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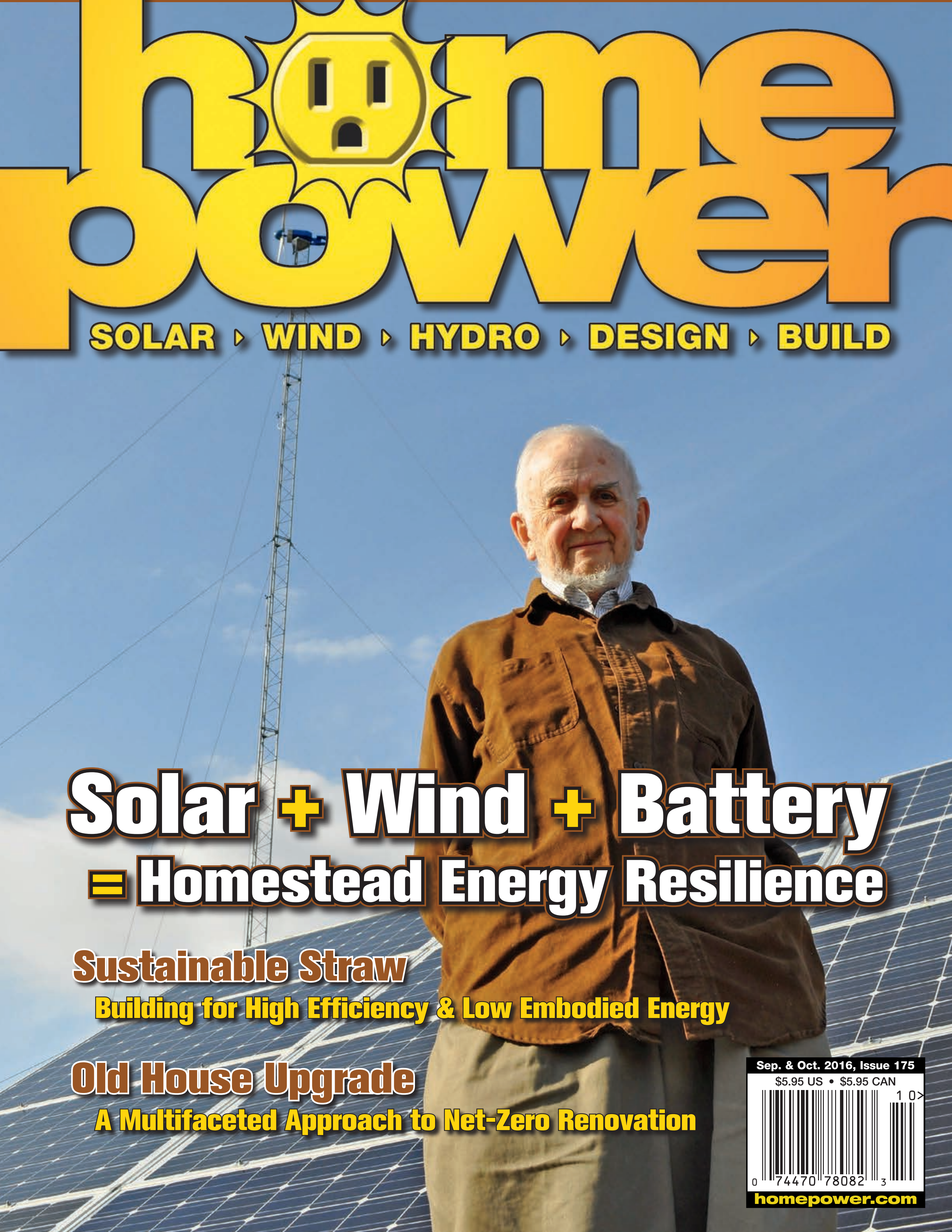

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The Grid-Tied PV System Compensation Shake-Up

Electricity from a grid-tied PV system will first go to a home's electrical loads, without interaction with the utility. If loads are greater than the PV system's production at that moment, utility electricity makes up the deficit. If loads are lower than the PV production, "excess" electricity is sent out to the grid. This is all accomplished seamlessly, keeping our homes humming along, so long as the grid is operating. Not only do residential PV customers take satisfaction in meeting most of their energy needs with the sun, but they often also reap financial benefits through incentives that pay for each kWh sent to the grid.

Ironically, the popularity of—and payouts to—these residential PV systems is now under scrutiny by utilities. The more residential PV energy that hits the grid, the more their profit margins are shrinking. They are also claiming that customers without PV systems end up contributing more than their fair share for the cost of maintaining the grid.

Under most net-metering programs, surplus solar electricity is credited at the utility's retail rate, with an annual true-up. These credits accrue over the year and can be "drawn upon" during times when the system produces less energy (like winter) and more utility electricity is consumed. (For a list of current PV incentives, see dsireusa.org.)

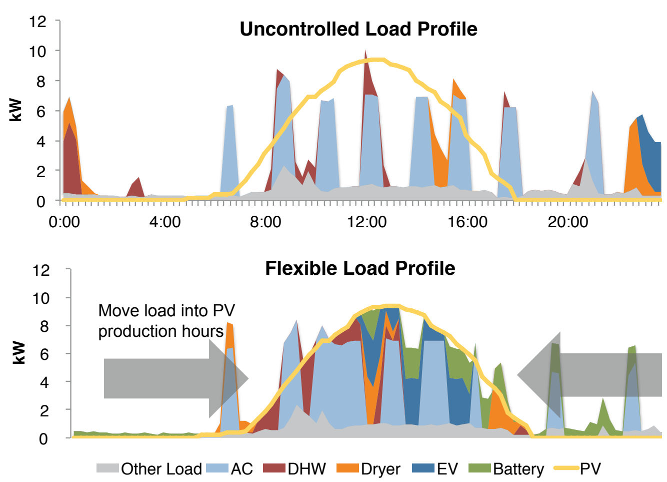
Utilities are trying to overhaul state net-metering programs, with significant consequences for system owners. In Hawaii, for example, the Hawaiian Electric Co.'s net-metering program is closed to new applicants. New grid-connected PV system owners receive a "PUC-approved credit for electricity sent to the grid"—about half of the retail rate. Last December, the Nevada Public Utilities Commission completely did away with one-for-one net metering for residential PV customers. (To find the state of net metering in your locale, see freeingthegrid.org.)

In response to threatened PV incentive programs, some system owners are using more of their own energy rather than letting it go to the grid—similar to how off-gridders might use diversion loads. According to the Rocky Mountain Institute, these "self-consumption" strategies include:

- Implementing an energy storage system (batteries) and programming the inverter to charge the batteries only when PV energy is available
- Using programmable smart thermostats to pre-cool homes and preheat water when PV energy is abundant. (A well-insulated home and hot water tank are important.)
- Charging an electric vehicle during daylight hours
- Using "smart" timers on electric clothes dryers so they run only when PV energy is available

—Claire Anderson, for the *Home Power* crew

Flexiwatts: Loads are scheduled to coincide with PV generation



Courtesy Rocky Mountain Institute

Think About It...

"Self-sufficiency is the greatest of all wealth."
—Epicurus, Greek philosopher (341–270 B.C.)

contents

september & october 2016

30

On the Cover

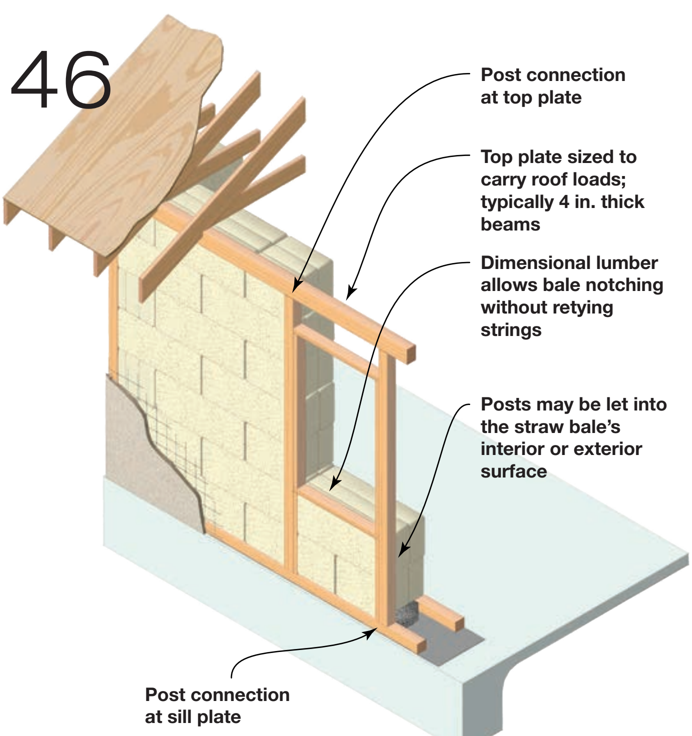
William Bassett with his grid-tied hybrid wind and PV system, which provides household electricity and electric vehicle charging.

Photo courtesy Jeb Mead

Main Features

continued on page 6

46



38

Photos: Courtesy Jeb Mead; California Straw Building Association; ©istockphoto/Eivaisl

contents continued


56

Up Front

More Features

In Back


64

16


Photos: Courtesy Jack & Sheila Herndon; Solar Energy International; Tom & Carol Godwin

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contributors

this issue's experts

Home Power Managing Editor **Claire Anderson** lives in a passive solar, (almost) net-zero-energy home she and her husband designed. She and her family are developing their 4.6-acre homestead to incorporate more resilience in their energy, food, and water systems. Chickens were new additions this spring.

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.

Brent Summerville is a Professional Engineer in North Carolina and president of his engineering firm, Summerville Wind & Sun. He started his career in graduate school at Appalachian State University (ASU), has worked in the wind industry for about decade, and is now teaching in the Sustainable Technology program at ASU.

William Bassett is Professor Emeritus in the Department of Earth and Atmospheric Sciences (EAS) at Cornell University, where he taught courses in mineralogy and crystallography. Since his retirement in 2000, he continues to serve Cornell as Curator of Geologic Collections.

Jim Reiland of Many Hands Builders is an Oregon general contractor and CASBA Advisory Board member.

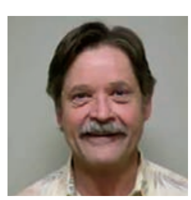
Rebecca Tasker is a general contractor and co-owner of Simple Construct, a design-build construction company specializing in straw bale building and other forms of efficient, low-carbon building. Simple Construct has been involved in the construction of more than 12 straw bale buildings in San Diego.

Massey Burke is a San Francisco Bay Area natural materials specialist who works with the California Straw Building Association, The Ecological Building Network, and other organizations compiling technical information to support the use of natural materials in construction. She is also an active natural builder.

Justine Sanchez is *Home Power*'s principal technical editor. She's held NABCEP PV installer certification and is certified by IREC as a Master Trainer in Photovoltaics. An instructor with Solar Energy International since 1998, Justine leads PV design courses. She previously worked with the National Renewable Energy Laboratory (NREL) in the Solar Radiation Resource Assessment Division. After leaving NREL, Justine installed PV systems with EV Solar Products in Chino Valley, Arizona.

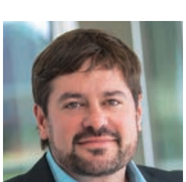
Art Weaver has lived and worked in upstate New York for 17 years. A scientist by disposition and training, his current project is Weaver Wind Energy—whose mission is to create the world's most reliable small wind turbines. Art believes that catastrophes of climate change will focus our attention for generations to come.

Author and educator **Dan Fink** has lived off the grid in the Northern Colorado mountains since 1991, 11 miles from the nearest power pole or phone line. He started installing off-grid systems in 1994, and is an IREC Certified Instructor for both PV and small wind systems. His company, Buckville Energy Consulting, is an accredited continuing education provider for NABCEP, IREC, and ISPQ.



Formerly a builder, **Nehemiah Stone** is now the chief building official and special advisor to the Chair of the California Energy Commission. He also is a consultant with Stone Energy Associates, and a member of the CASBA advisory board.

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.



Brian Mehalic is a NABCEP-certified PV professional, with experience designing, installing, servicing, and inspecting all types and sizes of PV systems. He also is a curriculum developer and instructor for Solar Energy International and an independent contractor on a variety of PV projects.

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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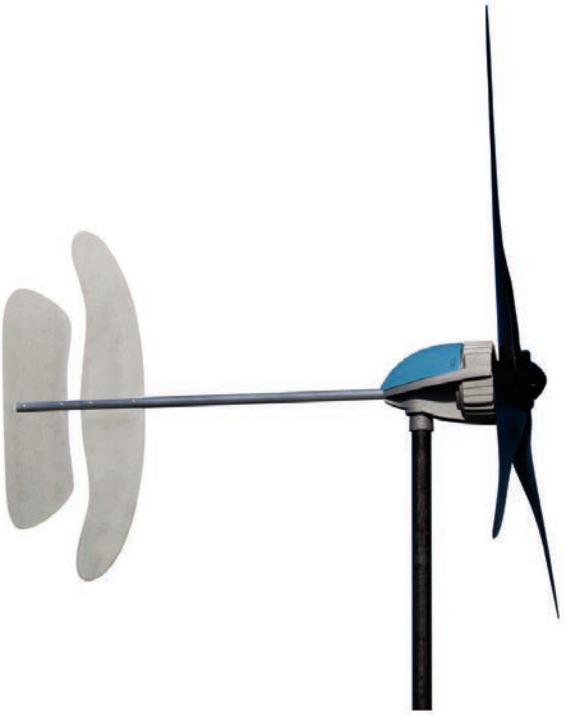
Courtesy Ginlong

Ginlong

Solis-US Inverters

Ginlong Technologies (ginlong-usa.com) offers its Solis-US residential string inverter in six capacities. The 6 kW, 7 kW, and 7.6 kW versions have three MPPT inputs; the 8 kW, 9 kW, and 10 kW units have four. This transformerless inverter offers a 120 VDC startup voltage and a 600 V maximum input voltage, with an MPPT voltage range of approximately 200 to 500 VDC (exact values depend on the model). Features include integrated arc-fault protection, a DC disconnect, and a NEMA 4X enclosure. The CEC efficiency listing is 97.5%. Options include WiFi and a web box for wireless data transmission, and web-based monitoring via the Solis Web app. A compatible rapid shutdown device is available. A 10-year standard warranty is included, and is extendable to 20 years.

—Justine Sanchez



Pika Energy

T701 Wind Turbine

Initially beta-tested in 2013, Pika Energy's (pika-energy.com) small wind turbine was certified by the Small Wind Certification Council (SWCC) early in 2016. This 9.8-foot-diameter machine uses glass-reinforced polymer blades to drive a brushless permanent-magnet alternator. It is a horizontal-axis, upwind-rotor, free-yaw turbine, with a tower-top weight of 93 pounds. The SWCC-certified rated energy output is 2,420 kWh per year in a 5 m/s (11.2 mph) annual average wind speed. At 38.3 dB, it is the quietest SWCC-certified turbine. Pika's inverters and charge controllers can also accept PV and wind inputs via the REbus 380 VDC bus. This turbine has a five-year limited warranty.

—Ian Woofenden

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PV Canopy for a Bocce Court

Tom and Carol Godwin had solar energy in the back of their minds when they designed and built their house in 2010, but didn't bring solar expertise onto their team until I entered the picture several years later. I found small, south-facing roof areas that were shaded by each other and nearby trees. Using the Solar Pathfinder, I identified the best site on their small, narrow property—at one end of their bocce court. A PV canopy over the court was a good fit. The couple installed a whole-house 12 kW generator when the house was built. With backup power already in place, a batteryless PV system seemed like an appropriate choice.

Tom is an investment planner, and PV made sense to him for stabilizing his electricity costs during retirement. He also wants to leave the planet in better shape for his great-great grandchildren. Mild peer pressure from close neighbors and friends, who have been using solar electricity for many years, was also a factor in the decision.

Building a freestanding structure added significant expense, but the Godwins ended up with more than twice the system the small roofs could have accommodated—plus better performance. Dana Brandt of Ecotech Solar designed the PV system, and his crew installed it in one eight-hour day. "I love that the structure not only supports the array but provides shade for the court. It feels like such a waste to build a ground-mount structure that does nothing but support the array," says Dana. "Any time a ground-mount system can serve an additional purpose, such as a carport, covered storage, or shaded area, feels like a win to me."

Architect Chris Keyser (who also designed Tom and Carol's house) designed and engineered the post-and-beam structure to support the array and complement the house. Bill Chagnon of Crater Lake Building and his crew constructed the structure, using pre-made galvanized steel brackets and stainless lag bolts to tie the 6-by-10 rafters to the 6-by-8 posts. Set on top were 4-by-10 purlin timbers. Made from pressure-treated wood, the structure is expected to outlast the 25-year module warranty, giving the homeowners reliable electricity for decades.

The 5.7 kW array uses 20 SolarWorld 285 W modules on Unirac SolarMount racks, and a Sunny Boy 5 kW inverter. The inverter has SMA's "Secure Power Supply" sunny-day backup capability. A subpanel and outlet was installed at the power center behind the bocce court, allowing some electricity use courtside.

The couple is pleased with the system's production. Tom checks the meters daily, and reports seeing modest production even on cloudy days. This spring, the system produced up to 40 kWh per day. The system's generation is zeroing out the couple's 11 kWh per day average usage, and, since the system's commissioning in April, a megawatt-hour of clean solar electricity has been made. When the system will be running net-positive, Tom may trade in his hybrid vehicle for a pure electric model.

—Ian Woofenden

continued on page 18

Ian Woofenden (2)

Left: A 5.7 kW PV array does double duty as a bocce court shelter.

Below: An SMA Sunny Boy 5 kW grid-tied inverter, with an outlet for courtside electricity.

continued from page 16

Overview

Project name: Godwin residence

System type: Batteryless grid-tied PV

Installer: Ecotech Solar

Date commissioned: April 2016

Location: Guemes Island, Washington

Latitude: 48.5°N

Average daily peak sun-hours: 3.85

System capacity: 5.7 kW STC

Average annual production (estimated): 5,900 AC kWh

Average annual electricity usage offset: 100%

Equipment Specifications

PV modules: 20 SolarWorld Sunmodule Plus SW285 Mono, 285 W STC

Inverter: Sunny Boy 5000TL-US, 5 kW

Array installation: Awning mount using Unirac SolarMount racks, south-facing, 30° tilt

Ian Woofenden

System owner Tom Godwin rolls a bocce ball, while solar neighbor Kevin Green waits his turn.

Warranty & Performance

I read Chris Corbett's comments (*HP172*) about my letter in *HP170*. His advice is sound on checking a warranty's fine points. However, I would guess that most people purchasing PV systems are as unlikely to check these fine details as they are when buying a car. My hope is that installers take Chris's advice, advising their clients on the details to help protect their clients from unfortunate circumstances like mine.

On another note, I am pleased to see the article in the issue on using solar irradiance meters to help check PV module performance ("Methods" in *HP172*). That will be the next test my contractor and I will do to determine if the delamination issue is decreasing performance enough to trigger the manufacturer's long-term production warranty. Keep up the excellent work!

Jack Herndon • Seattle, Washington

A pyranometer is oriented in the same plane as the PV array, and is used to verify that module output is meeting calculated expectations.

Toward Reducing Energy Consumption

Last winter I joined a sustainability discussion group here in La Crosse, Wisconsin. Several of the members expressed strong interest in installing solar-electric systems on their homes. Despite the cold winters here, people are remarkably uninformed about energy efficiency. It's cold outdoors here in the winter so they expect to be cold indoors as well—wrong!

Along the lines of what Tom Wehner wrote in "Mailbox" (*HP174)*, I asked each of the nine participants in the group to bring their annual propane bill, or their January and July natural gas bills. I then looked up the heating degree-day tallies on degreedays.net for the periods corresponding to the heating bills presented. Using the square footage of each of their homes, I calculated the values for Btu per heating degree-days (HDD) per square foot of home. The values ranged from 2.4 to 10. All of the homes were in good repair, or at least good condition, for their age.

I subsequently used thermal imaging and blower door tests at two of the members' homes. Lack of air-sealing was found in each—and both homeowners were surprised that anything could be done about this. The important lesson is that energy efficiency is usually much more cost-effective than using solar. But people want glitz, especially when they can get rebates and tax credits to pay for many thousands of dollars of glitz. But I can demonstrate that my house is draft-free, even during a raging blizzard.

My experience, like Tom's, suggests that a home that uses 4 or fewer Btu per heating degree-day per square foot may be an appropriate candidate for a renewable energy system. Thermal imaging and blower-door tests should be used to test homes that use more than 4 Btu/HDD/square foot. Then, the insulation should be increased and air-sealing defects should be remedied. Few people understand that going to the home center to buy $100 of air-sealing products is a much better use of their money!

Pete Gruendeman • La Crosse, Wisconsin

Courtesy Pete Gruendeman

Though the window itself is energy-efficient, improper installation allowed air infiltration around the frame, compromising the home's heating and cooling efficiency.

System Complexity & Safety

I installed a whole-house off-grid PV system more than 30 years ago, and live with an expanded off-grid system today. I admire the enormous progress in solar technology, but have concerns about the ever-increasing complexity of PV installations. A significant driver of complexity is the rules and codes intended to provide safety for installers, service and emergency personnel, and homeowners. Other drivers are efforts to increase efficiency and lower materials cost. All of these goals seem good, but they all interact. The systems that result are rarely evaluated as a whole and with adequate consideration of human factors.

continued on page 22

solar plus storage

(here's the plus)

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Pika ENERGY

Courtesy Paul Hoover

For example, the deployment of high-voltage DC strings reduces wiring cost and reduces resistance losses. It also requires automated switches to disconnect the strings in the event of faults or emergencies. Homeowners, untrained home service workers, children, and others are potentially exposed to much higher and more lethal voltages than in the past. Given the multitude of ways complex systems can fail, often through unforeseen sequences of events, this evolution in PV technology—especially in home applications—may not end well. Even highly trained utility workers are killed in electrical accidents involving high voltages. What happens when cousin Joe, who is always able to fix broken appliances, is called to help get the PV system working after a storm?

Paul Hoover • Burnsville, North Carolina

Thanks for writing. Yes, the complexity of systems often results from efforts to make them safer. And yes, the voltages in many modern PV systems are at a dangerous level. But so are the 120 and 240 VAC circuits that are already coursing through our homes. The whole point of the National Electrical Code *is to make electrical systems as safe as reasonably possible, to guard the home, the public, and firefighters against shock, electrocution, and fire.*

System owners should understand this, and nearly all will know better than to invite inexperienced people to work on the systems. If Cousin Joe does happen to volunteer his handy skills, hopefully he can read the signs, which clearly warn about the high voltages involved. Yes, it is likely that someone someday will be meddling where they shouldn't be—and will experience accident and injury. But you could use the same argument about driving at highway speeds, or standing up in a bathtub.

Michael Welch • Home Power *senior editor*

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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.

Selecting a Small Backup Generator

I've been living off-grid for about 10 years with PV and microhydro systems, a small battery bank, and a generator. While I very rarely need to use the generator, I can't do away with it completely. It's getting old now and the manufacturer no longer supports it, so I'm wondering what other generators might currently be available.

A 2 to 4 kW generator will be adequate. It needs to run on propane, have a remote two-wire battery start feature with no external power input required (other than an onboard starting battery), and a weatherproof enclosure. Any suggestions?

Ray Bowkley • Blue Grass, Virginia

The smaller the generator power output, the more difficult it is to find features like propane and remote electric start. There are a few options out there, but you won't likely be able to find them locally and will have to have them shipped.

On the lower end of the cost spectrum, Durostar, Powermate, and Power Trust Equipment all have electric-start propane generators in the 3 to 5 kW range. The higher-priced Cummins Onan has propane RV generators that will work for you. You may have to add the remote starting cable and switch yourself, but that's a relatively simple project.

Another option is propane conversion kits for gasoline generators. The kits are relatively simple to install, and come with detailed instructions.

There are a few features to consider when selecting an off-grid generator:

Fuel. Propane is an excellent choice because it never goes bad in storage, and water can't condense and get into the fuel. Trifuel models that use gasoline, LP, or natural gas are also available. Diesel is also a good choice for long engine life and low fuel consumption.

Power. Choose a generator powerful enough to charge your battery and cover all the loads you run—with extra capacity for any high startup loads (such as well pumps). And derate the output for altitude—3.5% less efficient per thousand feet above sea level; temperature—about 1% to 3% less efficient for every 10°F above rated "full-power" temperature; and fuel type—propane has a lower energy density than gasoline, making the generator about 10% less efficient.

Engine speed. Most generators spin at 3,600 rpm, but 1,800 rpm generators are available. They last longer and are quieter, but are also more expensive.

Remote start. Almost any generator with electric start can be retrofitted with a remote starting kit, which can even be homemade.

continued on page 26

continued from page 24

Automatic generator start (AGS). Many inverter/chargers can automatically start and stop a generator based on your battery bank's voltage or state of charge. This is controlled by the inverter's auxiliary relay and an add-on control module that can also convert a two-wire starting system to three-wire. I don't recommend AGS in most cases—there are too many things that can go wrong (see my article on vacation cabins in *HP174*).

Warranty. Generators can be finicky, and have lots of moving parts that can fail, so selecting a generator brand with a long warranty is often worth any extra cost. Be sure the warranty does not exclude off-grid use.

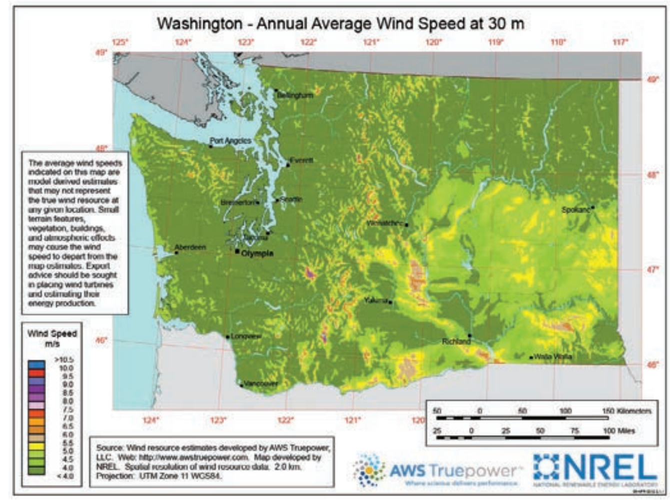
Dan Fink • Buckville Energy

Measuring Wind Energy Potential with an Anemometer

I would like to install a residential wind turbine at my lakeside property. Before I do, I want to measure the average wind speed to determine if there is sufficient wind energy. I want to use an exterior anemometer in an elevated location and measure the wind for several months. Can you recommend an anemometer that will best fit these requirements?

Ian Fairwell • Victoria, British Columbia, Canada

You are off to a wise start by making sure your site has sufficient wind. For a recent project, we purchased a wind measurement system from APRS World (aprsworld.com), and used their Solar Powered Wind Data Logger system (about $900). After the data was collected, we used Windographer, wind data analysis software from AWS Truepower, and Excel spreadsheet software to analyze the results.



Courtesy NREL

Measuring wind speed at the top of a relatively tall tower that matches the proposed turbine height is recommended for accurate wind-resource measurement (see "Wind Matters" in *HP158*). But having a taller tower quickly increases the monitoring system's cost. For example, APRS World sells a 97-foot tilting tower option from

continued on page 28

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continued from page 26

Bergey Windpower that lists for about $3,000. That puts your "wind interest" investment at $3,900, although you may be able to use the tower with your future turbine.

If you want to receive the data wirelessly, Etesian Technologies (etesian-tech.com) has a self-powered wireless anemometer and data logger. The anemometer alone retails for nearly $700 and they can provide a detailed quote for the entire system.

Renewable NRG (renewablenrgsystems.com) offers its 34m XHD NOW System, which includes a full suite of sensors and booms, plus cable and a data logger, and a 112-foot tilting tower. This cost of this system is about $8,000. The tower may be able to be used with a small-scale residential wind turbine after the data collection is complete—check with the turbine manufacturer to confirm turbine/tower compatibility.

Purchasing and installing a wind resource assessment system positioned near the proposed turbine height is expensive. Wind resource mapping has improved in accuracy and resolution, so the trend in residential wind has been away from direct wind measurement and toward a virtual assessment using wind maps, such as those offered by the U.S. Department of Energy (bit.ly/WindResourceMaps).

Some wind turbine suppliers perform free wind assessments for interested clients using wind-map data. Bergey Windpower (bergey.com) and their dealers have access to a digital wind resource map overlay for Google Maps, and can generate a report for your location. Primus Windpower (primuswindpower.com) will send you a wind assessment report given the details of your location. Others such as Pika Energy (pika-energy.com) provide self-assessment tools.

After a few months of measurement for our project, it was clear that our wind-map assessment agreed with the on-site measurements, confirming that the latest trend of relying more on digital wind map data is likely an acceptable pathway for residential wind.

Good luck in your endeavor. I hope your wind resource proves to be feasible for your residential wind turbine project.

Brent Summerville • Appalachian State University, Sustainable Technology Program

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.

Merging Wind, PV & Batteries

For RE & Independence

by William Bassett, with Ian Woofenden
photos by Jeb Mead

In 1978, my wife and I bought a 190-acre farm near Ithaca, New York, consisting of an 1840s-era farmhouse, a barn, pastures for our horses, lots of room for vegetable gardens, and a sizable woodlot for our wood heater, which backs up an oil-fired boiler and gas furnace. The farm was a great place to raise our kids; gives us a sense of security in an uncertain world; and allows us to be closer to the land and its resources.

Weaving Wind into the Energy Mix

Our loads were fairly typical for an older home. While we did not do a comprehensive energy audit and efficiency upgrades, we focused on the biggest energy load—heating. I redesigned our heating system to provide comfortable temperatures to fewer rooms. And we added a lot of insulation and then hired a local firm to add even more insulation to replace the vermiculite in the walls that had settled.

A few years ago, Art Weaver, an installer and builder of wind turbines, came to our place. We sat on our deck and watched the leaves blow in the wind as he told us about the benefits of wind energy. We seemed to have more wind than most of our neighbors because of our hilltop location.

Our home is grid-tied, but I was concerned about the security and robustness of our nation's electricity grid. I wanted to be as prepared as possible for outages, and installing a wind-electric system seemed a good way to diversify our energy sources for greater protection against utility failures.

Art studied the wind, topography, and surrounding trees, on which he based the tower height. A tower height of 120 feet was chosen, to raise the turbine 30 to 40 feet above mature trees in the area. This height gets the turbine above the most turbulent boundary layer and into much smoother winds. Smoother winds mean less turbine yawing—with less yawing you increase energy production and decrease wear.

Comment & Discuss this article @ homepower.com/175.30

William Bassett with the hybrid system that makes his 19th century farmstead energy independent.

In June 2013, the Weaver 5 wind turbine began producing energy. I read the meter faithfully and could see that it was going to fall short of our consumption, which hovers around 20 kWh per day. The daily wind fluctuations didn't surprise me as much as the seasonal changes did. I decided to add solar-electric modules and batteries to the system to further decrease dependence on fossil fuels—a key goal.

Pairing the PV Array

I wanted enough renewable electricity to be self-sufficient in the event of a lengthy grid failure, without having to resort to fossil fuels. This meant an allocation of at least 5 kW of PV to supplement wind for household consumption, and a little more than 5 kW of additional PV for the charging our electric car, a Nissan Leaf.

The wind system was originally a batteryless grid-tied system, with 3 kW and 7 kW SMA Windy Boy inverters. The 3 kW inverter is used at lower wind speeds (lower start voltage) and the 7 kW is used at higher wind speeds (higher start voltage). The addition of an 11.4 kW PV system, along with whole-house battery backup, required that the wind system also be able to charge the new 15.4 kWh lithium-ion battery. The solution was to AC-couple the SMA wind inverters to the AC load port of a 10 kW Princeton Power Systems DRI-10 inverter, which is able to accommodate a high-voltage lithium-ion battery. The PPS has four bidirectional ports—two DC ports (used for PV and battery) and two AC ports (used for grid and load). The Weaver 5 wind controller was also upgraded (by the manufacturer) to sense battery and load status in addition to grid status, and to safely control wind turbine output according to the availability of these loads.

We still need to do some "stress" testing on the system, by pulling energy out of the batteries under controlled conditions—such as intentional grid loss with and without PV and wind inputs. We want to test how well the inverter responds to changing generation levels and house loads, including EV charging. Art's team is developing Web page

A Weaver 5 wind turbine with 210 square feet of swept area and 11.4 kW of SolarWorld PV modules provide more than 100% of the grid-tied home's year-round energy use.

interfaces for both the Li-ion battery management system (BMS) and DRI inverter so we can monitor and tweak the systems. The ultimate goal is to simplify and make the whole system as robust, reliable, and manageable as possible.

Selecting & Using Lithium Batteries

Although lead-acid batteries are typical for battery-based RE systems, I wanted to try lithium-ion batteries. My research indicated that they can be superior in many ways if properly cared for, offering about twice the energy density of a lead-acid battery; four times the storage capacity in the same footprint; a longer cycle life; and half of the weight. Lithium-ion battery management systems continuously monitor every cell's voltage and temperature and actively manage each cell's state of charge (SOC) with a "balancing" circuit.

Our 15.4 kWh GBS battery appears modest compared to the estimated daily energy use of 20 kWh. However, having more than 16 kW of generating capacity guarantees that the battery bank will not be stressed by daily deep-cycling—even if the utility grid goes down for an extended period. I prefer to invest in ample generating capacity rather than massive storage capacity. If generation cannot keep a large battery bank charged, then the batteries will degrade faster, requiring premature replacement. Wind and solar energy are complementary—there's wind at night and in winter, and sun during the day and in summer. This characteristic allows a smaller battery without sacrificing energy reliability.

At the base of the tower are the short-circuit brake switch (left) and tail motor disconnect (right), both fitted with lightning arrestors. The box below the tail motor switch houses connection to additional wired anemometers on the tower.

We expect battery maintenance to be essentially zero. We also expect them to last two to three times longer than an equivalent lead-acid battery. The GBS lithium-ion batteries require no "watering" or electrolyte monitoring. If a cell in the series string goes bad (there are 120 cells), it will require replacement, costing less than $100. Individual cell monitoring lets us know if a problem develops in any cell.

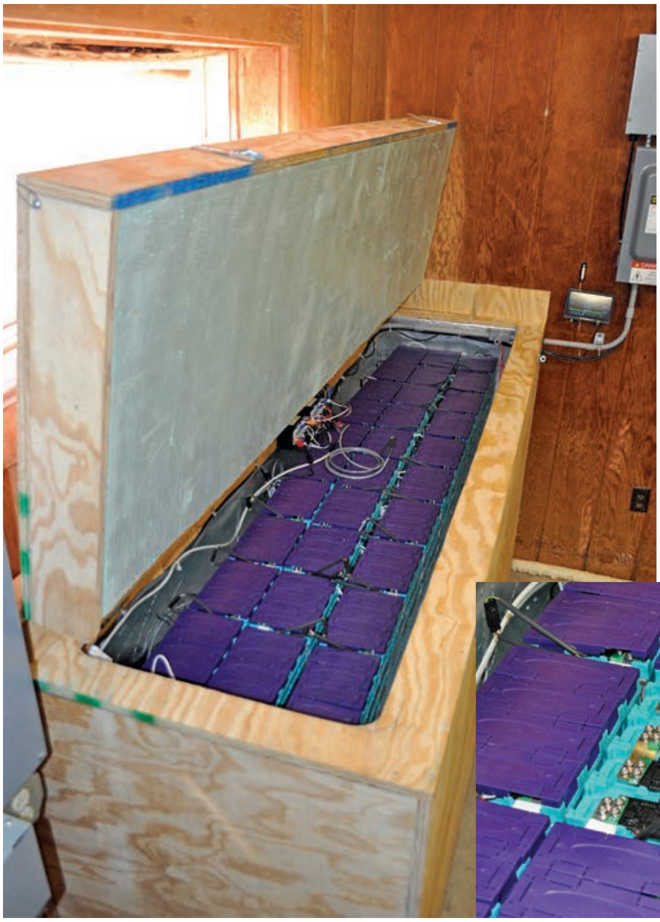
The DRI-10's high-voltage battery input is attractive for the same reason that high-voltage PV strings are attractive—smaller wire can be used without increasing voltage loss. We used #8 AWG to handle up to 40 A at 400 V (16 kW), which is surely more attractive (and cheaper) than conventional bulky 2/0 or 4/0 low-voltage battery cables.

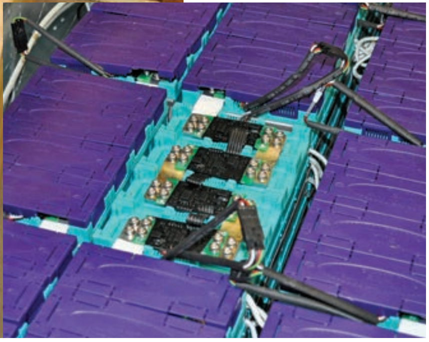
An Added Load

A day after the PV system was in, Art showed up in a 2103 Nissan Leaf electric vehicle (EV) and let me drive it. I was in need of a new car, and I liked the idea of fueling my car with energy from the wind and sun, so I decided to buy one!

I routinely charge my car's battery after each trip, even though I could easily make two trips. However, if the battery is fully charged when I set out from my home atop a hill, I cannot capture the benefits from regenerative braking. This means I'm using electricity to charge the battery, and then

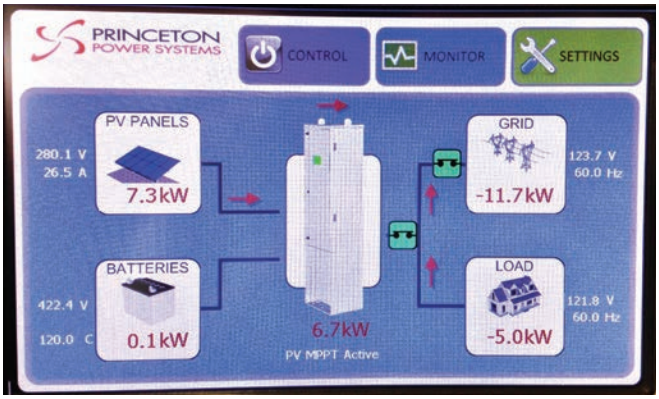
continued on page 36





Left: An insulated battery box houses 120 Elite Power Solutions GBS-LFMP40AH, lithium-iron-phosphate battery cells. Provides 40 Ah at 384 VDC.

Inset: LiFeMnPO4 batteries require a battery management system (BMS) for each 3.2 V cell.



Above: The DRI-10 inverter's touch screen displaying that there's 7.3 kW of PV power on the PV port and 5.0 kW of wind power coming in via the load port—the arrows indicate direction of current flow.

Left: With bidirectional DC and AC ports, the multimode DRI-10 inverter handles either PV or wind DC input and provides MPPT charge control for PV. It can be used with high-voltage battery banks, and can be connected to the utility grid, an AC generator, or neither.

Designer's Notes

The Bassett system features an AC-coupled wind system, lithium-ion energy storage, and the flexibility of a Princeton Power Systems DRI-10 inverter. AC-coupling is when the AC output of a generating source (like a grid-tied PV system, wind-electric system, or even a genset) is connected to the inverter's AC (load) port. Being bidirectional, this port allows AC to flow either in or out.

Several advanced, battery-based inverters have the ability to simulate a stable utility grid on their load port (AC output)—whether or not the utility grid is connected—so that any attached inverters will sync their outputs. This allows adding batteries without getting rid of existing batteryless grid-tied inverters, and without reconfiguring the PV array with DC charge controllers. The Bassett system AC-couples the wind-electric system rather than the PV system, which is managed on the DC side via the DRI-10's internal MPPT charge controller.

Care must be taken to make sure that the AC-coupled system's power is managed well, because unlike the real grid, the load port of such an inverter is not an infinite sink for backfed energy. Some mechanism must be able to curtail energy input from the AC-coupled generating sources, if the batteries become fully charged, the grid is down, and the house loads are not enough to consume all the energy.

If you have a wind generator that must always have a load to avoid turbine overspeed, and thus can't simply be open-circuited like PV can, a bit more strategy is needed to allow the wind turbine to "sense" the status of the inverter load, grid, and battery ports. We added voltage sense relays (for load and battery; it already sensed the grid) to the Weaver 5 wind controller so that it furls as necessary to curtail turbine output.

The other not-so-common feature of the Bassett system is the 384 V (120 cells times 3.2 V per cell) lithium-iron-phosphate battery attached to the DRI-10 inverter. This inverter can work with batteries ranging from 250 to 600 VDC—very different from the 12, 24, or 48 input voltages commonly used in other battery-based inverters.

While the DRI-10 has a battery management system (BMS) tailored for lead-acid chemistry, it also has an external BMS option in its firmware. We used this option with the BMS supplied by the lithium battery distributor to monitor the voltage and temperature status of all 120 cells and to automatically disconnect the battery from the inverter should the BMS sense an under- or over-voltage in any cell.

We also created a Web interface for both the DRI-10 and the BMS so that the designer, installer, and customer can monitor important system parameters, such as battery, PV, and grid status, at all times.

—Art Weaver

web extras

"Adding Battery Backup to Your PV System with AC-Coupling" by Justine Sanchez • **homepower.com/168.38**

Wind BOS Components

1. WWE wind turbine V2 controller
2. SMA Sunny WebBox data interface
3. Internet connectivity cabinet for WWE V2 controller, DRI-10, and SMA inverters
4. Turbine maintenance AC disconnect
5. SMA Windy Boy protection boxes
6. SMA LR6 diversion heater loads
7. Turbine maintenance DC disconnect
8. AC load center/combiner, with inverter breakers
9. SMA Sunny Boy 3000US inverter
10. SMA Sunny Boy 7000US inverter
11. Wind turbine kWh meter
12. Barn AC subpanel, grid connection

PV & Wind Hybrid System Tech Specs

Overview

Project name: Bassett residence

System type: Grid-tied, battery-based wind- and solar-electric

PV installation: Re-Source Power

Wind installation and overall system design: Weaver Wind Energy

Date PV system commissioned: November 2015

Location: Ithaca, New York

Latitude: 42.4°

Solar resource: 4.08 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: -7.6°F

Average high summer temperature: 84.2°F

Average monthly production: 1,161 AC kWh (estimated)

Utility electricity offset annually: 100%

Photovoltaic System

Modules: 40 SolarWorld SW 285, 285 W STC, 31.3 Vmp, 9.20 Imp, 39.7 Voc, 9.84 Isc

Array: Four 10-module series strings, 11,400 W STC total, 313 Vmp, 397 Voc

Array disconnecting combiner box: MidNite Solar MNPV4HV with 4 15 A, 600 V fuses

Array disconnect: Integrated with array combiner (see above)

Array mount: Iron Ridge ground-mount, 38° tilt

Energy Storage

Batteries: 120 GBS-LFMP40AH cells (Elite Power Solutions), 3.20 VDC nominal, 40 Ah, LiFeMnPO4 chemistry

Battery bank: 384 VDC nominal, 40 Ah total

Battery/inverter disconnect: 40 A, 600 V disconnect (at battery) and 63 A, 800 V breaker (internal to inverter)

Battery management system (BMS): Elite Power Systems BMS controllers, accessed via Modbus/RS-485 web interface

Balance of System

Inverter: Princeton Power Systems DRI-10, 254-600 VDC nominal input (batteries and PV input ports), 240 VAC output, 10 kW

PV charge controller: Integral to PPS DRI-10 inverter, 40 A, MPPT, 254-600 VDC nominal input voltage, 260-590 VDC nominal output voltage (MPPT range)

Backup generator: Generac 55030 (LP or natural gas)

System performance metering: Internal to DRI-10 inverter, accessed via Modbus

Wind System

Date re-commissioned: October 2014

Wind resource: 10.25 mph average annual wind speed at 120 ft.

Production: 224 AC kWh per month, average

Wind Turbine & Tower

Turbine: Weaver 5

Rotor diameter: 16.3 ft. (5.0 m)

Rated energy output: 330 AC kWh/month @ 12 mph average (5.4 m/s)

Rated peak power output: 5,030 W at 29.1 mph

Tower: 120 ft. (36.6 m) Nudd Towers, guyed lattice

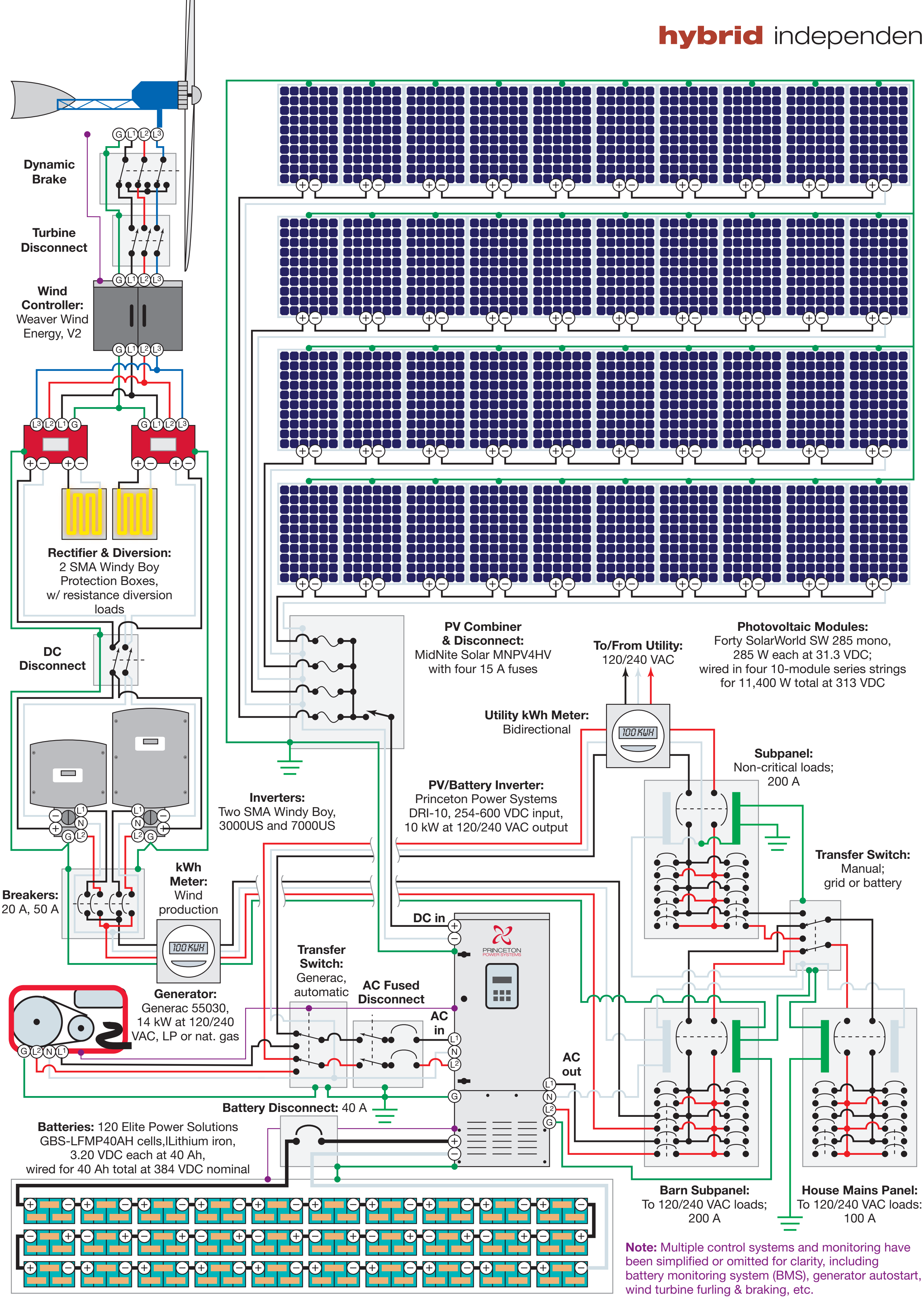
Wind Balance of Systems

Turbine controller: Weaver Wind Energy V2 controller, 30 A

Inverter #1: SMA Windy Boy 3000US, 200–500 VDC input, 240 VAC output; active at lower wind speeds (lower start voltage)

Inverter #2: SMA Windy Boy 7000US, 250–600 VDC input, 240 VAC output; active at higher wind speeds (higher start voltage)

Wind system performance metering: electromechanical kWh meter



Dynamic Brake
Turbine Disconnect
Wind Controller: Weaver Wind Energy, V2
Rectifier & Diversion: 2 SMA Windy Boy Protection Boxes, w/ resistance diversion loads
DC Disconnect
Inverters: Two SMA Windy Boy, 3000US and 7000US
Breakers: 20 A, 50 A
kWh Meter: Wind production
100 KWH
Generator: Generac 55030, 14 kW at 120/240 VAC, LP or nat. gas
Transfer Switch: Generac, automatic
AC Fused Disconnect
AC in
DC in
AC out
PRINCETON POWER SYSTEMS
Battery Disconnect: 40 A
Batteries: 120 Elite Power Solutions GBS-LFMP40AH cells,lLithium iron, 3.20 VDC each at 40 Ah, wired for 40 Ah total at 384 VDC nominal
PV Combiner & Disconnect: MidNite Solar MNPV4HV with four 15 A fuses
To/From Utility: 120/240 VAC
Photovoltaic Modules: Forty SolarWorld SW 285 mono, 285 W each at 31.3 VDC; wired in four 10-module series strings for 11,400 W total at 313 VDC
Utility kWh Meter: Bidirectional
100 KWH
PV/Battery Inverter: Princeton Power Systems DRI-10, 254-600 VDC input, 10 kW at 120/240 VAC output
Subpanel: Non-critical loads; 200 A
Transfer Switch: Manual; grid or battery
Barn Subpanel: To 120/240 VAC loads; 200 A
House Mains Panel: To 120/240 VAC loads; 100 A
Note: Multiple control systems and monitoring have been simplified or omitted for clarity, including battery monitoring system (BMS), generator autostart, wind turbine furling & braking, etc.

continued from page 32

using the conventional braking, which adds wear and tear to the car. Instead, I charge the battery to 80% so I can use the regen braking, and possibly extend the life of the battery and the car's conventional brakes.

Energy use for the Leaf is typically 3.5 to 4.0 miles per kWh. So if I drive 12,000 miles annually, that means it consumes 3,000 to 3,429 kWh each year, which is about equal to the wind generator's output. As such, the PV system's output—estimated to be about 14,000 kWh annually—covers all other household loads, about 20 kWh/day or 7,300 kWh per year. This leaves some surplus energy (about 6,700 kWh per year) that we could use, perhaps for electric space heating to displace some of the fuel we're currently burning.

We've never done a load analysis in our home, but by adding solar, we're producing more than our usage—even with charging the EV. Should the grid go down, I probably won't charge the Leaf until I verify that I have ample energy from the PV and wind systems. I have driven the Leaf 3,491 miles in the 17 months since I bought it, and all of those were within 15 miles of the center of Ithaca. So my driving habits fit very nicely with the Leaf's specs.

William with his Nissan Leaf electric car, which is powered entirely by the sun and wind.

Resources

Elite Power Solutions (lithium ion batteries and BMS) • **elitepowersolutions.com**

Iron Ridge (PV rack) • **ironridge.com**

Princeton Power Systems (DRI-10 inverter) • **princetonpower.com**

SolarWorld (PV modules) • **solarworld-usa.com**

Re-Source Power (PV installer): Joshua Brown

Weaver Wind Energy (Weaver 5 turbine and wind system design) • **weaverwindenergy.com**

Cost & Motivation

The cost—$127,000—for the wind, PV array, and battery systems seemed reasonable considering the system's novelty and complexity. The 30% federal tax credit applied to both the wind and PV systems. And a New York State Energy Research and Development Authority (NYSERDA) wind incentive of $11,525 reduced the upfront cost of the wind system. (There is also an NYSERDA incentive for PV systems. However, there were going to be delays in getting the DRI-10 approved for the NYSERDA incentive, so we sacrificed receiving this incentive to expedite the project.)

I've been asked how long the payback is, and what effect it has on my monthly bills. I don't know, because saving money was not my main motive, although I certainly have no objections to it.

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PV System

Rapid Shutdown

by Justine Sanchez

In 2014, section 690.12 "Rapid Shutdown of PV Systems on Buildings," was included in the *National Electrical Code* to safely allow firefighters and emergency responders to easily and quickly shut down energized PV system circuits on buildings. Here, we'll explain what needs to happen and which PV circuits are subject to this *Code* requirement, and discuss the methods and equipment available to achieve compliance. Additionally, we look forward to the upcoming 2017 *NEC* and how changes to the *Code* will impact rapid shutdown requirements.

Why is Rapid Shutdown (RSD) Needed?

Residential PV arrays are commonly installed with series string voltages up to 600 VDC (non-residential systems up to 1,000 VDC). A simple rooftop DC disconnect cannot protect emergency responders from these high voltages—during the day, full array voltage is produced on the conductors up to the input side of that disconnect. And on the output side of the DC disconnect, capacitors in the inverter can create high voltage between the DC disconnect and the inverter. Article 690.12 proposes solutions to rapidly reduce voltage to an acceptable level.

2014 *NEC* 690.12 Requirements

This *NEC* section is broken into five subsections. In 690.12(1), the *NEC* specifies which conductors must be controlled by a RSD method—PV system conductors of more than 5 feet in length inside a building, or more than 10 feet from a PV array. The 2014 *NEC* permits having a 10-foot zone around the PV array within which PV circuits on a building can still be at high voltage after shutdown is activated. This area will be reduced in the 2017 *NEC* as RSD requirements become more restrictive.

Sections 690.12 (2) and (3) specify that when RSD is activated, controlled conductors must be no more than 30 V (with a maximum power of 240 volt-amps) within 10 seconds. 30 V is considered the "touch-safe" voltage limit in wet environments. This voltage still allows for 24 V control circuits to be used, to allow RSD methods using contactors. Limited voltage and power is measured between any two current-carrying conductors and also between any conductor and ground.

Part 4 of 690.12 requires labels be provided, informing responders that the system is equipped with RSD, with instructions on how to initiate shutdown. Lastly, 690.12(5) specifies that equipment must be listed and identified, but not specifically for PV systems—off-the-shelf contactors, motorized switches, and shunt trip breakers can be used. This is another subsection that will be changing in the 2017 *NEC*. Under the 2014 *NEC*, installers can use any listed equipment to provide RSD, as long as it's not installed in a way that could violate the product's listing.

Courtesy Enphase Energy

Like all microinverters, this Enphase S230 offers RSD capability by default.

Batteryless Grid-Tied Systems

For batteryless grid-tied systems, "PV system circuits on or in buildings" refers to any circuit that is a part of the PV system on or in a building, be it a DC circuit from the array to the inverter or an AC circuit from the inverter to a backfed circuit breaker. (For a refresher on GT system layouts, see "Back Page Basics" in this issue.) These circuits must have RSD capability if they're on the building and located more than 10 feet from the array or inside a building and more than 5 feet in length. While this section is aimed at roof-mounted PV systems, ground- and pole-mounted systems have to comply if there are PV circuits from that system on or in a building (but RSD is only required on those circuits actually in or on the building).

RSD equipment is effective in reducing shock potential, but these *NEC* requirements are introducing new challenges for system installers. Thankfully, there are several scenarios that already offer RSD capability without the need for additional equipment, time, or expense. It is important to note that shutting down grid power to a utility-interactive inverter shuts off the AC output to the grid within 2 seconds, so that circuit already complies. Because that inverter AC output circuit is already covered, the RSD requirements for these batteryless grid-tied (GT) systems become focused on the DC circuit(s).

Grid-tied systems with module-level power electronics (MLPEs), such as with AC modules or microinverters, already offer RSD. Since these utility-interactive inverters are within the array itself—each module is paired with its own inverter—there are no DC circuits extending beyond the array. In this case, the RSD initiator could simply be the AC main service disconnect, and a label could be located identifying the system as having RSD that is initiated by switching the service disconnect to the "off" position.

RSD Solutions with MLPEs

Manufacturer	Model	Inverter-Specific	MLPE Type	Notes
ABB abb.com	MICRO 250 & 300	n/a	Micro-inverter	
APsystems apsystems.com	YC500A & YC500i	n/a	Micro-inverter	Two modules per unit
Darfon darfonsolar.com	GC320	n/a	Micro-inverter	
Enphase Energy enphase.com	M215, M250, S230, S280	n/a	Micro-inverter	
Magnum/ Sensata magnum-dimensions.com	MicroGT 500	n/a	Micro-inverter	Two modules per unit
Renesola renesola.com	Replus-250	n/a	Micro-inverter	
SMA America sma-america.com	Sunny Boy 240-US	n/a	Micro-inverter	
SolarEdge solaredge.com	Power Optimizer	SolarEdge inverter	DC-DC converter	
Tigo Energy tigoenergy.com	TS4	No	DC-DC converter	
	MM2ES			Two modules per unit


Courtesy SolarEdge

SolarEdge offers a fully RSD-compliant solution with its Power Optimizers (DC-to-DC converters), which are designed to be installed with SolarEdge inverters.

Similarly, DC-to-DC converters limit module output within the array with system shutdown, since each module is paired to a converter. Note that when using DC-to-DC converters, the array output conductors are connected to a string inverter—investigation is needed to make sure there is no high voltage present from the capacitors discharging on the DC side of the inverter after 10 seconds of system shutdown. It is common for transformerless (TL) string inverters to be able to meet this time-frame requirement. For other inverters, installers must verify the 10 seconds with the inverter manufacturer—otherwise, additional RSD equipment needs to be installed on those conductors to comply with 690.12.

Other scenarios with built-in compliance. In addition to systems using MLPEs, two other system setups do not need additional RSD equipment to comply with 2014 *NEC* 690.12. (These will not meet 2017 *NEC* requirements.):

- If the array is roof-mounted but the inverter is mounted within 10 feet of the array and all conductors are located external to the building.
- The array is ground- or pole-mounted with the inverter mounted at the array or the inverter is mounted in (or on) a building, but its DC circuits in (or on) the building are less than 5 feet in length.

When RSD devices are required, they need to be controlled from an accessible location. Options include remotely activated pass-through or combiner box solutions obtained from the inverter manufacturer (such as those from ABB, Fronius, Ginlong, OutBack Power, SMA America, and Solectria/Yaskawa) or from a third party (including options from Bentek, Innovative Solar, MidNite Solar, and Solar BOS). The RSD initiator can be the DC disconnect, a loss of utility AC power, or a separate control box with a specific rapid shutdown button, switch, or handle.

Courtesy ABB

This ABB low-profile RSD pass-through box fits behind a module, connecting to the series string positive and negative wires via the locking connector (H4) input leads. The output is connected to the output circuit routed to an ABB UNO or PVI inverter. This RSD solution is offered in one- or two-string models.

Courtesy Fronius

The Fronius Rapid Shutdown Box works with single or multistring arrays and with various Fronius inverters.

Courtesy Ginlong

The Ginlong Solis RSD is offered in one- and two-string models, and connects directly to the PV strings via MC4 cables.

Battery-Based PV Systems

More complex battery-based systems may require additional circuits be controlled to comply with 690.12. The scenarios already outlined for batteryless grid-tied systems' PV array DC circuits also apply to battery-based systems. Besides the PV array's DC conductors, some authorities having jurisdiction (AHJs) may also require that the battery-to-inverter DC conductors (if more than 5 feet in length); battery to DC loads conductors (if there are any DC loads); and the AC output circuit from the inverter to the AC loads be considered.

Battery-based inverters have no DC input capacitors, so that eliminates one RSD (unless it's an AC-coupled system, see below). However, charge controllers may have capacitors that may require RSDs on the incoming PV DC circuit conductors.

If battery-to-inverter conductors are more than 5 feet long, an RSD method may need to be included to activate their shutdown. *NEC* 690.71(H) also requires a disconnecting means at the battery bank when its conductors are longer than 5 feet. Because these conductors are in a building, a simple DC disconnect at the battery bank isn't sufficient—emergency responders need to be able to activate shutdown from an accessible location (i.e., outside of the building), so the RSD method will need to be remotely activated. Since the battery bank powers the inverter and any DC load, once that battery RSD device (and the PV DC circuit RSD) is activated, all other circuits (DC load circuits and inverter AC output circuits) are also shut down, so system shutdown is complete.

Grid-tied with battery backup systems are designed so that, during a utility outage, a critical load subpanel (and in some cases the whole house) will still energize loads from the inverter output, which is powered by the battery bank. Unlike batteryless grid-tied systems, the loss of utility AC power can't serve to initiate shutdown of this AC circuit—this would render the backup battery bank useless during a utility outage. An RSD initiator for this system must be independent of utility power.

SMA's TL inverter line offers limited backup power during the daytime with its SPS feature. The RSD solution shown here uses a remote switch, instead of loss of utility power, to initiate shutdown.

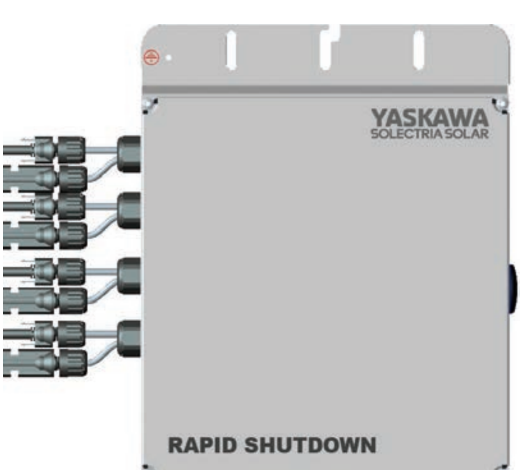
Courtesy SMA

RSD Solutions from Inverter Manufacturers

Manufacturer	RSD Model	Inverter Models Supported	System Type	AC Connection or External Power Supply Needed	Number of Input Strings	Number of Outputs	Input & Output Wire	Box Connection Type	RSD Initiator
ABB abb.com	Low-profile Rapid Shutdown Box, 1-string pass-through	PVI & UNO	GT	Yes, DC power supply included	1	1	Locking connector cables	Locking connector cables	Loss of utility power
	Low-profile Rapid Shutdown Box, 2-string pass-through				2	2			
	Rapid Shutdown box 2-string pass-through				2	2	Terminals	Conduit knockout	Loss of utility power or remote switch
	Rapid Shutdown box 2-string combined				2	1			
	Rapid Shutdown box 4-string combined				4	2			
Fronius fronius.com	Rapid Shutdown Box-Single String	Galvo, Primo, Symo	GT	No	1	1	Terminal & strain reliefs	Conduit	Loss of utility power or remote switch
	Rapid Shutdown Box-Multistring	Primo, Symo			4	2			
Ginlong ginlong.com	Solis-RSD-1G 1:1	US Solis TL*	GT	Yes—AC	1	1	Locking connector cables	Locking connector cables	Loss of utility power or remote switch
	Solis-RSD-1G 2:2				2	2			
OutBack Power outbackpower.com	ICS Plus Combiner and RS Initiator**	not inverter specific***	GT & BB	Yes—DC	6	1	Terminal & strain reliefs	Conduit knockout	Remote switch "RSI"
SMA sma-america.com	Rapid Shutdown Box	Sunny Boy-US & Sunny Boy-US TL	GT	No	4	2	Locking connector cables	Conduit knockout	Remote switch Rapid Shutdown Controller due to Secure Power Supply
Yaskawa—Solectria solar solectria.com	Rapid Shutdown Combiner	PVI3800TL thru 7600TL	GT	No	4	2	Locking connector cables	Conduit knockout	Loss of utility power

*Also compatible with other string inverters where max. system voltage is less than or equal to 550 VDC
**Additional components include DC breaker control, power supply, and relay trip breakers
***OutBack ICS Plus can be used with third-party battery-based or GT inverters

Even if batteries are installed within 5 feet of the inverter, a solution for controlling the backed-up AC circuits may need to be implemented per 690.12. A remotely activated switch or circuit breaker in the battery circuit or in the inverter-output circuit will suffice. Either of these options will shut down circuits that would otherwise remain energized without utility power.



Courtesy Yaskawa-Solectria Solar

The Yaskawa-Solectria Solar Rapid Shutdown combiner can accommodate up to four input series strings and is compatible with its PVI transformerless inverter line.

Courtesy OutBack Power (2)

The OutBack Power ICS Plus Combiner and RSI Initiator can work in grid-tied and/or battery-based systems, and are not dependent on using OutBack inverters.

Third-Party RSD Solutions

Manufacturer	RSD Model	Designed For	Module- or String-Level Control	Control Power Supply	Number of Input Strings	Number of Outputs	Connection Types	RSD Initiator
Bentek bentek.com	Rapid Shutdown System—2-string	GT string inverters	String	DNR	2	DNR	Locking connectors	Control Box "RSC"
	Rapid Shutdown System—3-string				3	DNR		
Innovative Solar innovativesolarinc.com	SolaDeck 2-Channel*	GT string inverters	String	Low-voltage DC or AC (with converter option)	4	2	Terminal & strain reliefs/conduit knockout	Loss of utility power, DC disconnect or remote switch (E-Stop)
	Polycarbonate 2-Channel				4	2	Terminals/conduit	
	Powder-Coated Steel 4-Channel				8	4	Terminals/conduit	
MidNite midnitesolar.com	Disconnecting Combiners, Shut Off Boxes & Birdhouse I**	GT or BB systems	String	Power supply board (MNDiscoPSB)	4 to 16 string combiner options	1 or 2	Combiner Box - terminal & strain reliefs; conduit knockout	Control Box "Bird House"
Phoenix Contact phoenixcontact.com	Solarcheck RSD***	GT string inverters	Module	Optional	N/A	N/A	Locking connector cables	Loss of utility power or DC disconnect
SolarBOS solarbos.com	Rapid Shutdown Solutions Pass-Through Disconnect—2-string	GT string inverters	String	Power supply assemblies (4 options)	2	2	Terminals/conduit	Power supply assembly (includes emergency button)
	Rapid Shutdown Solutions Pass-Through Disconnect—4-string				4	4		
	Rapid Shutdown Solutions Contactor Combiner—6-string				6	1		
	Rapid Shutdown Solutions Contactor Combiner—8-string				8	2		

DNR = Did not reply; *Flashing included
**Additional components include Battery Disconnect Module, remote trip breakers, and control cabling
***Startup unit required at inverter

The Bentek Rapid Shutdown system offers two- and three-string options for grid-tied inverters. The rapid shutdown controller shown here is used to initiate shutdown and is installed in an accessible location.

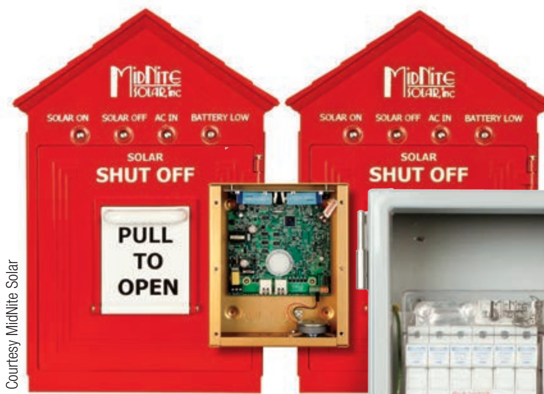
AC-coupled battery-based systems include both batteryless grid-tied inverters and battery-based inverters. In an outage, the battery-based inverter "tricks" the grid-tied inverters into thinking the grid is still present. This keeps the grid-tied inverters producing power, which is used by the critical loads and the battery-based inverter to charge the battery bank. And while these systems require a change in thinking about 690.12, generally they shouldn't require more RSD devices then a standard battery-based system. For example, an AC-coupled system with an array utilizing microinverters now cannot depend on loss of grid power to initiate rapid shutdown for the PV array. However, since the battery-based inverter relies on the battery bank power to function, a remotely activated DC battery switch or an AC switch that is required to shut down the battery-based inverter output will also automatically shut down the microinverters' output.

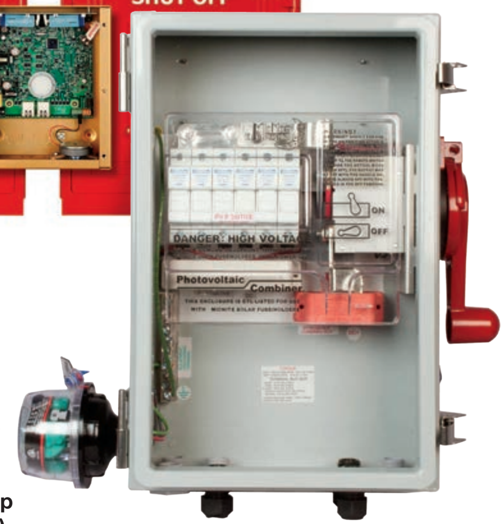
What's Ahead: The 2017 *NEC* & RSD Requirements

Many changes to the 2017 *NEC* will affect how PV systems need to comply with RSD requirements. In section 690.1, the *NEC* redefines the conductors considered to be part of the "PV system" as only those associated with the PV array and the output of a batteryless inverter. Battery-to-inverter circuits, DC loads circuits, and battery–based inverter AC output circuits are no longer included. This eliminates RSD


Courtesy Innovative Solar (2)

The Innovative Solar RSD is available as a SolaDeck flashed rooftop combiner or in a nonflashed, nonmetallic version. (An eight-string input version is also available.)





Courtesy MidNite Solar

The MidNite Solar Rapid Shutdown system, which can be used in battery-based and grid-tied systems, includes the Birdhouse (above) that controls disconnecting combiner boxes (right) and remote trip breakers (not shown).

Rapid Shutdown Examples

Batteryless Grid-Tied Inverter with Manufacturer RSD

- Array type: Roof-mounted batteryless grid-tied
- Inverter: Grid-tied string Fronius SnapINverter mounted on an external wall, with 20-foot-long DC array-output-to-inverter-input wire run, external to the building
- RSD solution: A Fronius Rapid Shutdown Box can be mounted within 10 feet of the array. The incoming PV conductors are connected in the Rapid Shutdown Box. The outgoing conductors (along with two signal wires) are passed through conduit, and land at the inverter. RSD happens via loss of AC power, which triggers a relay to open the contactor in the rapid shutdown box, de-energizing the PV output circuit, and simultaneously causing the inverter to discharge it's capacitors within 10 seconds, and system shutdown complete. (Approx. RSD equipment cost: $315 to $450.)

Batteryless Grid-Tied, Inverter without RSD

- Array type: Roof-mounted batteryless grid-tied
- Inverter: Grid-tied inverter without an RSD solution, additionally the inverter cannot discharge its DC capacitors within 10 seconds. The inverter is mounted on an external wall, with 20-foot-long DC array-output-to-inverter-input wire run, external to the building
- RSD solution: A third-party RSD device needs to be located within 10 feet of the array; another RSD device needs to be mounted near the DC input to the inverter. Bentek's rapid shutdown system (RSS) can be used and a Rapid Shutdown Module (RSM) mounted within 10 feet of the array. The RSM is connected to the input and output wiring via locking connectors; another RSM is mounted at the inverter. The Rapid Shutdown Controller (RSC) is mounted near the utility service entrance. The RSC's red "Solar Shut Off" button, which is the rapid shutdown initiator, remotely activates both the RSM at the array and the RSM at the inverter. Within 10 seconds of being activated, those DC circuits will measure no more than 30 V and rapid shutdown will be complete. (Approx. RSD equipment cost: $1,200.)

Grid-Tied with Battery Backup

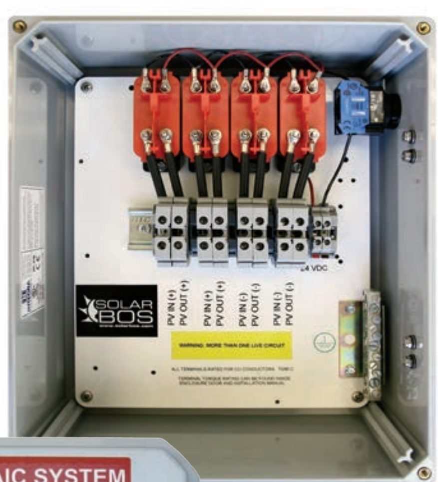
- Array type: Roof-mounted battery-based grid-tied, This system has the same rooftop array layout, where the array output conductors travel 20 feet in conduit external to the building. Then, however, the DC conductors enter the garage, traveling along an interior wall through 10 feet of conduit before landing at an DC power center.
- Inverter: Battery-based GT; this system uses a MidNite Solar Classic charge controller. The battery-to-inverter conductors measure 7 feet.
- RSD solution: RSD devices are installed at three locations—one at the array, within 10 feet; another at the input to the charge controller; and the last one on the battery-to-inverter conductors. MidNite Solar's Rapid Shutdown System can be used. The PV array input conductors will be routed through a MidNite Solar disconnecting combiner box (with their optional Power Supply Board installed) mounted within 10 feet of the array. The output PV circuit, along with a low voltage control cable, is routed through conduit into the garage and to a DC power center. This PV circuit is routed through a remote-trip circuit breaker connected to the input of the charge controller.

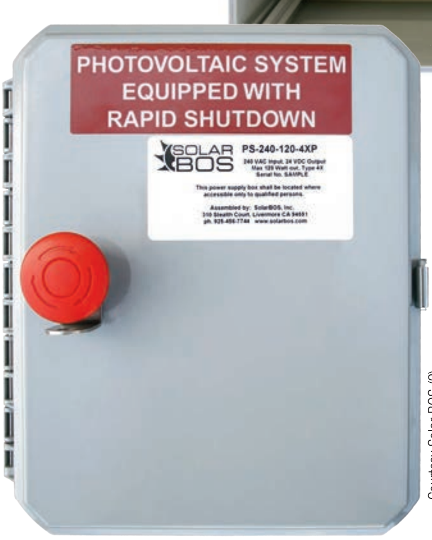
  MidNite Solar's Battery Disconnect Module (BDM) works with its large DC remote trip (RT) breakers in the DC power center to provide rapid shutdown for the battery-to-inverter circuit. The Birdhouse I Controls the RSD system. (Note: It requires 120 VAC from a dedicated AC circuit.) It is installed in an accessible location for first responders, communicating with the combiner box, remote trip breakers via the control cable to initiate rapid shutdown. (Approx. RSD equipment cost: $1,500.)

Courtesy Phoenix Contact

The Phoenix Contact SolarCheck RSD offers module-level rapid shutdown.

The Solar BOS line provides rapid shutdown of up to eight series strings, and works with grid-tied string inverters.





Courtesy Solar BOS (2)

requirements for those circuits, making compliance less complicated for battery-based systems.

Conductors requiring RSD control will be reduced from 10 feet to within 1 foot of the PV array, which will increase the numbers of systems needing RSD. The time frame for voltage to reach less than 30 V will be increased, from 10 seconds to 30 seconds, possibly decreasing the number of inverters that will require additional RSD on their input conductors (due to capacitor discharge time).

The 2017 *NEC* also will address requirements within the array boundary, offering three options for compliance:

- Option 1: List or field-label the PV array as an RSD PV array.
- Option 2: Limit controlled conductors within the array boundary to 80 V or less within 30 seconds of RSD initiation.
- Option 3: Install nonmetallic PV array with no exposed wiring and the array more than 8 feet from any grounded metal parts.

These new requirements for within the array boundary seem to imply module-level control may play a large role in meeting 2017 requirements, however the new requirements will not be enforced until 2019—giving the industry time to develop the necessary safety and certification standards and various manufacturers time to develop compliant solutions. Revised language will require listing of the RSD equipment as specifically providing RSD protection. Then, off-the-shelf contactors, motorized switches, and shunt trip breakers will only be able to be used if they are listed to a specific RSD UL-standard, which will need to be developed during this time frame.

Finally, section 690.56(C) revises field-labeling requirements for PV systems equipped with RSD, which will help first responders differentiate between systems designed to meet *NEC* 2014 versus 2017 (i.e. systems that do not control conductors within the array and those that do). In the situation that a building has multiple PV systems built to different *NEC* standards—such as no rapid shutdown (pre *NEC* 2014), *NEC* 2014 compliant, or *NEC* 2017 compliant. The plaque or directory needs to show a plan view of the building with a dotted line around array areas that remain energized after RSD has been initiated.

Various editions of the *NEC* are used across the country; not all areas are yet enforcing the 2014 *NEC*. Several states, including California, are currently operating under the 2011 *NEC*, and a few states are still enforcing the 2008 *NEC*. You can search nema.org to find out what *NEC* cycle is being enforced in each state (or by jurisdiction) and when it was adopted to get an idea of how quickly the next code cycle may be implemented.

In this effort to safely allow firefighters and emergency responders to easily and quickly shut down energized PV system circuits on buildings, the industry as a whole has stepped up with several solutions. With RSD requirements continuing to develop, it is important for system designers and installers to stay on top of the current standards, as well as the upcoming changes and the modern equipment and solutions being offered.

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Straw Bales & Solar Energy

A Natural Partnership

by Rebecca Tasker

Building with straw can completely change how we use resources in construction, how we heat and cool our homes, and how we relate to the buildings we inhabit.

Straw bale building has unique and important answers to a few broad questions that help us get to the heart of sustainable building:

- What materials will have the lowest environmental impacts during and after construction?
- What materials and techniques will result in the most effective building—one that is durable, efficient, safe, healthy, and comfortable?
- What materials can be used together to make a building appealing over generations because of its resonant beauty, sense of solid shelter, and peaceful comfort?

Straw bale walls can be part of a whole-house plan to achieve high energy efficiency while keeping embodied energy low.

Jim Reiland

Low-Impact Building

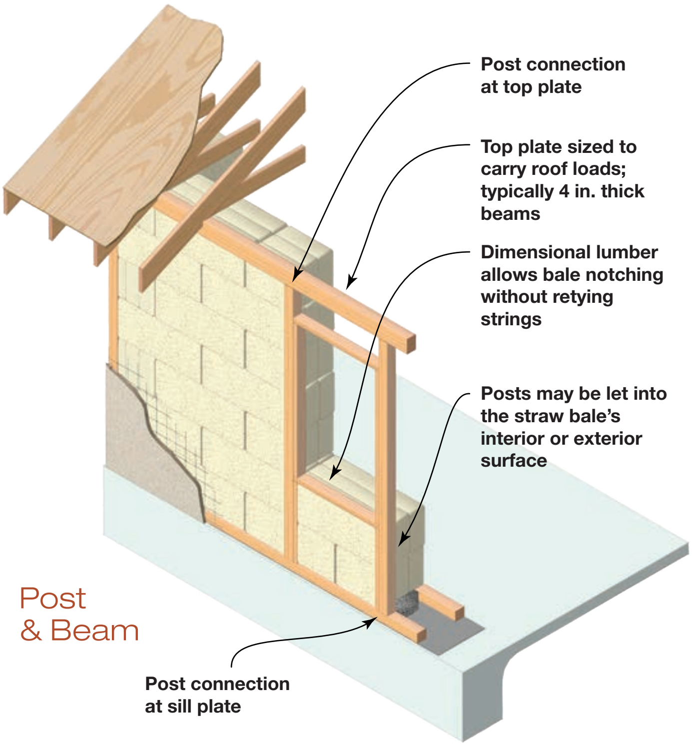
The straw in bales is left over from grain harvesting. Crops aren't grown just to make straw bales: the plants are being grown for rice, wheat, barley, or oats. Once the grain is harvested, the stalks are bundled together into bales.

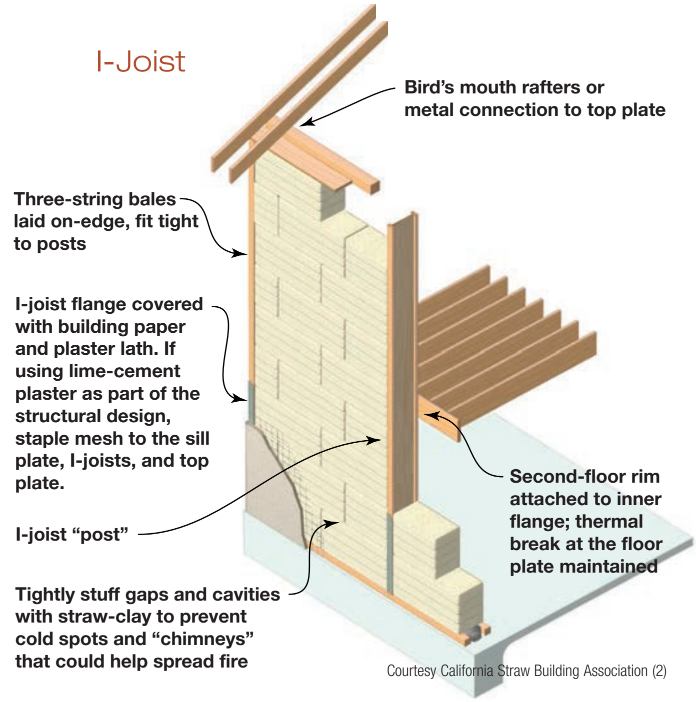
Straw is an abundant agricultural by-product with few uses, and using straw bales as a building material is a great example of upcycling. Unlike wood, straw is an annual crop and can often be sourced locally—frequently from less than 100 miles from a building site. That results in a small carbon footprint: other than the energy it takes to bale the leftover stalks and then deliver that bale to your job site, all of the other resources needed to produce that bale were used for the production of food.

The California Straw Building Association (CASBA) is currently studying how much carbon a straw bale wall sequesters. Plants draw carbon out of the air as they grow and lock it up, releasing it only when they decompose (or burn, which is what happens to many grain fields when the straw is not upcycled). By keeping the straw in the wall, the carbon is not released into the atmosphere (see "Carbon Sequestration" sidebar).

Plastered straw bales replace the insulation and drywall, and often the paint. They can reduce the amount of lumber needed for framing, and may even be part of the structure. Leftover straw can be used as fiber in the plaster, or used onsite as mulch without further processing. And at the end of a long life in a straw bale building, a straw bale is biodegradable.

Natural plasters used with straw bale construction also have lower impact than most wall finishes (such as cement stucco exterior or painted drywall interior), especially clay plaster. Clay is another abundant material, and can be found almost everywhere. Unlike cement—which uses a huge amount of energy during processing—clay requires little processing, so it has very low embodied energy.





Courtesy California Straw Building Association (2)

Straw Bale Walls

Bales are used flat or on edge. The terminology is simple, yet surprisingly hard to describe. "Laid flat" means that the bale is placed on its wider side so the bundled straws are horizontal and the strings that bind the bale face up and down. "On-edge" means that the bale is placed on its narrower edge, with the strings facing in and out, and the straws vertical.

In a load-bearing straw bale house, the bales are laid flat and stacked in a running bond. The combination of bales and their plaster skin resists shear forces. This building technique is well-suited for small buildings in low seismic areas with a reliably long period of dry weather, as the walls are exposed until the roof is on.

More commonly, straw bales are used to infill a post-and-beam wall system, usually made of 4-by dimensional lumber. The bales are again laid flat, notched around the posts, and stacked in a running bond.

In a post-and-beam system that utilizes I-joists as posts, the bales are laid on-edge between the I-joists, with no notching needed. Post-and-beam systems have the advantages of being more familiar to building code officials, having a roof overhead to protect the walls from moisture, and having more shear-wall options.

All straw bale walls need to sit on a double-sill plate or curb to protect against ground moisture. At the top of a load-bearing wall, the roof loads are transferred to the wall via a roof bearing assembly, which could be a wall-width box beam, or a 4-by top plate.

In a post-and-beam structure, bales are notched around the structural uprights, preventing thermal bridging.

Jim Reiland (2)

In an I-joist structure, bales are fit between the joists, which reduces thermal bridging compared to a conventionally framed structure.

Jim Reiland

Left: A bale wall will rest on a raised and insulated double sill.

Right: Author and builder Rebecca Tasker (center) helps homeowners ceremonially set the first bale.

Rebecca Tasker

When tracking the energy a building consumes, we can't overlook the energy that's consumed during the mining and manufacturing processes for the building materials. This embodied energy can greatly exceed a building's operating energy. In their presentation, "The Carbon Elephants in the Room," builders Chris Magwood and Jacob Deva Racusin compare the energy requirements and carbon emissions of embodied versus 35-year operational data for four different houses in two different climates. While operational energy use has been reduced greatly in high-performance homes, if they are constructed with conventional materials (like polyurethane foam insulation), their embodied energy can still be high. They found that the carbon embodied in the materials used to build such a home was greater than half of the home's 35-year operational carbon emissions. Furthermore, compared to a high-performance home made of low embodied-energy (EE) materials (such as straw), the embodied carbon of the conventional home was higher than the *combined* 35-year operational carbon and the embodied carbon of a low EE high-performance home.

To make the best dent in total energy use and carbon emissions, we need to reduce both operational and embodied energy. The building industry is beginning to pay attention to embodied energy and carbon emissions through metrics like the Living Building Challenge and LEEDv4. We're realizing that the energy meter shouldn't start running after the building is built—the energy that went into making the building matters, too.

Carbon Sequestration with Straw

Until recently, the prevailing view for high-performance building has been to choose materials primarily to support performance, without much consideration for the materials' embodied energy and carbon footprint. But accord is growing within the green building community that the embodied carbon emissions of construction materials—how much carbon dioxide is emitted in the manufacture and transport of the materials—is becoming critical to making a truly greener home.

The carbon emissions (as well as other pollutants) associated with various building materials—especially manufactured materials—have a large impact. In contrast, natural, organic, or biomass-based materials are usually net carbon sinks when used in a building.

Calculating the carbon sequestration capacity of straw bale building depends upon several variables: the type of straw (wheat, rice, oat, etc.) and where and how it was grown. Many other aspects of straw bale construction need to be studied before we know how much carbon straw bale can sequester and for how long. But current evidence suggests that straw bale construction and other uses of straw in the building envelope is a powerful tool for reducing the total emissions of a building. CASBA and other organizations are continuing to pursue this research.

—Massey Burke

Rebecca Tasker

Exterior stucco can be lime-cement or, for reduced embodied energy, earthen-based, and any plaster used must be vapor-permeable.

Effective Building

A building with the lightest footprint would probably be a mud and grass hut, but in many places that is not the most effective building to shelter us, to keep us safe and healthy in the long term. Straw bale buildings are high-performance. Everyone knows that a straw bale building is "natural" and "green," but fewer people know just how effective it is!

R-value. Straw bale walls have a relatively high R-value—the measure of a material's ability to resist the flow of heat. In the summer when it's hot outside and cool inside, the heat will work its way through the walls. The higher the R-value of the wall, the longer it will keep that heat out.

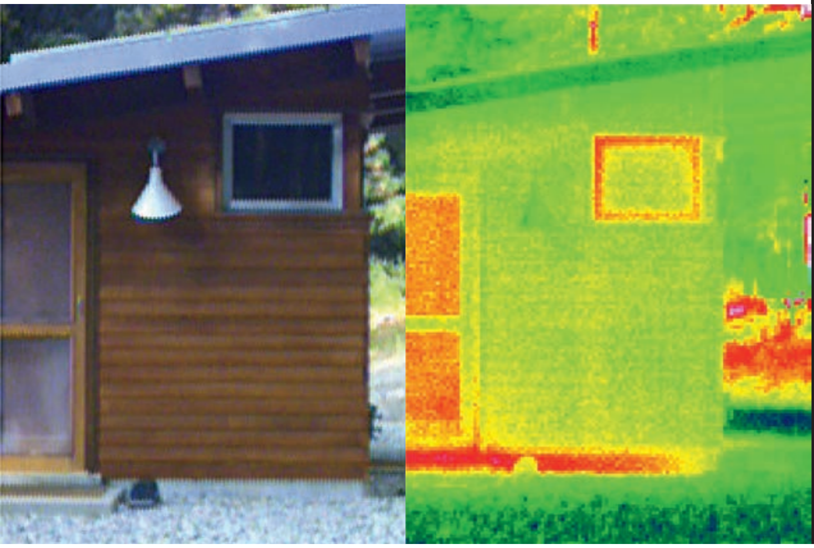
The accepted rating for straw bales is R-1.45 per inch, and bales are 18 to 23 inches thick when laid flat. The accepted rating when the bales are on edge is R-1.76 per inch, and the bales are around 15 inches thick. The result is a wall with an insulation value between R-26 and R-33 (see "Thermal Performance" sidebar). If you ask your local energy specialist about an R-30 wall, they will probably tell you is it's well-suited for most climates.

Thermal bridging is when a relatively non-insulating material, like wood, interrupts the insulation layer and bridges from one side of the wall to the other, more easily letting heat pass through. Because straw bale walls are so thick, penetrations are relatively shallow: the framing is on one side of the bales, usually only 4 inches deep, and electrical boxes penetrate only 4 inches. In an on-edge wall system, I-joists bridge the wall surfaces, but the wood webbing member is so thin and non-conductive that little heat is transferred.

Air leakage. Straw bale walls are pretty good at preventing air leakage, too. Because plastered straw bale walls have fewer edges than materials like plywood and sheetrock, there are fewer seams to seal. Well-built straw bale homes have reached Passive House standards for air-tightness—a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50). As with any tight building envelope, attention must be paid to getting fresh air through natural or mechanical ventilation.

continued on page 52

Bale wall systems have fewer thermal bridges that cause heat flow across the assembly.



Courtesy Arkin Tilt Architects (2)

Thermal Performance

Thermal resistance (R-value) of straw bale (SB) walls has been tested for 20 years, with the most reliable tests indicating R-values ranging from R-33 to R-50 (R per inch values of 1.46 to 2.25) for walls with three-string (22.5 by 16 in.) bales. The range results from variations in bale orientation, bale density, construction practices, and moisture content.

Standard stud-framed walls with R-19 insulation have an actual R-value of only about R-14 due to the lower R-value of the framing members (R-5.5 for 2 by 6 studs). Because straw bale walls do not have significant framing members to introduce thermal bridging, wall R-values are not similarly reduced.

In most climates, "thermal lag" increases the effective R-value of straw bale walls. Thermal lag is the time it takes heat to travel through a material. For straw bale walls, that's 12 to 15 hours. In temperate climates, this closely matches the daily change in outdoor temperatures (diurnal swing), so on cold days, the heat never escapes the exterior before daytime warming drives it back toward the interior. However, it takes weeks of simulated 0°F exterior conditions for straw bale walls to reach the steady-state heat flow that the official test—ASTM-236 (now replaced by ASTM C1363)—requires.

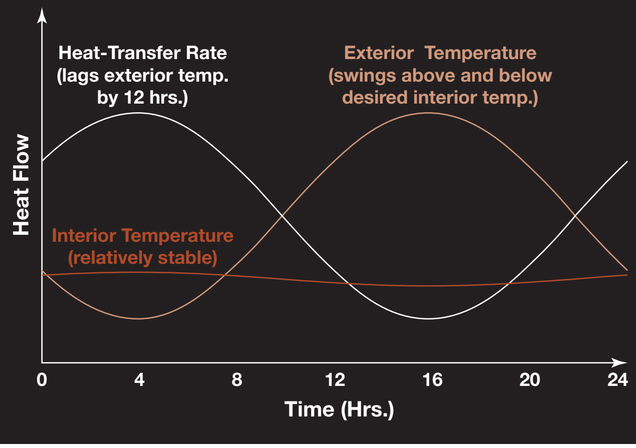
In the "hot box" test, one side of the wall is held as close to 70°F as possible with a small electric heater and small fan. The other side of the wall is held close to 0°F with a constant 15 mph fan-generated air current directed at it. Thermocouples across the surfaces of both the interior and exterior wall measure small fluctuations in temperature. Steady-state heat flow is defined as the point at which none of the thermocouples' readings change by more than 0.5°F in a five-minute period, and none of them change in the same direction during two consecutive 5-minute periods.

For an aluminum-framed window, steady-state heat flow is usually reached in less than 20 minutes. For a conventional framed and insulated wall, it takes an hour or two. For a straw bale wall, it takes two to three *weeks*. In climates where the temperature can stay at or below freezing for weeks, straw-bale walls perform closer to the tested R-values.

Our sense of thermal comfort depends more on mean radiant temperature (MRT, the average temperature of everything around us) than it does on air temperature. Straw bale walls have high thermal mass, which results in a very stable MRT. Combined with their other properties, they result in a very comfortable home.

—Nehemiah Stone

Thermal Lag Benefits



Well-sized roof overhangs protect the walls, and shade south-facing walls and windows from the intense summer sun.

Southern (Oregon) Comfort

Guided by images of thick-walled buildings in books and childhood memories growing up in Portugal's Azores Islands, John and Marie Galego set out to build their dream retirement home on rural land outside of Jacksonville, Oregon. They sold their 2,300-square-foot home in Boise, Idaho, moved to southern Oregon, and lived temporarily in two 200-square-foot straw bale buildings—one a kitchen and living space, the other with a bedroom and bath. This experience convinced them a small house would satisfy their needs and budget.

A double airlock entry reduces air exchanges by stopping blow-through when the outer door is opened.

Claire Anderson (2)

Home designer Anna Bjernfalk enthusiastically embraced the challenges posed by creating a small home that doesn't feel small. Ceilings in the main room and kitchen soar to a functional loft over the bedroom, bath, and pantry areas. South-facing clerestory windows illuminate both the loft and main living space. A large east-facing porch offers protected outdoor living space adjacent to the kitchen, and affords sweeping views of meadows and forested mountains. A south-facing double folding door opens onto what will one day be a garden patio, easing the boundary between inside and out.

Wood posts and beams hold up the roof; prefabricated steel bracing resists shear forces; and the plastered straw bales supply insulation and thermal mass. This structural system allowed John and Marie to use their abundant clay-rich site soil for base-coat interior plaster and for the earthen floor. Lime-plastered exterior walls offer durability in wind-driven rain. Locally sourced Douglas fir posts and beams support the loft floor, and make up the loft railings and access ladder. Kitchen counters and window stools are made of locally harvested walnut.

The house is set up for both rainwater collection and greywater use; the couple plans to develop these systems as time and budget allow. The orientation and design of the home allow winter solar gain and passive summer cooling. A 6 kW batteryless grid-tied system was designed to offset all of their electricity needs.

The Galego home received an Energy Trust of Oregon New Homes EPS (Energy Performance Score) score of 9, on a scale that ranges from 0 (best) to 200 (worst). For comparison, a similarly sized home in Oregon, built to minimum code standards, typically has a score of 60. The building's continuous plaster skin, combined with careful detailing at windows, doors, floor, and ceiling joints, inhibits air movement—the house had a blower-door test of 2 at ACH50.

The home and outbuildings—assembled in a clearing on a forested hillside, and surrounded by gardens and orchards—resemble the cheerful, ageless villages of their native country and make sensible use of the sun and abundant local resources—a good model to follow.

—Jim Reiland

Clerestory windows let in natural light and admit solar heat during winter.

Thick walls make deep windowsills, for an old-world feel.

High ceilings paired with well-placed windows promote convective cooling.

in a Solar Straw Bale Home

Overview

Dwelling: 960 sq. ft. straw bale home (895 sq. ft. heated)

Location: Jacksonville, Oregon

Owners: John and Marie Galego

Designer: Anna Bjernfalk, AB Design

Engineering: Snyder Engineers

General Contractor: Jim Reiland, Many Hands Builders

Energy

Passive solar: Long façade oriented east-west. Eaves sized to maximize winter heat gain and minimize direct summer sun. Thermal mass from 1.5-inch-thick interior earth plaster on straw bale walls and 1-inch earthen floor over compacted gravel.

Space heating: Hydronic floor, wood heater, heat-recovery ventilator

Cooling: Thermal siphon, with operable clerestory and gable-end windows.

Renewable energy: 6 kW grid-tied PV system

Other Features

Insulation: 18-inch-wide straw bales (R-26); R-15 rigid foam under slab and along foundation wall; R-50+ rock wool and rigid foam gable and clerestory walls; R-50+ rock wool ceiling

Envelope: Blower door test is 2 at ACH50

Windows: Double-pane, U-0.29

Lighting: LEDs

Water

Household: Well

Greywater (future): Collected from sinks, laundry, and shower; gravity flow to orchard

Rainwater (future): Collected from 1,700 sq. ft. steel roof; gravity flow to irrigation storage tanks

Materials

Roof: Standing-seam metal

Exterior wall finish: Lime plaster

Interior wall finish: Straw bale walls used site-dug earth-plaster base coats with locally sourced clay-plaster finish

Floors: Site-dug earth and locally sourced gravel

Claire Anderson (4)

A natural earthen floor covers R-15 insulation and provides thermal mass for storing passive solar gain.

Rebecca Tasker (2)

Multiple layers of natural plaster, both interior and exterior, mitigate diurnal temperature swings inside the building.

continued from page 49

Thermal mass provides heat storage. Imagine a rock sitting in the sun all day—the rock stays warm after the sun sets and the air temperature drops, because the rock has a lot of thermal mass and air has very little. The plaster on straw bale walls is 1-inch-thick evenly distributed thermal mass. This helps slow the transfer of heat through the wall and also slows changes in temperature, so a warm room stays warm longer.

Fire & seismic resistance. Plastered straw bale walls have a high fire-resistance rating: 1 hour for clay plaster and 2 hours for lime-cement, which both compare favorably to conventional building. Straw bales are so dense, it's like trying to burn a phone book—there isn't enough oxygen available for combustion: they just smolder, allowing a lot of time before the walls are compromised. For comparison, 0.5-inch-thick gypsum wallboard has a 15-minute rating. To achieve a two-hour fire-resistance rating for a conventionally framed exterior wall, you'd need an assembly with 1 inch of exterior cement stucco over 5/8-inch-thick fire-retardant sheathing over retardant-treated 2-by-6 wood studs, with two layers of 5/8-inch-thick fire-resistant gypsum wallboard on the interior.

Earthquakes are an important consideration in some locations. Seismic testing on straw bale wall assemblies demonstrate that they're up to the challenge. Because both the natural plasters and straw bales are flexible, they do well in earthquakes because they "bend" more than conventional materials before they break.

Vapor permeability. Straw bale walls are also vapor-permeable, which means that they allow water vapor to pass through them, though they don't allow air or liquid water to enter. People are damp—a family of four can produce as much as 2 gallons of moisture a day from breathing, showering, and cooking. If we choose a wall system that traps that moisture, we get moldy, sick buildings. If a building can't deal passively with moisture, we have to mechanically vent it.

The old adage about moisture was that "buildings have to breathe," but that's misleading because breathing entails air moving in and out—and we don't want air leaks. A better way to put it is that "buildings need to transpire." Clay or lime-plastered straw bale walls allow moisture to pass through without allowing air to pass through.

Clay plaster also has hygric mass, which is like thermal mass but for moisture—it "stores" moisture like a rock stores heat. Clay plasters can draw excess moisture out of the air when it is humid and store it until the air dries, then re-release it. This evens out spikes in humidity, making people feel more comfortable, and it reduces the risk of condensation and mold. Better indoor air quality is achieved using these nontoxic, zero-VOC materials that don't trap moisture, reduce the risk of mold, and balance humidity.

Pair this super-insulated, low embodied energy, thermally massive wall system with passive solar design, and you get a structure that has relatively small heating and cooling loads. Climate-appropriate glazing on the south side; roof overhangs to limit summer heat gain; and reduced glazing, where summer sun or winter wind impacts interior temperatures, are important. Windows that encourage a thermal siphon for nighttime cooling can help moderate interior temperatures, too. A well-designed straw bale building can be comfortable year-round with little energy used for heating and cooling.

Other Considerations

One potential drawback to straw bale building is the thickness of the wall, which can be significant. Matts Myhrman, one of the straw bale building revival's early leaders, famously quipped, "You can have anything you want in a straw bale house, except skinny walls."

Another disadvantage is that straw bale building often has a higher up-front cost, and unfamiliarity of designers and builders with this system can add to costs. A well-designed and well-managed straw bale project can cost 10% to 15% more per square foot to build than a conventional home.

web extras

See a load-bearing shake-table test at **youtube.com/watch?v=x8Uz-2PonEk**

Rebecca Tasker (3)

Thick walls make for deep door and window openings. There are several structural and aesthetic ways to approach this.

But be sure to compare apples to apples. If you compare straw bale to other well-insulated wall systems that can achieve R-30—such as double-stud and cellulose—the costs are very similar. And the main difference between a well-insulated wall system and conventional wall is that the energy bills will be significantly less over the building's life, making up for the higher up-front cost. If you consider the embodied energy "cost" of building an R-30 wall with bales versus other materials, straw bale is less. In his book, *Making Better Buildings*, Chris Magwood compares the embodied energy (EE) of various wall systems of a sample house. A wood-framed wall insulated to R-30 with cellulose, with drywall on the interior and OSB and lime-cement stucco on the exterior adds up to 40,497 megajoules (MJ). The EE of a bale-laid-flat, post-and-beam straw-bale wall with 2-by-4 framing at doors and windows, and lime-cement plaster on the interior and exterior, was about half, at 19,145 MJ.

Appealing Building

Approaching sustainability requires longevity: we take care of things we love and the longer something lasts, the lower its environmental impact. Unloved buildings get knocked down; then there's additional environmental cost to build new ones.

There's no longevity without durability. Most conventional buildings are built to last 30 or 40 years. Compare this to straw bale structures built in the late 1890s that are still in use today.

Straw bale building owners care about their buildings because they're charismatic. As soon as you start putting straw bales into a wall, people notice. People also notice a difference when they enter a straw bale home. Perhaps it's the thick walls that offer a sense of security, or the hand-applied finishes that harken to a time when buildings were crafted, instead of manufactured.

Straw bale buildings invite participation. Because the materials are nontoxic, there is a tradition of getting friends and family involved in the process with work parties—days when volunteers come to help stack bales or plaster walls, not unlike an Amish barn raising. Work parties don't make sense on every project, but can advance the construction process while engaging the community. Most people feel alienated from construction, and working on your own building is empowering: a foot in the door to further engagement. This leads to a feeling of commitment and stewardship for the building, which can lead to greater longevity.

Of course, straw bale is just the wall. For a truly healthy, high-performance building, attention must be paid to the rest of the building system, such as minimizing its overall size and its loads; incorporating renewable energy systems; selecting high-performance HVAC, electrical, and plumbing systems; and choosing nontoxic finishes throughout the building. With straw bale's Appendix S added to the *International Residential Code* in 2015, and the California Straw Building Association's (CASBA, strawbuilding.org) *Detail Book* soon to be published, this form of building will receive the acceptance and recognition it deserves.

The relatively simple, but labor-intensive, aspect of building with bales fosters community involvement with "bale raising" parties.

Courtesy Nunatak Alternative Energy Solutions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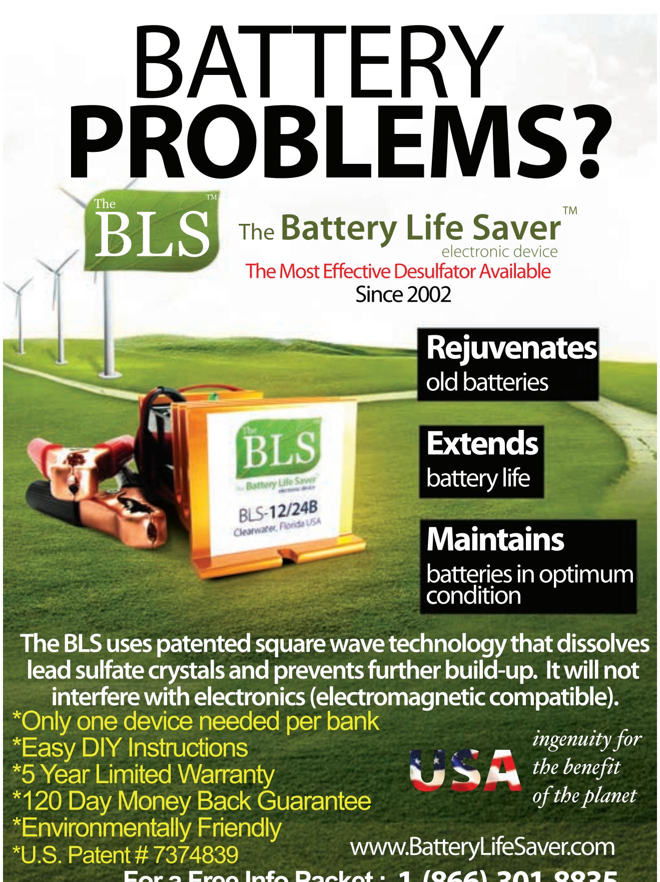
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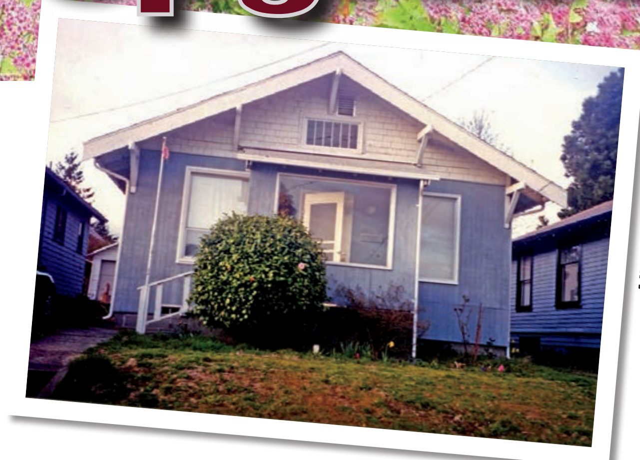
An Old House Gets A High-Tech Efficiency Upgrade

by Claire Anderson, with Jack & Sheila Herndon



All photos courtesy Jack & Sheila Herndon

The North Seattle bungalow as purchased in 1991—ready for efficiency upgrades.

Jack and Sheila Herndon's 1910 single-story, 850-square-foot home north of downtown Seattle, Washington, is an unassuming structure, typical of its neighborhood. For the Herndons, its draw was affordability and a reasonable commuting distance to Sheila's job.

The couple purchased the home in 1991, and immediately realized its potential for energy upgrades. "Restructuring the house to be greener was more of an evolution than a goal from the top," says Jack. "We addressed remaking the home in convenient pieces each year, starting with structural integrity. It made managing costs affordable without the need for construction loans. Plus, we didn't need to be displaced or disturbed for extended periods of time."

Getting to Work

Sheila, a medical lab technician, first worked on tearing out patchy grass and low-growing juniper, developing a low-maintenance yardscape for drought resistance, eye appeal, and for shading the southern front of the home. The backyard is their "personal oasis" and organic vegetable garden.

Jack, a retired facilities and environmental research laboratory manager with the University of Washington Civil & Environmental Engineering department, put his energy into mechanical and structural upgrades. "I have been an avid believer in the benefits of renewable energy and efficiency for the greater part of my life," says Jack. "I like to experiment at the house with new materials and processes toward that end. My passion is being a general handyman, inventor, and, to a lesser extent, an artist."

Tightening the Envelope

Once the structure was secure with earthquake reinforcements, they increased insulation throughout. Infrared photos and a smoke gun revealed air leakage and areas that needed additional insulation. First, ceiling penetrations and the tops of wall cavities were sealed. After that, paper-backed fiberglass batt attic insulation (R-21) was cross-laid over an older 3 inches of blown cellulose. This was topped by R-5 foil-backed fiberglass batts for a total of R-50+. The cross-pattern of batts helps block air movement through the insulation.

External wall cavities were filled with blown-in cellulose funded partially by a rebate from Puget Sound Energy. An exterior overlay of faux antique brick siding with an inch of wood-fiber insulation backing provides another insulative layer. Because it is interlocked, it also serves as a moisture- and air-infiltration barrier.

Replacing the old fir subflooring with tongue-and-groove plywood eliminated the last major air-infiltration points. Application of R-28 open-cell spray-foam between the floor joists in the crawl space helped block the air leaks at the bottom of the wall cavities.

The old aluminum-frame windows were replaced with double-pane Milgard fiberglass sash-style windows. Doors and frames were replaced with local, quality wood doors and frames. In both cases, care was taken to seal the space between the frames and wall structure with foam. This created a much tighter, quieter house.

Next, the old forced-air gas furnace in the attic was replaced with a 98% efficient, variable-speed Coleman gas furnace and a programmable thermostat. Since the attic space is unheated, Jack wrapped all flexible supply duct with an R-5 foil-backed fiberglass insulation; the return duct is wrapped with R-21 batts. During the heating season, their monthly gas bills average only $30.

After those additions, the house meets or exceeds the Seattle 2050 goals for carbon and energy footprint. The air exchange rate was initially measured at 0.37 air changes per hour (ACH). After foam insulation was installed under the floor, another blower door test was performed that yielded 0.31 ACH. This is a testament to Jack's detailed room-by-room sleuthing with the smoke gun, borrowed infrared camera, and a variety of sealing material.

A portable 1.4 kBtu backup heat-pump system is primarily used for heating a detached 130-square-foot shop, but is sometimes used to cool the house in summer. Most of the time, they maintain comfortable temperatures using a timer-controlled whole-house fan that pulls air in through the attic hatch. Air can exit through open windows in the bedroom and kitchen on the north side of the home, the farthest locations from the fan. In the morning, the timer turns off the attic fan, the ceiling fans are turned off, and the windows and shades are closed for the day to reduce heat gain. Normally, Jack says, the air temperature inside is 70°F to 75°F when outside temperatures are 80°F to 90°F.

All but one light is LED. The kitchen and bathroom, on the north side of the house, were initially dark enough in the day to require using the overhead lights. To bring in daylight, they added two 10-inch tubular skylights in

Jack and contractor friend George Walter get down and dusty adding batt insulation to the attic for R-50+.

Air-sealing and additional insulation were some of the first improvements, including a new subfloor over old leaky boards and lots of spray foam.

A high-efficiency Coleman forced-air gas furnace was installed in the attic.

The air-sealing and new windows and doors paid off in an air-exchange rating of 0.31 ACH.

the kitchen and an 8-inch unit in the bath. They also added a greenhouse window with dual-pane glass in the bathroom. These changes, say Sheila, dramatically improved the light in those spaces without the maintenance and heat loss and gain issues associated with conventional skylights.

Renewable Generation

The couple sold some inherited Exxon stock in 2005 to buy their first PV system, a 1,900 W batteryless grid-tied system. In 2014, they reroofed and added 1,520 W to the PV system. Along with their reductions in loads, that's enough to offset 100% of their yearly electrical needs. A new SMA America Sunny Boy 3000TL-US with a secure power supply provides backup electricity (up to 1,500 watts) when the sun is shining but utility power is down.

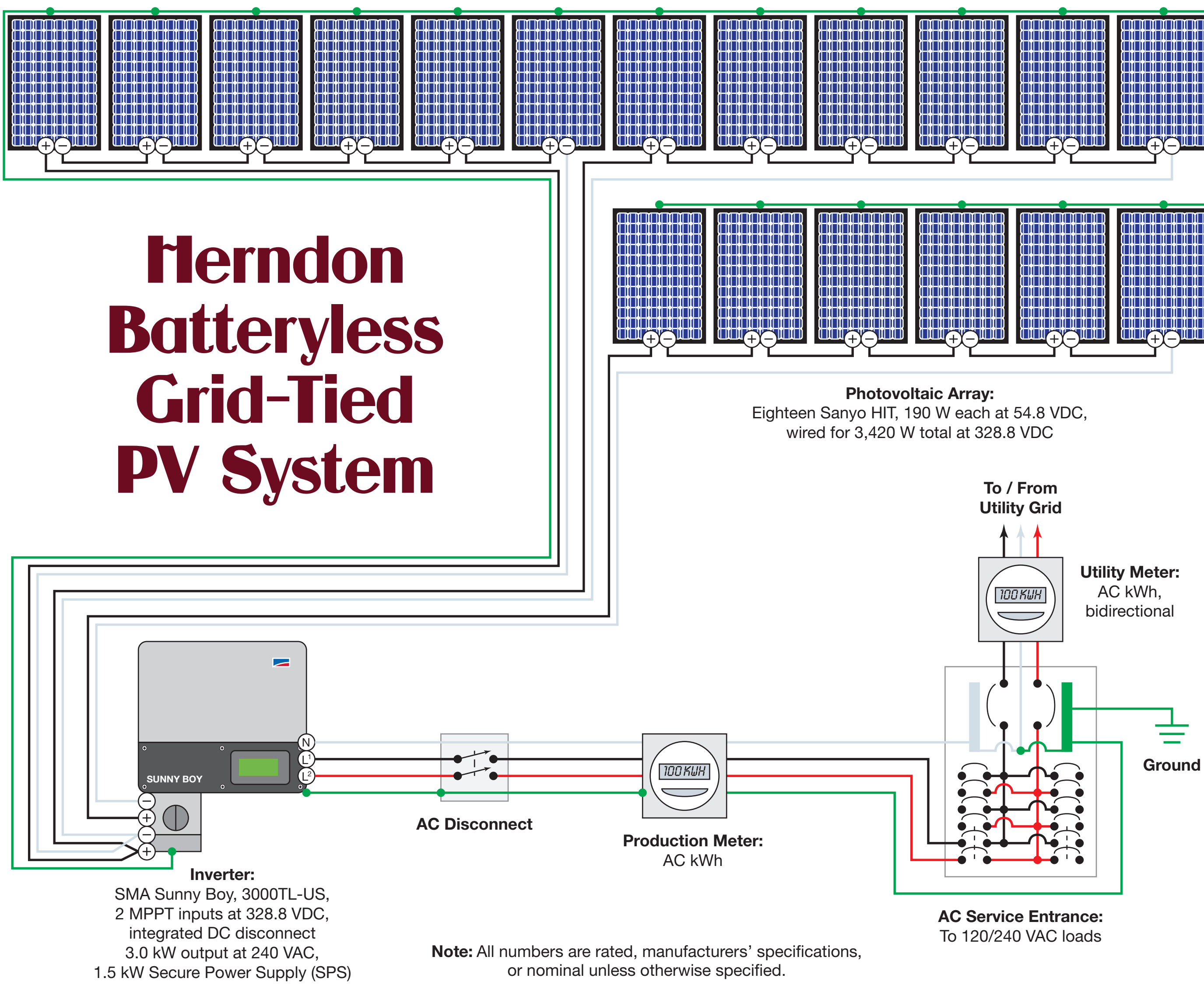
The kitchen brightens up: Before (left) and after (right) the installation of just one tubular skylight. A second was installed, creating abundant natural light and further reducing the need for electrical lighting.

With the state's renewable energy production incentive, the couple has received about $500 in annual payments for the last couple of years. Excluding the incentive, their monthly summer electric bills have a $7 to $10 credit; the winter bill is about $15 to $20 each month.

With the recent addition of an electric car and charging station, Jack says that they are considering investing in community solar to offset their extra electricity use and maintain net-zero electricity use. So far, they have driven about 2,600 miles in their first seven months, getting 4 to 4.5 miles per kWh. Jack estimates that they'll use an additional 1,000 kWh in 2016 just for recharging the car. In 2015, their PV system generated a surplus of about 400 kwh, so they'll need to figure out where they can get 600 kWh of clean energy to bring them again to net-zero annual energy use. If he had to do it over again, Jack says he would consider a home with south-facing roof exposure or yard space to mount a solar tracker for more effective PV generation. Their current system is mounted on a west-facing roof.

Eighteen Sanyo HIT 190 W PV modules provide 3,264 kilowatt-hours per year—enough to meet their electricity needs before the addition of electric vehicle charging loads.

An SMA 3 kW inverter with SPS backup ties the PV array to the house and grid.



PV System Tech Specs

Overview

Project name: Herndon residence

System type: Batteryless, grid-tied solar-electric

Installer: Puget Sound Solar

Dates commissioned: July 2006; June 2014

Location: Seattle, Washington

Latitude: 47.61°N

Solar resource: 3.75 average daily peak sun-hours

ASHRAE lowest expected ambient temperature: 19.4°F

Average high summer temperature: 84.2°F

Average monthly production: 272 AC kWh

Utility electricity offset annually: 100% (before addition of electric car)

Photovoltaic System Components

Modules: 18 Sanyo HIT, 190 W STC, 54.8 Vmp, 3.47 Imp, 67.5 Voc, 3.75 Isc

Array: Three series strings, six modules per string, 3,420 W STC total, 328.8 Vmp, 10.41 Imp, 405 Voc, 11.25 Isc

Array installation: S-5! clamps on west-facing roof at 26.5° tilt (parallel to roof)

Inverter: SMA America Sunny Boy 3000TL-US, 3.0 kW rated output, 600 VDC maximum input, 125–500 VDC MPPT operating range, 240 VAC output

System performance metering: SMA Sunny Portal & Brultech household & PV system monitoring (see SWH system specs)

A 20-tube Thermomax evacuated-tube thermal collector provides up to 75% of the household's yearly hot water needs.

In 2010, they installed a solar water heater—20 Thermomax evacuated tubes, a Resol pump, a Caleffi iSolas Plus controller, and a 60-gallon storage tank. A Rinnai R53e on-demand, natural gas water heater provides backup. The solar water heating system provides all of their hot water from March through October, and generates an estimated 70% to 75% of their year-round water-heating needs. Their PV installers (Puget Sound Solar) found a system for Jack and Sheila that had been on a demonstration house, which reduced the cost. Additional insulation wrapped around the storage tank decreases temperature drop overnight and retains heat longer.

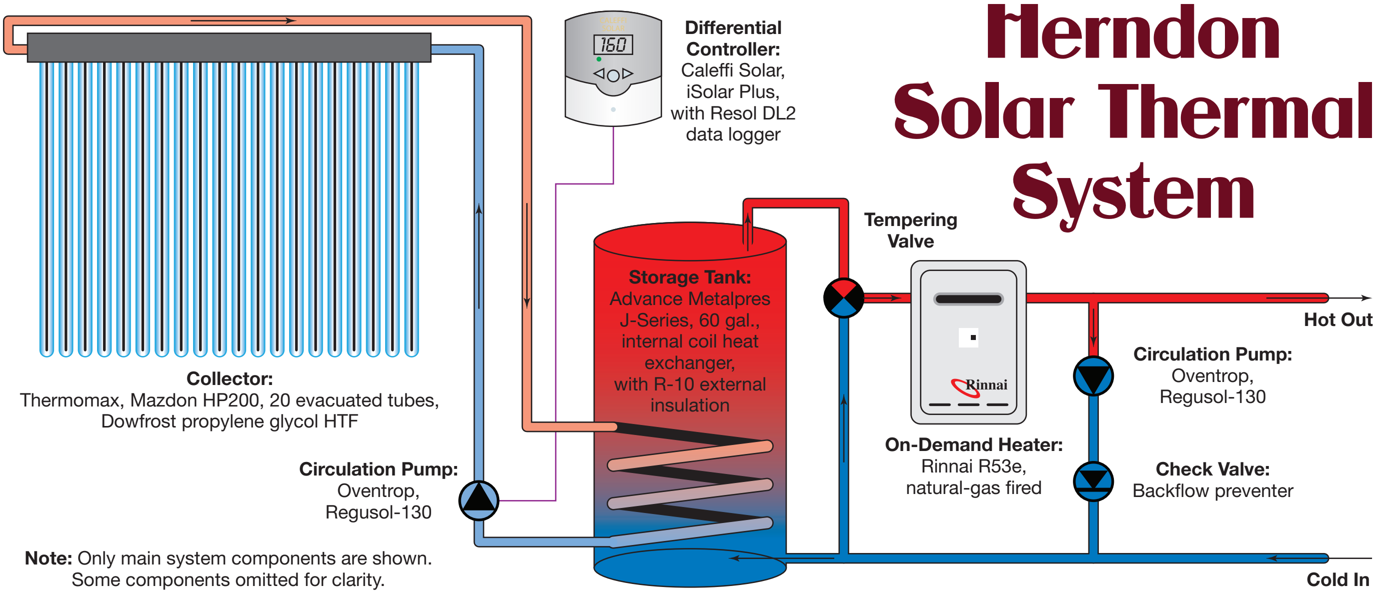
Combining solar water preheating with on-demand hot water system was a long, sometimes frustrating experiment, says Jack. The primary problem is the distance from the SWH storage tank to the on-demand heater. When the SWH and on-demand system are used together, the water heater would get up to operating temperature before the preheated water arrived, causing high-temperature spikes when the preheated water finally made it to the on-demand system. In the end, Jack's solution was to install a recirculation pump on an intermittent timer. They simply push a button next to the on-demand water heater control and the pump circulates hot water for 50 seconds—enough time to get past the temperature spike in winter or to pre-charge the hot water lines in summer, so water is not wasted. Jack says that there was a steep learning curve that has leveled out: "Now," he says, "it is a matter of checking the storage tank temperature and knowing when to turn off the water heater, plus remembering to run the water circulation pump before you need hot water for a shower."

A Caleffi differential controller is the brains between the collector and the 60-gallon storage tank.

A outdoor-mounted Rinnai natural gas on-demand water heater provides backup when solar isn't enough.

A hot water pre-circulator was added to eliminate temperature spikes caused by the Rinnai's reaction time.

Herndon Solar Thermal System



Solar Water Heating System Tech Specs

Overview

System type: Evacuated tube, heat exchange loop solar hot water

Production: 252 kBtu per month (average)

Climate: Mild temperate

Percentage of hot water produced annually: 70% to 75%

Equipment

Collectors: 20-tube Thermomax Mazdon HP200 evacuated tube, 21.5 ft.^{2}

Collector installation: Rooftop-mounted on 26.5° west-facing roof; 30° tilt from roof—tubes angled to approximately 60° for maximum winter solar absorbance and reduced summer overheating

Heat-transfer fluid: Dowfrost, propylene glycol

Circulation pump: Oventrop, Regusol-130

Pump controller: Caleffi Solar, iSolar Plus with Resol DL2 data logger

Backup DHW: Rinnai R53e on-demand, natural gas

Storage

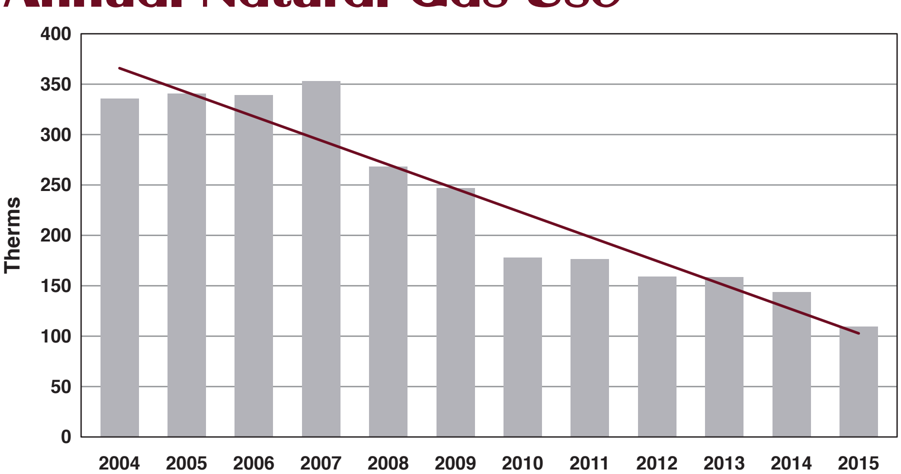
Tank: Advance Metalpres J-Series with additional R10 of external insulation wrap, 60 gal.

Heat exchanger: Single-coil, internal to tank

System Performance Metering

Electrical: Brultech, ECM-1240

Annual Natural Gas Use



The combination of insulation and air sealing, efficient furnace and appliances, and solar water-heating system have helped reduce natural gas use by 2/3 over the past 12 years.

Drought-tolerant ornamentals and rainwater-irrigated food crops grace the backyard.

Catching the Rain

In 2007, Jack designed and installed a rainwater catchment system that provides vegetable garden irrigation in the summer and toilet-flushing in the winter. The system includes three storage tanks totaling 2,300 gallons; a shallow well pump, a pressure tank, and a 5-micron filter. Storage needs were determined using past summer water bills. The upgrade to a metal roof in 2014 considerably improved the water color and quality, but installing a roof-wash system is still in the works. Jack says he would prefer to install rainwater holding tanks that are shorter, but larger in diameter to provide more storage per dollar of tank cost. However, yard space is at a premium, so taller aspect tanks were used, which required bracing for earthquake resistance.

Overall water use for the house is very low. In addition to the drought-tolerant landscape, water-efficient appliances (clothes and dishwashers) and fixtures (showerhead, faucets, and a dual-flush toilet) are key to reducing demand. Their daily water use averages around 25 gallons (for their two-person household), 75% less than the latest utility-reported normal residential use (2013).

Monitoring the Systems

A wall-mounted laptop computer in the kitchen is dedicated to logging system data. It provides real-time electricity use and PV system generation with a seven-channel monitor (Brultech); solar water heating system status (Resol); and on-site weather conditions (Davis Instruments). The computer is Internet-connected, enabling up-to-the-minute local weather forecasts and radar images of precipitation, which is handy when you're relying on an electric bike and motor scooter for transportation, as Jack and Sheila often do.

Left: One of three rainwater storage tanks.

Right: The rainwater irrigation system's pump box, with filter, and input and distribution shutoff valves.

Sheila and Jack with their electric car (center) and electric bike (right).

Jack says that the home monitoring systems took a lot of tweaking. For the Brultech power monitoring, he installed current sensors on each circuit, established a wired local area network, and worked out communication between the computer and the Brultech internet box. The SWH monitor required network communications and creating a graphic display. Both of these systems, he says, were "early" versions, with incomplete installation instructions and little standardization. He was thankful for manufacturers' patient technical assistance personnel.

Outside the Box

While he continues to innovate in his home, Jack says, "a low-impact home requires engagement of its occupants. Optimum performance and longevity for any home system is directly affected by lifestyle—being an active part of your house, like cleaning the gutter and filters for rainwater collection, making sure the refrigerator radiator is cleaned, washing dirt off the PV modules, checking filters in the furnace, or opening a window on a summer night. Systems in a home work as planned only when the owner recognizes their part in how a house operates."

Jack also realizes that renewable energy and home energy efficiency are only part of an environmentally balanced existence. "Food sources and transportation choices also have a big environmental impact. Our raised-bed organic garden, watered with collected rainwater, supplies us with vegetables year-round, since we also preserve a lot of what we grow. Most of my local transportation is by electric bike, a godsend with the hills of Seattle. We purchased a used Nissan LEAF this year with a goal of reducing gas vehicle use by at least 50%. So far it is looking more like a 60% to 65% reduction."

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Working Safely with Electrical Systems

by Brian Mehalic

Working with electrical systems has inherent risks, and working with RE systems is no exception. This "Code Corner" offers a look into the installer's world of required electrical safety guidelines and procedures.

OSHA & NFPA 70E

The mission of the Occupational Safety and Health Administration (OSHA) is to assure safe and healthful working conditions by "setting and enforcing standards and by providing training, outreach, education and assistance." OSHA addresses installing, servicing, and working near or on electrical systems and equipment in Parts 1910 Subpart S and 1926 Subpart K, providing guidance on "what" to do. The National Fire Protection Association's 70E, the *Standard for Electrical Safety in the Workplace*, is guidance on "how" to do it.

Formal development of 70E began in 1976 at the request of OSHA, with the first edition published in 1979. Its intent is to reduce exposure to the hazards of shock and arc-flash while working on electrical equipment. It is "tailored to fulfill OSHA's responsibilities [and be] fully consistent with the *NEC*." While not official OSHA doctrine, 70E is indirectly enforced through the General Duty Clause of the Occupational Safety and Health Act, and is listed as a reference for "information that can be helpful in understanding and complying." Updated on a three-year cycle like NFPA 70 (the *National Electrical Code*), the current edition of 70E is 2015.

NFPA 70E has three chapters: Chapter 1 covers work practices and procedures; Chapter 2 addresses safety-related maintenance requirements; and Chapter 3 modifies the first two for special equipment (which includes batteries over 48 VDC nominal, but does not address PV systems). The Informative Annexes at the back of 70E provide guidelines, templates, examples, and additional information.

Section 105.3 of 70E states the "employer shall provide the safety-related work practices and shall train the employee, who shall then implement them," and Section 110 provides guidance on electrical safety training programs. NFPA 70E, OSHA 10- and 30-hour construction, and specialized (scaffolding, fall protection, etc.) training is available and recommended—in fact, safety training is required to be a "qualified person" per NFPA 70 and 70E.

Electrically Safe Work Condition

Electrically safe means "disconnected from energized parts," "locked/tagged," and "tested to ensure the absence of voltage." As long as there is no danger of arcs or burns, electrical equipment that operates at less than 50 volts is not required to be de-energized. The Informational Note to the definition of "Voltage, Nominal" in 70E states that actual operating voltage can vary, meaning that 48 VDC nominal battery banks (with voltage that swings above and below 50 V due to state of charge) do not have to be de-energized to be worked on.

PV modules and batteries present unique challenges, in that it can be difficult or impossible to truly "turn off" the power, but *NEC*-required disconnects provide the means to isolate equipment from all power sources. Remember to always use a clamp-on ammeter to verify a lack of current before operating non-load-break rated disconnects, such as module quick connectors and touch-safe fuse holders.

Using a lockout ensures disconnected power sources stay disconnected, and a tagout shows who is responsible for the lockouts. Section 120.2 in 70E provides detailed requirements and sample procedures (Informative Annex G). Always use the appropriate locks, tags, hasps, and breaker and switch locks. Electrical tape over a breaker handle is not a lock!

Lockout and tagout gear is readily available for different types of switches and breakers. Always put your name and contact information on the tag, so others know who is responsible for the lockout.

Brian Mehalic

Section 110.4(A)(5) requires that when the circuit/system is 50 volts or more, "the operation of the test instrument shall be verified on a known voltage source before and after an absence of voltage test is performed." Test your meter on an outlet, a AA battery, or other power supply to make sure you don't get a false negative when verifying a lack of voltage.

Only qualified persons are allowed to work on equipment that is not in an electrically safe work condition. Regardless of the work, 110.1(H) requires a "pre-work meeting" to discuss the hazards and procedures for the job—and be sure to document it, so that it can be demonstrated to OSHA that the meeting happened.

Shock Hazard

The "limited approach boundary" signifies the distance at which unqualified personnel—such as homeowners, other contractors, or members of your crew who have not yet received the necessary training—must be kept back from exposed, energized parts due to the risk of shock. This is generally 3.5 feet for AC systems with a line-to-line voltage of 50 to 750 V (which includes typical residential and many commercial service voltages), as well as DC systems of 100 to 1,000 V [Tables 130.4(D)(a) and (b)]. A limited-approach boundary is not specified for AC systems below 50 V or DC systems below 100 V.

The "restricted approach boundary" is the distance from an exposed, energized wire or circuit at which there is an increased likelihood of shock for "personnel working in close proximity." The restricted approach boundary is 1 foot for AC systems of 151 to 750 VAC line-to-line, as well as for DC systems from 301 to 1,000 VDC. The boundary for 50 to 150 VAC and 100 to 300 VDC is "avoid contact."

Section 130.7(D)(1) provides requirements for insulated tools, nonconductive ladders, and other tools and equipment that must be used when working within the restricted approach boundary. A formal "energized electrical work permit" (see Annex J of 70E) is generally not required for qualified persons in the restricted approach boundary, provided they follow 70E guidelines and industry-accepted safe practices, and use the correct safety gear.

Arc-Flash Risk

Workers can accidentally create electrical arcs when testing, commissioning, or working on or around energized electrical equipment. These arcs can release tremendous amounts of energy and be extremely dangerous. The arc-flash boundary is the distance at which a worker could be exposed to a level of incident energy of 1.2 calories per square centimeter (cal/cm^2)—the energy level associated with second-degree burns.

Information for determining the arc-flash boundary is provided in Annex D, and an incident energy analysis can be performed based on the distance of the worker's face and chest from the circuit part being worked on. *IEEE 1584 Guide for Performing Arc Flash Hazard Calculations* also provides guidance for AC systems. If the task corresponds to one of the specific categories in 70E Tables 130.7(C)(15)(A)(b) or (B), then the boundary—and corresponding level of personal protective equipment (PPE)—from the table(s) can be used.

AC arc flashes are a significant risk in commercial and industrial applications, due to large fault currents available from the utility grid through the service transformers. An arc-flash hazard is much less likely to be present in residential grid-direct applications—usually the service transformer must be 125 kVA or larger. Additionally, residential-scale battery-based inverters are not capable of delivering enough current to present an arc-flash risk. Clearly defined guidance on how to assess these possible hazards is not provided in 70E or other sources.

For commercial applications (non-dwelling units), the AC output of a newly installed PV system must be considered when updating equipment labeling regarding the arc-flash hazard in accordance with 70E Section 130.5(D), and Sections 110.16 and 110.24 of the *NEC*.

Considerations for DC arc flashes were added to 70E in 2012, but the arc-flash hazard PPE categories in Table 130(C)(15)(B) do not address systems below 100 VDC. While two studies are referenced in Annex D, there is not a lot of data regarding arcs on batteries below 50 VDC nominal. While a short-circuited battery can melt a wrench, batteries present more of a thermal or acid-blast issue, and the actual arc-flash hazard may be minimal or non-existent.

For PV systems, 70E guidance, research and testing, and industry standards are even less developed. Residential PV arrays connected to string inverters fall within the DC voltage parameters of the arc-flash hazard categories in Table 130.7(C)(15)(B), but at relatively low and inherently limited levels of DC short-circuit current—they are insignificant compared to 4,000 A which is the first equipment rating in the Table. Larger PV systems may operate at levels of current the table considers, but in many cases at 1,000 VDC—above the 600 VDC maximum the table addresses. In some cases, electrical engineers can provide an analysis, but this can be a prohibitive expense for residential or smaller commercial arrays. There is a clear need for codes and standards to better address potential DC arc-flash hazards to keep up with the rapidly growing PV and energy-storage markets.

Personal Protective Equipment (PPE)

Appropriate PPE is required within the arc-flash boundary or when there is a shock hazard. Several tables in Section 130.7(C) provide guidance on when, and what level of PPE is required. In general, if there is an arc-flash hazard, PPE is required for tasks including:

- Removal of or opening of covers, which exposes live parts
- Examining insulated cable with physical manipulation
- Working on energized components (including voltage testing)

In some cases, arc flash hazard PPE is required for tasks where it otherwise would not be, such as when equipment shows signs of poor installation or maintenance, or of impending failure. That makes sense—if it is old and/or sketchy, treat it with extra caution!

Table 130(C)(15)(B) lists the PPE category for working on energized equipment within the arc-flash boundary, but remember that PPE is the last line of defense against hazards, which must first be eliminated and/or controlled. "Hot" work should only be performed for purposes of commissioning, maintenance, troubleshooting, or inspection—or when the circuit is truly an integral part of a continuous process (which is unlikely for our field of work). OSHA 1910 Subpart I provides information on all types of PPE; additional guidance and requirements are in 70E Section 130.7 and Informative Annexes H and M.

Eye protection is always required, and it must be labeled with the ANSI Z87.1 standard.

Rubber insulating gloves with leather protectors are required for shock protection in the restricted approach boundary. Typical ratings include Class 00 (750 VDC or 500 VAC) and Class 0 (1,500 VDC or 1,000 VAC). Sleeves (if your arm and not just your hand will be in the restricted approach boundary), insulated blankets, mats and bare line covers, and higher-voltage rated gear are also available. Be sure to follow industry best practices and requirements for taking care of your gloves—inspect and air test before each day's use. Get in-service gloves recertified every six months; gloves can be stored for up to 12 months before being placed into service.

For the lowest level of potential arc-flash risk, with incident energy of up to 1.2 cal/cm^2, non-melting or untreated natural fiber pants and long-sleeve shirts are required, along with a hard hat (class G or E); safety glasses or goggles; and hearing protection. As needed, use heavy-duty leather gloves or (when there is a shock hazard) insulated gloves with leather protectors.

Courtesy Solar Energy International

Safety first! Be sure to wear the correct PPE for the hazard level of the specific task.

When there is an arc-flash hazard greater than 1.2 cal/cm^2, arc-rated clothing must be worn—they will not continue to burn after the ignition source is removed and provide a thermal barrier during the extreme explosive, thermal event that is an electrical arc blast. When arc-rated clothing is required, underwear must also be non-meltable! Materials such as nylon, polyester, spandex shall not be worn next to the skin [130.7(C)(9)(c)], though there is an exception for an "incidental amount of elastic used on non-melting fabric underwear or socks."

Arc-rated clothing and additional PPE requirements are defined in four categories. Category 1 and 2 cover the majority of work that would be performed on residential and commercial-scale systems. Category 3 and 4 apply to higher-power and higher-voltage systems, and involve heavy suits and/or layering. Note that for all categories, if a jacket, rainwear, or hard-hat liner is worn to deal with the weather, it must be arc-rated to the appropriate level.

Category 1 (minimum arc rating of 4 cal/cm^2) requires an arc-rated long-sleeve shirt, pants, and face shield or hood; hard hat; safety glasses; hearing protection (ear canal inserts); and leather gloves (the ones satisfying the insulated gloves requirement, not a second set). Leather footwear is optional. Category 1 covers the majority of residential systems (if there is an arc-flash risk), some commercial AC applications, and some DC systems:

- 240 VAC or below, maximum 25 kA short-circuit current
- 100 to < 250 VDC, short-circuit current < 4 kA
- 250 to ≤ 600 VDC, short-circuit current < 1.5 kA

Category 2 adds a higher arc rating (minimum of 8 cal/cm^2), mandates leather footwear, and adds a requirement for a balaclava for additional protection of the neck, head, and face. Category 2 covers many commercial and industrial systems, and additional DC systems:

- Numerous 277 and 480 VAC applications
- 100 to < 250 VDC, short-circuit current 4 to < 7 kA
- 250 to ≤ 600 VDC, short-circuit current 1.5 to < 3 kA

In some cases, it is easiest to dress for the worst—wearing arc-rated clothing with a minimum value of 8 cal/cm^2 whenever on the job covers Category 1 and some of Category 2, which is the work most PV installers will be involved with (see Annex H Table H.2, and note that in some cases, depending on the hazard analysis, an arc-rating of greater than 8 cal/cm^2 may be required—Category 2 essentially covers 8 to < 25, where Category 3 begins). However, this same strategy could also be overkill for residential-only work where Category 1 or less may be sufficient—and especially so for the many non-energized construction aspects of installing a PV system, such as mounting modules, pulling conductors in conduit, or hanging inverters—which is the case regardless of system size.

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Country Canines

by Kathleen Jarschke-Schultze

My husband Bob-O and I have lived off-grid for 31 years. Nearly the entire time, we have owned dogs—always a spayed female Airedale, and always only one at a time. When you live in the country, two or more dogs become a pack and have a tendency to go running. We are our dog's pack, and she is family.

Terrier-ist

Just about everyone who lives in the country keeps a dog. Airedales are very active dogs and the wide-open country suits them well. We have lots of country to hike with our dog. Most of our dogs have been Oorang Airedales, which is a larger breed, weighing 80 to 110 pounds. Out here, a dog that's too small becomes part of the food-for-wildlife program.

The mere fact that a dog regularly lives (and piddles and poops) on your property is enough to deter some varmints. We like the terrier breed because they are varmint dogs. If it's a varmint, our Lucea will chase it. Lucea is so exuberant it is like having a two-year-old toddler in the house. She puts everything in her mouth, she loves attention, and if she is quiet, I better go see what she is up to. In our house, no shoe or squeaky toy is safe. Sometimes Lucea has some 'splaining' to do.

There is the occasional run-in with raccoons or skunks. Once, we were taking care of Max, a friend's big Labrador retriever, who had been friends with our third Airedale, Emma, since puppyhood, when I woke up in the night, smelling skunk. I found Emma, who had been stink-blasted on the side of her face and was trying to rub off the stench in the dirt. She was a stinky, muddy mess at two in the morning. Her buddy Max was unscathed, looking innocent, wagging his tail. I cleaned her up and went to bed.

The next morning I told my friend, "Well, at least Max was smart enough to stay out of the spray." She replied, "Don't kid yourself—if someone had chucked that skunk in the air, Max would have been the first on it." Terriers like our Airedale were specifically bred to hunt and kill varmints. Max, on the other hand, is a helper, not a hunter. Historically, Labrador retrievers were a fisherman's friend, helping bring in nets and fish, and fetch ropes.

Snake Training

During our hot, dry summers, we get a lot snake visitors. Most are harmless, in fact beneficial, eating mice, rats, gophers, and moles. I once found a gopher snake in my oven, squeezing a mouse to death (*HP12*).

I regularly set a gopher trap in our vineyard. One afternoon, when I was on my way to check it, I almost stepped on a big gopher snake. It slithered through the grass and went on its way. There was a gopher in the trap, so I quietly found the snake and threw the gopher right in front of its path. Manna from Heaven! It immediately wrapped itself around the gopher.

We also get rattlesnakes in our yard, greenhouse, garden, porch, etc. Because Lucea is not yet two years old, we took her to rattlesnake training class. I had never heard of rattlesnake training for dogs, although we had tried on our own to discourage previous dogs using a rattlesnake we had shot and an electric shock collar. We coiled the snake in the road, then I walked past with the dog, gasping and jumping back when we were near the snake. At the same time, Bob-O, hidden around a corner, buzzed the collar. That worked pretty well.

Our teacher used live rattlesnakes, which he raises specifically for his classes. He muzzles the snakes so they can't bite. It takes a half hour for each dog with one-on-one training. It was similar to our method—only the snakes were live. The teacher also used a shed snake skin, for smell identification, and a recording of a distinctive rattler sound broadcast by a small speaker hidden in the brush. After a half hour, rather than go near the snake, Lucea walked completely around the house to find Bob-O. Is this any kind of guarantee that my dog will not be snake-bit? No, but if the training makes her pause and move back, she has a good chance of avoiding a bite.

continued on page 70


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continued from page 68

Only once was one of our dogs bitten by a rattlesnake, and it did not envenomate (release its venom). The rattlesnake was lounging in the doorway of my greenhouse and Amelia (Airedale No. 2) bounded right over it and into the greenhouse without seeing it. The snake recoiled and started rattling. I didn't know what to do. I couldn't call the dog and she didn't look like she was going to stay. I tried talking calmly to the dog, telling her to stay. She didn't, she jumped back over the snake and it bit her foreleg on the way by. She yelped and bled a little but was not in pain, which is the first sign of envenomation. The snake fled into the greenhouse. I shut the door and waited for Bob-O to get home to dispatch the snake.

A Cautionary Tale

Although I know people who catch and release rattlesnakes, I do not. If they are where I walk in my yard, I shoot them. I don't count rattles or take trophies. I am sorry to do it, but I am too far away from emergency services to chance a snake bite.

A friend used to chide and lecture me about not relocating the rattlesnakes until he was bitten. My friend was taking out the house garbage when he noticed some weeds in a flower bed right outside the door. He set down the garbage bag on the steps and weeded the flowers. After about 10 minutes, he turned back, lifted the garbage bag—and uncovered a huge rattlesnake. He had successfully relocated his snakes for years, so he looked around for something to hold down the snake's head while he grabbed it. The only thing within reach was an Oregon Country Fair fairy wand with a big heart on top. He used the lobed heart end to stabilize the snake's head, but when he went to grab it, the snake struck. One fang dragged across his hand, breaking the skin and leaving a trail of venom.

My friend's daughter was visiting and she bundled him into the car and set off for the hospital, 45 minutes away. Venom is a neurotoxin. He told me it was the weirdest sensation—he felt like his body weighed two tons and it was very hard to move his limbs. He also felt like his face was contorting, but when he looked in the mirror his face was normal. It took 24 vials of anti-venom at $1,200 a vial. The antivenom is dry and is reconstituted with water—it has to be rolled between warm palms until dissolved. It was a small country hospital, so every nurse and doctor who was not actively treating patients stood around rolling the vials in their hands. It turned out my friend was allergic to the antivenom and he spent two days in the intensive care unit, and another two in the hospital proper. He doesn't chide me anymore.

Poisonous snakes are nothing to mess around with. If you don't know what you are doing, then don't do it. Rattlesnakes are a part of our dry summer landscape. Encounters are inevitable. If you can leave the snake alone that is the first choice. If you have to kill it, do it fast and sure. (We prefer using birdshot in a .22 revolver.) Dispose of the snake, especially the head, safely by burying it deep, where your dog won't find it.

A Ruff Life

As our dogs have passed on, we have buried them on our land—where they were happiest. Ringed with rocks and filled with dirt, the graves are now filled with growing flowers. We fondly call them the dog beds.

For country life, dogs are great pets. For the dogs, living rurally is a usually canine paradise. If you want a loyal, funny, helpful companion for your off-grid homestead, get a dog. They'll work for kibble, literally.

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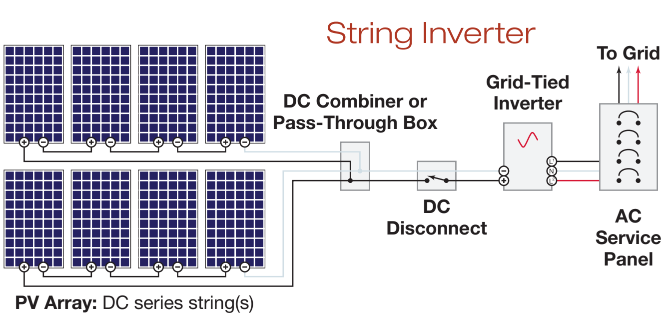
Residential Grid-Tied (GT) PV System Types

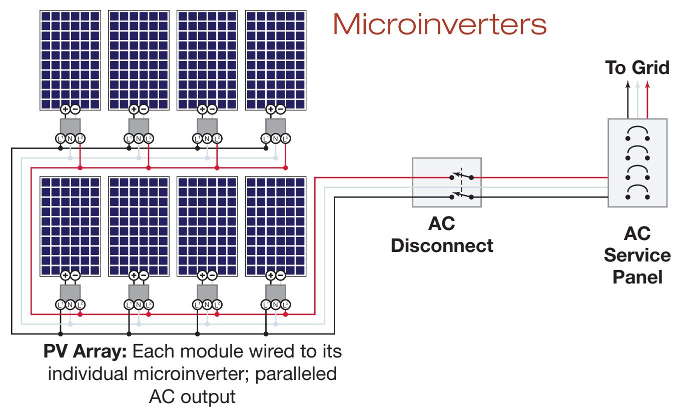
These common systems—also known as on-grid, grid-tied, utility-interactive, grid-intertied, or grid-direct—generate solar electricity and route it to the household wiring for the home's loads. Any excess generation goes to the electric utility grid. The drawback of these batteryless systems is that they provide no utility outage protection (with the exception of systems using SMA America's TL inverters, which offer a "secure power supply" feature). When the grid fails, these systems cannot operate. These systems are installed in three basic configurations:

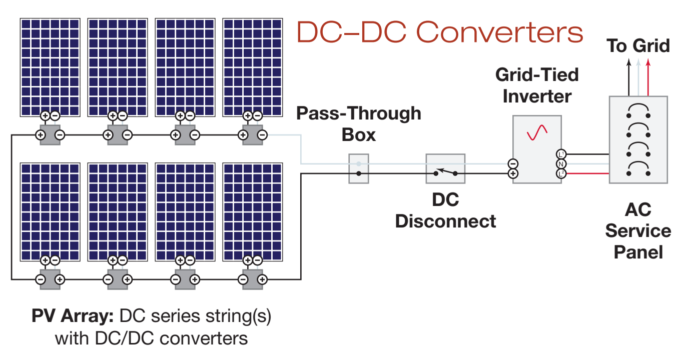
String inverter systems generate high DC voltage from one or more series-wired PV module strings (which makes voltage additive). Each string is either routed through a pass-through box or wired to a combiner box, the output of which is routed through a DC disconnect and then to the input of a string inverter. The string inverter's output (usually 240 VAC) commonly is attached to a backfed circuit breaker in the home's main service panel.



DC-to-DC converter systems have a converter attached to the output of each module to maximum-power-point track each module separately. Each converter has a DC output like a PV module junction box; thus, each converter's output is treated as the module's output. They are then wired in series to build array voltage, just as in a string inverter system. Each series string is either routed through a pass-through box or wired to a combiner box, the output of which is routed through a DC disconnect to the string inverter's input. The string inverter's output (240 VAC) then commonly attaches to a backfed circuit breaker in the home's main service panel.

Microinverter systems have a microinverter wired to each module, so that the output of each module-inverter pair is 240 VAC. This output is then often routed through an AC disconnect, usually going to a backfed circuit breaker in the home's main service panel.





Another type of home system, **GT with battery backup**, uses a battery bank to provide backup to some or all loads during utility outages. More components are required, including a battery-based inverter, and a charge controller to keep the battery bank from becoming overcharged when the utility grid is down. Configurations vary depending on the equipment, but a classic configuration has modules wired in series, though usually at a lower voltage than for batteryless systems.

This system's wiring is routed through a combiner box, with the output going through a DC disconnect and then to the charge controller, then through another DC disconnect and to the battery bank. The battery bank's output is routed through a large DC circuit breaker to the inverter. The inverter's AC output connects to a critical load subpanel. Another AC connection to the inverter is fed by a circuit breaker in the main service panel, which sends excess PV energy to other household loads and/or to the grid, or brings in power from the utility to charge batteries and supply the critical load subpanel.

—Justine Sanchez

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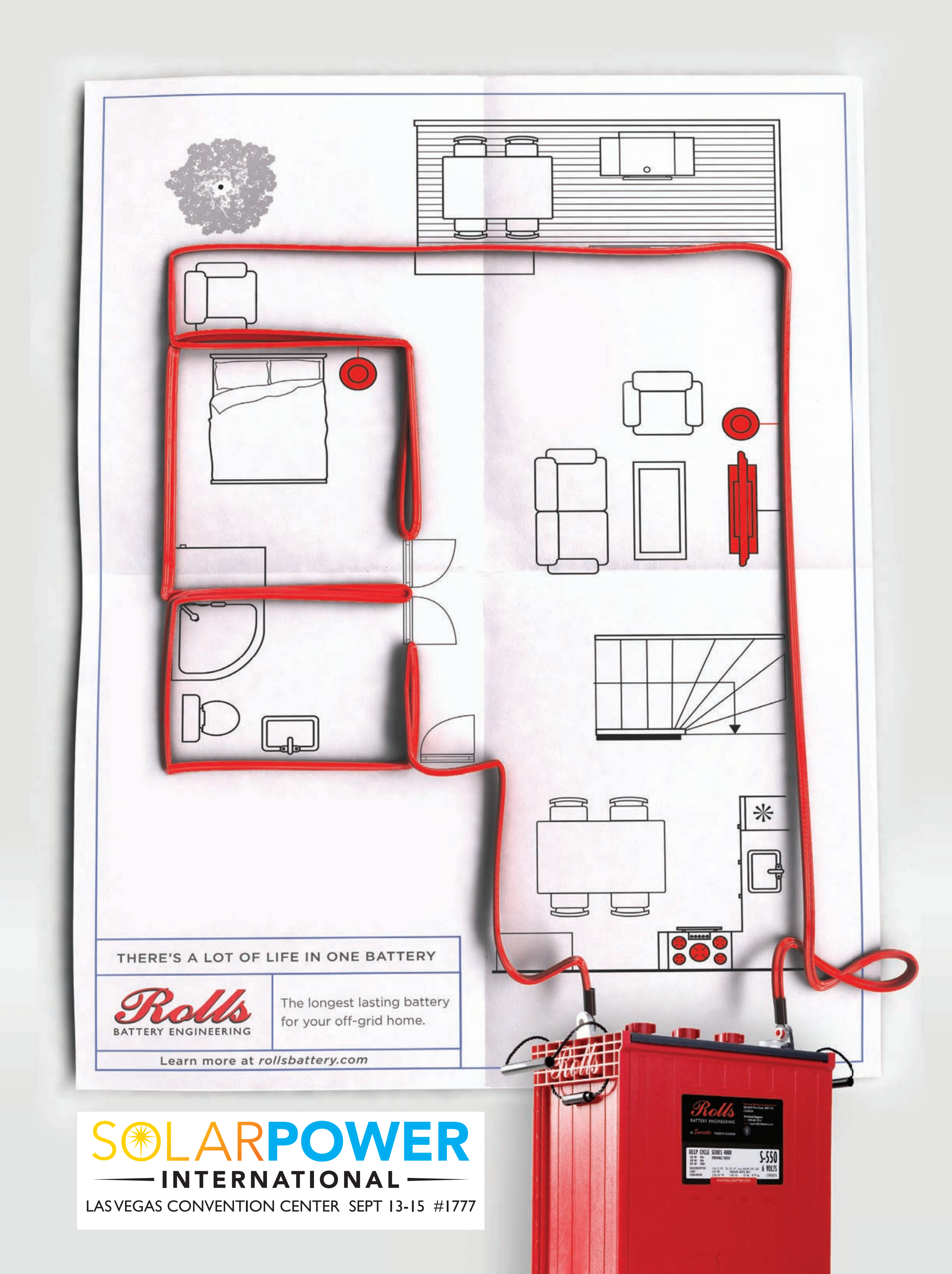
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