three strategies that can be used to increase self-consumption of PV-produced energy in the order of lowest to highest cost:

Grid-direct PV with load management. For batteryless grid-tied systems located in areas where utilities allow systems to export energy, the simplest and least expensive method is to manually control when loads operate. Examples include designating sunny weekend days to do loads of laundry or using your slow cooker only on sunny winter days. Using timers and relays can also reduce nighttime consumption.

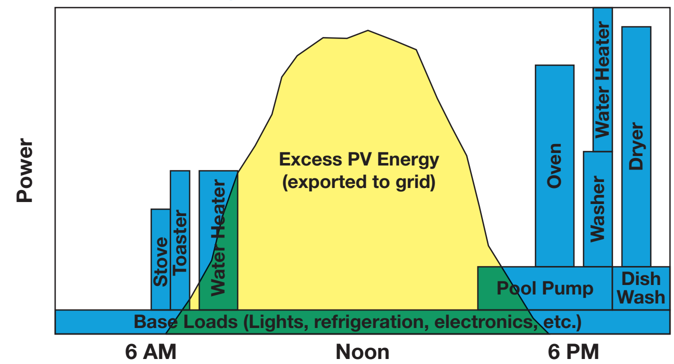
Inexpensive plug-in and hard-wired time controllers are available from hardware stores, and can be used to ensure that large, energy-consuming loads (such as water heaters) operate only during the daytime when the PV array is producing energy. "Smart" Internet-connected controllers are also available that allow adjustment of water-heater temperatures via a schedule or from your smartphone. This strategy is most appropriate in areas where the utility still allows PV systems to export energy, and would rely on the grid to power loads at night and during cloudy weather.

Grid-connected PV with limited energy storage. Adding a small battery bank allows storage of excess PV production during the day for powering loads later in the day or evening. The battery can be sized to cover a part of the typical loads, depending on one's budget. This can also be combined with a load-management system to shift as many loads as possible to solar production hours. This type of system would be well-suited in areas with export restrictions or where net-metering programs are not offered. The limited on-site energy storage could also provide sufficient battery backup for critical loads during utility outages.

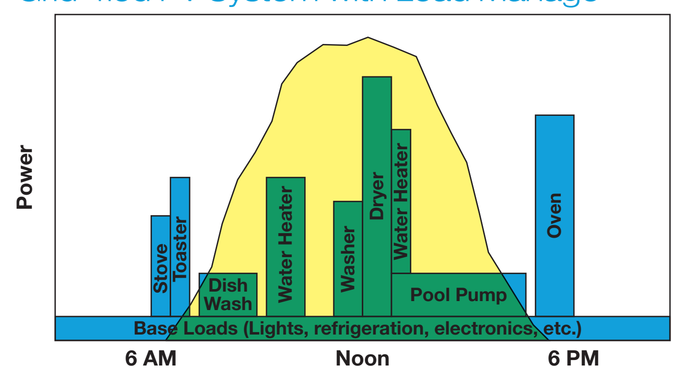
Whole-house energy storage system. A third strategy incorporates a battery that's large enough to provide all of a house's energy needs—the grid functions only as a backup during periods of cloudy weather or excessively high energy consumption. This is the most aggressive and expensive approach, but is suitable for those who want their homes to be 100% PV-powered, or want to avoid buying any energy from the utility. Since this system is designed to operate as if it is off-grid, utility outages during sunny weather don't affect it. If the battery bank has enough reserve capacity, outages during cloudy weather could be guarded against as well.

Self-Consumption Strategies

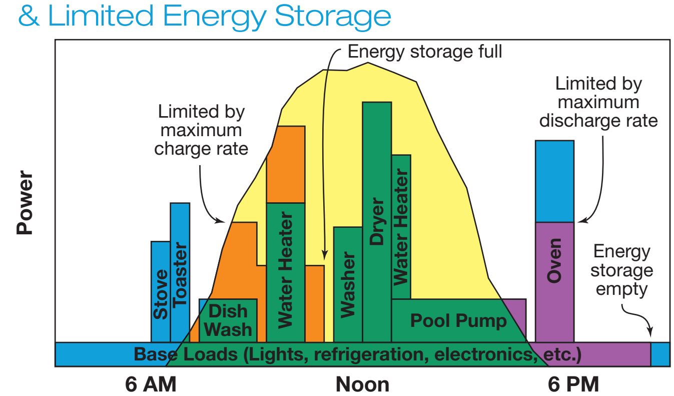
Grid-Tied PV System



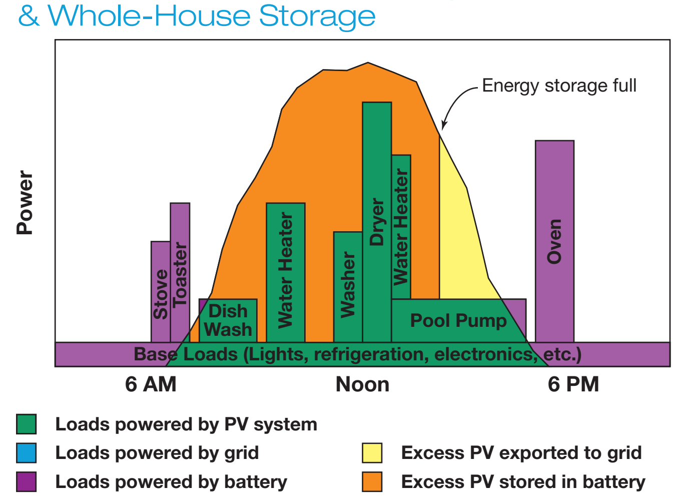
Grid-Tied PV System with Load Manage-



Grid-Tied PV with Load Management & Limited Energy Storage



Grid-Tied PV with Load Management & Whole-House Storage



Courtesy Leviton

Left: A simple electrical outlet timer can control when electrical appliances turn on or off, coinciding with PV production.

Right: Several new options for monitoring and controlling electrical outlets remotely with web-based apps have hit the market.

Courtesy iHome

Other Benefits

When energy storage is included to increase PV self-consumption, it can also provide other protection against rising utility rates and new rate structures.

Time-of-use (TOU) rates. Energy storage can reduce utility costs in TOU rate structures. TOU rates are higher during peak energy consumption periods and lower when consumption is down. Typically, a utility's peak TOU rate period is late afternoon through early evening, when people get home from work and turn on loads. In an SC system with energy storage, the batteries can store the PV-produced electricity from earlier in the day, when no one is home and loads are low, and then provide electricity to loads during the peak rate period to avoid buying high-priced utility energy.

Demand charges. When designing an SC system, consider both kWh (energy) and kW (power) consumption. Energy storage can be used to reduce the peak power (kW) drawn from a utility grid and reduce utility "demand charges." This type of utility fee is more common for commercial customers, but it is crossing over into the residential market as seen in the recent rate structure for Salt River Project (an Arizona utility).

Dispatchability. In the future, utilities may want to "tap" residential batteries to meet peak demand when customers are using the most power—such as on hot days, when many customers are using air-conditioning. With the right payment agreement and control/metering system, this could become an extra revenue source for the end user and would provide a controllable energy source for the utility, allowing them to operate the grid more efficiently with less standby capacity being required.

Backup energy. Energy-storage systems can also provide backup for critical loads, such as lights and communication, during a utility outage due to weather events or natural disasters. Backup can also be accomplished with fuel-powered generators, but they can be noisy, release emissions, and require fuel, annual maintenance, and regular exercising to ensure availability when needed.

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Proprietary control systems, such as Rheem's EcoNet, are designed to work with the companies' other equipment like water heaters, furnaces, and air conditioners.

Courtesy Rheem

Due to the size of a water-heater load in an efficient home, even a simple timer can help shift substantial amounts of energy consumption to times of high PV production.

Courtesy Intermatic

Courtesy SolarEdge

Above: SolarEdge's StorEdge inverter can be installed with lithium batteries from Tesla or LG Chem, along with its meter (for energy-management capability) and autotransformer to balance backed-up load panel circuits.

Courtesy JLM

Above: JLM Energy's Phazr lithium iron phosphate microstorage units pair with microinverters and mount behind the PV module (shown with the Measurz monitoring software system).

Example Equipment for SC Systems

Courtesy SMA

Left: Shipping in mid-2017, SMA's Sunny Boy Storage inverter can be used with high-voltage lithium battery banks (such as those from LG and Tesla) for energy management, such as peak load shaving, self consumption, and zero-export. Higher backup capacity is expected to be available by the end of 2017.

Courtesy sonnenBatterie

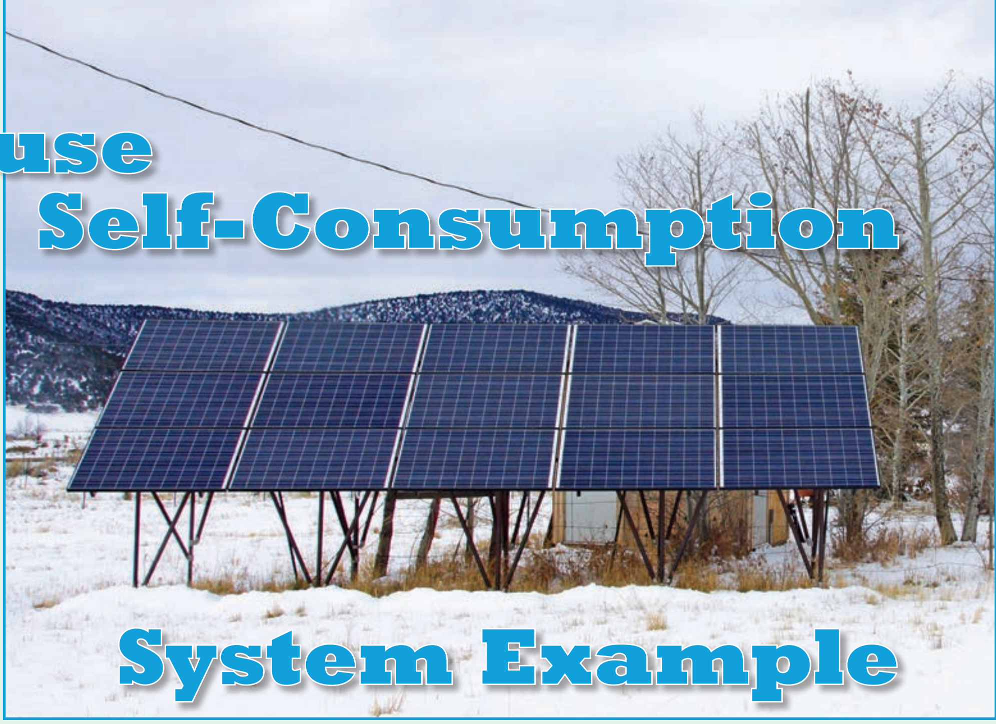
Left: Offered in 4 to 16 kWh capacities, the sonnenBatterie eco combines lithium iron phosphate batteries with the power electronics for a full-sized, prepackaged energy-storage system suitable for both energy management (SC and TOU shifting) and backup power applications.

Courtesy Enphase

Right: Integrating lithium iron phosphate battery chemistry with its microinverter, the Enphase AC battery has a 1.2 kWh capacity and can be AC-coupled (with up to 14 units per 20 A branch circuit) for use in self-consumption and TOU-optimizing systems.

Whole-House Self-Consumption System Example

Fairview, Utah, system installer Kienan Maxfield of Maxfield Solar details his client's self-consumption system.



With 3.825 kW of PV modules and 64 kWh of battery storage, this grid-connected system can operate as if it's a stand-alone system.

Why did your client choose a self-consumption system?

My customer wanted a system that would offset all of the home's electricity needs and provide backup power to the whole house during a long-term outage or in case of a "collapse of the grid." Additionally, the city-owned utility, Fairview City Power, wouldn't allow them to export any energy to the grid, so self-consumption was the best option.

What was the utility's rate structure like, and what were the savings after the system was installed?

The city utility uses a basic fixed-rate structure with no connection or "overhead" fees, so the savings that resulted from installing the PV system were about 95%. The homeowner only uses grid electricity when the system isn't keeping up (5% of the time) and then she conserves energy like an off-gridder.

What equipment did you use?

I used an OutBack Power Radian GS8048 inverter with a MATE3 display and controller; a FlexMax FM80 charge controller with a 3,825-watt PV array; and 64 kWh lead-acid battery bank.

How was the system programmed?

I programmed the system as a "HBX—high battery transfer." Under normal circumstances, the home is essentially off-grid, but when the batteries dip below 65% state of charge, it transfers the house loads onto the grid. The grid basically becomes the backup generator.

Did you need a secondary subpanel?

Not exactly. We powered the whole house through the output side of the inverter, and put all of the household circuits in the self-consumption subpanel.

How did you design the battery capacity?

I sized this as I would size an off-grid battery bank. I used the utility power bills to find my client's electricity usage, using 1.75 days of autonomy at 35% depth of discharge. After becoming more energy-conscious, the client's usage went down and the battery's daily depth of discharge was less than the original design. That means a longer battery life and longer autonomy.

What percentage of self-consumption is your design striving for?

One hundred percent, because no PV electricity can be exported onto the grid and any extra electricity produced and not used would be wasted by the charge controllers.

Did you also incorporate load-management strategies to shift loads to the times of peak PV production?

The load-management strategies are simply my client's energy awareness and manual control. Being retired, the client is able to monitor the PV production and the household's energy consumption and live like an experienced off-gridder.

Courtesy Kienan Maxfield (2)

Installer Kienan Maxfield with the balance-of-system components.

Smart thermostats like this Wiser Air from Schneider Electric are WiFi enabled, allowing settings to be adjusted via a smartphone.

Courtesy Schneider Electric/Wiser

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Monitoring & Control

Tracking and controlling electricity use is an area that is seeing a lot of developments in new PV inverter/energy-storage systems as they interface with the consumer, the utility, the loads, and the PV array to maximize self-consumption. Monitoring systems track energy use through the utility kWh meter and current-sensing transformers (CTs) that are part of the energy-storage system. They track the amount of electricity used and the time periods in which loads are operating. The system collects and stores this information. This data is periodically transmitted to an off-site computer server. Server software analyzes the information and provides historical performance reports, which can be viewed online or sent via email.

Load-control systems (LCS) can be installed for larger appliances such as water heaters, air conditioners, or pool pumps. This can be done by using hard-wired relays, or through internet-connected control devices, such as plug-in WiFi outlet load control boxes.

New "smart" loads are becoming available that can interface with the energy-storage system to allow more than just on/off control. One example is the Nest

"Smart" thermostats can be used to help manage energy consumption in new ways. Honeywell's Lyric thermostat (below) can sync to a utility's automated demand response system, shutting off air-conditioning for short periods when grid demand is peaking. Nest Labs thermostat (right) automatically programs itself for your utility's TOU rate plan, adjusting its operation to save energy and money.

Courtesy Nest

Courtesy Honeywell

Tech Specs

Overview

Project name: Wagstaff residence

System type: Battery-based, grid-tied solar-electric

Installer: Maxfield Solar

Date commissioned: August 2013

Location: Milburn, Utah

Latitude: 39.70°N

Solar resource: 5.43 average daily peak sun-hours

ASHRAE lowest expect ambient temperature: -2°F

Average high summer temperature: 91°F

Average monthly production: 480 AC kWh

Utility electricity offset annually: 95%

Photovoltaics

Modules: 15 REC 255PE, 255 W STC, 30.5 Vmp, 8.42 Imp

Array: Five three-module series strings, 3,825 W STC total, 91.5 Vmp

Array combiner box: MNPV6, with 15 A breakers

Array disconnect: PNL-80-DC, 80 A breaker

Array installation: SnapNrack Series 200 ground mount, facing 159°, at 45° tilt

Energy Storage

Batteries: EnerSys 24-85-21, 48 VDC nominal, 1,340 Ah at 20-hour rate, flooded lead-acid

Battery/inverter disconnect: Two 175 A breakers

Balance of System

Charge controller: OutBack FM80, 80 A, MPPT, 150 VDC max input voltage, 48 VDC nominal output voltage

Inverter: OutBack Radian GS8048, 48 VDC nominal input, 120/240 VAC output

System performance metering: OutBack FLEXnet DC thermostat, which can have its settings adjusted automatically by a control system to use surplus PV production during the middle of the day. In this way, a house can be "precooled" before solar production declines and electricity rates are higher. Another example is an air conditioner that can "store" excess solar energy by making ice to provide cooling later in the day. There are also heat-pump water heaters that can "store" excess solar energy by increasing the water temperature to higher-than-normal temperatures. Many modern air conditioner and heat-pump systems can also operate at variable power levels, allowing their energy consumption to be varied as the PV array's output varies. This makes the impact of the control system less noticeable and can improve the overall operating efficiency as well.

Many monitoring and control systems use a "cloud"-based software system to automatically make decisions about how to best operate the loads and manage the energy-storage system to maximize the use of the PV system's electricity production. More advanced systems use weather-forecasting data and utility power capacity information to maximize system performance in a predictive manner, instead of just reacting to changing conditions.

Solar self-consumption is becoming more common because of utility policy changes for crediting the electricity produced by distributed energy systems. By increasing self-consumption through load management or by using energy-storage systems, a higher amount of on-site electricity can be consumed, reducing the impact of these utility policy changes. Advanced load controls and smart loads will also not only reduce consumption through increased efficiency, but will allow new strategies to minimize the use of utility power during peak rate periods. Energy-storage systems will allow the consumption of PV-generated electricity to be shifted from daytime to evenings, while at the same time opening up new possibilities for residential PV systems to work with utilities to minimize use of fossil fuels and reduce carbon emissions.

Courtesy Ice Energy

The Ice Bear air conditioner stores energy as ice, to continue cooling after solar production drops off.

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Rapid Shutdown Requirements of the 2014 & 2017 *NECs*

by Ryan Mayfield

Many jurisdictions are adopting and enforcing new electrical codes. In some locations, such as Massachusetts, this means jumping on board with the 2017 *National Electrical Code (NEC)*, the most up-to-date version. Other locations, like California, are using the 2014 *NEC* as the new code. If you are unsure which code your jurisdiction is using, you can look it up on a NEMA map (see bit.ly/NEMAmap) or contact your local permitting office. Additionally, many states use the *NEC* as a model, but have amendments modifying some language.

Since the majority of states now use either 2014 or 2017, you'll be seeing the implementation of one of the most contentious sections in Article 690—rapid shutdown (RS). In the previous "Code Corner," Brian Mehalic introduced the changes for 2017. Given the different versions that have been implemented across the country and the varying levels of understanding on all the requirements, this article details RS in the 2014 and 2017 editions.

The intent of the 690.12 RS requirement is to remove PV system shock hazards to individuals, particularly firefighters. This is given further attention in 2017 with added language in the introductory sentence.

The Fronius Rapid Shutdown box is an RS solution for all Fronius SnapINverters in systems up to 600 V.

Courtesy Fronius

Section 690.12, "Rapid Shutdown of PV Systems on Buildings," was introduced in the 2014 *NEC*. This requirement applies only to PV systems with AC or DC circuits located on or in a building. The section consists of five requirements for controlling conductors:

(1) *Requirements for controlled conductors shall apply only to PV system conductors of more than 1.5 m (5 ft.) in length inside a building, or more than 3 m (10 ft.) from a PV array.*

(2) *Controlled conductors shall be limited to not more than 30 volts and 240 volt-amperes within 10 seconds of rapid shutdown initiation.*

(3) *Voltage and power shall be measured between any two conductors and between any conductor and ground.*

(4) *The rapid shutdown initiation methods shall be labeled in accordance with 690.56(B).*

(5) *Equipment that performs the rapid shutdown shall be listed and identified.*

Many installers have pointed out that the lack of more concrete requirements—such as a location for the RS controller—allow multiple interpretations. As for the last requirement, that "equipment that performs the rapid shutdown shall be listed and identified," there's currently no RS standard for equipment manufacturers to follow. This leaves installers often asking, "Listed and identified to what?" Thankfully, solutions are coming to market to help address these concerns. Also, there is a group working on the standard for the RS listing.

To meet the 2014 RS requirements, installers have several options, especially for residential applications. In both residential and commercial systems, using microinverters or DC optimizers will help meet the requirements. These module-level power electronics (MLPEs) control the output conductors to the appropriate voltage and power levels, meet the distance requirements by their location behind modules, and are listed and identified devices. This leaves the installer with labeling the RS system. Other than specific wording and use of reflective materials, the *Code* doesn't specify the exact location for that label. In my opinion, locating the label at the main PV disconnecting means and main service disconnect (if not co-located) is the best option.

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If MLPEs aren't part of the system design, there are options for installing RS devices with string inverters. Many manufacturers now have RS boxes that work in conjunction with their inverters. There are also third-party solutions that can be added to installations to meet the requirements (see "PV System Rapid Shutdown" in *HP175*).The first wave of manufacturer-supplied and third-party solutions is focused on 600 VDC systems, so commercial systems using 1,000 VDC systems may be harder to find a boxed turnkey solution for. As a workaround, a popular method has been locating inverters on the rooftop, adjacent to the array, thereby only having AC conductors, which are shut down automatically without grid connection, outside of the 5- or 10-foot distance dictated by *Code*.

If you are using string inverters and an RS box, planning is a key element in a successful installation. Many of these boxes require control wiring—separate from the PV array—to activate the RS feature. A common approach is to use a low-voltage DC circuit via an AC-to-DC power supply to operate the rooftop rapid shutdown box from the shutdown button location.

A disconnect inside the rooftop box activates to isolate the PV modules from the inverter. If necessary, contactors short out the PV output conductors wired to the inverter's input to discharge the capacitors, eliminating all DC voltage on all the conductors. In some cases, a disconnect alone isn't sufficient, as the capacitors in some inverters will keep the conductors charged beyond the 10-second allowed time frame. Therefore, you should properly plan for this circuit by providing control conductors and power supplies as required by the manufacturer.

In the 2017 *NEC*, 690.12 and the associated language in 690.56 grew considerably. Early in the additions is the definition of "array boundary," which stipulates a 1-foot perimeter around the array that will be used to define the exact requirements for controlling conductors. The definition of controlled conductors has also been changed—controlled conductors must be no more than 30 volts within 30 seconds of initiation of the RS.

Courtesy SMA

SMA's Rapid Shutdown System provides RS compliance for systems using Sunny Boy inverters, and allows continued use of the inverter's Secure Power Supply feature when the grid is down.

One of the biggest additions is 690.12(B)(2), which requires that the conductors within the array boundary (those under modules and attached to the racks) are controlled. For arrays not using MLPEs, this may be the most difficult subsection to comply with, although an allowance doesn't make this subsection a requirement until 2019.

The other changes do not have the same grace period. New requirements include more restrictive distances for the uncontrolled conductors. Under 2014, that distance was 10 feet from an array or 5 feet in a building. In 2017, 690.12(B)(1) stipulates that any conductors must be controlled if outside the array boundary, which is now 1 foot from the array or more than 3 feet from a point of entry into a building. The distances have been greatly reduced, but the electrical requirements only dictate a voltage limit.

Subsection 690.12(C) provides options for what constitutes an RS initiation device, which can be as simple as the main service or the PV system-disconnecting means, or an auxiliary switch that controls the PV circuits. If you can interconnect the RS with the AC electrical system such that turning the service disconnect to the "off" position enables RS, you aren't required to install an additional switch. In the case of one- and two-family dwellings, though, the initiation switch needs to be located outside the building at a readily accessible location. In that scenario, if the main service disconnect isn't co-located with the utility meter, installing a separate switch that initiates the RS at the meter location will likely be a better solution.

For labeling, pay special attention to 690.56(C) in the 2017 *NEC*. There were significant additions to the label requirements based on controlled conductors within and leaving the array versus those that are only controlled when leaving the array. To avoid the cost and time of reconfiguring an array to meet RS requirements, first discuss your plans with your AHJ.

Courtesy SolarBOS

SolarBOS's Rapid Shutdown Solution combiner for string inverters provides an RS solution for inverters located more than 10 feet away from the PV array.

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The Ladder

by Kathleen Jarschke-Schultze

Kismet. Fate. Serendipity. Are there no coincidences? I have felt for a long time that our meeting with *Home Power* publishers Richard and Karen Perez was meant to be. Our connection, that seemed random at the time, changed the course of our lives in wonderful ways that continue to this day.

My husband Bob-O and I were living on a mining claim called Starveout on the Salmon River in California. We were off-grid, using a small hydroelectric turbine to power our cabin. We had a scary old Tripp Lite inverter for when we needed 120 VAC, but the rest of the house was 12 VDC.

One wintry day in 1987, we were in town at the local laundromat and found a notice on the board about a renewable energy magazine called *Home Power*. We could get a copy at the laundromat office just for asking. We did, and Bob-O devoured the first issue while our clothes dried.

We liked what we read and subscribed. We told our off-grid friends about the magazine. In issue *HP2*, Richard wrote out the instructions to build a charge controller to use with a 12 V automotive alternator turned by a small gas-engine—a popular (and cheap) way to recharge batteries in those days. Bob-O, who needed a charge controller for our microhydro system, figured that he could adapt the circuit for that, and built one. It worked so well he sent a fan letter to Richard, who responded with an enthusiastic, "Far out!"

At about the same time as *HP5* was published, our friend Big Butch contacted us and said, "Let's go visit these people. They are not that far away." We met with Big Butch and Benny from Scott Valley Feed & Nursery and set off in Butch's four-wheel drive. Luckily, the weather was cooperative. We found the right dirt road and headed up—and up—toward Agate Flat, Oregon, where Richard and Karen lived. We were all ham radio operators, and Richard (N7BCR), was able to direct us (KG6MM, KB6MPI) the last few confusing miles on the two-meter radio band.

We met Karen and Richard face to face. We also became acquainted with Sam Coleman, aka the Wizard (who had a column in *Home Power*), the dogs, and a wealth of "puddy cats" (Karen's term of affection for her clowder of cats). Up to that point, Bob-O and I had believed that we lived "remotely," but Agate Flat won that description hands down.

After that visit, our correspondence with *Home Power* grew, and eventually Bob-O and I began writing articles for the magazine. When Richard upgraded their computer, we got their old "Fat Mac" to write our articles to floppy disk and mail them to the Flat, aka *Home Power* Galactic Central.

Meanwhile, because of the devastating wildfires on the river the year before, Bob-O was working felling dead, burned trees far up in the Salmon Mountains known as Betchawannaland ("once you get there, betchawanna go home"). A tree he was felling hit a burned hardwood, which lifted up off the stump and chased him along his escape route. The tree won the race and broke his leg. It was a compound fracture, and it was five hours and a helicopter ride before he saw a doctor. After the surgery, I told him, "You weren't fast enough to dodge that one and you're not any faster now. No more felling timber." Both Bob-O and his doctor agreed with me.

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TheEnergyFair.org

Kathleen Jarschke-Schultze

Richard, Karen, and Bob-O, circa 1989.

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We were sitting in Bob-O's hospital room, wondering what our next move would be. Our future felt like a deep, dark hole, although we had some savings. We really didn't want to use that money—we had earmarked it for buying land—but it looked like we would have to, to weather this storm. Suddenly, the door opened and Karen came in, with a growler of ale from the local brewery and a proposition for us.

The Home Power business had been renting a house off Agate Flat, which they were using for storage, paste-up of the magazine, showering, and a landline phone. The owners decided they didn't want to be absentee landlords anymore and were selling the house. Karen told us, "Buy the house and we will give you both jobs." It was an offer we didn't refuse.

Bob-O took over the day-to-day operation of Electron Connection, Richard's renewable energy installation business. The business had practically been abandoned as the pressures of distributing *Home Power* grew as fast as the subscriptions. Bob-O got his electrical contractor's license, first in California, and then in Oregon. I helped with whatever publishing job they needed, taking care of mail and subscriptions, mailing out back issues, and typing and editing articles. I also became the voice at the other end of the 800 phone number.

In those days, all magazines and most newspapers were "pasted up" on large sheets of thick paper, four or more pages to a sheet. The type was printed out on a quality laser printer, but all of the photos, camera-ready artwork, and ads had to be pasted onto the sheets in precisely the right spots. The bimonthly magazine paste-up day at our house became an event. Richard and Bob-O did the page paste-up on drafting tables strategically placed close to big windows for adequate light. Karen, John Pryor, and local artist Stan Krute were gofers, finding the articles and photos, and painting gum adhesive on the backs as Richard and Bob-O called for them. I spent that time cooking the most elaborate finger-food meals I could come up with. After paste-up was done and packaged to go to the printer, we would sit down to a well-deserved celebration.

After a year had gone by, Richard sold Electron Connection to Bob-O. For the magazine to be sent via second-class postage, the owners had to divest themselves of businesses connected to the magazine. Richard told me he had no qualms, as Bob-O had proven himself more than capable to carry on.

Our adventures together were legion. We traveled to energy fairs all over the country and a whole world of renewable-energy-minded people became our friends. Most of those friendships have stood the test of time.

In giving me advice on teaching my first solar cooking workshops at the fairs, Richard told me to anchor my points to a story. He said that people will remember the stories. My articles and my stories evolved into my "Home & Heart" column. It was Richard and Karen who gave me this platform.

Karen and Richard researched every choice made about the magazine's production exhaustively, with an eye toward its environmental impact. The kind of paper used, the type of ink, who did the printing—all of it, all the time. Corners were not cut. Richard and Karen devoted their lives to *Home Power*, enriching us all. As Richard used to say, "Let the mutant spore spread."

When it felt that we had fallen into a deep, dark hole, Richard and Karen Perez put down a ladder and helped us climb out into the sunlight. We will be forever grateful that they were our friends.

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Steps to Net-Zero-Energy Building Design

Building and designing affordable net-zero-energy (NZE) homes involves several integrated steps. NZE can use commonly available building materials and equipment, along with easy-to-learn building strategies.

Smart Design

Smart design is crucial, as the design will dictate everything else that follows. Good design includes understanding the site's benefits and limitations. Simplifying the building footprint and roofline can also be part of smart, efficient, and cost-effective building.

Use Energy Modeling

During design, energy modeling software should be used to estimate the home's energy use. Based on the results, design choices can be made or modified to balance building performance and construction cost.

Super-Seal the Building Envelope

Super-sealing the building envelope is the most cost-effective measure for improving the energy efficiency of an NZE home. Several proven air-sealing approaches are available. Choose an approach that matches your climate, skills, and budget.

Heat Water Wisely

Installing low-flow fixtures and water-efficient appliances helps decrease water-heating loads, which can then be offset by renewable energy technologies like solar hot water collectors or a solar-electric system.

Use Well-Insulated Windows & Doors

Windows and doors are like big holes in a well-insulated, airtight building envelope. Control their heat loss and gain by selecting appropriate products, and carefully sizing and placing them.

Use Sun & Shade for Solar Tempering

Using the sun for heating through south-facing windows during the winter lowers heating costs. Shading those same windows in summer lowers cooling costs. "Solar tempering" takes advantage of the sun's heat without maximizing solar storage with thermal mass. Some homeowners want to offset as much of their heating load as possible by adding thermal mass.

Create an Energy-Efficient Fresh Air Supply

A continuous source of fresh, filtered air and moisture control are critical to an NZE home's success. Energy-efficient ventilation systems, known as heat- or energy-recovery ventilation systems, expel stale air while transferring exhaust-air heat into the incoming fresh air.

Select an Energy-Efficient Heating & Cooling System

One good choice is an air-source ductless heat pump, also called a minisplit heat pump. These systems are efficient and don't have the shortcomings of central, forced-air systems or the high cost of larger heat pumps.

Install Energy-Efficient Lighting

Use daylighting when practical, and LED lights for supplemental lighting. They are more energy-efficient than compact fluorescent lamps, last many years longer, and contain no mercury. Select the right LED lights for the task, locate lights strategically, and use natural light as effectively as possible.

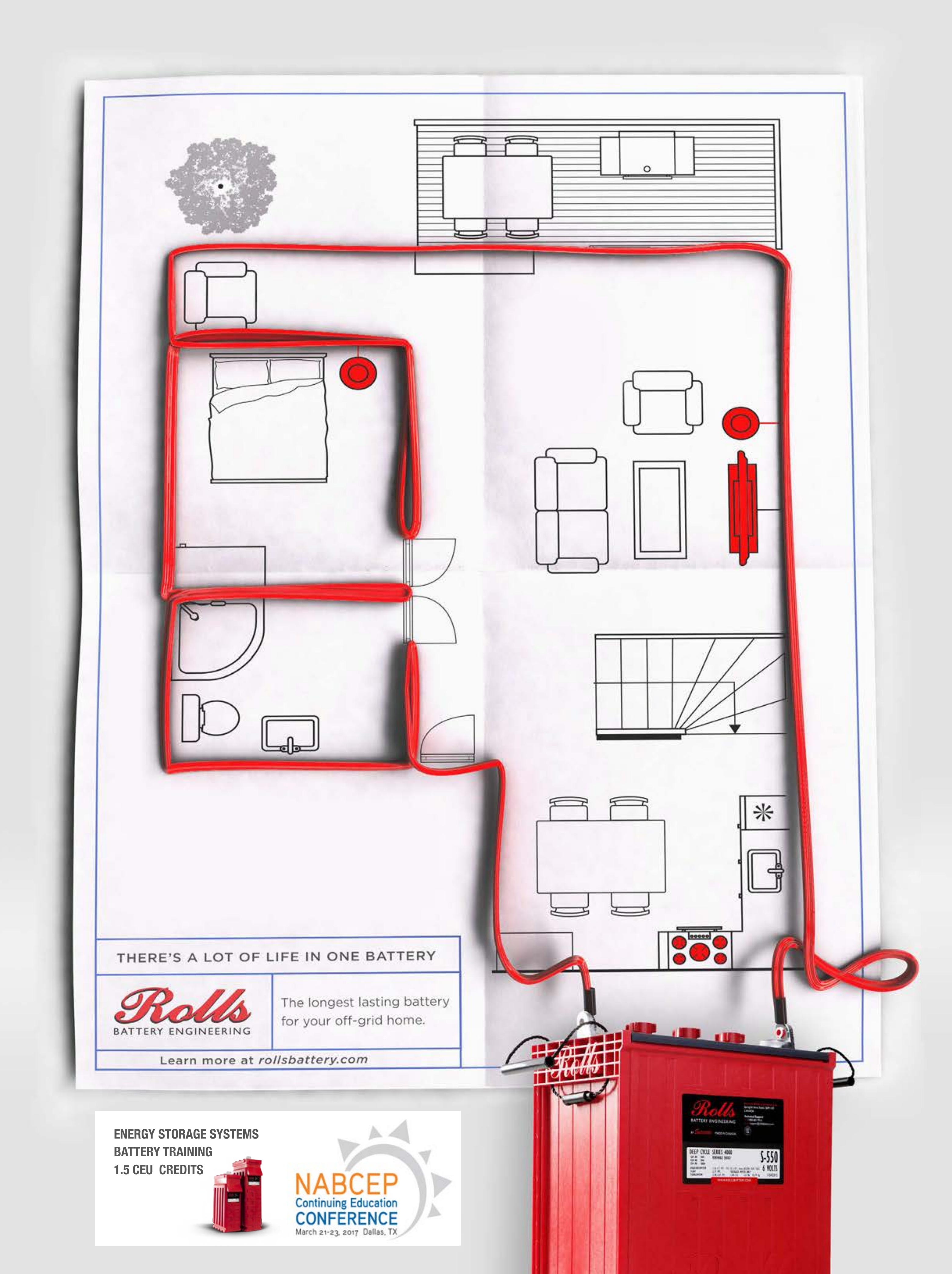
Select Energy-Efficient Appliances

Appliances and plug loads may account for up to 60% of the loads in an NZE home. Selecting energy-efficient appliances and managing "phantom" plug loads is essential. Phantom loads continue to draw energy whether or not the devices are being used. These can be curtailed by placing them on switched outlets, plug strips, or timers.

Use the Sun for Renewable Electricity

In most locations, a grid-tied PV system provides the most cost-effective form of renewable electricity required for an all-electric NZE home.

—Adapted from The Zero Energy Project (zeroenergyproject.org), a nonprofit educational organization that helps homebuyers, builders, designers, and real estate professionals radically reduce carbon emissions and energy bills by building NZE homes.



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