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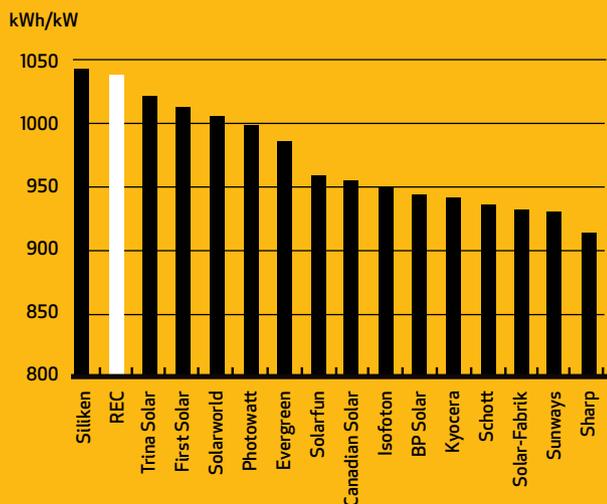
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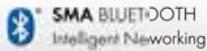
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Photo: Topher Donahue



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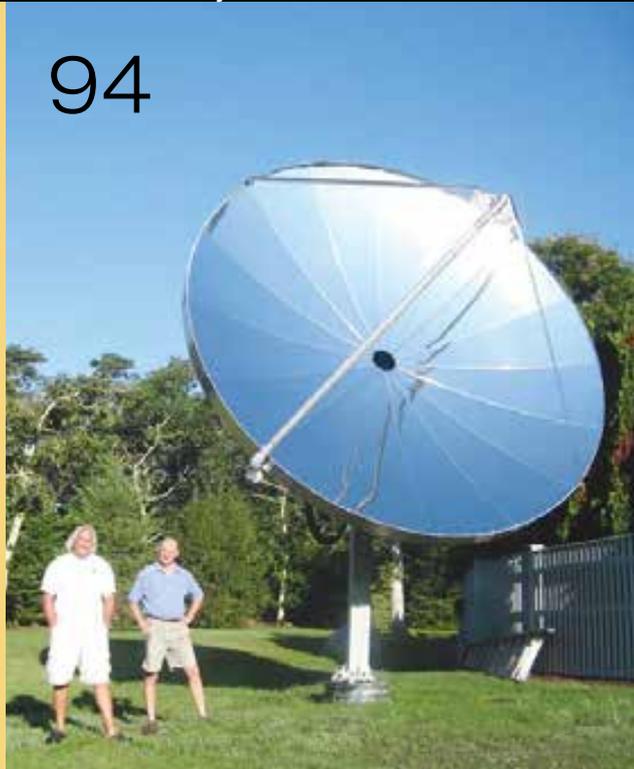
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# Occupy Rooftops

The "occupy" movement is one of the most newsworthy things to happen in the United States in quite some time. Whether you agree with their methods or not, many people can sympathize with the "occupiers'" message. They feel they have lost their freedoms and the democracy to which they are entitled—lost to powerful moneyed interests that are able to obtain better access to elected officials and regulators than common citizens.

Notably among those moneyed interests are the national banks and financial institutions that use their influence to make unimaginable sums of money. And possibly of greater concern to much of the *Home Power* readership is that those interests include utility companies that run electrical power plants, as well as the coal, oil, nuclear, and gas companies that bring us acid rain, greenhouse gases, mountaintop removal, deep-water oil wells, transcontinental tar-sands pipelines, hydraulic fracking, and uranium mine tailings scattered around our communities and pristine parklands.

For many of us, the obstacles that need to be overcome in the transition from polluting energy sources to clean, renewable ones seem larger than imaginable. It's no wonder that some of our citizenry is interested in doing whatever it takes to change things—even going so far as "occupying" the streets and media in an effort to turn things around.

Taking responsibility for our energy choices is one way we can use our influence and exercise our individual rights. There are few things as empowering as turning on your own rooftop solar-electric or water-heating system for the first time. "Occupying" your own home or business by installing a renewable energy system puts the power back in your hands. You become your own utility and an indispensable part of our clean-energy future.

—Michael Welch,  
for the *Home Power* crew



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Think About It...

*It isn't enough just to scream at the Occupy Wall Street demonstrations.  
We need our political system to start reflecting this anger back into, "How do we fix it?"*

—Colin Powell, former U.S. Secretary of State



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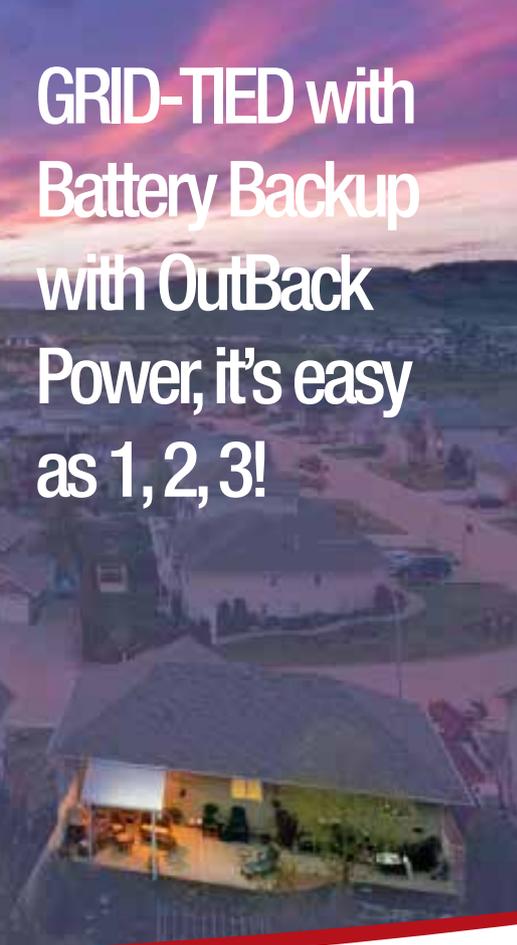
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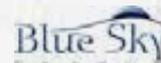


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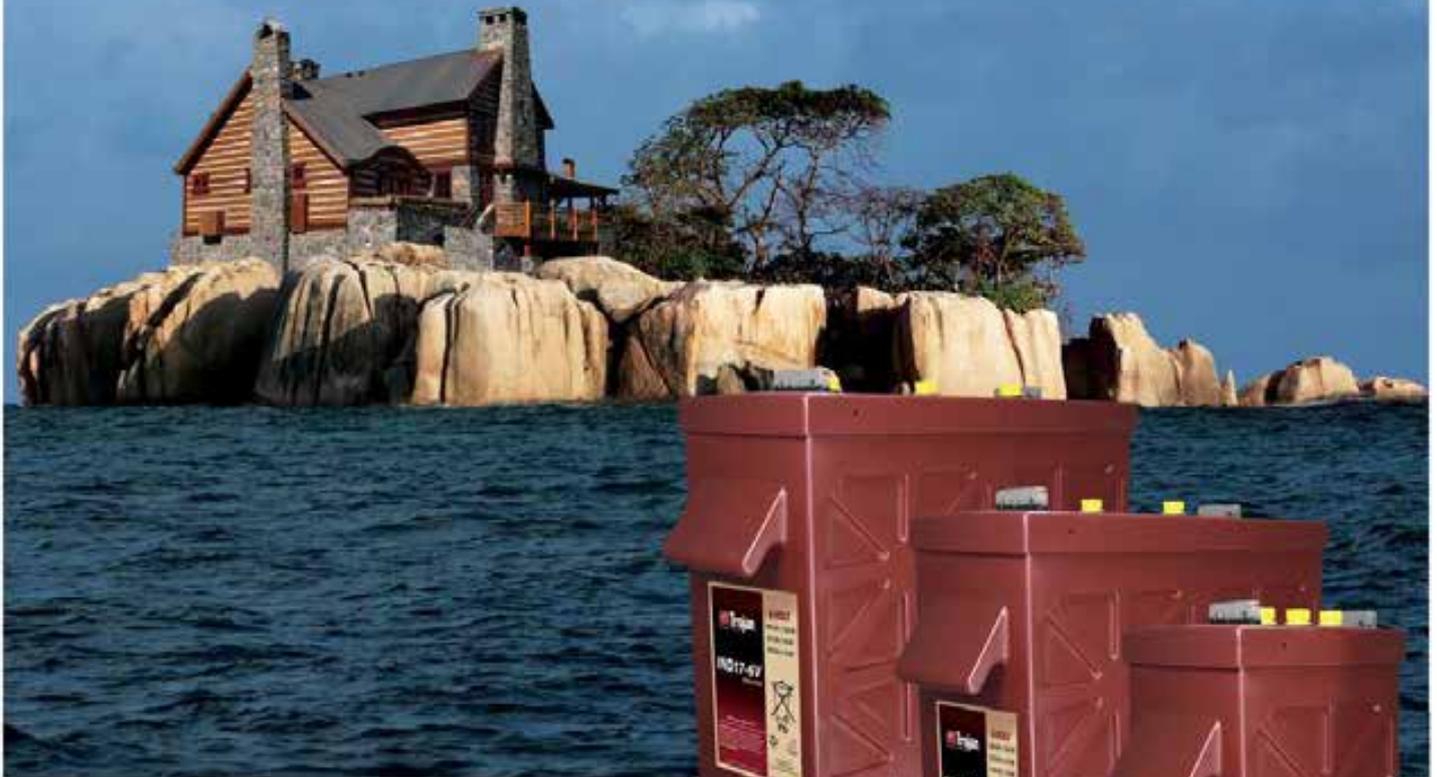
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IND13-6V	533	673	820	6 VOLT
IND17-6V	711	897	1090	6 VOLT
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# Solyndra & the Fate of Clean-Energy Loans

The government and an innovative solar energy company are taking heat for a clean-energy loan gone south. Who's—or what's—to blame for the default? And what does it mean for the future of solar subsidies and growing R&D efforts?

If you take your cues from the punditocracy, “Solyndra” is Latin for “scandal,” rather than the merging of two words: “solar” and “cylinder.” But is it a true scandal—with corruption, greed, and deception—or is it just a case of a business model that didn't work out as expected, planned, and hoped? Or something else, like bureaucratic ineptitude and malfeasance mixed with political miscalculations and grandstanding? Or was it just a marginal product that wasn't going to make it anyway?

## The Story

Solyndra's PV module is unusual—instead of flat squares of polysilicon crystalline cells, Solyndra uses copper indium gallium diselenide (CIGS) thin-film technology in cylindrical tubes, to capture *direct* sunlight as the sun arcs across the sky; *diffused* sunlight from the rest of the sky; and *reflected* sunlight that makes it through the spaces between the cylinders and reflects upward from the flat (ideally white) roof below (see “Solyndra for Flat Roofs” in *HP144*).

The Solyndra modules were innovative and the technology promising, but the business model was speculative, counting on polysilicon staying expensive. That turned out not to be the case.

“Between the period when Solyndra applied for [December 2006] and was awarded the loan guarantee [June 2009], the price of polysilicon went from about \$300 per kilogram to \$460 per kilogram,” says Ben Holland of the energy think-tank Rocky Mountain Institute. “By the end of 2010, it was selling for about \$60 per kilogram. It has remained around \$70 per kilogram.”

Subsequently, the price of crystalline modules also plummeted, dropping 46%

between 2009 and 2011 because of increased polysilicon supplies. In 2010, the Chinese government invested \$30 billion to make conventional silicon-based PV modules. That was good for U.S. consumers, but bad for U.S. companies like Solyndra—and also for Evergreen Solar and SpectraWatt, manufacturers of crystalline PV modules, that both filed for bankruptcy last year.

Although the legislation was approved in 2005 under the Bush administration, the first energy loan guarantees weren't issued until 2009, under the Obama administration. Both “clean” and “dirty” energy technologies were eligible. Solyndra's loan guarantee was \$530 million, out of a pool of \$38.6 billion “clean-energy” loan guarantees. Solyndra also raised \$933 million in unguaranteed private loans to launch its product.

Despite warnings from staff and from venture capitalist campaign donors, President Obama visited Solyndra's Fremont, California, manufacturing facility on May 26, 2010, and said a lot of nice things about Solyndra that have come back to haunt him. All the while, Solyndra was spending its loan funds and—because polysilicon prices had plummeted and competition was heating up—was selling its PV modules for far less than its manufacturing costs.

In December 2010, Solyndra “technically” defaulted on the government-backed loan, but, in February 2011, the U.S.



Courtesy: Solyndra (2)

Department of Energy (DOE) restructured the loan, moving its own place in the repayment line behind \$75 million of new private capital. Why? The DOE reasoned that Solyndra would certainly fail without the restructuring (and the taxpayers would lose their money), so why not give it a fighting chance? Solyndra limped along until declaring bankruptcy in August 2011. After the filing, the FBI seized Solyndra's files, although the Justice Department has not yet brought any actions against the company.

### The Result

The Solyndra incident is creating a political brouhaha. At an oversight and investigations subcommittee of the House Committee on Energy and Commerce hearing, Solyndra executives pleaded the Fifth Amendment, exercising their constitutional right to not testify against themselves. House Republicans had a field day scoring political points on the Democrats. They continue to do so, as they've now subpoenaed White House records.

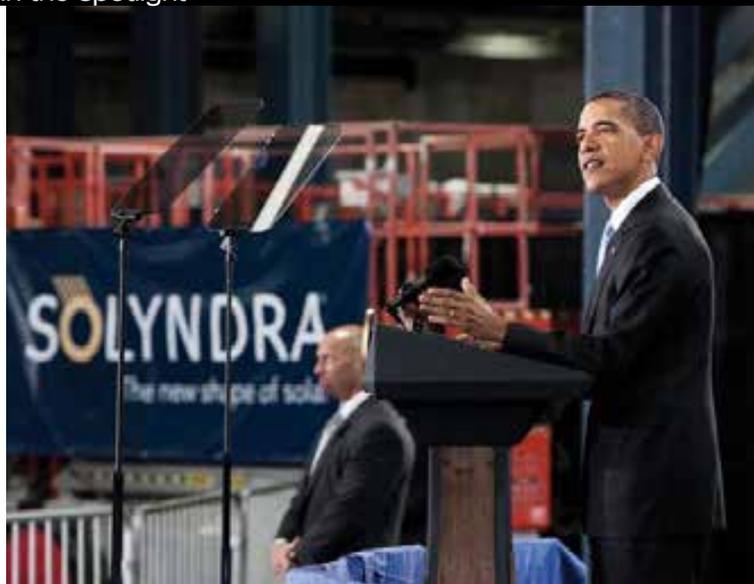
Ten of the 23 Republican members of the House Oversight and Government Reform Committee that is taking the Obama administration to task for the Solyndra default have advocated green-energy projects subsidies (in their congressional districts, coincidentally). And it should be noted that every Republican on the House Energy and Commerce Committee that now decries clean-energy loan guarantees supported them in 2005.

Central to the issue are the proper roles of government. Should government never be in the business of picking winners and losers? That if the private sector won't assume the risk, government should not either?

The federal government has a history of bailouts and industry alignments—like for Enron, Penn Central, Lockheed, Franklin National Bank, New York City, Chrysler (twice), Continental Illinois National Bank and Trust Company, the savings and loan industry, the airline industry after 9/11, Bear Stearns, Fannie Mae/Freddie Mac, A.I.G., General Motors, Citigroup, and Bank of America. Some were successful and even made money for government; some didn't.

Not only do companies compete against each other around the world, nations compete to attract these companies. Silicon wafer maker 1366 Technologies is getting a \$150 million federal loan guarantee. Says the company's CEO, Frank van Mierlo, "If 1366 were to build its plant in Germany, Singapore, China, or Taiwan, the government there would lay out a carpet of tax forgiveness, financing, construction support, and other incentives. The people who say we shouldn't be involved in this don't understand how these decisions are being made in other countries."

Some say it's okay for government to do basic research in science and technology, but leave investing in companies to the private sector. However, there is often a stage in the development of an innovation where the concept seems ready, but the market is not. If the government is going to step in, that is where it is most needed. If a technology is likely to have great social benefits, should government go where



private capital fears to tread? Think of life-saving drugs, the Internet, and improved agriculture—all include potentially high social benefits.

### The Fallout

According to the Brookings Institution, U.S. taxpayers are on the hook for \$3 trillion, spread across some 70 loan guarantees and 63 lending programs for just about anything you can imagine. Brookings calculates that the energy loan programs have generated \$4 to \$8 of private investment for every \$1 invested by the government.

Mature energy industries—like coal, oil, and gas—receive numerous tax breaks that are in unexpiring provisions of law. Emerging energy industries—like solar, wind, and others—must periodically seek subsidy renewal. New industries often don't have enough tax liabilities to use tax subsidies and rely more on direct government support. While it is much easier politically to convince the government to grant you a tax break than to give you a grant, the fiscal impacts are identical.

The Solyndra fallout is affecting other solar ventures. For example, in September 2011, the DOE withdrew its pledge to guarantee \$275 million in loans to SolarCity to build up to 300 MW of PV capacity on 120,000 military housing units. (SolarCity has since partnered with Bank of America/Merrill Lynch to move forward without any federal loan guarantee.)

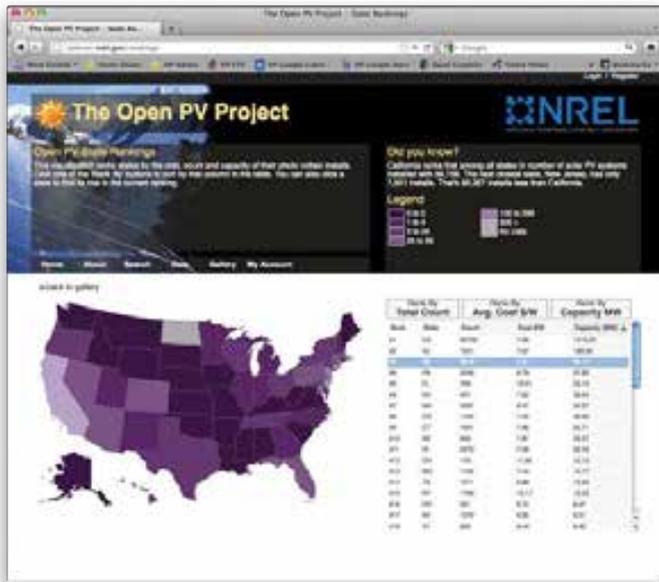
Although the money hasn't completely disappeared for clean-energy projects, the focus has shifted. As the loan program closed in September 2011, the DOE approved \$4.7 billion in loan guarantees for large solar construction projects.

But put this into perspective: Solyndra's \$528 million loss represents less than 2% of the DOE's loan guarantee program for new energy technologies. Of course, accountability is important in any lending situation, and the government should dig deep to get to the bottom of the Solyndra incident, and then take steps to make sure it doesn't happen again. However, an entire industry should not be punished for one company's mistakes.

—Andy Kerr

# The Open PV Project

A Website to Watch



To make effective and informed decisions, renewable energy policymakers need access to current data. The problem is that there is often a lag time between market events and the analysis and reporting of those events. The majority of industry data is compiled into annual reports that summarize market conditions, and up-to-date snapshots of the ever-evolving U.S. solar market are harder to find.

In an effort to provide supplemental data between annual report cycles, the National Renewable Energy Laboratory (NREL) is calling on the PV community to share data. The Open PV Project aims to build a comprehensive database of PV systems in the United States. The initiative is funded through the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy.

At the project's launch in October 2009, NREL "seeded" the Open PV database by requesting data from state-run incentive programs, large utilities, and other organizations. This initial

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data collection provided a base to build upon. Since then, more than 200 government organizations, installation companies, utilities, and roughly 2,200 individual homeowners and independent installers, have used the project's website to voluntarily contribute data. As of December 2011, the project currently has records for every state except North Dakota.

The database requires contributors to provide the installation date, capacity, location, and total installed cost for each project. To ensure the quality of incoming data, each contributor is assigned a reputation "score" based on their affiliation, or lack thereof, with a "trusted" entity, such as a state or federal incentive program with a defined data-collection process in place. Unaffiliated public users—like homeowners or independent installers—are assigned lower scores than a government entity but their scores can be improved once the Open PV team validates their projects.

Complex algorithms are used to identify duplicate projects, and run data-quality checks for corrupt records, bad or invalid data, and outliers (numerically out-of-range data) such as an abnormal cost-to-watt ratio. Records found to contain questionable data are flagged and dealt with on a case-by-case basis by the Open PV team, according to Ted Quinby, an NREL energy analyst and the project's lead technical director.

One limitation of the current platform, Quinby says, is that the costs reported by the database do not take into account tax incentives or cash rebates. Consequently, Open PV cost estimates are more conservative than many PV cost estimates. The project team is exploring ways to publish both pre-incentive and post-incentive data to provide a more comprehensive and accurate reflection of project costs.

Users can search the web-based database by ZIP code to see the details and locations of PV projects in their area, or check the state rankings map to see how their home state and even county measures up in numbers of installations and megawatt capacity. The site's "Market Mapper" displays key market data, including installed capacity and average cost.

—Kelly Davidson

## web extra

To learn more or contribute data about your PV installation, go to: <http://openpv.nrel.gov>



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# Exeltech PVAC Modules



Courtesy Exeltech

Exeltech ([www.exeltech.com](http://www.exeltech.com)), based in Fort Worth, Texas, and operating for 22 years, now offers an AC module certified to UL 1741 and fully compliant with the "Buy American" act. The PVAC modules have a CEC power rating of 212 watts and eliminate the need for DC cabling, as the AC module is a prepackaged module/microinverter pair with a 120 VAC output. The PVAC modules include an AC connector that can connect to the AC home run power cable at any point along the cable. There is no need to ground each inverter (module frame and rack grounding is still required). Should there be an inverter failure, the inverter is detachable (by four screws) from the module for field replacement. Similar to other distributed MPPT solutions, the PVAC offers module-level monitoring via Exeltech's Heliosentry data interface (sold separately), which also functions as a lockable AC disconnect and comes in a NEMA 4X enclosure for indoor or outdoor mounting. The Heliosentry comes with an irradiance sensor; three temperature sensors (to monitor indoor and outdoor ambient temperatures, and module temperature); and two clamp-on current sensors to measure total household energy consumed and PV energy fed to the grid. Data for up to 20 PVAC modules is available on an LCD display and over a home computer network. An Internet connection is not needed for monitoring. Internet access to system data is not supported at this time.

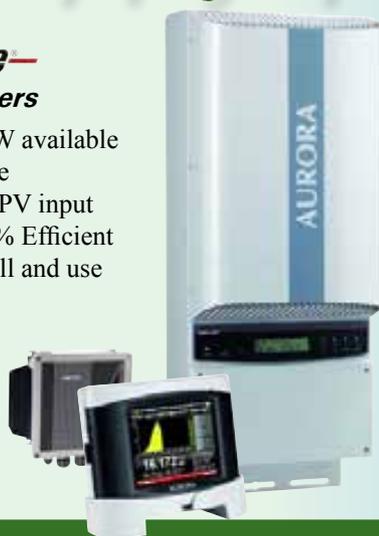
—Justine Sanchez

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# Schneider Electric

## XW MPPT 80 A, 600 V Charge Controller

Schneider Electric ([www.schneider-electric.com](http://www.schneider-electric.com)) has introduced its XW-MPPT-80-600 solar charge controller, designed for 24 or 48 V battery-based systems. Product features include a 600 VDC maximum input voltage, a “fast sweep” MPPT tracking algorithm (to help the array more consistently operate at maximum output), and built-in ground-fault protection. The voltage operating range allows a high-voltage and low-current PV array to be connected to the charge controller, often eliminating the need for a combiner box and associated DC circuit breakers, and allows smaller-gauge array wiring to be used. Built-in ground-fault protection can be configured for a negative, positive, or ungrounded PV array. The controller allows modules originally intended for grid-tied systems to be efficiently used in battery-based systems.

—Justine Sanchez

Courtesy Schneider Electric



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# Solar Sisters

Florence lives in rural Uganda and is a member of the Ntulume Village Women's Development Association. She's also a Solar Sister. Solar Sister, the brainchild of Katherine Lucey, is a social enterprise focused on eradicating energy poverty by empowering women with economic opportunity.

One-quarter of the world's population—1.6 billion people—don't have reliable access to electricity. The lion's share—70%—are women and girls who live in the developing world. Instead, they rely on kerosene lanterns and paraffin candles for light, choices that are both inefficient and hazardous, and they spend up to 40% of their incomes on these poor energy sources.

Lucey's innovative solution is to equip these women to become "solar entrepreneurs" and provide them with the tools to sell solar technology. The women sell an array of clean energy household products, including solar lamps, cell phone chargers, clean cookstoves, and hand-crank and solar radios.

Why focus on women? According to Lucey, "There is a gender-based technology gap combined with a distribution gap—often referred to as the 'problem of the last mile'—that keeps these life-changing solutions from being adopted."

"Through its network of women solar entrepreneurs, Solar Sister addresses both of these issues and has created the most effective 'last-mile' distribution system for rural Africa," says Lucey. She launched Solar Sister in 2010, after working as an investment banker focused on the energy sector for 20 years. Today, her enterprise has 150 entrepreneurs in Uganda, South Sudan, and Rwanda, bringing light and opportunity to more than 8,000 people. She has plans to expand the program to Kenya and Tanzania.



"Clean energy technology has been developed that is affordable, appropriate, and available. But it is not easily accessible to the people who need it most, the women and children in rural communities," Lucey says. "Through access to technology, Solar Sister creates critical, lasting change in the lives of women and girls living with the devastating effects of energy poverty."

Solar Sister works because it addresses a real need, the need for light and energy in communities without access to electricity. We do this by tapping into one of the most powerful, but overlooked, networks in the world, women's natural social networks of family, friends, and neighbors."

Solar Sister provides each entrepreneur with a "business in a bag," a complete startup kit of training, marketing support, and inventory access that gives a Solar Sister the tools she needs to be successful.

"At the household level, it is largely women who are responsible for utilities such as water and energy," says Lucey. "It is the women who go to town to purchase small amounts of kerosene and fill up their lamps, spending \$2 to \$4 per week simply for light."

If we are going to help women make a decision that it is better to buy a \$20 lamp that will last for years rather than spend \$2 every week for kerosene that is toxic, unhealthy, and [gives] poor light, then we have to reach her at the point of decision. The women-centered distribution system that Solar Sister uses—women selling to women—is the most effective and efficient distribution method for reaching women right at their doorstep."



Courtesy Solar Sisters (C)

The Solar Sisters, who earn a commission on each sale, don't pay for their inventory until they sell it, enabling them to create sustainable businesses. The profits are invested back into growing the network of Solar Sister entrepreneurs.

The impact Solar Sister has on its clients reaches beyond simple household economics: "When families have access to clean, affordable light, their children study longer and do better in school; they are healthier and suffer fewer injuries from burns or smoke inhalation; babies are born guided by a midwife who can see what she is doing rather than rely on a candle held between her teeth; and women can pursue income-generating activities and help their families make ends meet," Lucey says.

"The strength of our enterprise solution comes from the women themselves—it is their own ingenuity and commitment that builds their business," says Lucey. "We are just offering them the opportunity to help themselves.

Even small amounts of electricity can dramatically improve the lives of women living with acute energy poverty. Creating economic opportunities for women has a multiplier effect on social and economic progress of their communities and our world."

—Suzi Parrasch, adapted from [www.care2.com/causes](http://www.care2.com/causes)



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# Solar Double-Cropping

Piedmont Biofuels has become an incubator for sustainable enterprises in North Carolina. Its industrial park now serves as a home for its biodiesel facility (see *HP122* and *HP132*), the Abundance Foundation's off-grid office (see *HP145*), the Piedmont Biofarm, and several other developing businesses. It also is now home to a solar "double-cropping" project—lands that simultaneously produce energy from the sun and crops grown under three PV canopies that sit above an agricultural field.

"We need clean energy, and we need sustainable food," says Lyle Estill of Piedmont Biofuels. "This installation will enable both." The harmonious project between energy and land was orchestrated and financed by Miraverse Power and Light owned by Michael and Amy Tiemann. The Tiemanns recently opened a recording studio called Manifold Recording and, although the PV system is located a few miles away, the system size was determined and designed with the goal of making the recording studio carbon-neutral. The system will offset all of the studio's energy consumption and, says Michael Tiemann, "it will do it without removing any land from agricultural production." The shade the array provides will benefit the crops during the hot North Carolina summers.

Southern Energy Management (SEM), a North Carolina-based installer, put in the system. David Boynton of SEM, along with brothers Lyle and Glen Estill, designed the system with both energy- and vegetable-production goals in mind. PVsyst modeling software was used to predict energy output, while 3D modeling analyzed shade throughout the year. SEM determined that a 92 kW system on three large canopies would be best for energy production and achieving the proper sun-to-shade ratio.

High-efficiency SunPower modules were wired into 36 strings of eight modules each. The design uses 12 SMA America inverters instead of a single central inverter. SunPower's commercial monitoring system helps keep tabs on the array's performance.

To optimize crop growing, the sloped canopies are spaced 40 feet apart and tilted 10°, with the lowest edge 10.5 feet above the soil. During the cooler months, when the sun's path is low in the sky, this height allows sunlight to reach the plants underneath. In the summer, when the sun is more overhead, the canopy provides some shade. "There are vegetables that will benefit from some protection from the sun," says farmer Doug Jones. Having some shade can extend the growing season for plants like spinach, lettuce, cabbage, and broccoli that tend to bolt (go to seed) when the weather turns hot.

Michael Tiemann says that the "double cropping" concept serves as a sustainability example. "We hope that others copy these ideas, improve upon them, and share their improvements," he says.

It will be exciting to observe the total harvest—solar and otherwise—from this piece of land.

—Kyra Moore



Courtesy The Abundance Foundation

## Overview

**Project name:** Piedmont Biofuels "Solar Double Cropping"

**System type:** Batteryless grid-tied

**Installer:** Southern Energy Management

**Date commissioned:** December 2011

**Location:** Pittsboro, North Carolina

**Latitude:** 35.7°

**Daily peak sun-hours:** 5

**System capacity:** 92 kW STC

**Average annual production:** 134,000 AC kWh estimated

**Average annual utility bill offset (estimated):** 100%

## Equipment Specifications

**Number of modules:** 288

**Manufacturer & model:** SunPower E19/320

**Module rating:** 320 W STC

**Inverters:** 12 SMA America 8000 US

**Array installation:** Canopy

**Mount manufacturer:** Schletter, custom mount

**Azimuth:** 180°

**Tilt angle:** 10°

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# MPPT & Checking PV System Output

For more than a decade, maximum power point tracking (MPPT) has been standard in grid-tied inverters. Every PV cell has a unique IV curve that is constantly shifting with changes in light and temperature. The individual cell IV curves added together create the module's curve, module curves build into strings, and so on until the array has one aggregate IV curve built and averaged from all of the smaller ones. The challenge of MPPT is to quickly assess this shifting IV curve, and find the one spot where power output is highest at that moment.

MPPT is controlled by programming logic, and varies by manufacturer. How fast and accurately an inverter tracks the changing MPPT is its "adjustment efficiency," and affects an inverter's overall efficiency. MPPT adjustment efficiency is not reported separately in inverter specifications, but *Photon International* magazine regularly tests it and publishes the results, which are in the range of 97% to 99%.

To discover if your inverter is finding the MPP, compare a calculated output with the inverter's reported AC power output. This test should be done on a sunny day with regular irradiance, when there is no shading on the array. You'll need a pyranometer to measure available power in watts per square meter, and a sensor to measure module cell temperature. You will also need to know specifications for array power, the module Vmp temperature coefficient, and the inverter's CEC weighted efficiency. Here are the steps, with an example:

**1. Calculate expected power output.** Measure the irradiance in W/m<sup>2</sup>. Use the pyranometer to get an irradiance measurement in the plane of the array, holding it at the same angle and azimuth as the array. The W/m<sup>2</sup> reading will be divided by 1,000 to get the percent of STC irradiance to include in the calculation example.

**2. Calculate the temperature adjustment by measuring a module's cell temperature.** The most accurate measurement is taken from the back of a module's cell—not between the cells. This value, along with the temperature coefficient of Vmp (in units of % per °C) is used to calculate the percentage gain or loss in voltage due to cell temperatures that deviate from 25°C: (Cell temperature - 25°C) × TkVmp = % change. If negative (hotter temperatures), subtract from 100%; if positive (colder temperatures), add to 100%.

**3. Estimate the effects of soiling and module aging.** Are the modules clean? Are they a few years old? Estimate 0.5% loss per year of age. The soiling derate is estimated by actual conditions—2% to 5% loss (a factor of 0.95 to 0.98) is typical.

**4. Estimate or measure voltage drop between the array and inverter—2% (0.98) is a typical value.** (Be sure to wear proper protective gear if you are measuring.)

**5. Find the inverter efficiency in the equipment section of [www.gosolarcalifornia.org](http://www.gosolarcalifornia.org).** Then plug the above values into the equation:

$$\text{Array W} \times [(\text{W/m}^2 \div 1,000)] \times (\text{temperature adjustment}) \times (\text{soiling \& age derate}) \times (\text{voltage drop}) \times (\text{inverter efficiency})$$

Here is an example calculation:

1. Array DC STC W = 5,000 W

2. Irradiance = 800 W/m<sup>2</sup>  
800 W/m<sup>2</sup> ÷ 1,000 = 0.8

Cell temperature = 35°C

Temperature adjustment = (35°C - 25°C) × -0.41%/°C  
= -4.1% or 0.959

3. Soiling and age derate = 4% or 0.96

4. Voltage drop = 2% or 0.98

5. Inverter efficiency = 0.97

5,000 W DC × 0.8 × 0.959 × 0.96 × 0.98 × 0.97 = 3,500 W AC

If the resulting value is within a few percent of the inverter's display value, the system is working well. If not, there are three potential reasons why the inverter output would not match the calculation for an unshaded array:

- Array problems such as bad connections, failing modules or modules with power tolerances outside the range of +/-3%, and/or higher-than-estimated voltage drop or soiling (see "Potential PV Problems" in *HP143*).
- The array's DC power is greater than the inverter's capability—the inverter has to deviate from the MPP to keep the array's power output within the inverter's limits (see "Array-to-Inverter Ratio" sidebar in this issue's "Inverter Buyer's Guide").
- The inverter's MPPT isn't working properly.

Another gauge of MPPT effectiveness is to check the inverter on a day with passing clouds. Watch the power output display—it should be varying almost instantaneously as cloud cover changes—lower as the clouds block sunlight, and higher as clouds clear. If the inverter output is static or stays extremely low during breaks in cloud cover, the MPPT is poorly designed or ineffective.

—Rebekah Hren



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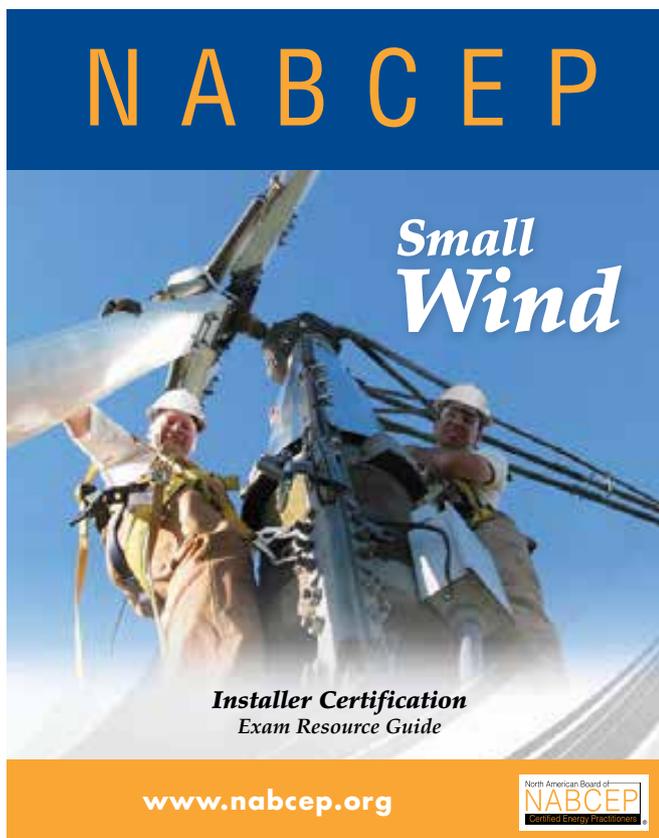


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## NABCEP Wind

About a year ago, the North American Board of Certified Energy Practitioners (NABCEP) rolled out the first Small Wind Installer Certification exam. Dozens of small-wind installers worked to develop the job task analysis, the requirements to sit for the exam, the exam resource guide, and the actual exam. This certification parallels the photovoltaic and solar thermal installer certifications, yet few in the small-wind industry are aware of it.

The NABCEP small-wind installer certification covers all manner of wind turbines and towers with an upper limit of 100 kilowatts in nameplate turbine capacity. The exam and certification cover all end uses for small wind, from single- and three-phase installations to battery-charging off-grid applications.

An installer can follow a number of paths to qualify for the exam, but all require a minimum amount of training and real-world experience. Applicants can qualify as contractors, through apprenticeship programs, as graduates of an accredited institution of higher learning, by taking workshops, or as seasoned small-wind professionals or trainers. The requirements to sit for the exam can be found at [www.nabcep.org](http://www.nabcep.org). Regardless of the training pathway, applicants must have had a responsible role in at least four wind installations during the preceding four years.

NABCEP's small-wind installer exam is intended to test an installer's understanding of what is involved in a successful wind installation, covering the core competencies in the task analysis, which was developed by a committee of installers and reviewed by dozens of stakeholders from the small-wind industry to assure its completeness and relevance ([bit.ly/smallwindjta](http://bit.ly/smallwindjta)). A resource guide is available at [bit.ly/swguide](http://bit.ly/swguide).

Achieving NABCEP small-wind installer certification is a great way for an installer to rise above the ever-growing field of people who claim competence, but who have little or no practical knowledge or installation experience. Certification does not guarantee competence, although it is usually assumed that anyone who successfully passes the exam is indeed qualified. Grant programs are increasingly looking for NABCEP certification as a way of ensuring that installers know their stuff.

Mick Sagrillo •  
NABCEP board of directors,  
co-chair of the Small Wind Technical Committee,  
NABCEP-certified small-wind installer

## Module Testing

Your "2012 PV Module Guide" in *HP146* was very useful, but I wish that you had pointed out that the state of California does not randomly select the PV modules that are tested in independent labs, as does the solar heating certifying organization, SRCC.

PV modules vary considerably in their output, and the fact that they are not randomly selected [for testing] seems to make the California PTC ratings not as meaningful. Since the manufacturers can select their best-performing modules to be tested, how significant are the PTC ratings and the PTC-to-STC ratios? The same cherry-picking is apparently also allowed in the case of the independent testing done to determine manufacturers' STC ratings.

Until articles like yours identify this problem of manufacturing companies selecting their own modules for testing, it seems to me nothing is likely to be done about it. For an industry that is as large and rapidly growing as the PV module industry, this lack of random selection in the testing process seems shocking.

Lotus, President, Rocky Mountain Solar & Wind, Inc. •  
Colorado Springs, Colorado

## Non-Electric Range

After much research and some great letters and articles from *Home Power*, I recently purchased a Peerless-Premier SFK249 30-inch gas range for our off-grid cabin. It was one of a very few that still use spark ignition for the oven.

Most ovens now use a glow-bar heating element as an ignition source; these draw 300 watts or more continuously and cannot be used without electricity! Clearly, this was not an option for our situation.

A number of ranges use a standing pilot—a small pilot that burns continuously. It ignites the main pilot, which in turn ignites the oven burner. While the main pilot has a thermocouple safety, the small standing pilot does not; if it extinguishes for some reason, the gas continues to flow. The vendors I spoke with about this assured me that the gas volume would be minimal and would never amount to an explosion risk. Nevertheless, I didn't want to risk entering a cabin that had been filling with gas for a week while we were away.

The Premier is one of the few remaining ranges that uses a spark ignition and can



also be lit manually with a match. We absolutely love it. As a bonus, it has a fifth burner that converts to a griddle.

Wilf Steimle • Innisfil, Ontario, Canada

## Errata

The "PV Pergola" article in *HP146* listed the incorrect rack manufacturer on pages 60 and 63. SnapNrack ([www.snapnrack.com](http://www.snapnrack.com)) manufactured the PV mounting rails shown in this article.

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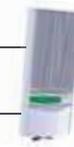
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With over 20 years of solar experience and author of "Complete Idiot's Guide to Solar", David has the ability to eerily predict happenings in the solar universe. Whether you have a question about ancient Rome or future solar projections, David is your guy.



## Understanding Battery Capacity

How do you calculate battery capacity in amp-hours (Ah) at different “C” rates? For instance, I know that a battery with a capacity of 200 Ah at C/20 has a different capacity at C/100.

When you size a PV system with a battery bank of, say, 800 Ah, how do you tell what C-rate the battery bank is using?

Geoffrey Kaila • via e-mail

C-rates are also called “hourly rates,” and are based on the length of time of discharge. A C/20 rate means that battery capacity is calculated based on completely discharging it over the course of 20 hours. So, if you have a 1,000 amp-hour battery bank, charging or discharging at 50 amps would be a C/20 rate (1,000 Ah ÷ 50 A = 20 hrs.).

The informal solar industry standard for comparing deep-cycle battery capacity is at the C/20 rate, because it approximates the 24-hour discharge period of most off-grid systems. Many battery manufacturers’ data sheets also provide capacity information for C/5 and C/100 rates, which are useful in other industries.

It is possible to calculate battery capacity at any given C-rate, if you know Peukert’s exponent for the battery. Peukert was a German scientist who derived the formula for the relationship between battery capacity and discharge rate. Battery manufacturers do not typically provide Peukert data on their spec sheets, but it may be available by contacting them.

**It = C × [C ÷ (I × H)]<sup>k-1</sup>; where**  
**H = rated discharge time in hours;**  
**C = rated capacity at that discharge rate;**  
**I = actual discharge current in amps;**  
**k = Peukert exponent**  
**It = effective capacity at the discharge rate “I”**

Most flooded lead-acid batteries have a Peukert exponent between 1.2 and 1.4, while most absorbed glass mat (AGM) batteries are between 1.05 and 1.2—but keep in mind that these figures will increase as the batteries age. Peukert’s exponent for a given battery can also be calculated if the manufacturer provides you with the capacity ratings at two different discharge rates. That math is complicated, but there’s a helpful spreadsheet (and detailed information on applying Peukert’s law) at [www.smartgauge.co.uk/peukert\\_depth.html](http://www.smartgauge.co.uk/peukert_depth.html)

A typical renewable energy system will be charging or discharging at different C-rates throughout the course of any given 24 hours. With a battery monitoring system that logs data to a computer spreadsheet, it’s possible to calculate the C-rate at any given instant. And though it seems strange, your usable battery bank capacity is continuously changing.

Fortunately for the typical home RE system owner, discharge C-rates are, on average, quite low. Consider a 48 V battery bank of 1,000 Ah in a system that’s designed to provide 10 kWh of backup energy per day. Those 10 kWh equal 208 Ah. This divided by 24 hours equals 8.7 A. That’s a daily average rate of C/115 (1,000 ÷ 8.7), far slower than the C/20 rate used for comparison when selecting batteries. It’s true that large loads that are used during those 24 hours will increase Peukert effects and reduce usable battery capacity, but this example is also figured with no solar input. On sunny days, the C-rate of discharge will be even slower.



Dan Fink

**These Surrette batteries are rated at 546 Ah each at C/20; 426 Ah at C/8; or 770 Ah at C/100.**

Folks working with electric vehicles must pay closer attention to Peukert’s law. A typical EV’s battery bank has much lower capacity than one in a typical solar home, since both battery weight and bulk must be minimized in vehicles. Also, EV motors use battery energy at very high rates—under some conditions, the battery might be fully discharged in less than an hour.

For solar energy applications, simply using proper system sizing guidelines such as online spreadsheets or consultation with your local RE dealer will keep the batteries’ C-rates reasonable, usually much better than C/20. Peukert’s exponent will only raise its ugly head if you drastically undersize your battery bank for your loads, or in specialized applications like electric vehicles.

Dan Fink, Buckville Energy Consulting • Masonville, Colorado

## Of Mice & Generators

We live off-grid on 16 heavily wooded acres near Boston. We have a PV system with a battery bank, inverter, and a propane generator. In the summertime, the PV is almost always enough, but not in winter.

We are looking for our third generator in 10 years! In both cases, the problem was that mice damaged the wires (control and alternator) so badly that the generators couldn’t be repaired. The current failing generator is a Kohler 8.5RES (8.5 kW).

**The small PV module that sits on top of this Kohler generator keeps the remote-start battery (not pictured) charged between uses.**



Allan Sundejar

# Big wave surfer. SolarWorld Authorized Installer. *Work-life balance achieved.*

## Kohl Christensen, Oahu, Hawaii

"I have been traveling to remote locations on surf trips for years and now, after becoming a solar contractor and teaming up with SolarWorld, it feels really good to be able to travel back to these spots and share some of my knowledge... I am glad I can help."

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Do you have suggestions for choosing a rodent-proof, reliable generator that would meet our needs: usage hours much higher than what an on-the-grid house would use for backup and a remote-start function in our cold climate?

Mark Bramhall • Acton, Massachusetts

You have identified issues common to off-gridders dependent on a generator during winter months. You may find general guidance on what to look for in my article on generators in *HP131*, available at [www.homepower.com](http://www.homepower.com).

First, keep the starting battery close to the generator—inside the generator's enclosure is best. Beyond a short distance, the starting current will necessitate using large, expensive wire. The starting battery can be kept charged by adding a dedicated PV module and charge controller. For a simple generator with analog controls, typically a 1 to 1.5 W "battery maintainer" module sold for RVs in storage is enough. With many modern generators with electronic controls, a 20 W to 30 W module will work in sunny regions; a 50 W module may be needed in your cloudy location to keep the starting battery charged between uses. A small charge controller with temperature compensation will prevent overcharge. Make sure to locate the module where the winter sun is available, since many generators are hidden away behind buildings and trees.

You are correct that most modern generators are designed for utility backup service and don't stand up to extended runtime hours in off-grid applications in cloudy winter climates. Over the last decade or so, many manufacturers have moved away from simple, well-built generators suitable for off-grid use toward the larger sales market for "home standby" models for residential grid backup. These units include features such as electronic controls, block and carburetor heaters, and battery chargers that continuously draw utility power. They seldom see many hours of use, so longevity is sacrificed in favor of low price to the consumer. In fact, many home standby generators, including your Kohler RES, are not typically warranted for off-grid applications. (Note that Kohler has recently added a limited warranty for some units in off-grid applications, including this model).

Rodent damage can be a problem. Some generators have better sealing against critters than others. The 8.5RES has holes in the



Courtesy Generac

**This Generac EcoGen model is specifically designed for off-grid use.**

chassis for attaching lifting handles, but is supplied with plugs to seal these holes. A diligent sealing job, plugging all openings, will generally work to prevent rodent access.

I recently installed a new 6 kW EcoGen generator, developed by Generac specifically for off-grid applications, and it has caused me to favorably reconsider Generac for your type of application. The unit has a heavy base and a full steel enclosure with a gasketed, hinged top and screened vents—it has been securely built to repel rodents. I haven't seen any evidence of mice inside the unit.

The heavy-duty engine runs at 2,600 rpm, using a vertical shaft and belt drive to spin the armature at 3,600 rpm, while reducing sound and increasing engine life. It has standard two-wire remote signal and electric start, a large external oil reservoir, and a 500-hour recommended maintenance interval. It comes with a three-year/2,000-hour warranty when used in off-grid applications.

This is a new model without a track record. Your application sounds ideal as a test site for it, given your heavy winter use. If you decide to try one, please let the crew at *Home Power* know the results, so others can benefit from your experience.

Allan Sindelar, Positive Energy • Santa Fe, New Mexico

## Wind Generator Blades & History

I found three wooden propeller blades in my garage attic that look like they may belong to an old wind turbine. The only identification marks are the number "33" stamped onto the back of each blade near the hub. The blades are each 84 inches long with five holes for the hub.

Could you please help identify what I have? Any information about the blades' age, manufacturer, and value would be appreciated.

John Lezamiz • via e-mail

Your blades are from a Winpower wind turbine, made in the 1930s and 1940s in Newton, Iowa. It was a downwind machine with a blade-pitching governor, the blades pitching out of high winds to limit output. At 84 inches long, I'd guess that the blades came from a 2,500-watt wind turbine.

The turbines from that era were typically 32 VDC nominal for charging a battery bank. Wind was a rural technology serving people who did not have utility electricity. That included most country folk from the Ohio River Valley to the Rockies, but especially those in the Great Plains, an area with an abundance of wind. Other wind turbine manufacturers included Jacobs, Wincharger, Air Electric, Allied, Rural-lite, Parris-Dunn, and Wind King. The smaller wind turbines of the era were typically called "radio chargers" and, at 6 VDC, only powered a radio and a few kitchen lights. Larger units were 32 VDC, and powered any and every appliance or tool that you can think of. They were advertised as "bringing all the conveniences of the city to the country."

It's reported that more than 1 million people lived off-grid with wind turbines in the 1930s and 1940s. This was the Great Depression era—any expenditure for a device like a wind turbine when money was scarce must have held great value for the owner. If you live

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Courtesy John Lezamis

**Old Winpower turbine blades, circa 1930s.**

anywhere near Clarinda, Iowa, you might visit the Nodaway Valley Historical Museum. Set up as a small village, the museum depicts many of the appliances and tools from that era, along with a small Parris-Dunn radio charger.

The 84-inch blades are unusually long, as most blades that I've seen are only 6 feet long. I'm wondering if someone didn't make these as a replacement set. The original blades would have had the brass or copper leading edge tacked on with small nails, or maybe staples. The balance weight on one of the blades looks to have been added

later. However, the blades appear to have an original silver paint, typical for many wind turbine blades of that era, although many Winpower blades were varnished with the wood left natural.

Anything that you do to "restore" the blades will diminish their historic value. If your goal is historic value, leave them as-is.

More information and plenty of photos about the Winpower and other wind generators of that era can be found at [www.windcharger.org](http://www.windcharger.org).

Mick Sagrillo, Sagrillo Power & Light • Forestville, Wisconsin

## Off-Grid Battery Charging

Recently, I had a professional solar installer inspect my self-installed off-grid system. He recommended that I install a separate, more powerful battery charger. He said I would get a fuller charge, and my batteries would have a longer lifespan, with a better charger.

My system consists of:

- Twenty-eight 120-watt modules
- Twenty-four 6-volt L-16 batteries, 1,110 amp-hours at 48 volts

- A 4,000-watt Trace inverter
- A 15,000-watt, 240-volt Olympian generator
- A 240-volt to 120-volt AC transformer

Should I get a separate battery charger more powerful than the one in my Trace inverter? If yes, how do I size the battery charger?

John Barnett • Occidental, California

The only 4,000-watt 48-volt Trace inverter was the SW4048 which was rated at 60 amps of continuous charging capacity, using up to roughly 44 A of AC input current to do so at 120 VAC.

Your 1,110 Ah divided by 60 A yields a C/18.5 maximum charging rate. Your batteries can handle about double that rate if they're in good shape—that is, not sulfated. A higher charge rate will also reduce generator run time. Yes, I would encourage you to increase the battery charge rate, but my first choice would not be a separate battery charger.

The battery charger that was built into the Trace SW-series inverter was quite capable and reliable. In addition, it could be digitally programmed for voltage, current, absorption

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The Trace SW4048 inverter.

time, and equalization, and included automatic temperature compensation. All of this was part of the basic design of this excellent legacy product.

The few industrial battery chargers that I have seen are just that—designed for an industrial environment with repetitive, predictable requirements, such as recharging a forklift each night between shifts. One will work in this application, but will lack the programmability of the SW4048. Also, any single-phase industrial charger is likely 240 VAC, so it would be wired in parallel with the 240 V primary side of your step-down transformer.

You hail from cool, coastal California, so your generator needs no derating for elevation or temperature. You use a transformer to step down your generator's 240 V output to 120 V, which gives you access to the generator's full power capability. But at 15 kW, your generator is capable of supplying the amps to charge your batteries at a much higher rate than your single SW4048 can handle.

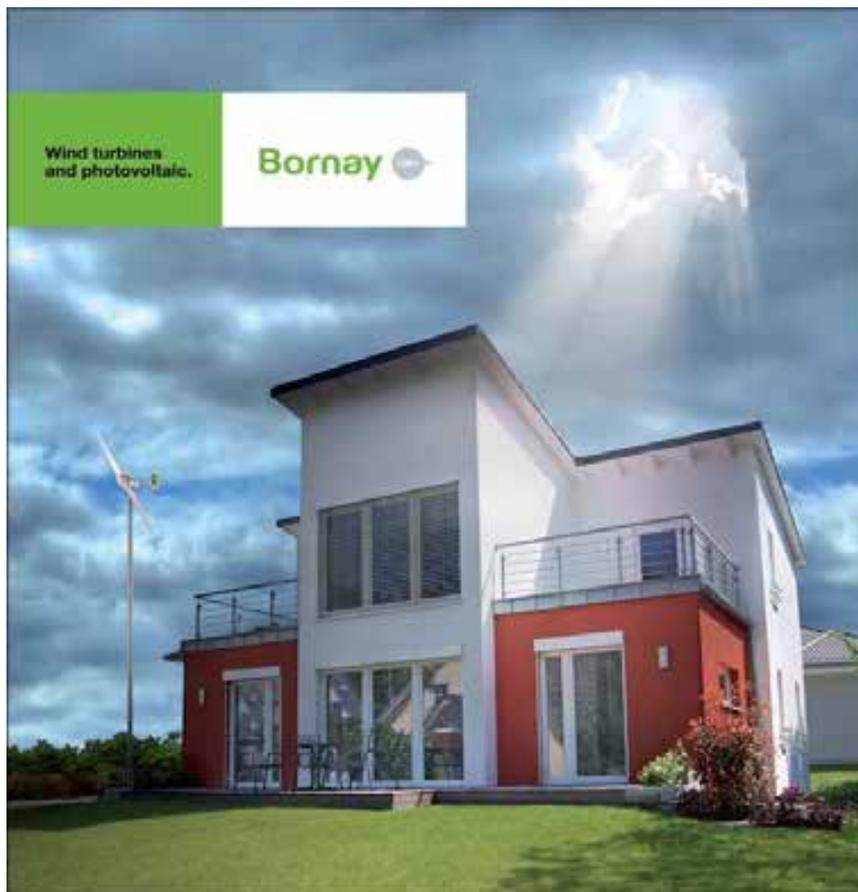
I suggest installing a second SW4048. To find one, search Craigslist or eBay, or do an Internet search. While these units have been out of production for years, there were thousands built and you will eventually find one in good working order. Wire its AC2 input to the unused leg of your generator (eliminating your step-down transformer), and set it up only to charge. You won't need a "series stacking cable," since the chargers will synchronize with the generator's waveform. If you locate a SW5548, you may use it as well. Program the two units identically, except reduce one unit's absorption time by 10 minutes so that the units don't fight each other during the transition to float stage.

Until you find a second unit, you can improve your battery charging success by carefully matching charge times with the weather. You have more than 3 kW of PV power, which is,

in theory, enough to match your inverter's charging capacity. Especially when you equalize, use your generator to charge to about 100% full by 10 a.m. on a sunny day; then set your charge controller to equalize along with the inverter. This approach will help achieve full battery equalization in a few hours. For regular bulk charging in inclement weather, this approach will make little difference.

Allan Sindelar, Positive Energy, Inc. •  
Santa Fe, New Mexico

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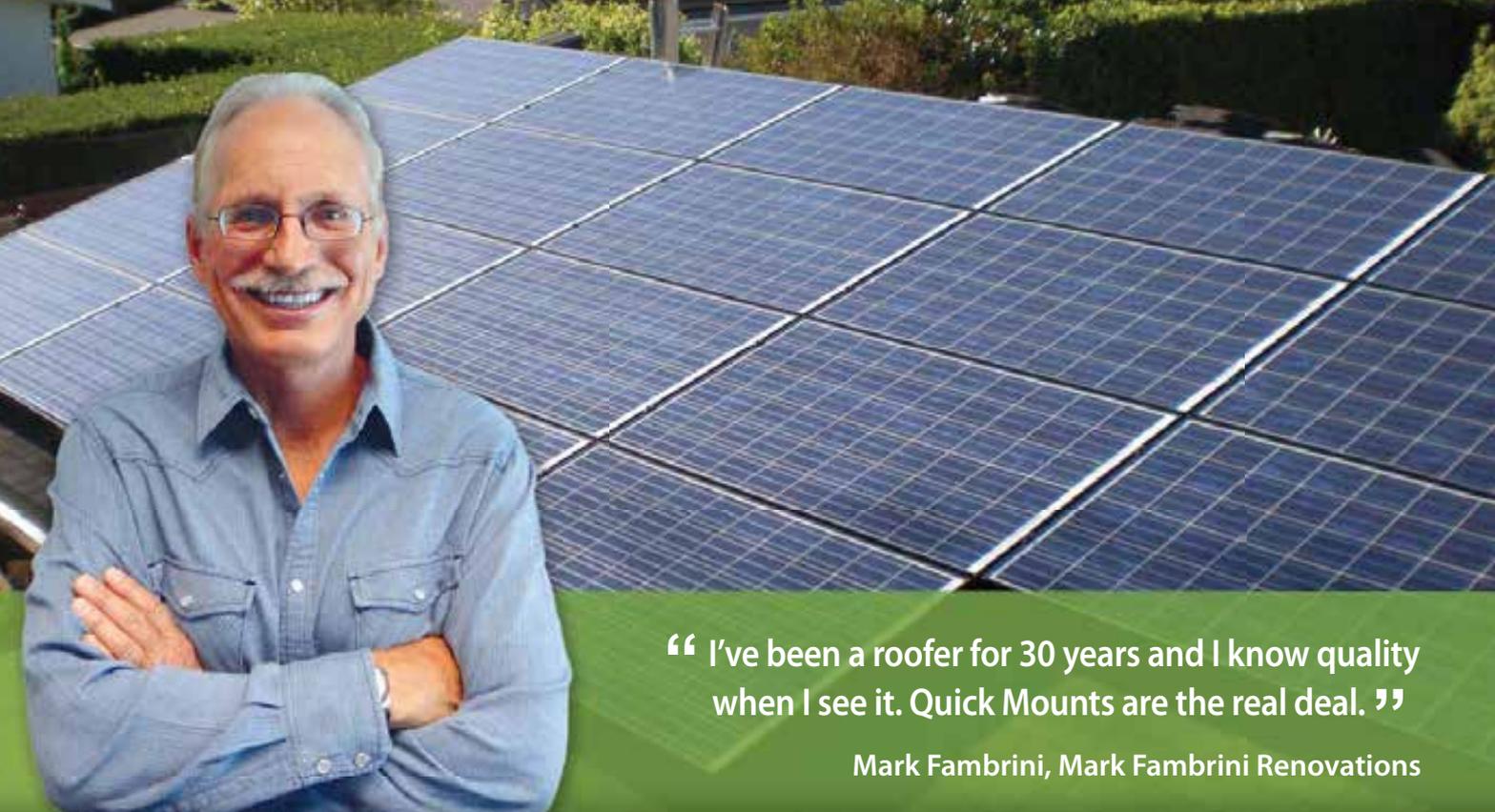
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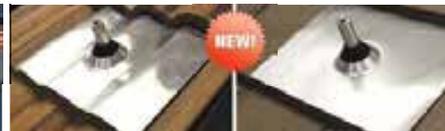
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# Expanding Your PV System

by Brian Mehalic



Sometimes system expansion is planned from the start, and sometimes it is done out of necessity. So how can you best anticipate changes, and meet those future needs?

Can I add more modules to my system next year? Should I oversize my inverter from the get-go? PV system designers and installers are frequently asked these very questions. Sometimes system expansion is planned from the start, and sometimes it is done out of necessity. The reasons are many, ranging from a limited budget, to increased loads putting additional strain on an off-grid system, to changes in module prices and rebate structures. So how can you best anticipate changes, and meet those future needs?

Here are the component considerations (and challenges) for expanding your PV system.

## More Modules

Increasing the length of existing PV source circuits by putting more modules in series may be one option for expanding the system. However, sourcing modules of the same make and model may be difficult. Models change and manufacturers come and go. Some larger integrators may keep extra modules on hand, often as replacements for damage that may occur—but don't count on it. Besides aesthetics, mixing new and old modules means paying attention to size constraints and additional wind and weight loading on the roof or mounting structure.

Module size has increased dramatically over the years. Not that long ago, 80-watt, 12-volt (~18 Vmp) nominal modules were common; today, 200 W (or larger) modules, ranging from about 30 V to 60 V, are more typical. If different modules are going to be used, the new ones should have voltage and current characteristics as close to the originals as possible. Note



Courtesy: Electron Connection

**PV modules have always been touted as “modular,” and therefore easily added to, but the variables throughout the rest of the system complicate expansion.**

that wiring additional modules in an existing series string doesn't allow much expansion, as maximum circuit voltage will typically limit the number of modules that can be installed. For example, if a module's maximum voltage is 44.1 V (based on low temperature data and the temperature coefficient of open-circuit voltage), and there are already 12 modules in series ( $12 \times 44.1 \text{ V} = 529.2 \text{ V}$ ), then only one more module could be wired in series without exceeding the 600 V maximum limit for dwellings (14 modules in series would equal 617.4 V—too high—while 13 in series would be 573.3 V).

Grid-tied inverters do their best to deal with array current-voltage curves affected by the inherent, slight differences between all modules. The greater the dissimilarity—for instance, adding 200 W modules to an array of 85 W modules—the more difficult it is to extract maximum power.

When modules with different currents and voltages are connected in *series*, the current of the new string will more closely reflect the module(s) with the lower currents. For example, if a 7-amp module is wired in series with a 4 A module, the higher-current module will be current-limited to about 4 A. The voltage will be additive, as expected with series wiring, but the overall gain in power will be limited by the lowest-current modules.

## Inverters

**Central String-Inverters.** For grid-tied systems, the size of the string-inverter can limit expansion. It is common to design systems with an array-to-inverter power ratio of 80% to 120%, depending on the location of the system and where the inverter is installed (see the “2012 Grid-Tied Inverter Buyer's Guide” in this issue). For example, a 4,000-watt inverter may be coupled with a PV array ranging from 3,200 to 4,800 W STC. However, a design in this range will not allow for significant future expansion. For expansion purposes, consider installing a 7,000-watt inverter in place of the 4,000. Because inverter efficiency curves are relatively flat once the array size exceeds 30% of the inverter rating, loading an inverter “halfway” to allow for a future doubling of the array size does not greatly reduce the inverter's operational efficiency.



Courtesy: Power-One

**Most manufacturers offer inverters with various output ratings in similarly sized enclosures, making “buying large” in anticipation of expansion an easier choice.**

**Some models (like this Power-One PVI) offer multiple, separately tracked inputs for adding PV subarrays with different voltage and current characteristics.**



Courtesy Guy Marsden

Using microinverters and with full racking, this system was designed for expansion. Adding new PV modules (even different models) is as easy as mounting and wiring them. For more about this system, see the complete article in *HP136*.

A larger inverter can allow for additional PV source circuits, or “strings”—for example, adding eight 200 W modules to an existing 3,200 W array of 16 modules. Ideally, the original system was installed with a 5,000-watt inverter with future expansion in mind. Because installers must size the AC output wiring based on the full inverter capacity, the required AC output wiring and overcurrent protection for the expanded array is already in place. Sizing additional components, such as transition boxes, conduit, and disconnects on the DC side for the future full array, is a big help when it is time to add the new string.

As systems age, expansion and maintenance are likely to go hand in hand. Inverter replacement is a known maintenance cost—most inverters are only warranted for 10 to 15 years, while most PV modules carry a 20- to 25-year warranty. When the time comes to replace an inverter, a concurrent expansion

in system size is a possibility. If expansion is likely to occur, then designing for it can make adding more power much easier.

Issues with mixing and matching modules still pertain, but—especially with an older array—it may also be helpful to recalculate the operating voltage of the older modules. As they age, modules lose some voltage; additional resistance in the connections and terminations in the circuit result in further reduction of operating voltage. If a new inverter is being installed, make sure to test voltage (or measure the IV curve) of the existing modules to verify that the new inverter’s DC input voltage window matches.

**Multiple MPPT.** String inverters that have multiple MPPT inputs make it easy to add strings of different modules because the inverter is able to track two separate subarrays. Multiple MPPTs minimize losses when source circuits are on different roof orientations or a string of new modules is added to an old array.

**Microinverters & AC modules.** Using microinverters or AC modules can avoid future inverter-size limitations—each module is connected to its own inverter. While wiring and rack considerations must be taken into account (as there is a limit to how many can be connected to a single AC branch circuit), using microinverters or AC modules can allow system expansion one module at a time.

If an existing string inverter has no room for adding more modules, microinverter/module pairs can be added to increase the system’s size. Depending on their definition of “photovoltaic system,” local inspectors may require a separate conduit from the DC circuits for the microinverters’ AC output. Most microinverter systems require a 15 A or 20 A interconnection breaker, which can also limit the ability to add on (see “Adding a Second System” sidebar).

**DC-DC converters.** Similar to microinverters and AC modules, these are connected to each module individually and offer module-level MPPT. Thus DC optimizers can allow

## Adding a Second System

Adding a second, separate system is an option for expanding a grid-tied PV system. For systems connected on the load side of the main AC service, the size of the existing equipment can limit this option, as the amount of breakers supplying power to the busbar are limited to 120% of the busbar rating. For instance, if an existing PV system backfeeds a 30 A breaker in a 200 A service with a 200 A main disconnect and busbar, only 10 A of additional backfed PV breakers could be added without reconfiguring the interconnection or service.

Two separate systems, side by side: A little forethought allowed the use of shared AC and DC disconnects, a wiring chase (gutter), and connection to the mains panel.



Courtesy Electron Connection

# Battery-Based PV System Expansion

## Inverters for Battery-Based Systems.

Residential battery-based inverters are often large enough to handle the total power of all loads that would operate simultaneously, and still have additional capacity.

However, if significant loads are added, or if additional battery charging via a generator is required, then more inverter capacity will be needed. This can be planned for by installing a system where multiple inverters can be “stacked”—either in parallel to increase capacity at the same voltage, or to create a 120/240 VAC system if the original system was 120 VAC only. Using AC and DC disconnect boxes with room for additional inverter breakers will facilitate this future upgrade.

It is difficult to mix old and new inverters. Replacing the older inverter may be the best option. Modern inverters are more efficient and have more features, but also may involve significant rewiring of the balance-of-system components.

**Batteries.** Adding new batteries to an old bank is not a good idea, as the newer ones will perform at the level of the oldest ones—think of it as paying new prices for an old battery. Frequently replacing one leads to another, then another, and soon enough it

would’ve been a better idea to replace the whole bank. Also, old battery interconnects and leads to the inverter may be corroded and need either cleaning or replacement. If a larger inverter is installed, larger conductors may need to be installed between the battery and inverter.

An old adage in the off-grid market is to not buy the Cadillac of batteries if you’re just learning to drive. While it may take more, smaller batteries to make an equivalently sized bank, and they may not last as long as larger batteries, the price per amp-hour will be less. Any battery, regardless of size or quality, is subject to the effects of abuse, so “learning to drive” on a less expensive bank—which can still provide years and years of reliable service—makes sense. When the batteries eventually need to be

battery bank. Many older controllers are able to operate at 12, 24, or 48 VDC, but this would also require a change in the battery bank and inverter.

Increasing the DC system voltage, say from 24 to 48 V, means that existing conductors can carry twice or more the power. Rewiring the array for a higher voltage (150 V is common) and using an MPPT controller with voltage step-down means that existing conductors can carry more current—and thus more power, leaving the battery bank and inverter at the original nominal voltage.

Another option is to add array power with a new controller. This adds redundancy, as long as the old unit still works well.

Initially sizing for future expansion by installing a larger charge controller means



**Power panels designed for stacked inverters and multiple charge controllers don’t need to be populated all at once, allowing easy future expansion.**

replaced, higher-capacity batteries can be installed. If loads have also grown, you may need a larger battery bank. A cost/benefit analysis should be performed to determine which battery is best, including a realistic assessment of the likelihood of regular maintenance.

**Charge controllers.** Charge controller choices have increased dramatically, with numerous options for expanding old systems.

In many older battery-based systems, the array’s nominal voltage matches that of the

array size can be increased in the future by adding parallel strings. High-voltage charge controllers may allow modules to be added in series to the existing array.

The redundancy provided by having more than one charge controller increases system reliability—but you’ll definitely need to plan ahead for this. It’s important to consider the conductors required for a second charge controller (or more) when initially installing the system. Installing a DC disconnect box that can hold additional array and controller breakers is also a smart idea.



Courtesy OutBack Power Systems (2)

**Higher-voltage charge controllers that can step down voltage can provide more power at the same amperage as nominal voltage charge controllers.**

different modules to be added without module-matching concerns, and allow expansion by one or more modules at a time, as long as the existing string inverter can handle the additional power.

### Other Components

Installing larger wires than required adds to the initial system expense, but will pay for itself in the long run if expansion occurs. Match the conductor with an appropriately larger overcurrent device so that it doesn't need to be replaced, either. As long as the overcurrent device protects the conductor, loading it lightly simply means less voltage drop. Just be sure to consider voltage drop when the current level increases from expansion. Combiner boxes also can be oversized so that they will hold the additional conductors and fuse-holders or breakers that will be required when additional PV source circuits are added to the array.

Most existing systems weren't planned for expansion, so don't underestimate the costs to add to a system. Expansion may require upgrading conductors so that they are code-compliant, adding overcurrent protection and conduit, and dealing with other "issues" from the original system. This can make the cost of an addition significantly more than that of a new installation. Depending on the demands of the local inspector, adding to an existing system may also mean retrofitting newly required components—such as the arc-fault protection now mandated by the 2011 NEC.

### Layout & Installation

There is a range of design and installation considerations for systems that will be expanded. Installing additional racking in advance is only cost-effective when the expansion will absolutely happen, or to allow for the addition of one or two modules. This is particularly effective for pole- and ground-mounted systems—for example, installing a 10-module rack but only including eight modules initially.



Courtesy MidNite Solar

**This combiner box by MidNite Solar can handle two wire runs, for PV arrays with dissimilar voltage characteristics that can't be wired together in parallel. Planning ahead with these types of components can save time and money in the future.**

For roof-mounted systems, carefully utilizing the available space is important. Rather than centering an array in the middle of a large roof, putting it to the side or higher or lower will make it easier to add modules.

If expansion will be additional source circuits on a roof with a different orientation, then using distributed MPPT equipment (i.e., microinverters, AC modules, DC-DC converters, or a string inverter with more than one MPPT) can alleviate issues due to differing voltages and currents.



Topher Donahue

**This homeowner wisely positioned the first PV array in anticipation of expanding the system later on.**



Ben Root

Due to the roof penetrations, there isn't much room to expand this system. The reality is that the majority of existing grid-tied systems can be difficult to expand for these, and other, reasons.

While upsizing conductors in advance is a good strategy, a less expensive alternative is to install larger-than-necessary conduit that can hold additional conductors. For ground- and pole-mounts, an easy solution is to put an extra conduit in the ground and cap it on both ends, leaving a cord inside to pull conductors. This makes adding extra wires a snap.

## Permitting, Finances & Rebates

Don't forget to consider the impact of rebates, financing, and permitting on system expansion. Paying twice for permits might be avoided if it includes the future expansion. The same may hold true for other requirements, such as interconnection paperwork. If a system is financed or leased, it may be difficult or financially less attractive to use the same method to add to the system size. Plus, the installed cost per watt may be higher for system upgrades.

Some tax credits, utility rebates, and incentives may not be available when increasing the system size, or programs may have changed. In other cases, existing incentives such as renewable energy credits (RECs) may have to be renegotiated.

### Access

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# Why I switched to SunWize



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2012

# Grid-Tied Inverter

## BUYER'S GUIDE

by Justine Sanchez

**T**he rapid growth of the grid-tied residential PV industry has spurred an increase in inverter manufacturers and products. To reduce system costs and introduce handy new features, inverter technology is shifting. Transformerless inverters, more microinverters, and even a few AC modules are on the scene. This article focuses on Underwriters Laboratories (UL)-listed residential batteryless grid-tied inverters.

The table shows residential inverters that were included in the California Solar Initiative (CSI) list of eligible inverters as of November 2011. Inverter manufacturers serious about delivering and supporting products in the United States aspire to meet the incentive eligibility requirements for California, the country's largest solar market. Technical data listed was supplied by the inverter manufacturers or found on inverter specification sheets and owner's manuals.

### THE SPECS

Inverter specifications, and their relevance to PV system design, are described below. (For a list of all of the specifications shown in the table, see our previous grid-tied inverter buyer's guide in *HP133*.)

**Transformerless.** Many new inverters are transformerless. While these inverters offer several advantages, neither DC current-carrying conductor is grounded. Ungrounded systems must still "equipment ground," i.e., connect all metallic enclosures, module frames, and racking to a common grounding conductor. Ungrounded systems have additional requirements per *National Electrical Code* Article 690.35. For transformerless inverter advantages and requirements, see the "Less is More" sidebar.

### DC Input Variables

**Maximum Recommended PV Power.** PV arrays typically produce less than their standard test condition (STC) rated power due to higher cell/module temperature, soiling, production tolerance, etc., so arrays are often sized so that their rated power exceeds inverter output.

Each inverter manufacturer specifies the maximum recommended array power for each inverter model. The maximum ratio between array and inverter outputs generally ranges from 115% to 125%. Determining the ideal ratio will minimize power clipping and maximize PV system output. However, there can be competing factors that can instead maximize the financial return (\$/year) that a PV system can generate, and thus recommending a particular ratio has become an increasingly contentious issue (see "Array to Inverter Ratio" sidebar).

**Maximum Open-Circuit Voltage (Voc).** Voltage is electrical pressure, and all electronic components, including inverters, have a maximum voltage they can withstand. This specification is the maximum input voltage that the array may reach under any condition. The array voltage is dependent on module make and model, the number of modules in series, and the module's temperature, which in turn is dependent on ambient temperature. System designers must calculate the maximum voltage to make sure it is within the limitations of the inverter (see "Determining PV Array Maximum System Voltage" in *HP146*).

**Maximum Power Point Tracking (MPPT) Window.** The MPPT window is a voltage range that the inverter can work within to find the maximum "knee" of the array's IV curve to maximize array output as conditions vary.

**The Kaco 00xi series transformerless inverter has a CEC weighted efficiency of 96.5%.**



Courtesy Kaco New Energy

## Array-to-Inverter Ratio

A typical PV system design starts with a target array size, rated in STC watts. From this, an inverter is chosen. The ratio of the inverter's size, in maximum AC watts output, to the size of the array, in DC STC watts, is known as the array-to-inverter ratio. For example, a 4 kW PV array with a 4 kW inverter has a 1:1 or 100% ratio. A 5 kW array with a 4 kW inverter has a 125% ratio ( $5 \text{ kW DC} \div 4 \text{ kW AC}$ ).

Most arrays only spend a small portion of their life operating at their full STC rating, and array output power is typically lower than the rated wattage. (Voltage declines at temperatures greater than 25°C; and irradiance is often below 1,000 W/m<sup>2</sup>, resulting in lower-than-STC power.) Because of this, the rated array power can be somewhat larger than the inverter's without worrying about losing power during normal operation.

So what ratio should you aim for? Many inverter manufacturers list a maximum array STC power in their specifications—this number should not be exceeded, as the *National Electrical Code* requires following the manufacturer's instructions. For example, SMA America lists the maximum array STC wattage as 125% of the inverter output; Fronius lists a lower ratio of 115%. Design practices for different climates and incentive programs lead to different design ratios.

Arrays located at high elevations (which often have higher than 1,000 W/m<sup>2</sup> irradiance) and/or arrays that routinely experience daytime cell temperatures below 77°F (which, depending on the mounting method, means ambient air temperature is around 32°F or lower) can operate close to, or even above, STC ratings. When the array wattage is higher than the inverter output capability, the inverter will “clip” the power, shifting the operating point off of the maximum power point (MPP) on the IV curve, thus lowering the array's power output. Over time, this can result in significant energy loss. In this type of climate and conditions, a ratio closer to 100% keeps energy loss to a minimum.

Arrays in warm climates will usually operate below STC ratings and are not likely to experience power clipping if the array-to-inverter ratio is within the manufacturer's specifications. But hot climates have another potential problem: high inverter temperature. A hot inverter (simply due to the ambient air temperature) operating at, or close to, its maximum capacity (which causes more heating) will move off of the MPP of the IV curve in an attempt to keep the internal electronics from overheating, which causes additional power loss. This situation can be avoided by locating the inverter in a well-ventilated, conditioned space.

Some incentive programs define system size by inverter rated watts, decreasing payouts as the inverter power rating increases. For example, in a feed-in-tariff program in Ontario, Canada, rooftop PV arrays connected to inverters rated less than 250 kW earn a higher FIT payment than systems with larger inverter capacities. A high array-to-inverter ratio could potentially keep a larger array with a smaller inverter in a higher-paying tariff category, sweetening the financial equation.

—Rebekah Hren

**Suitable for smaller residential systems, this Solectria 1800 inverter has a maximum recommended PV array of 2,200 W.**



Courtesy Solectria Renewables

Courtesy Fronius



**This Fronius IG Plus V 11.4 inverter, suitable for large residential or small commercial installations, can handle a 13.1 kW PV array.**

An array voltage operating either too high or too low will result in less output. Just like with the maximum Voc specification, designers must design the array to operate within the limitations of the inverter's MPPT voltage window.

To ensure an array design will be within an inverter's maximum Voc and its MPPT window, most inverter manufacturers provide online string-sizing tools that take into account all of these factors along with their inverter requirements, to help step system designers through the array design process. PVSelect.com is another online tool for string-sizing calculations for various modules and inverters. It is helpful for comparing various designs using different modules and inverters, as it provides users with a single Web tool, rather than having to navigate between the various inverter manufacturers' sizing programs.

**Both of these inverters offer wide MPPT voltage windows. The MPPT range for the Delta Solivia inverter (below) is 150 to 500 VDC. The Power-One PVI inverter (right) has an MPPT range of 90 to 580 VDC.**



Courtesy Delta Energy Systems



Courtesy Power-One

# Grid-Tied String Inverter Specifications

Manufacturer	Model	Transform- erless	DC Input Specs				AC Output Specs			
			Max. Rec. PV Power at STC (kW)	Max Voc	MPPT Range (V)	Max. Usable Input (A)	Max Isc	CEC Rated Power (kW)	Nominal Output (V)	
<b>Advanced Energy</b> www.advanced-energy.com	PVP2000	No	2.50	500	115-450	18.5	26.00	2.00	240	
	PVP2500	No	3.13	500	140-450	19.0	26.00	2.50	240	
	PVP2800	No	3.50	500	180-450	16.5	26.00	2.80	208	
	PVP3000	No	3.75	500	170-450	19.0	26.00	3.00	240	
	PVP3500	No	4.30	500	200-450	18.5	26.00	3.50	240	
	PVP4600	No	5.75	500	205-450	24.0	48.00	4.60	208	
	PVP4800	No	6.00	500	200-450	25.5	48.00	4.80	240	
<b>Delta Energy</b> www.deltaenergysystems.com	PVP5000 <sup>1</sup>	No	6.00	500	200-450	26.5	48.00	N/A	240	
	PVP5200	No	6.50	500	240-450	23.0	48.00	5.20	240	
	SOLVIA 2.5 TR	No	3.20	600	150-500	8.6	19.00	2.50	208/240	
	SOLVIA 3.3 TR	No	4.00	600	150-500	13.0	24.00	3.30	208/240	
<b>Exeltech</b> www.exeltech.com	SOLVIA 4.4 TR	No	5.20	600	150-500	15.1	31.00	4.40	208/240	
	SOLVIA 5.0 TR	No	6.00	600	150-500	17.2	37.00	5.00	208/240	
	XLGT18A60	Yes	2.45	600	200-600	9.5	10.00	1.80	120	
<b>Fronius</b> www.fronius.com	IG Plus V 3.0-1UNI	No	3.45	600	230-500	14.0	18.00	3.00	208/240/277	
	IG Plus V 3.8-1UNI	No	4.40	600	230-500	17.8	22.00	3.80	208/240/277	
	IG Plus V 5.0-1UNI	No	5.75	600	230-500	23.4	29.00	5.00	208/240/277	
	IG Plus V 6.0-1UNI	No	6.90	600	230-500	28.1	35.00	6.00	208/240/277	
	IG Plus V 7.5-1UNI	No	8.60	600	230-500	35.1	44.00	7.50	208/240/277	
	IG Plus V 10.0-1UNI	No	11.50	600	230-500	46.7	58.00	10.00	208/240/277	
<b>Ingeteam</b> www.ingeteam.com	IG Plus V 11.4-1UNI	No	13.10	600	230-500	53.3	67.00	11.40	208/240/277	
	IngeconSun 5 U	No	6.50	550	200-450	30.0	30.00	5.00	208/240/277	
<b>KACO</b> www.kaco-newenergy.com	IngeconSun 5TL U	Yes	6.50	550	200-450	30.0	30.00	5.00	208/240/277	
	1502xi	No	2.00	550	125-400	14.3	21.45	1.50	208/240	
	2502xi	No	3.00	550	200-450	13.5	21.45	2.50	208/240	
	3502xi	No	4.00	600	200-510	18.5	28.00	3.50	208/240	
	5002xi	No	6.00	600	200-510	26.5	40.00	5.00	208/240	
	6400xi	Yes	DNR	550	320-550/365-550	21.0	36.00	6.40	208/240	
<b>Motech</b> www.motech-americas.com	7600xi	Yes	DNR	550	320-550/365-550	24.0	36.00	7.60	208/240	
	PVMate 2900U	No	3.60	600	200-550	16.0	24.00	2.7/2.9	208/240	
	PVMate 3840U	No	4.90	600	200-550	20.0	24.00	3.33/3.84	208/240	
	PVMate 4900U	No	6.20	600	200-550	25.0	30.00	4.3/4.9	208/240	
	PVMate 5300U	No	6.70	600	200-550	25.0	30.00	4.6/5.3	208/240	
	PVMate 6500U	No	7.00	600	230-500	35.0	44.00	6.50	208/240/277	
<b>OPTI-Solar</b> www.opti-solar.com	PVMate 7500U	No	8.00	600	230-500	35.0	44.00	7.50	208/240/277	
	GT 1500	Yes	1.88	450	150-450	7.5	< 30	1.50	208/240	
	GT 2000	Yes	2.50	450	150-450	10.0	< 30	2.00	208/240	
	GT 3000	Yes	3.75	450	150-450	15.0	< 30	3.00	208/240	
<b>Power-One</b> www.power-one.com	GT 4000	Yes	5.00	450	150-450	20.0	< 30	4.00	208/240	
	PVI-3.0-OUTD-S-US	Yes	3.50	600	90-580	10.0 <sup>3</sup>	12.5 <sup>3</sup>	3.00	208/240/277	
	PVI-3.6-OUTD-S-US	Yes	4.15	600	90-580	16.0 <sup>3</sup>	20.0 <sup>3</sup>	3.60	208/240/277	
	PVI-3.8-I-OUTD-S-US	No	4.00	520	160-470 <sup>2</sup>	12.5 <sup>3</sup>	20.0 <sup>3</sup>	3.3/3.8/3.8	208/240/277	
	PVI-4.2-OUTD-S-US	Yes	4.82	600	90-580	16.0 <sup>3</sup>	20.0 <sup>3</sup>	4.20	208/240/277	
	PVI-4.6-I-OUTD-S-US	No	4.80	520	170-470 <sup>2</sup>	14.0 <sup>3</sup>	20.0 <sup>3</sup>	4.60	208/240/277	
<b>Schneider Electric</b> www.schneider-electric.com	PVI-5000-OUTD-US	Yes	5.30	600	90-580	18.0 <sup>3</sup>	22.0 <sup>3</sup>	5.00	208/240/277	
	PVI-6000-OUTD-US	Yes	6.40	600	90-580	18.0 <sup>3</sup>	22.0 <sup>3</sup>	6.00	208/240/277	
	Conext 2.8	No	3.10	600	195-550	14.9/15.4	24.00	2.7/2.8	208/240	
	Conext 3.3	No	3.50	600	200-400	16.5/17.5	24.00	3.1/3.3	208/240	
<b>SMA America</b> www.sma-america.com	Conext 3.8	No	3.6/4.2	600	195-550	19.5/20.8	24.00	3.5/3.8	208/240	
	Conext 5.0	No	4.8/5.4	600	240-550	20.0/22.0	24.00	4.5/5.0	208/240	
	SB 700-US	No	0.88	250	125-200	7.0	18.00	0.70	120	
		No	0.75	200	100-160	7.0	18.00	0.60	120	
		No	0.58	150	77-120	7.0	18.00	0.46	120	
	SB 2000HF-US	No	2.50	600	175-480	15.0	25.00	2.00	208/240	
	SB 2500HF-US	No	3.13	600	220-480	15.0	25.00	2.50	208/240	
	SB 3000HF-US	No	3.75	600	220-480	15.0	25.00	3.00	208/240	
	SB 3000-US	No	3.75	500	175-400/200-400	17.0	24.00	3.00	208/240	
	SB 3800-US	No	4.75	600	250-480	18.0	25.00	3.80	240	
	SB 4000-US	No	4.375/5.0	600	220-480/250-480	18.0	25.00	3.5/4.0	208/240	
	SB 5000-US	No	6.25	600	250-480	21.0	36.00	5.00	208/240/277	
	SB 6000-US	No	7.50	600	250-480	25.0	36.00	6.00	208/240/277	
	SB 7000-US	No	8.75	600	250-480	30.0	36.00	7.00	208/240/277	
SB 8000-US	No	10.00	600	300-480	30.0	36.00	7.68/8.00	240/277		
SB 8000TL-US	Yes	10.00	600	300-480	28.0	45.00	8.00	208		
SB 9000TL-US	Yes	11.25	600	300-480	31.0	45.00	9.00	208		
SB 10000TL-US	Yes	12.50	600	300-480	35.0	45.00	10.00	208		

1. Available in Canada only. 2. With parallel configuration for MPPT. 3. Per MPPT channel. 4. Power box spec. 5. Controlled by power boxes. 6. One input per MPPT channel.

Performance				Integrated Disconnects & Combiners				Inverter		Weight (Lbs.)	Warranty Standard/Extended (Yrs.)
Max. Output (A)	Max. Output OCD Rating (A)	CEC Weighted Efficiency (%)	Ambient Temp. Range (°F)	DC Disconnect Standard	AC Disconnect Standard	DC/AC Disconnect Rating (A)	Fused Combiner Standard	Removable from Wiring Box			
8.5	20.0	92.0	-13-104	Yes	Yes	48/40	No	Yes	93	10	
10.5	20.0	94.5	-13-104	Yes	Yes	48/40	No	Yes	107	10	
13.5	20.0	92.0	-13-104	Yes	Yes	48/40	No	Yes	107	10	
12.5	20.0	93.5	-13-104	Yes	Yes	48/40	No	Yes	107	10	
15.0	20.0	95.5	-13-104	Yes	Yes	48/40	No	Yes	121	10	
22.5	30.0	95.5	-13-104	Yes	Yes	48/40	No	Yes	162	10	
20.5	30.0	96.0	-13-104	Yes	Yes	48/40	No	Yes	162	10	
21.0	30.0	N/A	-13-104	Yes	Yes	48/40	No	Yes	162	10	
22.0	30.0	96.0	-13-104	Yes	Yes	48/40	No	Yes	162	10	
11.0/12.0	15.0	94.5/95	-13-158	Yes	No	40	Yes	Yes	58.4	10/15,20	
16.0/14.5	20.0	95/95.5	-13-158	Yes	No	40	Yes	Yes	58.4	10/15,20	
24.0/19.5	30.0	DNR	-13-158	Yes	No	40	Yes	Yes	81.6	10/15,20	
24.0/22.0	30.0	DNR	-13-158	Yes	No	40	Yes	Yes	81.6	10/15,20	
15.0	20.0	96.5	-4-104	Yes	Yes	20/20	N/A	Yes	14.0	5/10	
14.4/12.5/10.8	20/20/15	95.0/95.5/96.0	-13-131	Yes	No	40	Yes	Yes	55.0	10/15,20	
18.3/15.8/13.7	25/20/20	95.0/95.5/96.0	-13-131	Yes	No	40	Yes	Yes	55.0	10/15,20	
24.0/20.8/18.1	30/30/25	95.5/95.5/96.0	-13-131	Yes	No	60	Yes	Yes	81.0	10/15,20	
28.8/25.0/21.7	40/35/30	95.5/96.0/96.0	-13-131	Yes	No	60	Yes	Yes	81.0	10/15,20	
36.1/31.3/27.1	45/40/35	95.0/95.5/96.0	-13-131	Yes	No	60	Yes	Yes	81.0	10/15,20	
48.1/41.7/36.1	60/60/45	95.0/95.5/96.0	-13-131	Yes	No	80	Yes	Yes	110.0	10/15,20	
54.8/47.5/41.2	70/60/60	95.0/95.5/96.0	-13-131	Yes	No	80	Yes	Yes	110.0	10/15,20	
25.0	32.0	95.5	-4-149	Yes	No	30	Yes	Yes	168.0	10/20	
25.0	32.0	96.0	-4-149	Yes	No	30	Yes	Yes	62.0	10/20	
8.0/8.0	15.0	95.0/95.5	-4-140	Yes	Yes	40/36	No	Yes	42.0	10	
12.5/12.5	20.0	95.0/95.5	-4-140	Yes	Yes	40/36	No	Yes	52.0	10	
16.0/17.0	25.0	95.5/95.5	-13-140	Yes	Yes	40/36	No	Yes	69.0	10	
24.0/24.0	30.0	95.0/95.5	-13-140	Yes	Yes	40/36	No	Yes	70.0	10	
31.0/27.0	50.0	96.5	-4-140	Yes	No	DNR	Yes	Yes	95.0	10	
37.0/32.0	50.0	96.5	-4-140	Yes	No	DNR	Yes	Yes	95.0	10	
13.0	20.0	95.5/96.0	-13-130	Yes	Yes	30/30	Yes	Yes	51.0	10	
16.0	20.0	95.5/96.0	-13-130	Yes	Yes	30/30	Yes	Yes	51.0	10	
20.7	30.0	96.0/96.0	-13-130	Yes	Yes	30/30	Yes	Yes	62.0	10	
22.1	30.0	95.5/96.0	-13-130	Yes	Yes	30/30	Yes	Yes	62.0	10	
23.5/27.1/31.3	55.0	95.5/96.0/96.0	-13-149	Yes	Yes	40/40	Yes	Yes	90.0	10	
27.1/31.3/36.1	55.0	95.5/96.0/96.0	-13-149	Yes	Yes	40/40	Yes	Yes	90.0	10	
7.2/6.3	14.0	94.5	-13-113	Yes	Yes	20/30	Yes	No	33.1	10	
9.6/8.3	18.8	95.0	-13-113	Yes	Yes	20/30	Yes	No	33.1	10	
14.4/12.5	28.1	95.5	-13-113	Yes	Yes	20/30	Yes	No	35.3	10	
19.2/16.7	37.5	95.5	-13-113	Yes	Yes	20/30	Yes	No	48.5	10	
14.5/14.5/12.0	20/20/15	96.0	-13-140	Yes	No	25	No	Yes	46.0	10/15	
17.2/16.0/16.0	25/20/15	96.0	-13-140	Yes	No	25	No	Yes	46.0	10/15	
16.0	20.0	96.0/96.5/96.5	-13-140	Yes	No	25	No	Yes	61.0	10/15,20	
20.0	25.0	96.0	-13-140	Yes	No	25	No	Yes	46.0	10/15	
22.5/20.0/20.0	30/25/25	96.0/96.5/96.5	-13-140	Yes	No	25	No	Yes	61.0	10/15,20	
24.0/20.0/18.0	30.0	96.0/96.5/96.5	-13-140	Yes	No	25	No	Yes	66.0	10/15	
29.0/25.0/21.6	30.0	96.0/96.5/96.5	-13-140	Yes	No	25	No	Yes	66.0	10/15	
13.0/11.7	20.0	93.5/94.0	-13-149	Yes	Yes	25	No	Yes	66.6	10	
14.9/13.8	20.0	95.0/95.0	-13-149	Yes	Yes	25	No	Yes	70.0	10	
16.8/15.8	25/20	95.0/95.0	-13-149	Yes	Yes	25	No	Yes	80.3	10	
22.0/21.0	30.0	95.0/95.5	-13-149	Yes	Yes	25	No	Yes	84.0	10	
6.6	15.0	91.5	-13-113	No	No	N/A	No	N/A	51.0	10/20	
5.7	15.0							N/A			
4.4	15.0							N/A			
10.0/8.5	25.0	95.0	-13-113	Yes	No	36	Yes	Yes	51.0	10/20	
12.0/10.4	25.0	95.0	-13-113	Yes	No	36	Yes	Yes	51.0	10/20	
14.4/12.5	25.0	95.0	-13-113	Yes	No	36	Yes	Yes	51.0	10/20	
15.0/13.0	30.0	95.0/95.5	-13-113	Yes	No	36	Yes	Yes	84.0	10/20	
16.0	30.0	96.0	-13-113	Yes	No	36	Yes	Yes	84.0	10/20	
17.0	30.0	95.5/96.0	-13-113	Yes	No	36	Yes	Yes	84.0	10/20	
24.0/21.0/18.0	50.0	95.5	-13-113	Yes	No	36	Yes	Yes	141.0	10/20	
29.0/25.0/22.0	50.0	95.5/95.5/96.0	-13-113	Yes	No	36	Yes	Yes	141.0	10/20	
34.0/29.0/25.0	50.0	95.5/96.0/96.0	-13-113	Yes	No	36	Yes	Yes	141.0	10/20	
32.0/32.0	50.0	96.0/96.0	-13-113	Yes	No	36	Yes	Yes	145.0	10/20	
40.0	60.0	98.0	-13-113	Yes	No	36	Yes	Yes	77.0	10/20	
44.0	60.0	98.0	-13-113	Yes	No	36	Yes	Yes	77.0	10/20	
48.0	60.0	97.5	-13-113	Yes	No	36	Yes	Yes	77.0	10/20	

# Grid-Tied String Inverter Specifications, continued

Manufacturer	Model	Transform-erless	DC Input Specs				AC Output Specs			
			Max Rec. PV Power at STC (kW)	Max. Voc	MPPT Range (V)	Max. Usable Input (A)	Max Isc	CEC Rated Power (kW)	Nominal Output (V)	
SolarEdge www.solaredge.com	SE 3300 US	Yes	4.13	500	5-60 <sup>4</sup>	N/A <sup>5</sup>	30.00	3.30	208/240	
	SE 3800 US	Yes	4.75	500	5-60 <sup>4</sup>	N/A <sup>5</sup>	30.00	3.80	208/240	
	SE 5000 US	Yes	6.25	500	5-60 <sup>4</sup>	N/A <sup>5</sup>	30.00	5.00	208/240	
	SE 6000 US	Yes	7.50	500	5-60 <sup>4</sup>	N/A <sup>5</sup>	30.00	5.2/6.0	208/240	
Solectria Renewables www.solren.com	PVI 1800	No	2.20	400	125-350	11.0	13.00	1.80	208/240	
	PVI 2500	No	3.20	400	125-350	15.0	18.00	2.50	208/240	
	PVI 3000	No	3.60	600	200-550	16.0	24.00	2.7/2.9	208/240	
	PVI 4000	No	4.90	600	200-550	20.0	24.00	3.4/3.9	208/240	
	PVI 5000	No	6.20	600	200-550	25.0	30.00	4.3/4.9	208/240	
	PVI 5300	No	6.70	600	200-550	25.0	30.00	4.6/5.3	208/240	
	PVI 6500	No	8.10	600	230-500	35.0	55.00	6.50	208/240/277	
PVI 7500	No	9.30	600	230-500	35.0	55.00	7.50	208/240/277		

2. With parallel configuration for MPPT. 3. Per MPPT channel. 4. Power box spec. 5. Controlled by power boxes. 6. Option on panel assemblies.

## AC Variables

**CEC Rated Power.** The California Energy Commission’s (CEC) test protocol allows comparing inverter output for different makes and models by using the same test conditions for each. Electronics function better at cooler temperatures, and when ambient air temperature increases, inverter performance is reduced. This output rating is what each inverter can maintain at 40°C (104°F) and helps designers know what each can produce at higher temperatures.

**AC Output Current.** This specification is the output amperage to be used in overcurrent protection and conductor-sizing calculations. In addition to these *NEC* requirements, designers use this value in voltage drop calculations, as AC conductors must be sized for a very small voltage drop (for example, 1.5% or less). Just like on the inverter’s DC input, the AC side also has a voltage range it must operate within. Keeping the voltage drop low reduces the likelihood of nuisance tripping when grid voltage is high. Some inverter manufacturers offer online AC voltage drop calculators to help designers determine appropriate AC output conductor size.

## Performance Variables

**Efficiency (Peak and CEC).** An inverter’s efficiency is a ratio of output power to input power. Because inverters lose some electric energy as heat, as does any kind of conversion, efficiency will always be less than 100%. Efficiency varies depending on conditions, such as ambient air temperature, inverter temperature, and array voltage. In particular, that value depends on how much power the inverter is trying to process. Peak efficiency is the highest ratio between power out to power in, given ideal conditions and power input, and isn’t necessarily representative of efficiency during common operating conditions.



SMA America’s online voltage-drop calculator.

Courtesy SMA America (2)



The Sunny Boy TL (transformerless) inverter line has a CEC weighted efficiency ranging from 97.5% to 98%, the highest on our list.

Performance				Integrated Disconnects & Combiners				Inverter		Weight (Lbs.)	Warranty Standard/Extended (Yrs.)
Max. Output (A)	Max. Output OCD Rating (A)	CEC Weighted Efficiency (%)	Ambient Temp. Range (°F)	DC Disconnect Standard	AC Disconnect Standard	DC/AC Disconnect Rating (A)	Fused Combiner Standard	Removable from Wiring Box			
16.0/14.0	40.0	97.0/97.5	-4-120	Yes	Yes	30/40	N/A	Yes	52.0	12/20	
18.5/16.0	40.0	97.0/97.5	-4-120	Yes	Yes	30/40	N/A	Yes	52.0	12/20	
24.0/21.0	40.0	97.0/97.5	-4-120	Yes	Yes	30/40	N/A	Yes	52.0	12/20	
25.0/25.0	40.0	97.0/97.5	-4-120	Yes	Yes	30/40	N/A	Yes	52.0	12/20	
8.7/7.5	15.0	92.5	-13-131	no <sup>6</sup>	no <sup>6</sup>	N/A <sup>6</sup>	No	N/A	34.1	5/10	
12.0/10.4	15.0	92.0/93.0	-13-131	no <sup>6</sup>	no <sup>6</sup>	N/A <sup>6</sup>	No	N/A	36.3	5/10	
13.0	20.0	95.5/96.0	-13-131	Yes	Yes	30/30	Yes	Yes	47.0	10	
16.3	25.0	95.5/96.0	-13-131	Yes	Yes	30/30	Yes	Yes	48.0	10	
20.7	30.0	96.0/96.0	-13-131	Yes	Yes	30/30	Yes	Yes	58.5	10	
22.1	30.0	95.5/96.0	-13-131	Yes	Yes	30/30	Yes	Yes	60.0	10	
31.3/27.1/23.5	40/35/30	95.5/96.0/96.0	-13-131	Yes	Yes	44/45	Yes	Yes	88.9	10	
36.1/31.3/27.1	50/40/35	95.5/96.0/96.0	-13-122	Yes	Yes	44/45	Yes	Yes	88.9	10	

## Less is More: Transformerless Inverters

The largest recent shift in inverter technology is the availability of transformerless inverters in the United States. They have long been popular in Europe, but now most inverter manufacturers have added a transformerless option to their existing inverter line. Without a heavy transformer, they weigh about 50% to 70% less than a transformer-based inverter of similar output, and the size of the inverter housing can be (but isn't always) reduced. Inverter efficiency is also increased—there are no longer losses associated with having a transformer to step up the voltage. And because the transformer (which is comprised of copper windings on an iron or steel core) is eliminated, they are less expensive to produce.



Courtesy Exeltech



Courtesy Ingeteam

The majority of inverter manufacturers are now including a transformerless inverter line. Exeltech (below, far left), Ingeteam, and SolarEdge are a few examples.

However, transformerless inverters are not without some drawbacks. They require the DC wiring to be ungrounded. Because neither the positive nor negative conductor is connected to ground, they must meet more *NEC* requirements, per *NEC* 690.35, including the use of PV wire (a double-insulated single conductor cable having added sunlight and mechanical protection) for exposed wires (i.e., module interconnects and exposed home run wiring). Overcurrent protection and disconnect devices are required on both the positive and negative conductors, since they are both ungrounded. Arrays that require the positive conductor be grounded (those using SunPower modules, for example) are not recommended for use with transformerless inverters, because the array must be ungrounded.

Some installers contend that ungrounded systems are inherently safer, since the equipment-grounding conductor (which is connected to all metallic enclosures, the module frames, and racks) is no longer connected to a current-carrying conductor (commonly the negative). This reduces short-circuit potential should the positive current-carrying conductor come into contact with grounded metallic components. (For example, during a system checkup of a grounded system, if your screwdriver inadvertently comes in contact with a positive terminal and grounded metal in an enclosure, this short-circuits the positive and negative conductors.)



Courtesy SolarEdge

## Microinverters & AC Modules

While the majority of grid-tied inverters are string inverters, microinverters and “AC modules” (modules prewired with installed microinverters) are available. A few other manufacturers, such as SMA America and Power-One, are expected to introduce microinverters in the near future.

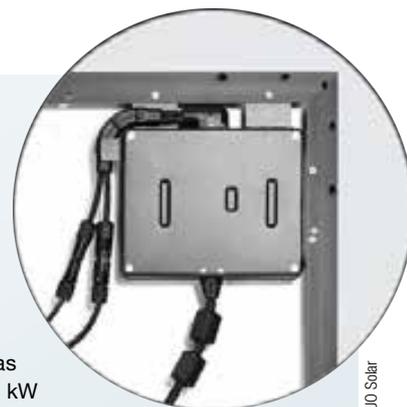
Microinverters and AC modules are gaining popularity as they offer some benefits over the traditional string inverter. Both can simplify design—for microinverter systems, you simply need to make sure your module is on the compatible module list. DC series string calculations are not required. With both microinverters and AC modules, installation is considered easier and safer by some installers more familiar with standard AC wiring because there is only conventional AC electricity and not high-voltage DC. System output is often improved because the modules operate independently. This is especially helpful when modules have partial shading, differing orientations, or variations in soiling. And it is possible to have an array comprised of different module makes and models. These systems usually offer module-level monitoring, which is a fantastic tool for short-term and long-term performance verification and troubleshooting (see “Potential PV Problems” in *HP143*). And they make future PV system expansion an easier task (see “Expanding Your PV System” in this issue).

Up-front equipment cost can be higher with microinverter systems, and depends on the system size. A brief Internet search found microinverter pricing at about \$0.80 per watt. A 2.5 kW string inverter was priced at \$0.70 per watt; a 5 kW string inverter was about \$0.55 per watt. These price differences can be manageable in the smaller residential market, due to the added-value items such as module-level monitoring, but with larger systems (greater than 4 kW), the price disparity can be a barrier for microinverter systems.

With more electronics involved (and more things subjected to high temperatures) the potential points of failure increase. If a microinverter or AC module malfunctions, field replacement can be a daunting task, especially for a flush-mounted pitched-roof system, since you’ll likely need to remove several other modules to access the failed unit, sometimes while working on a steep roof. However, if one microinverter or AC module goes down, the output of the other modules in the system isn’t affected. If a string inverter shuts down, the whole array connected to that inverter goes offline.

Whether microinverters save installation time is much debated. They require no combiner box, nor do they have a DC disconnect or a central inverter to deal with, which can save installation time. On the flipside, you’ll be attaching one inverter to your mounting structure for each module (or, for dual microinverters, one for each set of two modules), plus attaching and securing cabling assemblies between each microinverter. AC modules negate the steps of having to mount each inverter and connecting the module DC wiring leads into the inverter.

Debating the merits and drawbacks of microinverters and AC modules versus string inverters will certainly continue as more of these products enter the market. As competition increases, cost should come down and new solutions may be developed to speed installation, such as new cabling assemblies and single-point mounting for microinverters.



**This AC module is comprised of an AUO Solar module preinstalled with a SolarBridge microinverter.**

Courtesy AUO Solar



Courtesy Enphase Energy

**This Enphase M215 is the company’s third-generation product, which includes “single-bolt” mounting to speed installation.**

**Enecsys recently released its microinverters in the United States.**



Courtesy Enecsys

**Exeltech offers its PVAC module (see Gear in this issue).**



Courtesy Exeltech

# Microinverter & AC Module Specifications

Manufacturer	Model	Type	DC Input Specs					AC Output Specs					Warranty Standard/Extended (Yrs.)	
			Max. Rec. PV Power at STC (W)	Max. Voc	MPPT Range (V)	Max. Usable Input (A)	Max Isc	CEC Rated Power (W)	Nominal Output (V)	Max. Output (A)	CEC Weighted Efficiency (%)	Ambient Temp. Range (°F)		Module-Level Monitoring
Direct Grid www.directgrid.com	DGM-460	Micro-inverter	480	75	53–65	8.10	10	479	240	2.00	92.5	-40–149	Yes	20
Enecsys www.enecsys.com	SMI-S240W-60-UL	Micro-inverter	260	44	23–35	12.00	16	225	240	0.94	93.5	-40–185	Yes	20
	SMI-D360W-72-UL	Micro-inverter	380	54	30–42	13.40	16	340	240	1.40	94.5	-40–185	Yes	20
Enphase Energy www.enphase.com	M190-72-240-S12/3	Micro-inverter	230	56	22–40	10.00	12	190	240	0.80	95.0	-40–149	Yes	15
	M210-84-240-S12	Micro-inverter	240	62	31–50	10.00	12	210	240	0.88	95.5	-40–149	Yes	15
	M215-60-2LL-S22/S23	Micro-inverter	260	45	22–36	10.50	15	215	240	0.90	96.0	-40–149	Yes	25
Exeltech www.exeltech.com	PVAC	AC Module	240	N/A	N/A	N/A	N/A	212	120	1.80	94.5	-40–158	Yes	5-10-20
SolarBridge/AUO www.solarbridgetech.com	P235LV-240	AC Module	250	48	18–36	11.25	14	225	240	0.94	94.5	-40–149	Yes	25
	P235HV-240	AC Module	250	64	25–50	8.00	14	225	240	0.94	94.5	-40–149	Yes	25

The CEC-weighted efficiency is more akin to real-world conditions, because it considers the amount of time arrays normally spend at various power levels. Each inverter is tested at several power levels, ranging from 10% to 100% of rated power and at low, medium, and high DC input voltages to calculate a single average efficiency value.

The weighted efficiency is independently verified and is used by designers for comparing inverters. It is also used in calculations that determine an overall system DC-to-AC derate value used in system sizing and energy performance estimates.

**This Advanced Energy inverter’s removable, integrated AC/DC disconnect is listed to UL 98 (“Enclosed and Dead-front Switches”) and designed to meet NEC requirements for PV system disconnects.**

**Schneider Electric has released its Conext inverter line, which has an NEC-compliant, integrated Square D DC/AC disconnect.**



**Ambient Temperature Range.** Exceeding the manufacturer’s acceptable ambient temperature range can result in erratic inverter operation, damage, and premature failure. Going over the limit can also violate *NEC* 110.3(B), which requires that equipment be installed in accordance with manufacturer’s instructions. Some inspectors are abiding this specification closely—in some cases, local temperature determines which inverters you are limited to using, if you do not want to put the inverter in a conditioned space. Because of this, some installations are limited to microinverters or AC modules, which have a wider operating temperature range. Some string inverter manufacturers will provide additional documentation allowing exceptions outside of the limits shown on their specifications sheets, but acceptance is up to the authority having jurisdiction (AHJ).

## Mechanical Specifications

**Integrated Disconnects & Combiners.** Many inverters include integrated DC and AC disconnects, along with fused combiner boxes. This can eliminate installing external disconnects and combiners, reducing costs and installation time. Local AHJs and/or incentive program requirements may have additional requirements beyond the *NEC*, so external disconnects may still be required. Another consideration is that inverter servicing/removal is much easier and safer if workers are not subjected to exposed wiring coming in from the PV array or utility grid. Thus, a feature worth considering is the ability for the inverter to be detached from the integrated disconnect/wiring box (without dismantling the disconnect/wiring box).

## Access

Justine Sanchez (justine.sanchez@homepower.com) is a technical editor with Home Power and an instructor for Solar Energy International. She is certified by ISPQ as a PV Affiliated Master Trainer.



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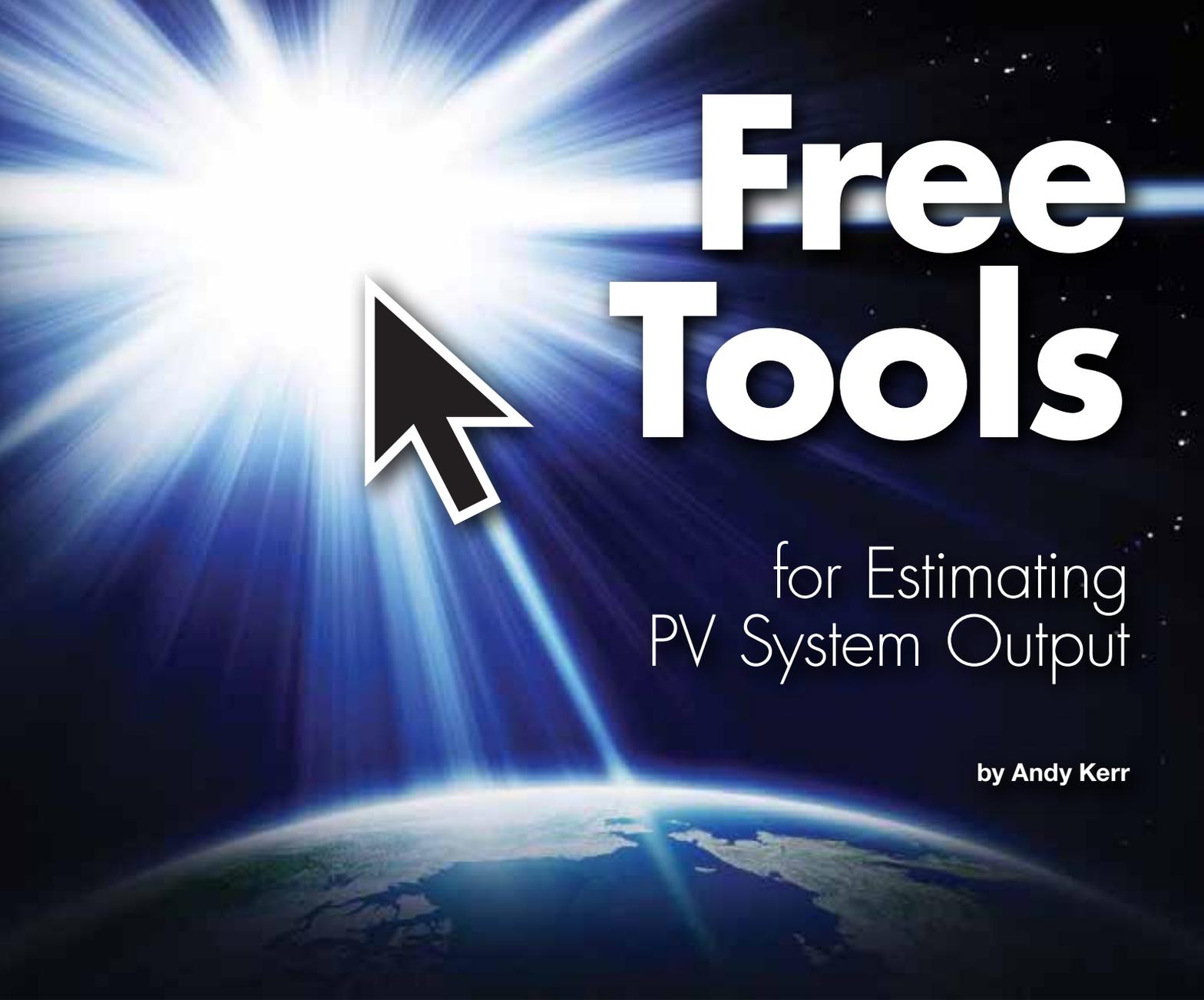
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# Free Tools

for Estimating  
PV System Output

by Andy Kerr

© iStockphoto.com/loops7

Thinking of installing a photovoltaic (PV) system but want to know how much energy and at what time of year a system would produce the most energy? You could contact some vendors and get some proposals to compare. But if you want to become an educated consumer and have a better idea of your site's solar potential before you start soliciting vendors (or to verify what they told you), these free online tools can estimate your energy production and utility savings. They can be easy to use by relying on default assumptions, but the more custom data you enter, the more accurate your results can be.

PVWatts version 1, PVWatts version 2, and the new kid on the block—IMBY (“In My Backyard”)—are courtesy of the U.S. Department of Energy’s National Renewable Energy Laboratory, the federal government’s research and development center for renewable energy and energy efficiency. The three tools are interrelated and are basically three ways to answer the same questions.

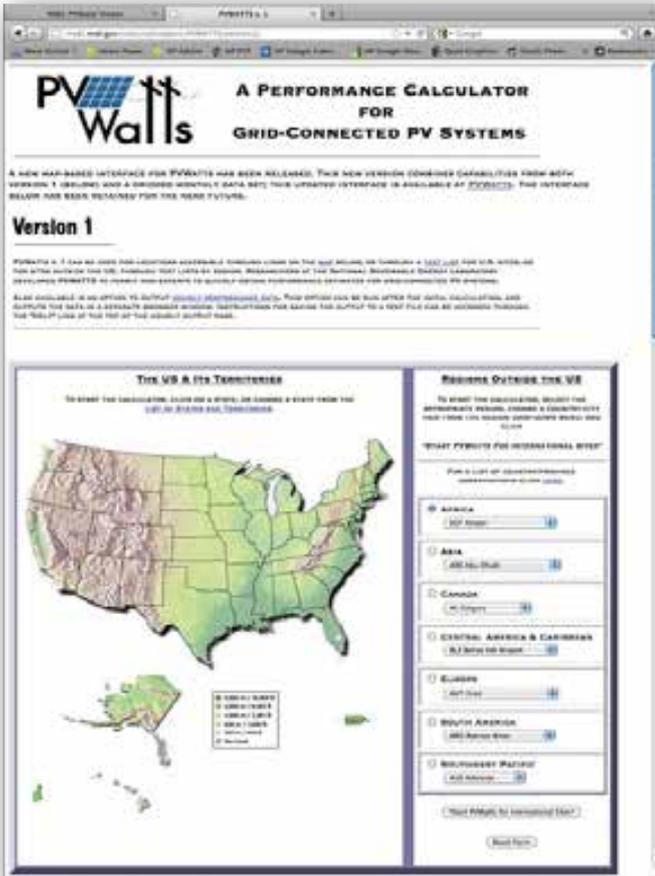
## PVWatts Version 1

Site-Specific Data Calculator

[www.nrel.gov/rredc/pvwatts/site\\_specific.html](http://www.nrel.gov/rredc/pvwatts/site_specific.html)

This version was launched in 1999, and allows users to choose the closest of 239 locations in the United States and its territories (and more than 360 additional sites around the world). For example, Washington, DC, residents choose the nearby Sterling, Virginia, option. A “site-specific data calculator,” Version 1 uses hourly solar radiation data derived from 30 years of data collection (1961–1990) from the National Solar Radiation Data Base. This data is used by the calculator to estimate monthly and annual energy production and financial savings. The tool calculates production based on characteristics of a grid-tied, crystalline-module PV system.

Many parameters can be adjusted to refine the system details, such as the array’s DC rating; the DC-to-AC derate factor;



whether it is fixed tilt or tracked; and, if it is a fixed array, the tilt and azimuth. Version 1 also gives you a default electricity cost, but it's based on generalized 2004 data. It's best to enter your current electricity cost for more accurate results.

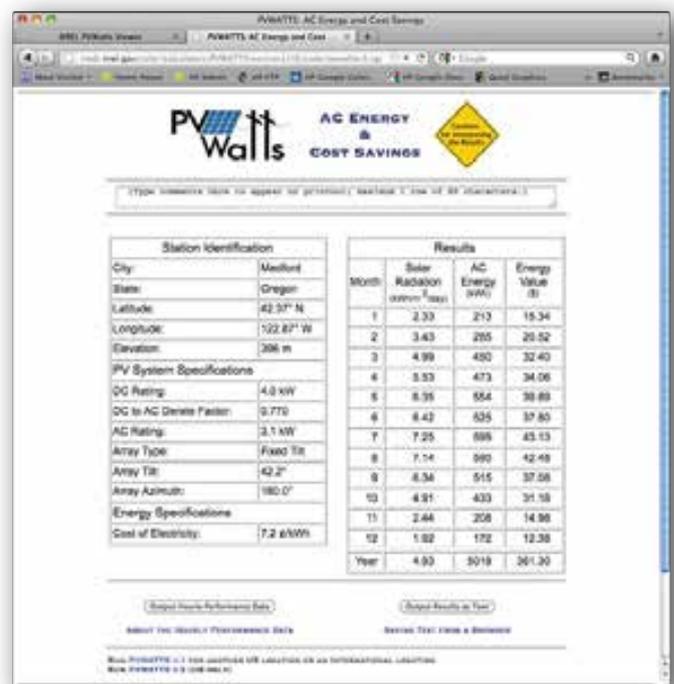
You can also customize the DC-to-AC derate factor, which is the percentage of available AC energy compared to the DC rating of the array (see "Derating a System" sidebar). The yielded values are accurate to ±30% for monthly calculations and ±10% for the annual value.

The biggest limitation of Version 1 is that you can only choose from four or five locations in each state, so regional climatic variations aren't factored in. However, it can yield hourly data over the year, which is useful to evaluate the benefits of time-of-use (TOU) metering available with some utilities—you can see if your proposed PV system's output should be peaking (or not) during the same time of high utility rates.

Above & upper right: PVWatts Version 1 allows you to choose from the closest of about 600 sites worldwide for representative solar data.

Below: Once you've picked a nearby data site, specific PV system parameters can be entered.

Lower right: PVWatts then calculates average projected kWh for each month, and a yearly total.



## System Derating Calculations

PVWatts translates weather and solar radiation data into a usable form, estimating the PV system's output (in AC kilowatt-hours) from the array's DC rating. PVWatts uses the following to determine an overall DC-to-AC derate factor:

**PV Module Nameplate DC Rating.** To account for module production tolerance, PVWatts reduces this rating by 5% (i.e., the default value is 0.95). This derate is a good default value for modules with a +/- 5% production tolerance, but if you purchase modules with a smaller or positive-only value, you can reduce this derate. For example, if your chosen modules have a +/- 3% production tolerance, you can use 0.97.

**Inverter and Transformer.** No inverter is 100% efficient, and to account for this, PVWatts uses a default value of 0.92. However, many inverters on the market today are more efficient (commonly 95% and higher). Enter the actual number, which can be found on the State of California Inverter Efficiency Ratings list at [www.gosolarcalifornia.ca.gov/equipment/inverters.php](http://www.gosolarcalifornia.ca.gov/equipment/inverters.php).

**Mismatch.** The current/voltage characteristics of every module will vary slightly. When strung together in an array, this will make them perform a little differently than they do individually. PVWatts uses a default of 0.98 (98%) efficiency—a 2% loss due to module mismatch. However, if you choose to use module-level maximum power point tracking, such as the case with systems employing microinverters, the mismatch derate factor can be set to its maximum of 0.995.

**Diodes and Connections.** To prevent the reverse flow of current, diodes are used internally in modules. Diodes use energy, and thus decrease the array's output. The default value is 0.995 and also accounts for resistive losses in electrical connections.

**DC Wiring.** Wiring has resistive losses, and generally a 2% voltage drop is considered acceptable on the DC side of the inverter—a default value of 0.98. This is another area where microinverters can increase output, since there is very little DC wiring to consider (each module directly plugs into a microinverter located at or close to the module).

**AC Wiring.** There are similar line losses on the AC side of the inverter—from the inverter and the utility connection. The AC voltage drop is usually limited to 1% or less (keeping the voltage drop on this wire run low reduces the likelihood of nuisance tripping of the inverter during times of high grid voltage), so the default value here is 0.99.

**Soiling.** Dirt builds up on modules, and studies show an average annual 5% loss for arrays that are not periodically cleaned, hence a default of 0.95.

**System Availability.** Maintenance, inverter down time, and utility outages mean your system isn't always producing energy. For PVWatts, the default reduction is 2% (0.98 efficiency), which translates to 7.3 days per year that your system would be out of commission. On average, how many days per year do you suffer from utility outages? If you know, you can figure out a better derate factor. In most areas, the grid is pretty reliable. For example, if the average total days is 1.5 each year, that would be  $363.5 \div 365 = 0.996$ . (However, this estimate doesn't account for any potential downtime due to system issues such as inverter shutdown.)

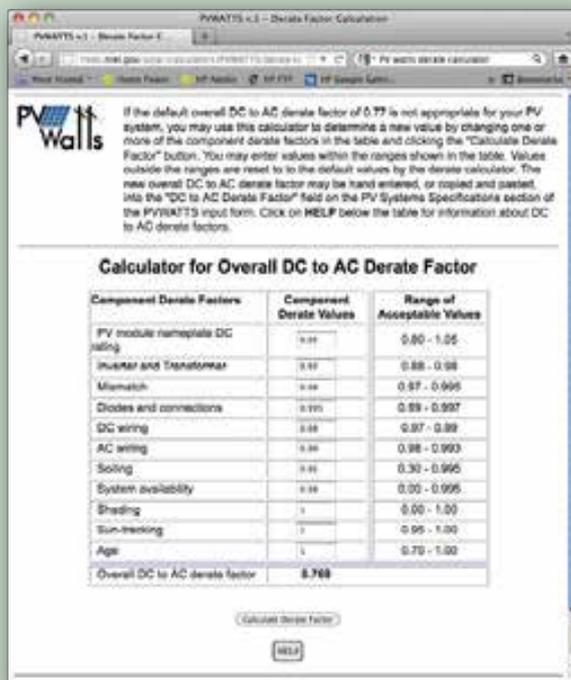
**Shading.** If a shading analysis has been performed at your site, plug in the actual value here. Otherwise, PVWatts will assume no loss due to shading. There are very few sites that have absolutely no shading, so it is important to perform a shade analysis at your proposed array location to determine its shade factor. Even if your solar window is wide open from 9 a.m. to 3 p.m., you should find out how much shading you have before and after. Also, if you're planning to use a central string inverter, even partial shading of one module can seriously derate an entire array.

**Sun Tracking.** Although the PVWatts default assumes no losses due to one- and two-axis tracking systems, the reality is that some tracking systems aren't always in perfect sync with the ever-moving sun. You may want to enter a derate value here.

**Age.** If you are judging the performance of an existing system, conservatively figure on an annual decline of 1% of the nameplate rating each year. The default setting is 1—PVWatts assumes that the system is in its first year of operation.

The overall derate is calculated by multiplying all of the individual factors together. Since subsidies and/or solar renewable energy credits are increasingly based on PVWatts estimates, using accurate individual derate factors is critical.

PVWatts was developed when a central inverter was the only option. Since then, microinverters—individual inverters attached to each module—have entered the scene, and have changed the derate picture. Microinverter manufacturers claim lower derate values (by negating or reducing factors such as mismatch and DC wiring losses), and overall higher system efficiencies. For instance, microinverter maker Enphase suggests values that result in an overall derate factor of 83.2% rather than the PVWatts default of 76.9%.



Setting specific derate factors will generate a more-accurate estimate of system performance.

## PVWatts Version 2, 40 km Grid

Grid Data Calculator  
[www.nrel.gov/rredc/pvwatts/grid.html](http://www.nrel.gov/rredc/pvwatts/grid.html)

A more refined version of PVWatts— 40 km Grid (aka Version 2) entered the picture in 2001. It allows U.S. users to zero in on their location by ZIP code, by street address, or by latitude and longitude coordinates. One gets most of the same information as with PVWatts version 1. While you can see where your house is on the satellite image, the data is intended for the entire 40-kilometer (25-mile) square that includes your street address. The downside is that hourly system output is not calculated.

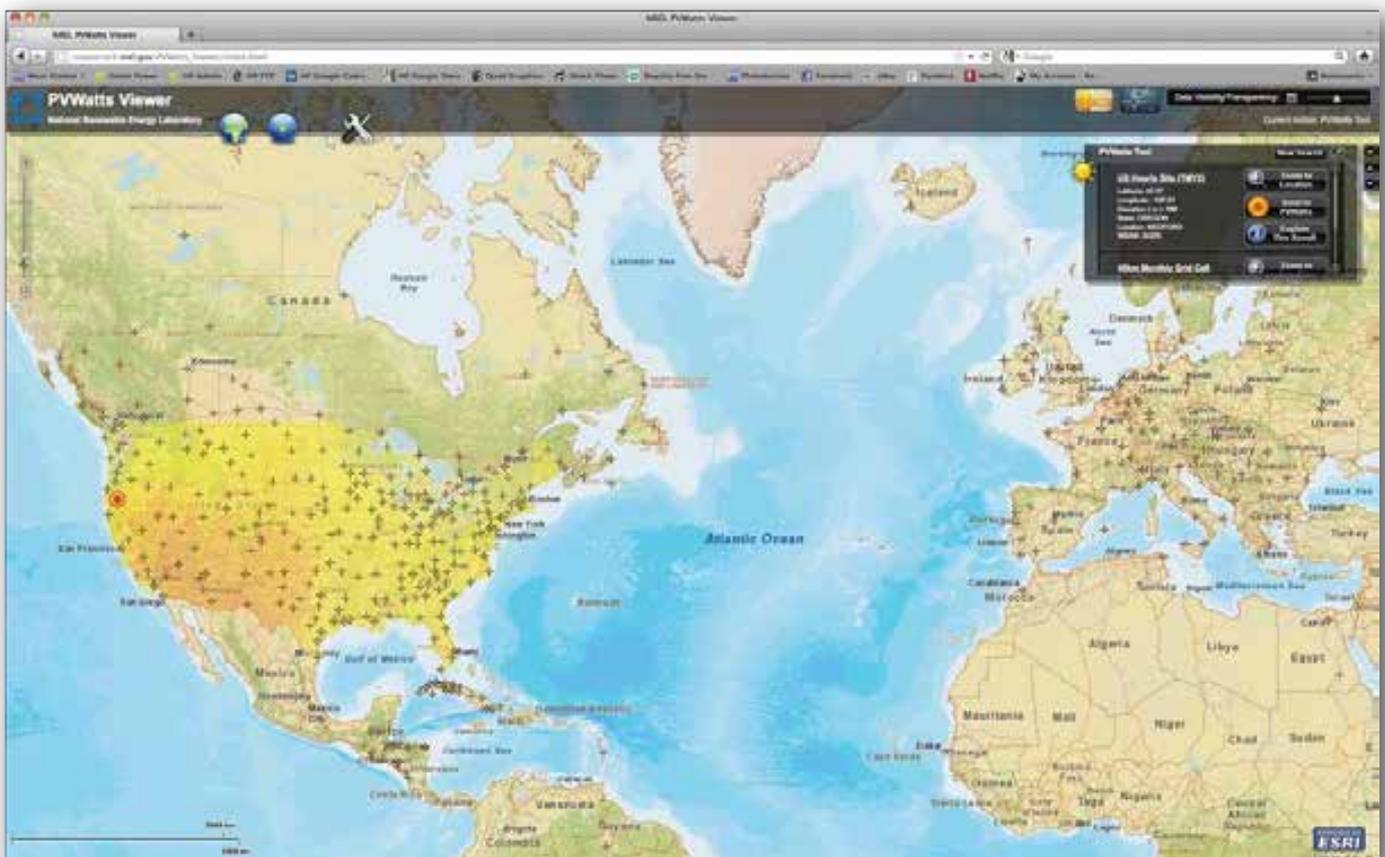
### Portal to Both PVWatts

The new PVWatts Viewer is now the interactive, map-based gateway to either version of PVWatts (it queries both simultaneously and selects the one to give you the most accurate results). You can tell which one you are in by looking at the top band across the browser window. Either you specify a location (U.S. ZIP code, full street address, or latitude and longitude) or you can click on the map and zoom around to the spot you want either in map or satellite

views. Once you specify your location, you are taken to a PVWatts calculator where you can enter additional information:

- **DC Rating.** The total rated kW for the array. For example, if you have twenty 225 W modules in your array, the array's DC rating is 4.5 kW ( $20 \times 225$  W).
- **DC to AC Derate Factor.** The default value for this is 0.77, but can be adjusted based on the type of inverter used, module power tolerance, DC and AC wiring losses, etc. (see "System Derating Calculations" sidebar).
- **Array Type.** Choose from fixed or tracked: one-axis (east-west) or two-axis (east-west and up-down).
- **Array Tilt.** This value defaults to equal the site's latitude but should be adjusted, especially for roof-mounted systems where the array is likely to be mounted parallel to the roof plane.
- **Array Azimuth.** The default value is  $180^\circ$  or true south, but you'll need to adjust this according to your array's orientation.
- **Cents per kWh.** The default value relies on your state's 2004 generalized data, so for more accuracy you should enter your own utility rate, which can be found on your monthly electric bill.

The opening interface of PVWatts Viewer displays about 600 worldwide data locations, as well as the 40 km grid of the continental United States. From here, you can zoom and scroll to your location. PVWatts then can work from Version 1 or 2.





The Viewer allows custom settings, including a map view (above left) and an aerial photo view (above right), which makes locating your site easy, and a bit fun, too.

PVWatts calculates the solar radiation (kWh per m<sup>2</sup> per day), AC energy (kWh), and energy value (\$) by month with annual totals. If the Viewer uses Version 1 you can also get an output of hourly performance data. If that button is dimmed, you are using 40-kilometer gridded data and cannot access the hourly data. In either case, you can print the monthly and total output results to a new browser page, in spreadsheet-friendly CSV output.

**PVWatts Version 2 is based on satellite image data for solar insolation over a 40-km (25-mile) grid, which can be displayed as a transparent overlay. If your site is close to a grid line, consider running calculations for adjacent areas, too.**



## In My Backyard (IMBY)

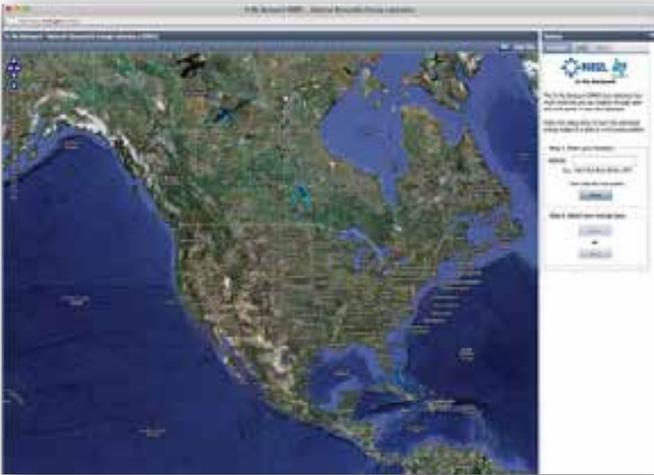
[www.nrel.gov/eis/imby](http://www.nrel.gov/eis/imby)

IMBY is a positive spin on the derogatory phrase “not in my backyard—NIMBY” (which refers to people who oppose the siting of nuclear power plants, toxic waste dumps, etc. near them—but not anywhere else). This tool estimates the energy that can be produced with either a residential-sized PV or wind system (see “IMBY and the Wind” sidebar) *at a specified location*.

IMBY can pinpoint locations in 49 states (sorry, Alaska) and part of northern Mexico. Enter your address information, click Find, and the satellite image goes to your location. Using a drawing tool, you can delineate the precise area for a PV array. IMBY then offers an estimate of PV array size in DC kW.

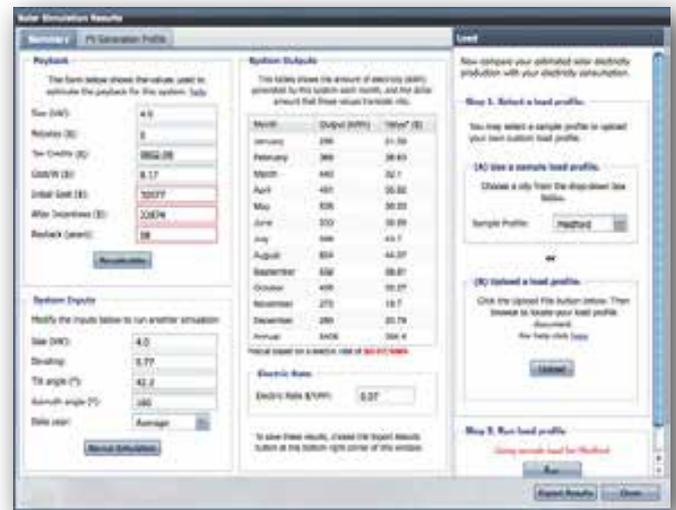
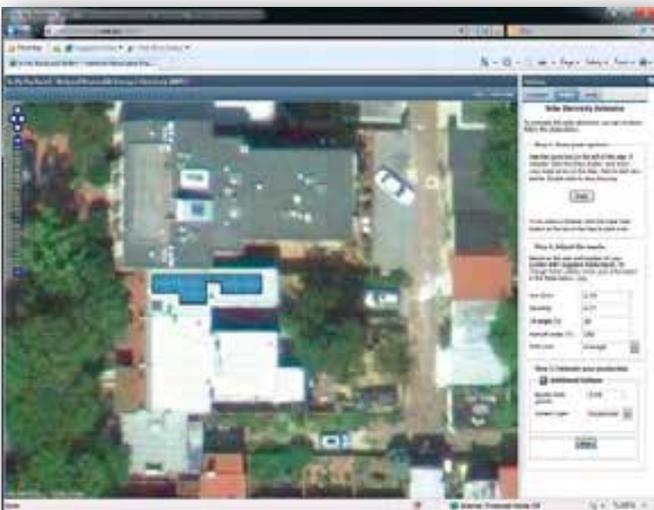
Its summary provides customizable Payback, System Inputs, and Electric Rate categories, allowing users to more precisely calculate initial cost and payback (in years), factor in rebates and tax credits, and adjust the initial cost per watt of the system. Just like PVWatts, you can enter your per kWh electricity cost, and modify system parameters, such as the tilt, azimuth, and derate amount. IMBY calculates your gross system cost with a default setting of \$8 per watt. Fortunately, you can change it, as actual prices have been decreasing. Of course, you won’t know your per-watt cost until you get some bids, so this feature is not useful if you haven’t started shopping. IMBY then estimates a simple payback in years—an unsophisticated financial analysis technique. Return on investment and net present value would be more helpful.

The simulation also provides monthly and annual production estimates, and assigns a dollar value to the energy produced. IMBY will graph your projected production, as



IMBY estimated a 10 kW array. In reality, due to required setbacks and the specifics of the chosen module size, about 9.7 kW of modules will fit. After delineating the existing array on rooftop B, IMBY came back with very close to its actual 3 kW nameplate rating. The drawing tool is precise, so going short or long by a pixel will change the results. For rooftop C, IMBY's results were 40% below its actual DC nameplate rating of 7.1 kW.

IMBY only calculates fixed-tilt PV arrays. It uses high-resolution satellite-derived solar radiation data, rather than historical data. While IMBY lets you change the overall DC-to-AC derate factor, it doesn't allow you to modify the individual derate variables as does PVWatts. For this, you'll need to calculate the derate factor in PVWatts and enter this new value in IMBY.



IMBY lets you enter location information to zoom to a close-up aerial view (above), but system performance projections are based on tracing an array area directly on the photo (below).

You can input your data in the Payback box, but it's rather clunky. IMBY's financial calculators need work.

well as your demand. Do so by either by choosing one of the 15 sample profiles or uploading a comma-separated file of your electrical demand during the 8,760 hours of one year—but one is unlikely to have such information on hand.

While a great concept and a beautifully styled tool, IMBY still has some big bugs to work out. Using several different browsers on both Mac and Windows platforms, IMBY proved unstable, with tendencies to be slow and to lock up. It often won't do the same thing twice or upchucks (a technical computer term) when you try to enter some data, or jumps to an extreme satellite close-up in Colorado (not kidding). You may need to switch browsers to see how it holds up. With Chrome it consistently crashed. But using Firefox on the same computer, it ran without a hiccup.

The ability to be able to zoom in on your property or rooftop and precisely draw even an irregularly shaped PV array is a terrific function. We tested IMBY by delineating several rooftops that already had PV arrays. For rooftop A,

IMBY can graph your system's estimated production against your locale's average residential electricity consumption. If you want to be more precise, you can upload your own demand data for graphing.



## Which Tool is Best for You?

- If you live in the United States, PVWatts 40 km Grid will likely give you the best results.
- If you don't live in the United States, use PVWatts version 1 if you are near one of the more than 360 international data locations.
- If you want to compare generation and consumption information, use IMBY.
- If you want to measure the area available for your PV array and get a rough estimate of possible system size, use IMBY.
- Whether IMBY works correctly or works with your computer operating system and chosen browser is another matter.

## IMBY & the Wind

If you live in one of the 30 U.S. states for which the data is available, you can also use IMBY to estimate wind energy potential for your site. The map's drawing tool allows you to plot one or more turbine locations; choose either 3 kW or 10 kW turbines; and select the tower height in 10-meter increments. IMBY's wind outputs are more limited than its PV analysis, but are a step in the right direction.

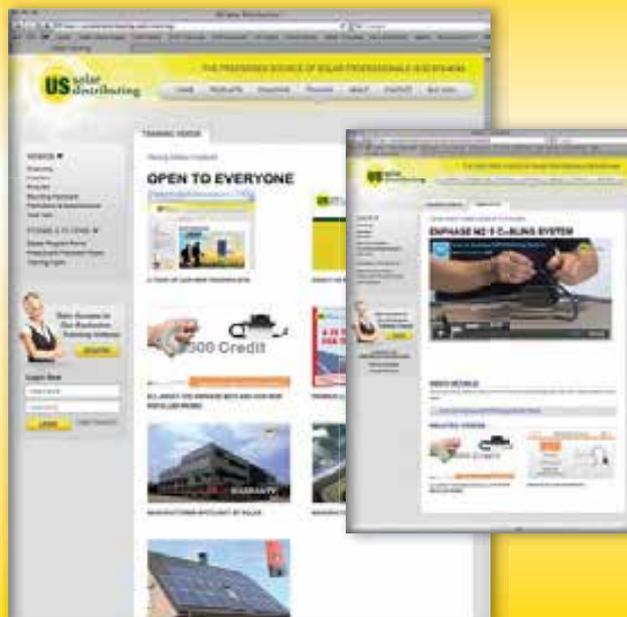
## Access

Andy Kerr ([www.andykerr.net](http://www.andykerr.net)) consults and writes about public lands, wildlife, and energy topics. He splits his time between Ashland, Oregon, and Washington, DC. Over the years, he's owned five solar hot water and four photovoltaic systems.



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# Choosing the Best



Courtesy U.S. Battery Manufacturing Company

# Batteries

by Lena Wilensky

**W**ithout batteries, you'll be in the dark with your grid-tied RE system during utility outages. For off-grid folks, batteries are required to store and smooth out the electricity from an RE source—imagine your electricity shutting off every time a cloud passes overhead. Even when the sun is shining, a battery bank provides the surge current necessary to start motors (such as in power tools, well pumps, blowers, and compressors), which often exceeds a PV array's capability.

However, the tradeoff is that battery-based systems are more complex and expensive, and require more knowledge and interaction from owners. Batteries can be temperamental and can fail us if not given due respect. But if we start out with appropriately matching the battery to the job, they can provide years of loyal service.

## Deep-Cycle Lead-Acid

There have been many recent battery innovations, mostly focused on smaller, lighter batteries for electronics and electric vehicles (like lithium batteries). And older battery technologies, such as nickel-iron, are resurfacing as an option. But for most RE applications, deep-cycle lead-acid (L-A) is still the battery of choice due to functionality, availability, and cost.

Daily charging and deep discharging can wreak havoc on batteries if they are not designed for that type of use. Even battery backup systems, which may stay in float (fully charged) for many months at a time, still follow similar discharge/recharge cycles when utility power goes down.

There are several lead-acid battery types, and each has its pros and cons for different applications. Choosing the right one for the job is critical to a well-functioning and long-lived system.

**Trojan Battery's version of two of the most common batteries used in RE applications, the L16 and the golf cart.**



Courtesy Trojan Battery Company

**Flooded batteries** are the main workhorses in RE systems. They are proven in the field, and can take a fair amount of abuse. These batteries contain a liquid electrolyte, which will bubble during charging from the hydrogen (H<sub>2</sub>) and oxygen (O<sub>2</sub>) gas coming out of the solution. Since the gas is flammable and corrosive, the batteries need to be adequately vented. And they need to be periodically topped off with distilled water to replace the H<sub>2</sub> and O<sub>2</sub> that have been released. Caps on each cell allow the gas to escape but keep the liquid electrolyte contained, and are removable for refilling.

Flooded batteries are well-suited for regularly maintained off-grid systems. Because they require watering, summer cabins or other homes where no one is present to monitor the batteries for long periods may not be the best situation for flooded batteries.

**Sealed batteries** are also called valve-regulated lead-acid (VRLA) batteries. They do not have removable cell covers and thus cannot be refilled with distilled water. There are different types of sealed batteries, but they all are considered “maintenance-free” because they do not need watering. They have valves to relieve excess pressure from gas buildup, but unless these batteries get too hot or are overcharged, they should not release much gas. Most gassing that occurs during normal charging is recombined within the battery. Because the electrolyte cannot spill, sealed batteries do not have to be upright, providing more installation options and easier shipping.

Sealed batteries are great for standby and seasonal-use systems, where regular maintenance might not be possible or desired. However, they cost about twice as much as their flooded counterparts, and are more sensitive to high temperatures and being overcharged, as any gas that escapes cannot be replaced.

Absorbed glass mat (AGM) and gelled-electrolyte batteries are the main types of deep-cycle sealed batteries. AGM batteries have glass-fiber separators between the plates, which absorb some of the electrolyte. They tend to lose a little less capacity than gels do under cold temperatures, but

## Size Codes & Common Names

Although each manufacturer has their own model numbering system, standard sizes exist for commercial batteries. Battery Council International (BCI) is a trade organization that sets some battery standards, including sizing codes. Some batteries have acquired less-official names from their intended use—for example, “GC2s” got theirs from being used as golf cart batteries. Batteries with the same code or name will have approximately the same dimensions, but their capacities may differ significantly, especially between flooded or sealed units. The table shows some of the more common sizes seen.

### Battery Sizes & Approx. Dimensions

Size	Volts	Length (In.)	Width (In.)	Height (In.)	Capacity @ C/20 (Ah)	Weight (Lbs.)
Group 24	12	10.00	7.00	9.00	70–85	50
Group 27	12	12.00	7.00	9.00	85–105	60
Group 31	12	13.00	7.00	9.50	95–125	70
4D	12	20.75	8.75	10.00	180–215	130
8D	12	20.75	11.00	10.00	225–260	160
GC2	6	10.50	7.00	11.00	180–225	70
L-16	6	11.50	7.00	16.75	325–415	120

all lead-acid batteries lose some capacity as temperatures drop (see “Chilly Temps” sidebar). AGMs also tend to be marginally less expensive than gels.

Gel batteries use an electrolyte that has the consistency of petroleum jelly. Because their electrolyte is viscous and can't be stirred up, gel cells can be prone to stratification, where stronger electrolyte “settles out” to the bottom of the cell, and the weaker rises toward the top. This results in inefficient charging and discharging within the cell, and will cause the battery to lose capacity, shortening its life. Many manufacturers of higher-end gel batteries claim to have solved this issue with improved electrolyte formulas and battery assembly.

Besides a full flooded line, Deka Battery offers a solar line emphasizing sealed, maintenance-free batteries in a variety of sizes.



Courtesy Concorde Battery Corporation



Concorde (left) offers a complete AGM line for renewable energy systems that ranges from 34 Ah at 12 V to 1,215 Ah at 2 V.

Courtesy Deka Battery

## Lead-Acid Battery Choices

Type	Maintenance	Vented Area Required	High Temperature Tolerance	Low Temperature Tolerance	Price	Orientation
Flooded	Watering	Yes	Yes	No	\$	Upright
AGM	Minimal	Minimal	No	Yes	\$\$	Any
Gel	Minimal	Minimal	No	Yes	\$\$	Any

Note: Exceptions exist, especially with higher-end manufacturers.  
 Also: Some sealed batteries need to remain upright, like their flooded lead-acid counterparts.

Gel batteries require lower charging current, and both AGM and gel batteries require lower charge voltage than flooded ones. Most RE system chargers can be programmed to meet these requirements, but other charging sources, such as DC generators or car battery chargers, can permanently damage the battery.

### Industrial Batteries

Many battery manufacturers offer industrial models that have higher capacities than commercial batteries. Most industrial batteries are individual 2 V cells which are connected together, often custom-configured into large battery banks and can be specified with their own cases and/or racks. Because of their higher Ah capacity, it's possible to build a large battery bank with fewer parallel connections (see "Equality in Design" sidebar).

Industrial batteries can be flooded or sealed, with the sealed versions often used for uninterruptible power supply (UPS) and other battery backup situations. Industrial batteries also come with a more substantial warranty than their commercial counterparts, are more expensive, and often require mechanical lifts to move.

### Deciphering Capacity Specifications

Deep-cycle battery capacity is rated in amp-hours (Ah). The power equation dictates the relationship between amps, volts, and watts:  $A \times V = W$ . When you add in the time factor for figuring energy capacity, the same holds true for the relationship between Ah and Wh:  $Ah \times V = Wh$ .

To compare the energy capacity of batteries of different voltages, it's easiest to convert to Wh. For example, a 250 Ah, 6 V battery has half the capacity of a 250 Ah, 12 V battery.

$$6 \text{ V} \times 250 \text{ Ah} = 1,500 \text{ Wh}$$

$$12 \text{ V} \times 250 \text{ Ah} = 3,000 \text{ Wh}$$

Battery capacity specifications also depend on how quickly the battery is charging or discharging. The faster the charge/discharge rate, the less overall capacity a battery will have. For example, a battery may have a 100 Ah capacity when powering 2 A of LED lighting, but only 75 Ah with 8 A of compact fluorescents. To make matters worse, not all battery manufacturers clearly show what the charge/discharge rates are for the Ah ratings on their spec sheets. It's common to see C/100 rates (quite slow) to make a battery look like it has more capacity. Most folks in the RE world like to use a C/20 rate, which is close to the typical daily (24-hour) cycling found in RE systems.



Courtesy Surrette Battery Company

**Rolls (aka Surrette) is known for its high-capacity batteries, including an 820 Ah, 6 V model and a 2,430 Ah, 2 V model.**

**The high-capacity HuP Solar One batteries use removable 2 V cells in a durable steel case, making transport easier.**

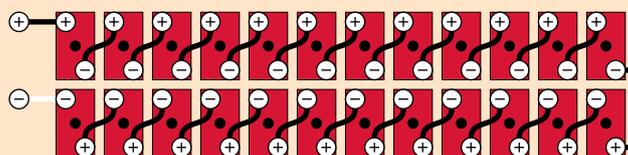


Courtesy Northwest Energy Storage

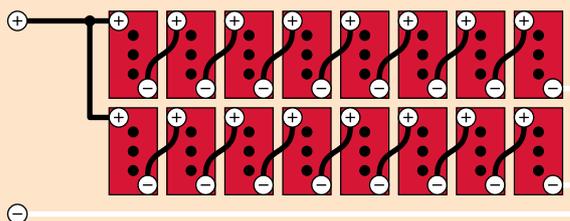
## Equality in Design

To promote equal charging and discharging within a battery bank, it's important to limit the number of parallel connections. One series string is best for equal charging/discharging, but some designers prefer two strings for redundancy—in case one battery or cell fails, there will still be one functional series string at the correct voltage to rely on until the failed battery can be replaced. Three parallel strings are considered marginally acceptable, but more parallel connections introduce too many paths for the electrons to choose from when entering or leaving the battery strings. Some cells can be chronically undercharged due to minute variations in cell and interconnection resistance, decreasing the life of the bank. The best design uses batteries with higher amp-hour capacities and limits the number of parallel connections.

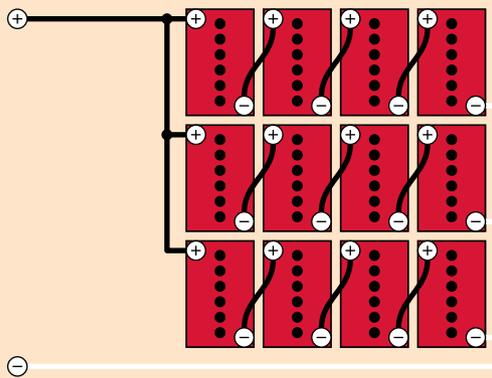
It can be tempting to design a battery bank with plans to add capacity in the future, but this is not good practice. Because of batteries' sensitivity to unequal charging/discharging within the bank, they should all be of the same make and model, and ideally manufactured in the same batch. Adding new batteries—even the same make and model—to a battery bank more than a year old is inviting problems, as the old batteries will already have higher internal resistance. Always size for the future from the beginning!



**Most Desirable: Single Series String**  
e.g., 24 2 V cells at 1,000 Ah each  
for 1,000 Ah at 48 V total



**Acceptable: Two Series Strings**  
e.g., Two strings of eight 6 V cells at 500 Ah each  
for 1,000 Ah at 48 V total



**Less Acceptable: Three Series Strings**  
e.g., three strings of four 12 V cells at 333 Ah each  
for 1,000 Ah at 48 V total

**Undesirable: More than Three Series Strings**  
Multiple parallel connections create unequal string resistances, resulting in premature cell failure

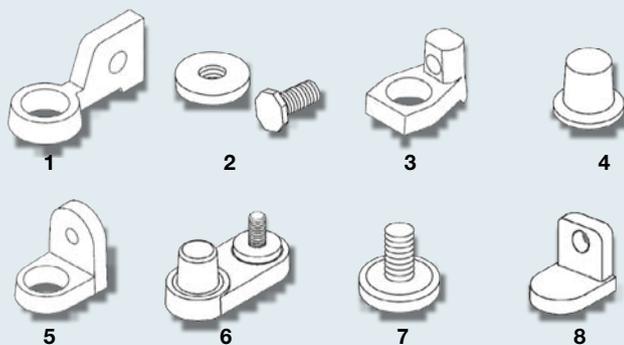
Courtesy U.S. Battery Manufacturing Company



This U.S. Battery L16 includes helpful battery labeling with amp-hour capacities at various C-rates, as well as stepped charge and temperature compensation specifications.

## Battery Terminals

Connections for battery cables come in various shapes and sizes, and often can be custom-ordered. Some are more compatible with the heavy-duty battery cable and lugs needed for larger inverters in residential PV systems. L-terminals are perhaps the most common, and are easily bolted to cable lug ends. Finding UL-approved connectors for batteries with automotive-type vertical posts can be difficult. The important part is to be sure your battery cables and terminals are compatible and appropriate for their application.



1. Flag terminal with  $\frac{3}{8}$  in. hole
2. Insert with  $\frac{5}{16}$  in. threaded bolt
3. Offset post with horizontal hole
4. SAE "automotive post"
5. Heavy-duty L-terminal with  $\frac{3}{8}$  in. hole
6. Molded-in offset SAE post, with vertical  $\frac{5}{16}$  in. threaded stud
7.  $\frac{3}{8}$  in. stud post
8. L-terminal with  $\frac{1}{4}$  in. hole

## Chilly Temps

Most battery capacity specifications are based on the ideal battery temperature of 77°F. That's an attainable temperature for conditioned spaces, but if your batteries are out in the cold, you'll need to make some adjustments. Flooded and sealed batteries behave a little differently under various temperature regimes, so be sure to check manufacturer's specs (see "Correction" table).

### Sizing Correction Factors

Temp. (°F)	Flooded	AGM	Gel
77	1.00	1.00	1.00
50	1.19	1.08	1.11
32	1.39	1.20	1.25
14	1.70	1.35	1.42

Source: Trojan Battery

For a system requiring 1,000 Ah of capacity using flooded batteries in Arcata, CA, with common 40°F winter temperatures, you would have to extrapolate in the "Correction" table to get a correction factor of 1.29.

1,000 Ah × 1.29 = 1,290 Ah battery bank size for winter temperatures

Beware of below-freezing temperatures and flooded batteries. Since the electrolyte becomes very weak (closer in composition to water) in discharged flooded batteries, the electrolyte can freeze solid, which will ruin a battery! Cases can crack from the expanded ice, and internal connections may be damaged. For those conditions, sealed batteries are a better choice because their electrolyte solution has a much lower freezing point.



Courtesy Lara Wilensky

It's a cold snowmobile ride to maintain this remote data-monitoring system powered by a PV system with an AGM battery.



Courtesy Honey Electric

Proper temperature, ventilation, and spill containment are important for a safe, long-lasting battery bank.

### Other Considerations

**Location.** Make sure to have adequate and appropriate space. Batteries need to be near the inverter for a short (usually less than 10 ft.) cable run, protected from unauthorized access, and properly enclosed and vented to keep corrosive, flammable gasses outside of occupied spaces. High temperatures will shorten a battery's life, especially sealed batteries, so keep them out of direct sun and provide air circulation if needed. Good access is critical for inspection, cleaning, watering (if flooded), and eventual replacement. If they're hard to get to, they'll be hard to maintain.

For remote systems, consider the ease of transporting and installing the batteries. Bumping up a rutted road and hand-carrying more than 4,000 pounds of preracked industrial batteries may not be an option, whereas more loads of 120-pound L16 batteries is much more feasible and may be able to provide the same overall energy storage.

**Sources.** Although most major RE distributors carry deep-cycle batteries, shipping can be expensive because of weight, time, and their hazardous materials designation. Finding a local battery distributor can ease the pain of high freight costs, and provides a local ally in case problems or questions arise. Also, most distributors add a fee onto battery sales to encourage the recycling of old batteries. This "core charge" can be avoided by returning the old batteries after purchasing new ones—a difficult prospect when your distributor is far away.

**Budget.** Folks who are new to off-grid living may want to start with relatively inexpensive batteries. It's a little easier to replace a \$5,000 five-year battery bank after two years of mistakes and learning, than a \$15,000 set that should have lasted 20 years! And sometimes, even though sealed batteries might be a better match in terms of functionality (RV use, for instance), price difference will be the deciding factor. A flooded battery bank can be replaced twice as often as a sealed one for the same price.

## Car Batteries

When true deep-cycle batteries were not readily available, determined off-gridders used car batteries. Though this can work initially, after a year or two of marginal service, the batteries would need to be replaced—an expensive and labor-intensive endeavor.

Car batteries are designed to start large motors—yielding lots of power over a very short time period—and then need to get recharged right away. They have many thin plates, which provides more surface area for the chemical reactions to happen more quickly and to discharge a lot of energy at once. Deep-cycle batteries have much thicker plates to stand up to frequent deep discharge and recharge cycles. The thinner plates on car-starting batteries will warp and pit when deeply discharged, ending their life prematurely, and making them a poor candidate for RE systems.

## Protect Your Investment

The next step after choosing the right batteries is to take care of them. Warranties do not cover mistreatment or human mistakes. And high-end batteries fail almost as easily as their economy counterparts if they are not maintained. Stay tuned for “Part 2: Battery Installation & Maintenance” for tips and tricks on keeping the relationship with your batteries a good one!

## Access

Lena Wilensky (nunatakenergy@gmail.com) owns a small RE design and installation company in the mountains of Colorado. She is a Solar Energy International instructor, a NABCEP-certified PV installer, and is certified by ISPQ as a PV Affiliated Master Trainer.

### Further Reading:

“Choosing the Best Batteries” in *HP127*

“Off-Grid Batteries, 30 Years of Lessons Learned” in *HP140*

“Battery Box Design” in *HP141*

### RE Battery Manufacturers:

Concorde Battery • [www.concordebattery.com](http://www.concordebattery.com)

Crown Battery • [www.crownbattery.com](http://www.crownbattery.com)

Deka/MK • [www.dekabatteries.com](http://www.dekabatteries.com)

Discover Energy • [www.discover-energy.com](http://www.discover-energy.com)

Exide Technologies • [www.exide.com](http://www.exide.com)

Fullriver Battery • [www.fullriverdcbattery.com](http://www.fullriverdcbattery.com)

Hawker • [www.hawkerpowersource.com](http://www.hawkerpowersource.com)

Interstate Batteries • [www.interstatebatteries.com](http://www.interstatebatteries.com)

Iron Edison • [ironedison.com](http://ironedison.com)

Solar-One/Energys • [www.hupsolarone.com](http://www.hupsolarone.com)

Surette/Rolls Battery • [www.surette.com](http://www.surette.com)

Trojan Battery • [www.trojanbatteryre.com](http://www.trojanbatteryre.com)

Universal Power Group (UPG) • [www.upgi.com](http://www.upgi.com)

U.S. Battery • [www.usbattery.com](http://www.usbattery.com)



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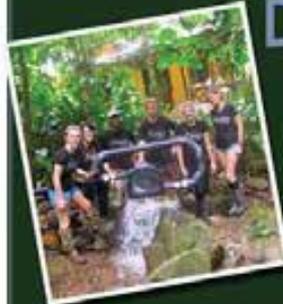


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# The Electric Motorcycle

A **DIY** Primer

**ALERT**  
Potential for  
Obsession-Inducing Project!



Story & photos by Ted Dillard

The finished electric motorcycle—road-ready for miles of fun.

There are a lot of projects that you can take up over a short period of time; start, complete, enjoy, and use. This project may, if you're not careful, lead you down a path of obsession.

Motorcyclists are generally rabid enthusiasts, and some electric motorcycle builders are quite new to motorcycling, having come from the electric vehicle path. Electric vehicles are riding a wave of technology development. Combining the two can be electrifying.

## Why Build an Electric Motorcycle?

Common reasons range from environmental to economic. Some people do it just to save gasoline.

The deeper implications of building an EV, especially one salvaged from the junkyard, can get interesting. Some people just like being backyard mechanics. Many builders like keeping about 500 pounds of scrap out of the junkyard by salvaging, and sometimes restoring, vehicles that others have passed off as not worthy of repair—it's reduce, reuse, and recycle. And by solar charging, EV/PV enthusiasts can

power their rides with completely renewable energy—a 0% carbon footprint.

Many love the attention their unique vehicle gets, using them for RE evangelism wherever they go. They spark questions, conversation, and enthusiasm for the work and ingenuity to convert a gas bike to electric, even among hardcore motorcyclists.

Electric trail bikes have their fans because they open up areas to riding that, because of the noise of gas trail bikes, might not be tolerated.

There is, however, one thing in particular that stands out about electric motorcycles: the power. Electric motors deliver power in a completely different way than their gas counterparts. Power (torque, in particular) is instantaneous, and the power increases the faster the motor spins. There's no gear shifting, and going from 0 to 60 feels like holding onto the tail end of a rocket. Many people build an electric motorcycle simply because it's an affordable way to experience the feeling of an ultra-high performance electric drive train.



This 1984 Honda VF500F Interceptor donor bike has its frame stripped and primed, ready for paint.



It will make an excellent medium-weight sport bike after its conversion.

## Planning the Build

Going into your project, have a clear and realistic idea of what you want to accomplish. Assess your skill level, and determine the type of donor bike, the desired performance, and how you want to use the completed bike.

Aiming for 100 mph top speeds *with* a range of more than 100 miles is a recipe for disappointment. Start with a more conservative target: Most bikes can hit a top speed of about 75 mph, with a range of 30 to 40 miles.

Don't grab the first donor bike you see if it doesn't suit your plan. Too often people try to make a heavyweight cruiser out of a medium-weight sport bike; a lightweight café from a monster frame; or even a street bike out of a trail bike chassis. Start with the style and weight that you want to end up with.

Check the condition of the chassis you are considering. You need a safe, reliable ride, so consider the brakes, tires, bearings, and suspension, just as if you were buying a gasoline-fueled bike. To register it, it's got to have a clean title.

## The Motor

The permanent magnet DC (PMDC) motor has a good price, fairly simple control systems, and reasonable weight and efficiency. Brushless DC (BLDC) or AC motors don't need maintenance, operate at a high rpm, and the controller electronics allow more precise motor control. They are heavier and more expensive, but have more power capacity.

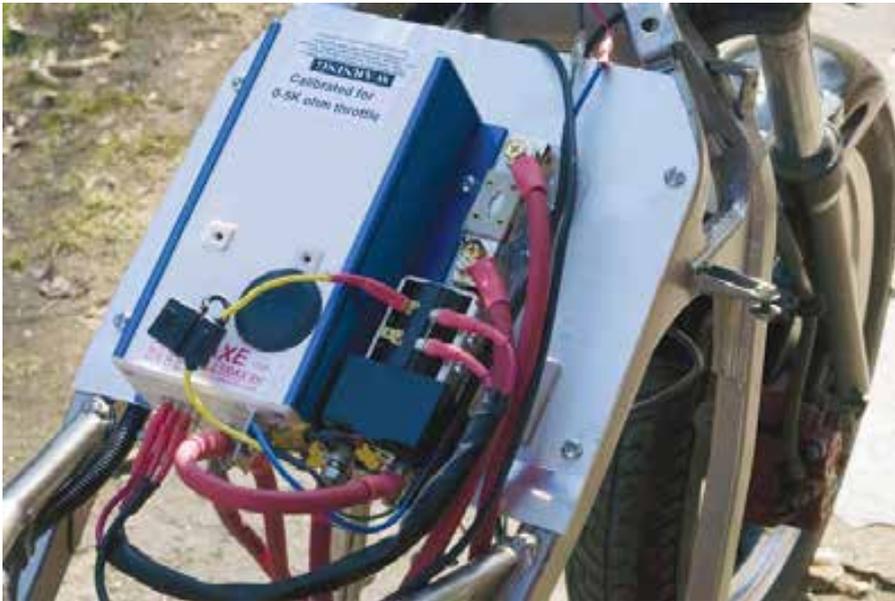
Most motors are mounted where the gas engine used to be, but designing and building a motor mount that's in the right spot and can handle the stresses of the higher torque requires fabrication skills and careful planning. Another option, the hub motor, is integrated into the rear wheel of the bike, eliminating the motor mount, chain, sprockets, and space in the frame demanded by conventional motors.

## The Controller

The controller is the "brain" of the propulsion system. Using pulses of current, or pulse-width modulation (PWM), the controller allows a twist-grip throttle to precisely vary the motor's speed and power. Pulse-width modulation (PWM) looks like small on/off bits of full power, and is how any DC motor speed control works. AC motor controllers manage the timing of the pulses to synchronize with the AC motor's rotation. A controller can also turn the motor into a generator during deceleration (regenerative braking), feeding the generated current back to recharge the batteries. Controllers are generally programmable and, in some cases, can also handle data logging.

Different motors are available, like AC brushless motors (top), PMDC brushed motors (middle), and BLDC hub motors (bottom).





The controller, contactor (lower right), and fuse (upper right), with everything neatly laid out, will be hidden under the old fuel tank.

Usually, the controller and the motor are chosen together. In the case of a PMDC motor, there are some that work better with certain motors. With BLDC or AC motors, the controller must be matched to the motor. Very often you can buy the controller and motor as a matched set. If you can't, follow the motor manufacturer's controller suggestion.

### The Contactor

A motorcycle's electrical power is potentially dangerous. It's usually 48 to 72 VDC, and between 250 to 400 amps. A safety switch—one designed handle the bike's voltage and current—is needed. This contactor is a high-current electromagnetic relay, and is standard equipment on virtually every type of EV from golf carts to cars. It allows turning on and off the main pack power, using a small, lower-current switch—a safety cutoff switch that mounts on the handlebars.

### The Batteries

Many think that an EV's power comes from the motor, and a bigger motor gives you more power, but the power really comes from the batteries. How fast the batteries can deliver current, and the battery type and performance will be a big factor in determining how powerful and fast the bike will be. Simple lead-acid batteries can't deliver large amounts of current for long periods of time. Batteries like lithium-polymer (Li-po), used in radio-control cars and planes, can deliver high current for extended periods—and current equals motor power. The motor, as well as the controller, must be able to handle the power the batteries can deliver. If you have small, low-discharge batteries, you can run a

smaller motor. If your batteries are the big, high-discharge lithium type, you're going to need a big motor to handle the heat and strain.

A battery's Ah capacity determines the bike's range. For a motorcycle, the minimum would be about 20 Ah. At 72 V, my 22 Ah lead-acid batteries lasted about 12 miles at normal speeds. The Brammo Enertia production motorcycle, for example, has 40 Ah of batteries with a range of about 40 miles.

On the one extreme, you can set up a bike with 72 V of comparatively inexpensive lead-acid batteries and it will be heavy, but the batteries will only provide a limited amount of current. On the other, you can set it up with lithium-ion batteries for a lot more money, have about half the weight and bulk, and get a discharge rate that will melt even the most robust motor if it's not handled properly. Lithium battery technology is remarkably "power dense," yielding light weight and small size—but is also dangerously volatile. Modifying lithium with the use of lithium-ion technology takes full advantage of lithium chemistry, but is considerably more stable, safe, and reliable. These batteries still, however, require special handling, charging, and management to provide the best performance and lifespan, compared to lead-acid types.

To get a little more familiar with specific types of batteries, let's take a look at the two extremes. You can set up a bike with 72 V of lead-acid batteries and it will be heavy, but cheap, and the batteries will only be able to provide a limited amount of current. Or you could set the bike up with the highest-performance lithium-polymer batteries for a lot more money, at about half the weight and bulk, and get a discharge rate that will melt even the most robust motor if it's not handled properly. Or you can do something in the middle of the two extremes. There are several variations of lithium-ion battery technology that are moderately expensive, light, and have very good power density, like lithium iron phosphate (LiFePO<sub>4</sub>) batteries, which are increasingly common for electric vehicle applications.

With lithium-ion batteries, you'll need a management system (BMS); and need to pay attention to high- and low-voltage limits;

### web extra

Want to geek out on batteries? Visit Battery University at [www.batteryuniversity.com](http://www.batteryuniversity.com), where you can learn just about everything you need to know about battery terminology and technology.



and balancing cells—all issues that, because of the cost and volatility of lithium chemistry, have to be handled properly.

Consider starting with lead-acid batteries, with the idea that you'll eventually replace them with a lithium-ion system. As for the rest of the system, the battery type doesn't matter, as long as you're supplying the required voltage. The system is, by nature, "battery agnostic."

## The Charger

The charging system has to be tailored to the battery system since every battery chemistry has its own charging profile. Also consider the charger's size—will it be mounted on-board, or will it sit in the garage? The charge rate usually dictates a charger's size and cost. A fast, powerful charger is going to be larger, heavier, and more expensive, and may not be practical to carry on the bike.

Don't wait to purchase your charger—when your batteries arrive, you'll want to fully charge and test them. Especially in the case of lithium-ion batteries, you'll need to make sure they are balanced, and then, if possible, cycled a few times to break them in gently. You can do this while working on the rest of your bike project, if you have the charger in hand.

## Tools

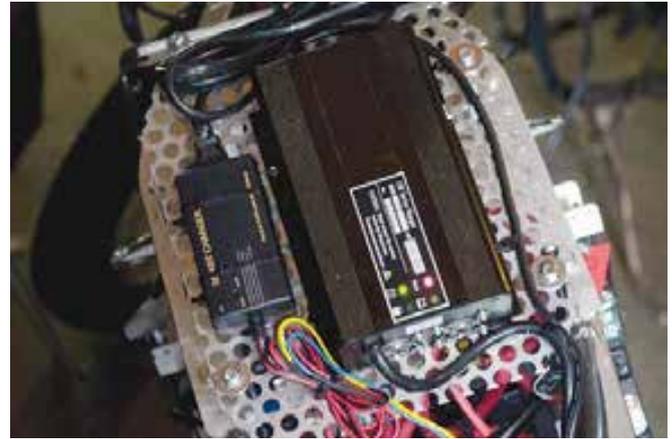
Besides the basic tools, you'll need fabrication tools like a drill press, a power metal saw, a big, sturdy vise, and other basic metalworking equipment. Here's a list of tools that will make the project go smoother.

## Commonly Built E-Motorcycles

**Trail bikes.** A lightweight, off-road bike can make a great first project. You don't have to worry about your state's department of motor vehicles roadworthiness requirements, you don't have to worry about the 12 V electrical supply for the horn and lights; and it really doesn't matter how pretty it is. You can use a small battery pack, since you're probably not going far. Here, "range anxiety"—worrying about getting stranded—isn't as much of an issue. You can even design the bike with quick-swap batteries and the components can be low-power and inexpensive.

**Small street bikes.** A bike that started off in the 250 to 500 cc range is a great size for a starter project. The components don't need to be overly powerful and because of low weight, the battery capacity doesn't have to be enormous to get decent performance. The Kawasaki Ninja 250 has a great, open-bottom frame, and the older Honda Interceptors, with their large, boxy frames, can accommodate lots of batteries—and both are pretty easy to find.

**Heavy sport bikes.** Larger sport bikes are at the top end of the performance scale, but need a lot of battery capacity to pull the chassis weight and larger motors. A worthy target for an experienced builder, a large sport bike is probably not best for the novice, if for no other reason than AC motor and battery expense.



Both the charger and the controller generate some heat, but airflow around the aluminum mount will keep things cool. Note the two chargers: one is a 72 V charger for the main pack. The second, smaller one is a 12 V charger for this bike's separate 12 V system battery.

- **Soldering iron.** Get a powerful iron rated for the gauge of wires you're working with. There's nothing as frustrating as trying to make a good connection with an underpowered iron.
- **Multimeter.** A digital display makes it easy to get fast, precise readings. Top-end meters aren't necessary, but good ones are nice to work with, and quite versatile.
- **Cable crimper.** Assembling your battery pack requires cutting large cable and solidly affixing appropriate lugs—a good crimper is essential. They range from \$14 for hammer-type tools to about \$60 for fancy manual ones. The basic ones work fine for low-volume production.
- **Heat gun.** Every electrical connection on the bike should be insulated with heat-shrink tubing. The best way to work with heat-shrink is to use a heat gun.
- **Die grinder.** For sanding, grinding, removing corrosion, and even cutting and shaping, these tools are a joy to use. They can save an enormous amount of time.
- **Angle grinder/cutoff tool.** This tool will let you tackle just about any cutting or grinding task.

Safety first: All of the tools that will be used on a bike that has "live" power should have rubber-coated handles to keep from coming into contact with live, high-voltage connectors. Wear eye protection and gloves—not only are you working with machinery and cutting tools, you're working with a lot of electrical power.

## Building the Bike: The Plan

We started with a 1984 Honda VF500F Interceptor, a common bike to convert. This one had a clean title and a seized engine. The Motenergy ME0709 motor has long been the standard of the light EV world, and the controller that matches it is the Alltrax 7245. Highway speed is the goal, so we're aiming at 72 V—the higher the voltage, the faster the motor can spin. We used sealed lead-acid (SLA) "mobility" 22 Ah batteries. That should provide about 10 to 15 miles of range, a top speed of

about 65 mph, and a battery pack of less than 100 pounds. This will be a good beginning project, and provide a fun bike to ride.

### The Motor Mount

The motor and battery mounts require some fabrication to withstand the weight and torque stresses safely. Recruiting some professional help for this is wise if you don't have the necessary skills—especially where welding is concerned.

The fabricated motor mount usually attaches to the frame using the rear motor mounts the gas engine used. If possible, locate the electric drive sprocket with the same center as the original internal combustion sprocket, since the travel of the rear suspension pivots near that point and affects the chain tension. You can move it a little forward or back in the frame, but up or down (relative to the pivot point of the swing arm), will create chain wear and safety problems.

The stresses on a motor mount are large. First, there's the motor's weight. Then there's movement—the motor takes stress from every direction as the bike hits bumps, accelerates, turns, and brakes. Then there's the motor's torque and a strong pull on the shaft to the rear caused by the chain trying to pull the motor backward.

If the motor is a long, AC-type motor, its face and rear both need to be supported. Shorter PMDC motors, such as used in this project, only need to be supported at the face. Most common EV motors use a standard mount pattern, called a NEMA-C face mount so they can easily be switched with four bolts.

I made a CAD drawing of the mount, printed it, cut it out of cardboard, and then tested the fit. After a few tweaks, I e-mailed the template to a fabricator friend who made the mount out of 1/4-inch steel for \$100. The mount fit into the frame like a glove, and static testing showed it to be strong and rigid.

**Battery mounts are another place where hefty design and redundancy are wise.**



**An example of a basic motor mount with a Motenergy ME0709 motor. The mount bolts to the frame at the top and bottom, and a bar counters the rear pull of the chain.**

### The Battery Mount

The “duct tape method” is common for testing where to locate the batteries or other components. There are challenges to designing a battery mount. First, it has to carry the weight of the batteries securely, in a way that protects them against damage and accidental electrical discharge. You've got to think past normal use, too. Consider the stresses the mounts may be subjected to—include laying the bike down while riding, and possibly more severe crashes.

Another challenge is the design flexibility. Suppose you want to start with SLA batteries, but plan to switch to lithium-ion later. You'll need a mount that will allow you to swap out batteries, or at least change mounts.



**Using duct tape to test component placement.**



**This mount has three sets of hold-down brackets, able to handle the 90 pounds of batteries.**



Courtesy Jake Saunders

**The Cycle Analyst display tracks vehicle speed and the propulsion batteries, including voltage, power consumption, and remaining capacity.**

A common solution for lead-acid batteries is an angle-iron frame and shelf that can be bolted into the frame. We created a bracket solution that allows the batteries to be clamped into place.

### Keeping It Under Control

You can use the standard controls that are on your donor bike, with the addition of a kill switch that controls the power to the contactor and a high-voltage main cutoff switch. Often, you'll see the addition of some fairly sophisticated monitoring devices like the Cycle Analyst, which reports battery state of charge and estimated range, along with speed. It even serves as a data logger and provides GPS information for plotting data over the course of a ride. Some owners just run a simple voltmeter.

Lead-acid batteries can indicate state of charge by their voltage, to the practiced eye, but lithium-ion technologies need more sophisticated monitoring to provide an accurate state of charge. Because the voltage stays pretty high throughout the charge/discharge cycle, it's not a very good indication of lithium SOC.

For this motorcycle, the throttle is a simple twist-grip Magura matched to the controller we're using. It slips over the bars, just as the stock gas throttle did, and is controlling a fairly simple 0- to 5-ohm potentiometer inside the twist grip. This gives you direct electrical control of the motor speed controller, eliminating any cabling other than a relatively fine electrical wire.

### The 12 V System

The battery propulsion pack voltage is too high to power the lights and horn, so you'll need a 12 VDC power source. Do not just connect the lights to one of your 12 V batteries, since it will dramatically affect the balance of the pack, leading to premature battery failure.

**Two 12 V SLA scooter batteries, wired in parallel to give enough capacity for lights and a horn.**



**The kill switch operates the main battery contactor to cut power in an emergency.**



**The throttle, which is electrically connected to the controller, is used to increase and decrease the power that goes to the motor.**



A simple solution is to just add another battery, independent of the main pack. (Naturally, you're going to have to add another simple 12 V charger for this, but a simple 12 V "wall-wart" type charger does nicely.) Another common and less heavy method is to add a DC/DC converter, which will take the high voltage of your main pack and step it down to 12 V.

### The Controller/Contactor/Fuses

The controller, along with the contactor and the main fuse, is usually mounted on the top part of the frame and covered by the tank. Neatness translates into safety—if you give this some detailed consideration, there's less chance of making the wrong connections and high-voltage connections are less likely to come undone. Well-routed wires also minimize chafing and breakage.

On a medium-sized bike, there's likely room to mount the chargers onboard, in our case above the controller and

contactor. This allows you to plug in wherever you park the bike to get an “opportunity charge.” Even if you give it just a little boost when you’re having your morning coffee and donut, it can make the difference between an exhilarating ride home or finding yourself babying the bike back to the garage.

## Cabling

Typically, you need to use at least 4 AWG high-voltage cables for all of your propulsion applications. In some cases, 2 AWG is used, and if you have doubt, err on the side of bigger. If your cables heat up at all in use, they certainly need to be increased.

It’s essential to work with a good wiring diagram. You may be able to find information on various wiring configurations on common EV controller manufacturer websites. The Alltrax AXE controller site, by far one of the most commonly used, is where we started, and then made slight modifications.

## Getting Help

The devil is in the details, and as you build your electric motorcycle, you’re undoubtedly going to have questions and challenges. The best place to look for help (and do your basic research) is in online communities. EIMoto.net is a very authoritative online group for electric motorcycles—a great group of generous people with vast experience. For general EV technology, Endless Sphere Technology has an enormous amount of information.

Sign up, and start reading. Almost every question will probably already have been asked and answered, so start with the online search feature. Once you get a feel for the group, introduce yourself and your project, and ask away. Just prepare to be bombarded with advice and opinions. Be prepared with photos of your build, too. As the saying is often repeated there, “Photos, or it didn’t happen!”

Another great resource is the EV Album site where you can browse hundreds of projects like your own, and review the specifications, component combinations, and performance results. There’s a lot to be learned from seeing what others have done—what’s worked, and what hasn’t.

## The Final Product

Our medium-sized motorcycle gets up to 15 miles per charge, more than enough for my errands around town even with some aggressive curve-riding on the way. It takes about two hours to recharge with a 72 V, 8 A battery charger. The bike weighs about 300 pounds, including about 95 pounds of SLA batteries, about 150 pounds less than the original stock motorcycle. The total cost was about \$1,200 (including selling some of the original unneeded parts), and it took roughly three months of evenings and weekends to complete. With the same size and weight of lithium-ion batteries, that range (and cost) will more than double.

It’s turned a few heads, too. One older Harley-riding gent, after taking it for a spin, came back with a huge grin. “I’ve GOT to build one of these things!” were the first words out of his mouth.

## Access

Ted Dillard is a 40-year veteran motorcyclist, editor of *The Electric Chronicles* ([www.evmc2.com](http://www.evmc2.com)), author of *...from Fossils to Flux*—A



**The author’s son Tyler takes a spin on the newly converted electric motorcycle.**

*Basic Guide to Building an Electric Motorcycle*, and an incorrigible electric vehicle evangelist. He’s just completed his latest bike, the R5e, a 1971 vintage road racer restored and converted to electric power, and is back to scouring the classified ads for his next “roller.”

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 Juiced Drag Racing • [www.juiceddragracing.com](http://www.juiceddragracing.com)  
 Noah Podolefsky’s GSX-E • [www.gsx-e.com](http://www.gsx-e.com)  
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### Suppliers:

Cloud Electric • [www.cloudelectric.com](http://www.cloudelectric.com)  
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### Part Fabrication Services:

BigBlueSaw • [www.bigbluesaw.com](http://www.bigbluesaw.com)  
 First Cut • [www.firstcut.com](http://www.firstcut.com)

### Classifieds & Used Parts:

EV Tradin’ Post • [www.evtradinpost.com](http://www.evtradinpost.com)

### Other References:

Asphalt and Rubber • [www.asphaltandrubber.com](http://www.asphaltandrubber.com)  
*Build Your Own Electric Motorcycle* by Carl Vogel  
 Electric Vehicle Technology Explained by J. Larminie  
*...from Fossils to Flux* by Ted Dillard • [www.evmc2.wordpress.com](http://www.evmc2.wordpress.com)  
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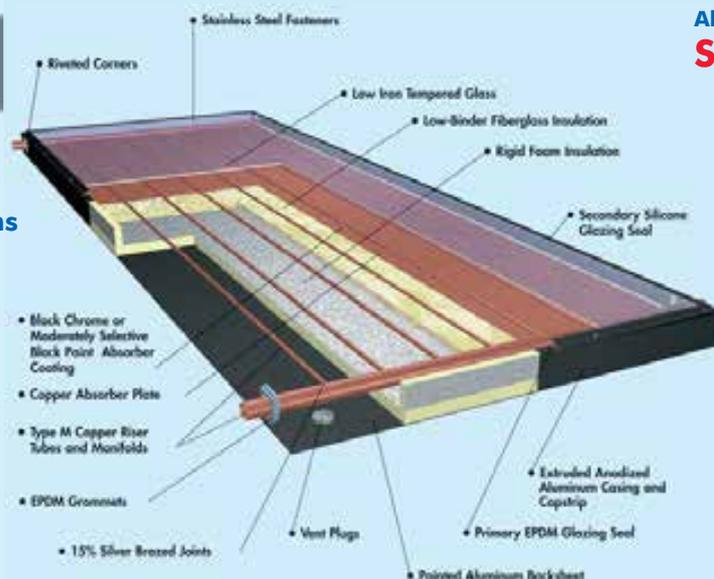
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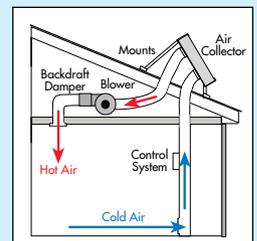
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# Commercial Wind Turbines

by Jenny Heizen

Do you have a wind-swept ranch, farm, or business? Do you use more electricity than the “average” household and have big utility bills? If so, you may want to consider capturing that clean, renewable resource with a small commercial wind turbine.



Jennifer Heizen (2)

Wind turbines are often put into one of two categories—"small" or "large." In many cases, including incentive programs, local zoning ordinances, and the 2011 *National Electrical Code*, the line between small and large wind energy systems is drawn at 100 kW. This nominal rating may inadvertently lead one to believe that all small wind turbines are similar in design and application, but it's not quite that simple.

Within the realm of "small" wind turbines, there is a distinct difference between systems that use off-the-shelf inverters to regulate the variable power and frequency from the turbine, and those that have gearboxes coupled to induction generators excited by the electrical grid—without inverters. For this article, the former will be referred to as "residential" and the latter as "small commercial" wind energy systems, since this often coincides with their market share. There is no kW rating to distinguish the two, as small commercial wind turbines with induction generators are available in a variety of sizes.

Unlike the design of a variable-speed generator, excited by permanent magnets or a DC field, the induction generator gets its excitation from the AC power and frequency on the electrical grid to which the system is interconnected.

If your interests lie mainly in off-grid applications, read that last sentence again; these machines are not for you. Here's why: In a simple permanent magnet generator (PMG), the spinning *rotor* contains magnets—usually multiple sets. This rotating magnetic field, powered by the wind, is placed in close proximity to the *stator* or stationary windings within the generator. Electricity induced or forced from the rotor into the stator is AC, and the voltage and frequency of this AC output depends upon the rotor's speed.

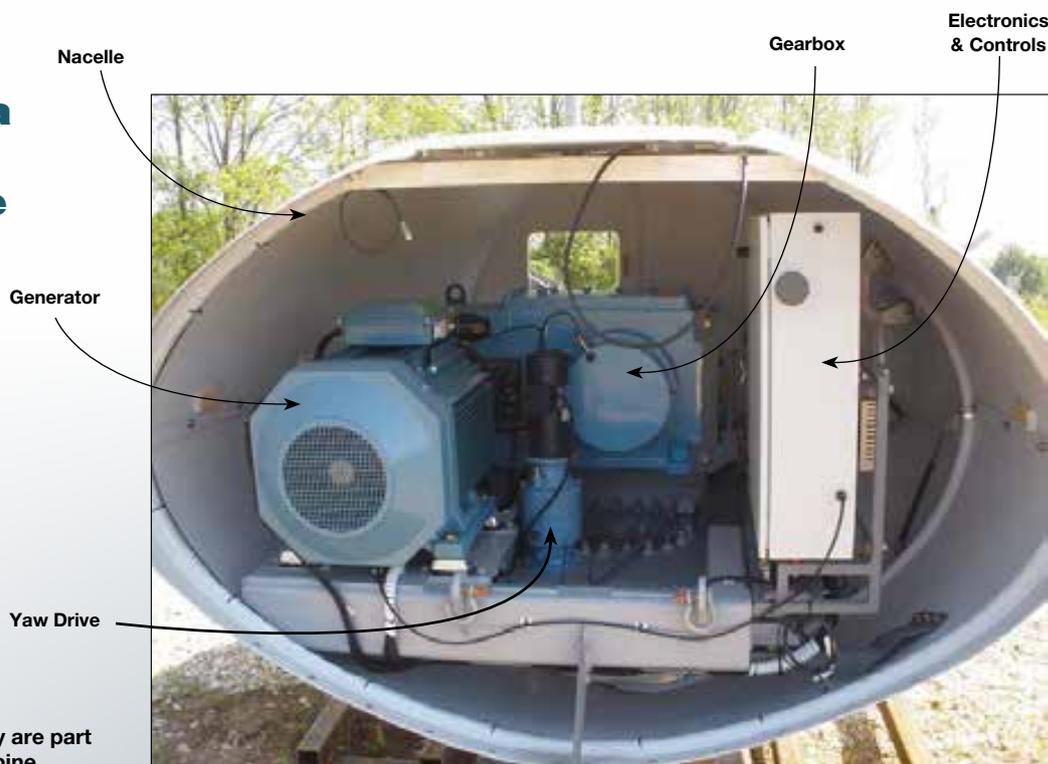
Some wind turbines bring this "wild" AC down the tower and to the electronics, where it is changed into DC and then inverted into a nominal AC voltage like 240 or 480, which can be interconnected with the customer's existing electrical service. Other designs rectify the AC into DC at the turbine through a series of diodes, and bring the output down the tower as DC—where it can either be inverted to AC or brought to a DC charge controller and battery bank, as in off-grid applications.

Induction generators are constructed essentially the same as induction motors, with a squirrel-cage rotor and wound stator. They operate on the principle of electromagnetic induction, and generate electricity when driven above their synchronous speed. They do not contain permanent magnets or DC field windings; their excitation is delivered through reactive power from the electrical grid. Yes, that's right—electricity has to be available to produce electricity. And even when these machines are not generating electricity, they are using at least a little of it from the grid to run the "watchdog" controls.

Here's how it works. As long as the customer's electricity is within a designated tolerance of voltage and frequency (agreed upon by manufacturer and/or electrical utility), a relay closes and enables the wind turbine to operate, provided wind is present. If the grid is experiencing a brownout or blackout, or if the customer's electrical service is otherwise turned off, the controls of the machine are disabled and the fail-safe brakes automatically slow, stop, and park the spinning turbine.

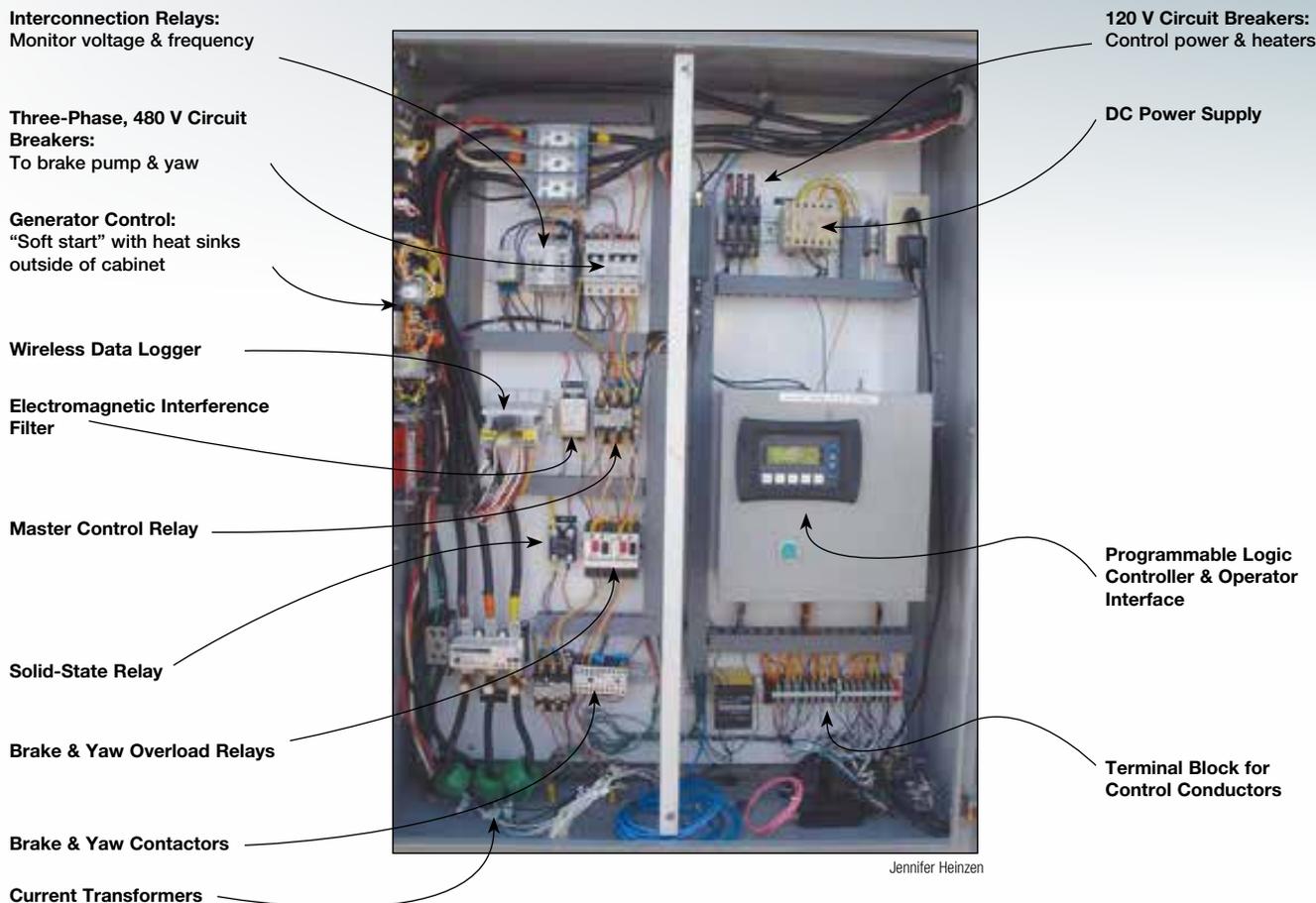
If grid power is available to the generator, once the wind is strong enough to get the blades turning at a predetermined rpm programmed in the controller, a small amount of excitation current is sent to electromagnets on the generator's

## Anatomy of a Commercial Wind Turbine



Extra equipment and complexity are part of a commercial-scale wind turbine.

## Anatomy of a Wind Turbine Controller



rotor. From there, since the rotor is excited with the same voltage and frequency as everything else in the customer's service or feeder, the induced voltage and frequency matches exactly. If three-phase, 480 V at 60 Hz goes in, three-phase, 480 V at 60 Hz comes out. No synchronization, rectification, or inverter needed; it's automatic.

### Gearboxes

Small commercial wind turbines with induction generators use gearboxes between the low-speed shaft (hub, where the blades are attached) and the high-speed shaft that spins the generator's rotor. Since the machine's rotor (blades) must be kept at a constant speed, and the wind resource is continually changing direction and intensity, the gearbox is the system's transmission—and it's much better suited to handle high torque and extreme forces than directly coupling to the generator. (Generators work best when they run at high speeds under low torque, which decreases vibrations.)

Additionally, to get a wind turbine with an induction generator spinning just above the synchronous speed of the grid, the wind would have to be very strong. Incorporating a gearbox allows the rotor to spin much slower than the generator—10, 20, or 30 times slower, depending upon the machine's size and gearbox ratio.

### Controllers

Controllers are to induction generators what programmable thermostats are to HVAC systems, with a few more functions. The controller continually monitors the wind resource, the status of the grid, and all the devices associated with the system. It responds to sensor input—the controller is the "brain" of the machine.

Those more familiar with the residential permanent magnet generators are sometimes perplexed by the absence of an off-the-shelf inverter, and in its place an interconnection relay, programmable logic controller (PLC), and all of the

associated contactors, overloads, power supplies, and capacitor banks found in the controller. Without a doubt, prior experience with industrial electrical controls is an advantage.

PLCs are industrial computers that read and react to input from generator-associated devices like anemometers, wind vanes, proximity sensors, limit switches, and operator controls. Outputs can include brake contactors, yaw motors, gearbox oil heaters, and power-factor correction.

Most induction generator controllers are not UL-listed, as they are more of a control cabinet housing multiple electrical devices and controls than a single “box” like a typical inverter. According to 705.4 in the 2011 *National Electrical Code*, utility-interactive inverters must be listed and identified for interconnection service. Article 705 also allows equipment that

## Performance Comparison of LTC’s Three Turbines

Characteristic	Vestas V-15	Entegrity EW15	Endurance E-3120
Rated power (kW)	65	50	50
Tower	Lattice, 110 ft.	Monopole, 120 ft.	Lattice, 120 ft.
Orientation	Upwind	Downwind	Downwind
Yaw control	Active	Passive	Active/Passive
Brakes	Hydraulic	Tip brakes (+electric)	Pneumatic
Rotor diameter (ft.)	50.0	49.2	63.0
Swept area (ft. <sup>2</sup> )	1,963	1,901	3,120
Gearbox ratio	1:22	1:28	1:11
Annual energy production (kWh)	50,000*	35,000*	90,000*

\*Average wind speed at site is 12 mph at 120 ft.

Below: The Vestas V-15.

Inset: Induction generator in the V-15 nacelle.



Jennifer Heinzen (2)

has been approved for such use. This means engineering stamps and UL-listed interconnection relays (like the SEL-547, pictured at left) are commonly accepted by electrical utilities and inspectors. However, some manufacturers are pursuing UL listings for their entire controller assembly.

### Performance & Maintenance

As with all wind turbines, rated power and peak power curves can be deceiving when it comes to evaluating actual energy production (kWh). A 50 kW rated machine may out-produce a 65 kW rated machine, even in the same wind resource. Swept area, wind speeds, reliability, and availability are key characteristics to consider when judging the performance of a small commercial wind energy system.

It cannot be stressed enough that the kW or “nameplate” rating of a wind turbine does not translate into, or even suggest estimated energy production in kWh. Most systems are rated at their *peak* power production, when winds speeds are very high. Since this only happens a small percentage of the time, it is not a reliable way to judge the systems’ overall performance. Nothing will tell you more about a turbine’s potential than wind speed (cubed!) at the site and the size of the rotor.

### Machines in Action

The design of the basic small commercial wind turbine originates from what were once deemed utility-scale machines installed in California decades ago. In fact, many small commercial wind systems running today are remanufactured California turbines, like the 65 kW Vestas V-15 that operates where I work at Lakeshore Technical College (LTC) in Wisconsin.

With nearly 30 years of operation already clocked, this machine got a complete overhaul—a new tower and a new controller. Its smaller, belt-driven “pony” generator for harvesting lower wind speeds was removed. This machine is best suited for higher wind regimes. Its intentionally oversized gearbox and overall rugged drivetrain design make it a solid,

## The Entegreity EW15.

reliable machine. (Regular maintenance is required to keep it that way!) Of course, all machines require attention sooner or later. Some of the issues with the LTC Vestas V-15 in the past six years have included a leaky gearbox seal, cracks in the fiberglass blades, and a worn yaw drive. Problems will definitely arise with time, so make sure you have a competent and trustworthy maintenance technician to help you as needed.

Another wind turbine at LTC with an interesting history is the Entegreity EW15 (also known as the EW50). This machine is unique because of its tip brake design. It was installed in the summer of 2010, along with the Endurance E-3120 in early fall, as part of



Jennifer Heinzen (3)

feasibility grant from Wisconsin's Focus on Energy program and We Energies, the electrical utility that serves the college.

The Entegreity's tip brakes are meant to keep the rotor from overspeeding. Each tip contains a limit switch (for proof that the plate is closed); a rectifier (to change AC into DC); and an electromagnet (to complete the circuit). When all three electromagnets from the blades are electrically "closed," a small amount of current is registered in the controller through current transformers, which allows the machine to run. If this circuit is not complete, the user interface will display the "tip brake current error." To service the tip brakes, one must use the five-foot platform that my students have coined "the plank." It's not for the faint of heart.

This turbine requires monthly attention. No need to climb monthly, but the tower cables need to be checked for excessive twisting. This machine, unlike the Vestas and the Endurance, does not monitor number of rotations or yaw position in the controller. There are no yaw sensors, encoders, or wind vanes. It's a passive yaw system that must be mechanically locked into place for maintenance. When the cables are twisted, they must be disconnected and manually untwisted.

**The Entegreity EW15 has tip brakes, visible from the tower. Inset: The platform for servicing the tip brakes.**





Jennifer Heinzen (2)

**The Endurance E-3120.**

Besides the tip brakes and the cable twists, this Entegrity has had other issues. This downwind machine has been caught running upwind on numerous occasions. And it's the most audible turbine on campus. Entegrity declared bankruptcy before the generator could be installed, but several former employees of the company who have now ventured into their own business (Ethos Distributed Energy) have been a tremendous help.

The Endurance E-3120 has been a welcome addition to the college. With wind and production data accessible from a laptop and technical support that can't be beat, this machine runs quietly and smoothly. Its energy production has been impressive, due mostly to the turbine's large rotor diameter. Data shows this system runs better than the others in lower wind speeds, and for an area with roughly 12 mph average wind speeds at 120 feet, it's a great fit. We have only one

recommended change for Endurance; an operator interface at ground level to view faults and data would be nice instead of having to log on to the system remotely.

### The Market

There is only one small commercial wind turbine that does not conform to the standard gearbox/drivetrain/induction generator design—the Northwind 100. It's a 100 kW, direct-drive, permanent magnet machine. Both designs (permanent magnet with no gearbox and induction generator with gearbox) have performed well in the field; it's really a matter of manufacturer's preference. Kudos to Northwind for trying something different, as gearboxes can often be a source of maintenance headaches.

What most small commercial wind systems seem to have in common is their market. These are typically not the machines that interest homeowners. Most of these machines are larger than standard residential turbines, and often make more kWh than some utilities are willing to net meter. It's typical to see these 50 to 100 kW turbines installed where three-phase power is available, like at schools, farms, and businesses, although many models also allow for single-phase interconnection.

The average American home uses 800 kWh each month; let's round up and say approximately 10,000 kWh annually. That's much less than what most small commercial wind energy systems make in a year, so they may be overkill for the "typical" homeowner.

Because of restrictions in some incentive programs to limit how much excess electricity a customer makes beyond their average annual consumption, these systems are best suited for those who use large amounts of electricity, and are more concerned about offsetting their consumption than selling back to the utility at retail rate.

In these cases, and although it sounds odd because it contradicts what most residential wind and PV installers tell homeowners, use more electrical appliances. Get rid of the

**Here, LTC students torque fasteners on the blades of a Vestas V-15 as part of a regular biannual maintenance regime.**



propane and the natural gas. Have you considered electric heat? Thinking about geothermal heating and cooling, but worried about the large electrical pump load? What about charging electric vehicles? These are all options if you have the ability and the option to install a small commercial wind turbine.

Which small commercial turbine is best for you? Check with your local incentive programs ([www.dsireusa.org](http://www.dsireusa.org)) and electrical utility to see if you have kW or kWh restrictions. Know your annual consumption and work with a reputable installer to find the machine that fits your needs. Remember that all wind turbines require regular care and maintenance, and your installer should have the skills needed to successfully interact with these larger systems and their components. With proper care, these turbines can last for decades.

Maintenance should be scheduled every six months. Your installer can perform the maintenance, or you can do it yourself, with proper training. Tower climbers need extensive training—working safely at height is obviously imperative to the job of wind energy system installers and technicians, along with rescue, evacuation, first aid, and CPR training.

Most of the tasks performed during biannual maintenance are mechanical. All fasteners need to be checked for proper torque. Bearings, gears, and moving parts need lubrication. Blades should be thoroughly inspected for signs of wear

or cracking. Brakes should be checked for proper seating, response, and operation. And the tower itself requires attention; always look for signs of damage, weakness, and rust. Keen electromechanical skills are absolutely necessary to keep a turbine running at its optimal performance. If a small wind manufacturer tells you his or her product is “maintenance-free,” put the pamphlet down and step away.

Working with electricity requires a unique set of skills and training, like lockout/tagout, arc flash, and an in-depth understanding of the *National Electrical Code*. In some states, electrical work can only be performed by licensed electricians, so do your homework and discuss this with your installer. The North American Board of Certified Energy Practitioners (NABCEP) offers certification for small wind installers, and that certification covers the entire scope of topics discussed in this section.

## Access

Jenny Heinzen is a wind energy technology instructor at Lakeshore Technical College in Wisconsin. An electrician by trade, she teaches courses in wind-electric systems, solar electricity, farmstead rewiring, and the *National Electrical Code* for LTC and other energy organizations. She serves on committees for DWEA, NABCEP, and RENEW Wisconsin in her spare time.



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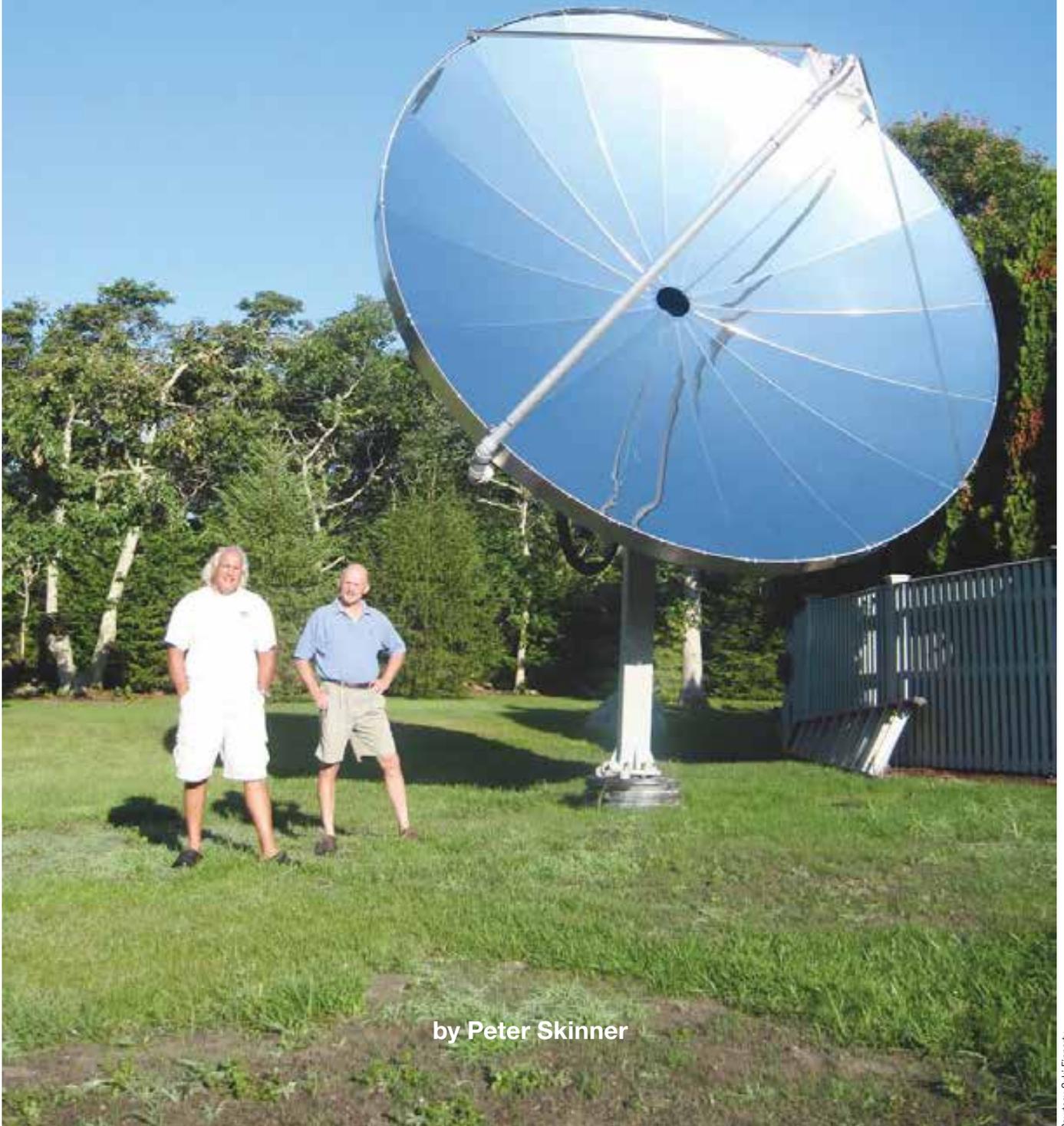
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by Peter Skinner

Courtesy Suki Finemey

It's 6:30 a.m. and Paul Adler has been awake for hours, e-mailing and hatching new ideas; then pacing the driveway until the sun peeked over the trees near his four-story home on the south side of the island. "Kramer!" he bellows when he sees me, "Can't we increase the solar loop flow rate and get more Btu?"

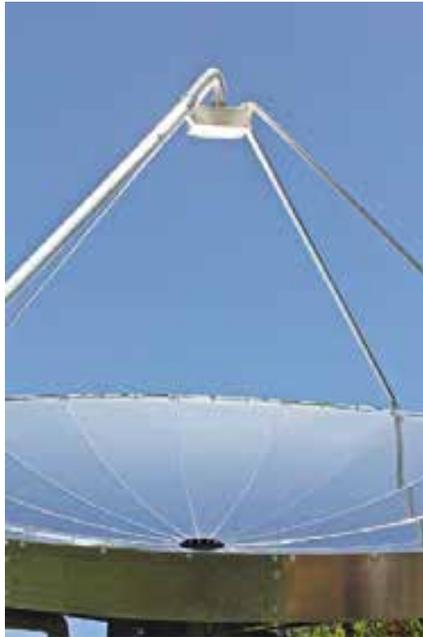
I'd like to think he nicknamed me after Seinfeld's crazy character because, like Kramer, I'm an enthusiastic out-of-the-box thinker. One glance at the large silver disk hovering over the hedge outside might confirm this. Especially when, this morning, I see what appears to be steam rising from the shrubs around the pool.

"Steam?" Paul gasps, and rushes outside to inspect the dish. A beam of concentrated sunlight has strayed too close to a wet branch, so Paul trots back inside and manually adjusts the angle of his new SolarBeam parabolic dish thermal collector. (He'd been too impatient to wait for the installation of the computer cable that automatically aims the dish in the proper direction.) It appears that I am not the only Kramer-like character on this island.

### Back to the Future

In May 2011, I was attending the American Solar Energy Society (ASES) conference in North Carolina when I got a phone call from an enthusiastic potential client (Paul Adler) who wanted an experienced solar thermal designer/installer to hook up the tracking parabolic solar thermal dish he'd just bought. "Why not a simple flat-plate or evacuated-tube array?" I wondered. (I would soon find out that this new device delivers Btu very efficiently.) But over the phone, I conjured up the image of Doc Brown from the movie *Back to the Future* and told him to fly down to ASES and learn about solar thermal himself. He booked a flight immediately and met me in the convention center—definitely the wild-haired innovator Doc Brown in the flesh!

Adler is no stranger to mechanical stuff. He's been a general contractor on the island of Martha's Vineyard near Woods Hole, Massachusetts, for decades. He sleeps little, is curious almost to a fault, and is obsessed with saving energy and optimizing everything in his castle.



Courtesy Suki Finnelly (2)

**Parabolic-dish concentrators need to be carefully tracked so that the energy falls on the small receiver. The SolarBeam concentrator has a gear drive for east-west adjustment and an actuator for tilt adjustment. Both are queued by a GPS.**

In early 2011, he became intrigued with Solartron Energy Systems' two-axis tracking parabolic concentrator for solar water heating. He was convinced that its shape, operation, and size could replace his conventional solar pool array, heat his household water, and even cut his hydronic space-heating expenses.

But he needed a design—and an installer—for the system he envisioned. We found that we both shared a passion for innovation and quickly forged a creative partnership. Based upon the information Adler and Solartron provided and one site visit, I designed the solar heat management scheme and partnered with Alan Paul of APEX Thermal Services to design the controls, which would properly sequence DHW tank loading and divert heat for space heat/pool contributions. I also asked Jessica Baldwin of Pipeworks in New York City to help with the installation. Finally, Paul asked local electrician Jason Archambault to help me wire the whole thing. Adler took responsibility for building the foundation, erecting the tower, affixing the dish, and installing the underground pipe network. Our close collaboration helped me complete the install of the balance-of-system components and the control system in two visits of several long days.

### How It Works

Solartron's tracking dish, the SolarBeam, perches on a 12-foot-high metal pillar. Its curved metallic collector reflects and focuses sunlight from a 15-foot-diameter mirror onto a 10- by 10-inch aluminum absorber plate, where heat transfer fluid (HTF, 45% glycol) removes the heat. As long as the absorber is hotter than the HTF, the solar loop pump operates. The dish continuously follows the sun using a tracking system. If the sunshine falls below 150 watts per square meter, the SolarBeam will not track the sun. If the temperature of the

### web extra

Check out videos of Paul Adler's concentrating solar thermal system at [www.youtube.com/watch?v=j1y03o8PRQg](http://www.youtube.com/watch?v=j1y03o8PRQg) and [www.youtube.com/watch?v=6Dlesj-mKgg](http://www.youtube.com/watch?v=6Dlesj-mKgg)



## A Closer Look at Collector Differences

Flat-plate and evacuated-tube collectors can use both direct-beam radiation—unclouded sunlight that casts a shadow—and the (less intense) diffuse radiation that is available when some sunlight is absorbed by clouds, haze, or pollution. There isn't any data available on exactly how much diffuse radiation flat plates and evacuated tubes collect, but it is generally accepted they collect some useful energy on light, cloudy days. Concentrating collectors need direct-beam radiation as their resource.

Point-focus collectors that resemble a very large dish must track the sun on both a north/south and east/west axis to produce heat, and rely on a mount and motors to move with the sun, whereas fixed flat-plate and evacuated-tube collectors are stationary, with no active tracking parts. The simpler fixed-mount systems are typically less expensive and more reliable.

Besides more mechanical requirements for concentrators, there are resource differences for collectors depending on the climate in which the system is located. This, in turn, will influence

production. The *Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors* (aka the "Redbook") contains 30-year solar data on direct-beam and total radiation (direct and diffuse) available for hundreds of locations (<http://rredc.nrel.gov/solar/pubs/redbook/>).

Collector price per square foot and system efficiency must also be evaluated to determine what type of collector is the best value. Concentrators are more commonly used for generating electricity in desert climates, since they are capable of producing the high temperatures needed to power steam turbines. It isn't possible for flat plates or evacuated tubes to efficiently produce those high temperatures (more than 400°F).

For additional information, see *Back Page Basics* in *HP136* and *HP140*.

—Chuck Marken

HTF exceeds 193°F or the line pressure falls below 7 psi, HTF flow stops and the dish changes its orientation to prevent system overheating. When the HTF temperature reaches 110°F (user-settable), the DHW circulator associated with the pump module turns on, transferring solar-generated heat to the tanks (or pool).

The dish faces the sun at sunrise, to capture available heat right away. It cannot, however, capture energy from diffuse light, as conventional collectors can.

The collector's small receiver reduces heat loss to the air during operation—even when the HTF gets hot or air temperatures are low. As a result, output drops only 13%

when the absorber exceeds air temperature by 122°F (SRCC Category D-E). So, even in the winter (if it's sunny), the system will produce significant heat. The "Delta Efficiency" graph shows that the dish has a higher efficiency compared to evacuated-tube and flat-plate collectors, especially as the HTF heats up more than outside air temperatures.

### Balance of System

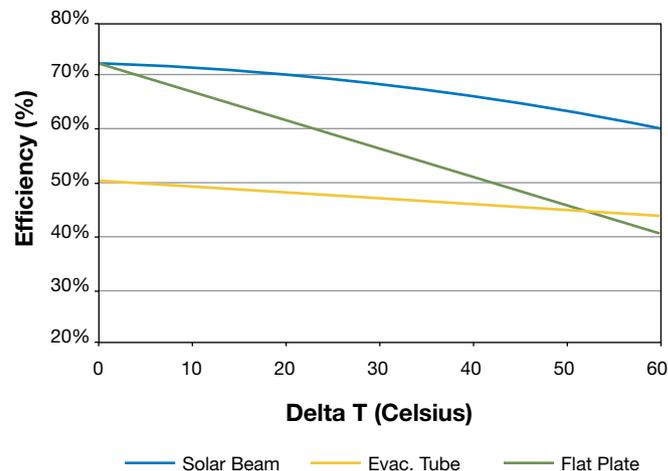
Adler procured most of the equipment. He and his wife Lisa assembled the dish and erected the tower on an 8-foot-deep concrete foundation. They buried a 1-inch, insulated cross-linked polyethylene/aluminum line-set (this type of pipe



SolarHot's SolVelox pump station was used in concert with the solar water heating system.

Peter Skinner

### Delta-T Efficiency



features a layer of aluminum foil sandwiched between two layers of PEX) to the pump station in the house and a tee'd pair to the pool shed outside. The pipe insulation is five layers of aluminum-foil bubble wrap inside an HDPE pipe, which reportedly loses less than 1°F per 100 feet.

A standard SolarHot SolVelox pump station with its flat-plate heat exchanger inside transfers heat from the HTF to the circulating domestic hot water. The Solartron control box, mounted near the breaker box, energizes the solar or pool pumps to move the HTF. I assembled a custom relay board to control where the HTF travels—either the house or the pool. In the house, a three-way valve distributes heated DHW among the three storage tanks in a sequenced fashion (see “Heating System Priority Sequence” table).

Unlike other solar thermal controllers, the SolarBeam controller does not use a solar tank-temperature sensor to activate the solar-loop pump. Instead, it uses two sensors on the concentrator’s absorber plate to trigger the solar pump operation. If the HTF temperature exceeds 193°F, the dish is directed away from the sun. This and other safety features (like low solar-loop pressure of 7 psi; high wind; and power outage controls) assure that the powerful solar beam does not damage the absorber and other equipment. Moving the dish turns off solar collection in seconds, eliminating HTF overheating. The HTF temperature limit of 193°F protects the PEX line-set. A set of 20-foot-long, high-temperature flexible hoses near the dish serves as a thermal break between the potentially hot absorber plate and the PEX line-sets to the house and pool.

Before the dish installation, the house relied on a large flex-fuel (oil and wood) boiler for its hot water all year long, thanks to its two tankless coils plumbed in parallel. Integrating the DHW plumbing for the new system into his rat’s nest of piping was no picnic. The new solar hot water system allows Adler to shut down the boiler in the summer, and use the electric element in the first tank for DHW backup. In the winter, the boiler provides DHW backup and space heating through a baseboard hydronic system.



Courtesy Paul Adler

**The author next to Tank No. 1, the domestic hot water storage tank.**



**Tanks No. 2 and No. 3 are operated in parallel to double storage, and feed the home’s hydronic heating systems.**

Courtesy Suki Finemty

Since the solar tanks lack heat-exchanger coils, designing the Btu sequencing plumbing so that cold water would not find its way into the wrong tank and at the wrong tank level proved to be the biggest design challenge. We used the tanks’ dip tubes and multilevel tank penetrations to make it work.

Adler’s space-heating system uses simple baseboard emitters that feature high return temperatures (120°F to 150°F). Typically, solar systems in the Northeast can only make a modest contribution to the large heating loads, especially when the weather turns cloudy and cold and the return temperatures are high. Like so many other solar installations where the client and installer work closely together, energy-efficiency improvements in the house were made that might not otherwise occur. For instance, Adler reduced the temperature settings on his boiler to give his solar thermal system a better chance to contribute heat, and insulated the bare pipes in the utility room. He is also considering replacing some of the baseboard emitters with higher-output types that can heat the house with lower supply temperatures, and installing a more efficient boiler.



Courtesy Suki Finnelly

When the storage tanks are hot, the system automatically routes the hot HTF to an exchanger to heat the pool—a rather enjoyable diversion load.

### Solar Heat Distribution

The heat is directed sequentially among the tanks, the pool, and space heating. The final DHW supply tank (#1) gets first dibs on any solar heat available until it reaches 140°F, as set on the aquastat near the three-way valve. (An aquastat is a simple setpoint controller.) Once that temperature is reached, the aquastat energizes a valve to redirect heated DHW to preheat tanks 2 and 3 (see “Heating System Priority Sequence” table).

In the summer, when tanks 2 and 3 reach a set temperature (chosen by the Adlers), the heat is sent to the pool, but only if the pool’s circulation pump is operating. Relays in the control system shut down the SolarHot pump station in the house

## Heating System Priority Sequence

Priority	Summer	Winter
1	Tank No. 1 to 140°F	Tank No. 1 to 140°F
2	Tanks Nos. 2 & 3 to 120°F	Tanks Nos. 2 & 3 to 185°F
3	Pool to 85°F	DHW preheat
4	Tanks Nos. 2 & 3 to 185°F	Space-heat feed to 150°F

## Tech Specs

### Overview

**System type:** Single-loop flat-plate heat exchanger (DHW); shell-and-tube heat exchanger (pool), antifreeze, pressurized indirect, concentrating dish collector

**Location:** West Tisbury, Martha’s Vineyard, Massachusetts

**Solar resource:** 3.6 average daily peak sun-hours

**Production (projected):** 77 MBtu/yr.; 212,730 Btu/day ave.

**Climate:** Marine temperate

**Percentage of hot water produced annually:** 94%

### Equipment

**Collector:** Solartron SolarBeam, 177 ft.<sup>2</sup>

**Collector installation:** Tower; two-axis tracking

**Heat-transfer fluid:** DowFrost HD, 45%

**Circulation pump:** Wilo Star 32

**Solar pump controller:** Solartron’s controller relay operates the pump when two temperature sensors show a delta T of at least 4°F

**DHW circulation pump controller:** Solartron’s controller relay delays operation of this pump until the solar loop HTF reaches predetermined temperature

### Storage

**Tanks:** Two SunEarth 120 gal. tanks for space heating and DHW pre-heating; SunEarth 120 gal. tank for DHW, with electric element for summertime backup heating

**Heat exchangers:** SolarHot SolVelox flat plate (DHW) and Bowman 5102-2T pool shell-and-tube for the pool loop

**Backup DHW:** Electric element in tank 1, 4,500 W; two tankless coils on oil/wood boiler, 120,000 Btu/hr.

**Solar pump for DHW:** Wilo Star 32 Bronze

**Solar pump for pool loop:** Grundfos 15-58 SuperBrute

**DHW pump:** Wilo Star 32 bronze

**Boiler pump:** Grundfos 15-58 SuperBrute and Taco 006 bronze

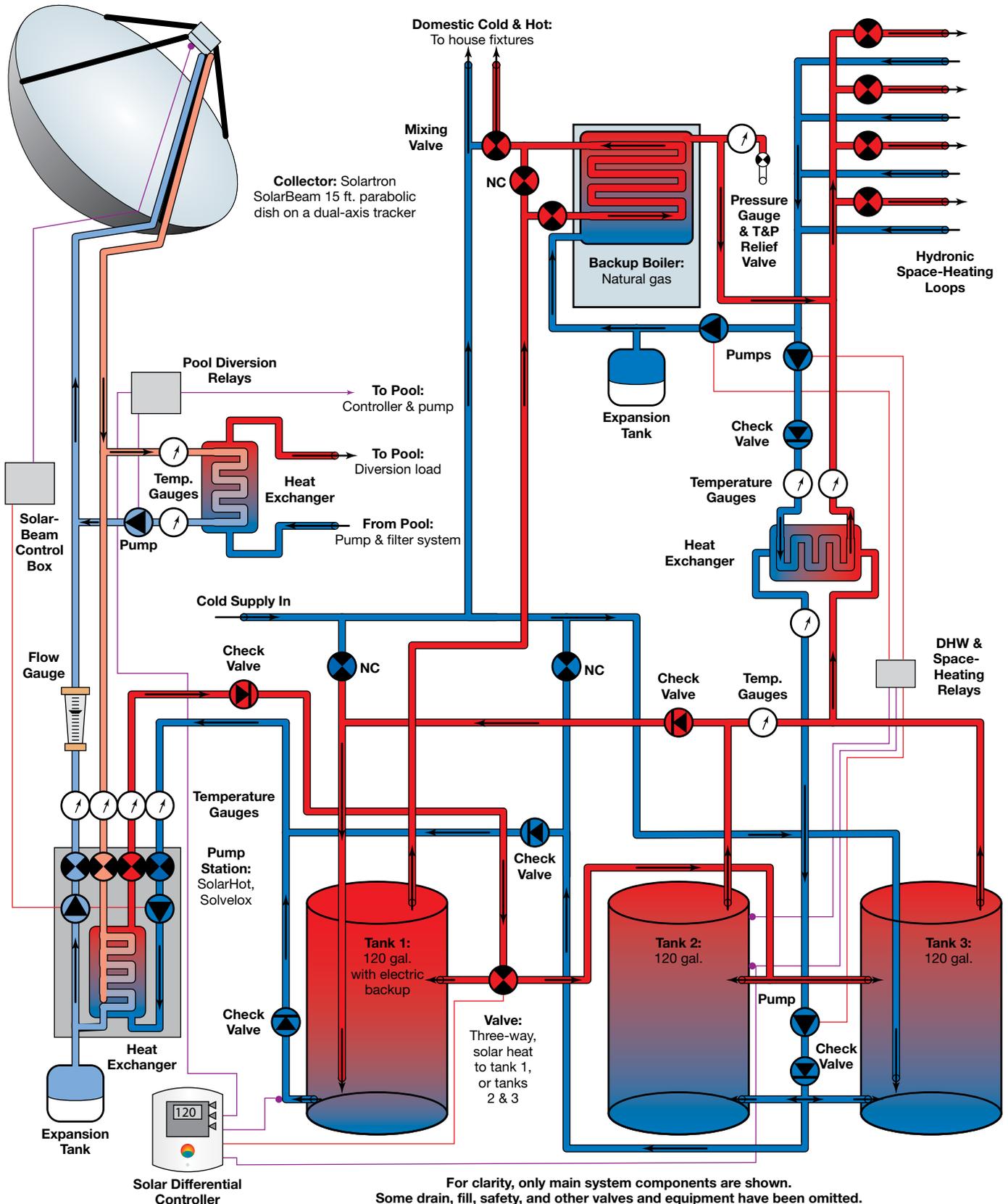
**System performance metering:** Solartron Web-based dashboard with operating information and Btu display production. Steca-based Web portal provides additional tank and pipe contents temperature data

**Thermometer:** Many analog dials, 6 Steca 603 thermister sensors, Solartron collector thermister sensors

**Flow meter:** Pulse meter connected to Solartron controller & Blue White visual flow meter

**Pressure:** Expansion tank—Extrol 60, system pressure set to 27 psi; expansion tank at 25 psi

# ADLER SOLAR THERMAL SYSTEM



For clarity, only main system components are shown. Some drain, fill, safety, and other valves and equipment have been omitted.

Collector performance data is captured and uploaded to a Web-accessible operations dashboard for assessment.



and turn on the pool-heating circulator, redirecting HTF from the dish to a heat exchanger in the pool shed. The pool loop operates until the temperature in tanks 2 and 3 falls to its set-point; then the pump station in the basement turns back on to heat the tanks.

If the boiler's main circulator is operating (only in the winter; Adler is able to shut down the large boiler in the summer) and the temperature in tank 2 exceeds 150°F, an aquastat on tank 2 energizes the space-heat pumps.

## SHW System Costs

Item	Cost
Solartron collector	\$16,285
Misc. plumbing	5,288
Misc. electrical & electrical labor	4,817
Installer costs	4,600
Lineset parts & trench labor	3,149
3 Sun Source tanks, 120 gal.	2,888
Steca control & monitoring	1,423
Collector foundation	1,204
Solarhot pump station	1,095
SEC heat exchanger	603
Permits & fees	315
Propylene glycol	279
Caleffi flow meter	140
Educomp uninterruptible power supply	128
Digital display	83

Total \$42,297

Massachusetts State Rebate	-\$4,495
NSTAR Utility Rebate	-300
Federal Tax Credit	-11,251

Grand Total \$26,251

## High-Tech Control & Monitoring

A Steca TR 0603mc controller displays data from six different temperature sensors on its own screen and also sends it to a display in Paul's office and to a website. The dish controller continually sends operating data to Solartron's server in Nova Scotia, where it is uploaded to an operations dashboard also that is Web-accessible.

These performance and operating diagnostic tools (and Paul's keen observational skills) identified a number of heat distribution problems that required some system modifications. E2G installed four spring check valves to block unexpected flow patterns. Monitoring devices were relocated when early data showed that temperature sensors mounted on pipe surfaces routinely read 5°F to 10°F low. Continuing system modifications and its short operating history have limited the amount of performance data available at this time.

## Access

Peter Skinner, P.E., is a solar thermal system installer, educator, author, and consultant. He teaches a full array of solar thermal courses, and has designed and installed dozens of custom solar hot water and combi-systems. He is a NABCEP-certified solar thermal installer and an approved solar thermal installer in New York and Vermont. His book, *Solar Hot Water Fundamentals*, and other information are available at [www.e2gsolar.com](http://www.e2gsolar.com).

### System Components:

SolarHot • [www.solarhotusa.com](http://www.solarhotusa.com) • Heat exchangers

Solartron Energy Systems • [www.solartronenergy.com](http://www.solartronenergy.com) • Collector

Steca • [www.stecasolar.com](http://www.stecasolar.com) • Controller



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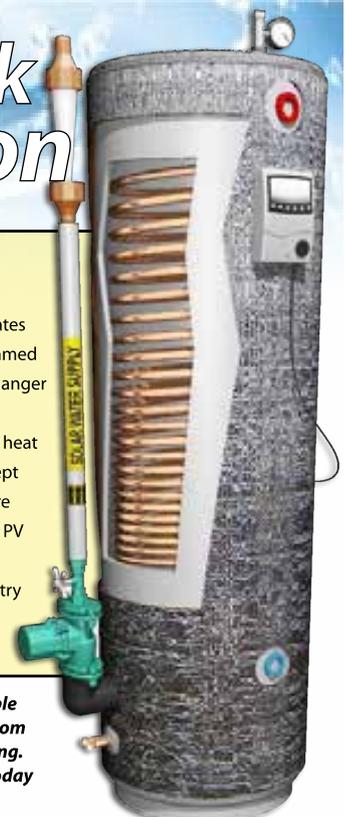
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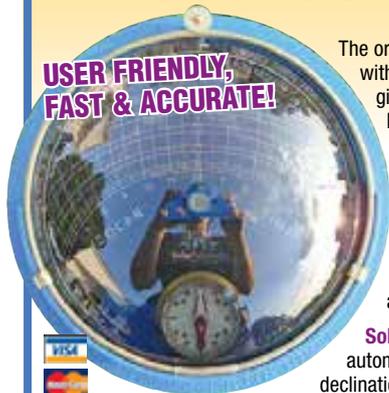
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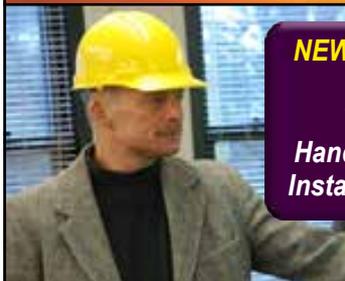
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# Wiring & Protection

by Ryan Mayfield

Chapter 2 of the *National Electrical Code*—Wiring and Protection—is lengthy and important, covering a number of topics. PV installers must appropriately apply those sections that pertain to PV systems.

## Conductor Identification

Chapter 2 starts with Article 200, Use and Identification of Grounded Conductors. Many in the PV industry refer to the DC conductors from the PV modules as “positive” and “negative,” but that nomenclature is of less importance in modern systems.

In the majority of PV systems installed today, the inverters use an isolation transformer. For PV systems using these inverters, the *NEC* requires bonding one of the current-carrying conductors on the PV side of the inverter to ground. Typically, this is accomplished across the ground-fault protection device located in the inverter—bonding the negative conductor to ground creates a negatively grounded system. Some PV systems require bonding the *positive* conductor to ground. (Note that nearly all PV modules can be positively grounded.) To top off that variability, there are now ungrounded inverters, in which neither PV conductor is bonded to ground. These systems are covered in Section 690.35, Ungrounded Photovoltaic Power Systems.

Given the different wiring configurations, it’s most accurate to refer to the conductors in terms of “grounded current-carrying”; “ungrounded current-carrying”; and “grounding conductors” rather than “negative,” “positive,” and “ground conductors.” This terminology also helps clarify how each of these conductors should be identified, which brings us back to Article 200, which sets the requirements for identifying the grounded current-carrying conductors for all electrical systems, including PV systems.

Section 200.6 details those identification methods. Subsection 200.6(A) deals with identifying conductors that are 6 AWG and smaller. In residential grid-tied PV systems, it is likely that all the conductors used will fall into this size category. Section 200.6(A) lists eight appropriate identification methods, one of which is specific to PV systems (discussed later). The first three methods and the PV-specific requirement are the most commonly used. The grounded current-carrying conductors can either be white, gray, or marked with three continuous white stripes on top of any

color insulation other than green, which is reserved solely for grounding conductors.

Given those requirements, for most PV systems the negative is the grounded conductor and should follow one of those identification methods. If the positive conductor is the grounded conductor, it will follow those rules. And for ungrounded systems, neither conductor is marked that way.

Now that you have identified the grounded current-carrying conductor(s), you can identify and mark the ungrounded current-carrying conductor(s). These can be any color other than those listed in 200.6—not white, gray, or with three continuous white stripes; nor green or green with yellow stripes. In the case of negative-grounded PV systems, I recommend that the ungrounded color be red. This will meet *Code* and helps identify the positive polarity of the conductor. Regardless of the chosen color-coding, I also recommend using marking tape at the termination to identify the polarity of all of the conductors.

It is important to cover the marking allowance specific to PV systems—200.6(A)(6) allows the installer to mark small PV *source* circuit with distinctive white markings at all terminations. This is an exception to the general rule for small conductors, so you may need to bring this to an inspector’s attention. The exposed USE-2 or PV cable can be black and marked at the terminations made inside junction or combiner boxes. Just remember that once you transition to an interior wire such as THWN-2, that conductor type is outside the scope of this allowance and must meet one of the other requirements listed.

For conductors 4 AWG and larger, 200.6(B) outlines the rules you are required to follow. The first three methods are identical as the requirement for small conductors. The fourth method allows for distinctive white or gray markings that encircle the conductor at the termination point.

## Overcurrent Protection

Article 240, Overcurrent Protection, sets the rules on how to properly select, locate, and enclose overcurrent protection devices (OCPDs) to protect conductors from overload, short-circuit, and ground-fault conditions. Section 240.4 contains some critical information on the required methods to properly protect conductors. Conductors must be protected against overcurrent in accordance with the conductor’s

ampacity values (as listed in Section 310.15), unless otherwise required or allowed within 240.4(A) through (G). In general, a conductor needs overcurrent protection at a value less than or equal to the conductor's ability to carry current.

A general rule is often followed up with specific cases and/or exceptions. In 240.4(B), an allowance is made for overcurrent devices rated at 800 A or less. When specific conditions are met, a conductor can be protected by an overcurrent device with an ampere rating greater than the conductor. The next higher standard-rated device can be used to protect the conductor if the conductor's ampacity doesn't correspond to a standard OCPD ampere rating, the next standard OCPD doesn't exceed 800 A, and the conductors being protected are not part of a branch circuit supplying multiple receptacles. For PV systems, once you adjust a conductor's ampacity for conditions of use and continuous duty, that conductor can be placed on an overcurrent device with a rating greater than the conductor. For example, let's say you are using a 10 AWG conductor to connect a string of modules to an inverter. After applying correction factors if that 10 AWG conductor has an ampacity value of 21 A, you can use a 25 A OCPD.

Section 240.4(D) lists special requirements for small conductors, namely the limitations of OCPD ampere ratings based on the conductor size. So, unless specifically allowed in 240.4(E) or (G), the OCPD protecting small copper conductors cannot exceed:

- 15 A for 14 AWG Copper
- 20 A for 12 AWG Copper
- 30 A for 10 AWG Copper

When sizing conductors, you may have a scenario where one of the above listed conductors must be protected by an OCPD with a smaller rating than the conductor's ampacity. The 240.4(D) section simply defines the maximum OCPD rating, even if the conductor's ampacity exceeds the OCPD rating. For example, after correction factors are applied, a 10 AWG conductor may have an ampacity value of 35 A. The Code requires that this conductor is protected by an OCPD with a maximum ampere rating of 30 A.

Article 240.6(A) lists standard OCPD ratings, the values referenced when determining the proper OCPD for protecting conductors. The standard values start at 15 A and go up to 6,000 A. Per 690.9(C), for OCPDs protecting PV source circuits, the standard ratings are 1 A to 15 A in 1 A increments. After that, the standard values listed in 240.6 are applicable. Practical examples of this selection process, as well as conductor sizing will be covered in an upcoming *Code Corner*.

Section 240.24 covers the location and accessibility requirements for OCPDs. Generally, all OCPDs must be readily accessible and the center of the grip on the OCPD's operating handle may not exceed 6 feet 7 inches above the working platform when in its highest position. Two allowances to this rule may apply to a PV installation. One

is that OCPDs may be accessed by portable means, such as ladders, if the OCPDs are mounted adjacent to the equipment they are protecting. The other is not an exception listed in 240 but rather an allowance in 690. In 690.9(C), the *Code* allows the OCPDs protecting PV source circuits to be accessible, but doesn't require that they be readily accessible (per *NEC* definition of "readily accessible"—again we see that it is acceptable to access particular OCPDs via a ladder and so forth).

Section 240.24 specifies that OCPDs be located where they are not exposed to potential physical damage. This may require protecting the OCPDs with barriers (for example, bollards may be used to prevent potential damage to OCPDs by vehicular traffic). Section 240.24(D) prohibits locating OCPDs in the vicinity of easily ignitable material, such as in clothes closets. And finally, OCPDs are not allowed in bathrooms [240.24(E)] or over steps [240.24(F)].

Part III of Article 240, which covers enclosures for OCPDs, affects many PV installations, and Section 240.32 is of particular importance. If the OCPDs are located outside, you'll need to verify that the enclosure used to house the OCPD complies with 312.2, as referenced in 240.32. This is to prevent moisture from entering and accumulating within the enclosure. Article 312.2 has requirements for raceways and cables entering the enclosure, stating that if an enclosure is being entered above uninsulated live parts, the fittings used to enter the box must be listed for wet locations. Thankfully, PV installers have multiple options for enclosures listed for various applications. For enclosures that will be mounted on an outdoor vertical surface, you can use NEMA 3R-rated enclosures. Some manufacturers of NEMA 3R enclosures have listed their products for installation on a tilted surface; this should be verified on a per-model basis. Typically, for enclosures mounted in a non-vertical orientation, a NEMA 4 enclosure should be used (see *NEC* table 110.28 for more information on enclosure types).

## Setting up Your Installation

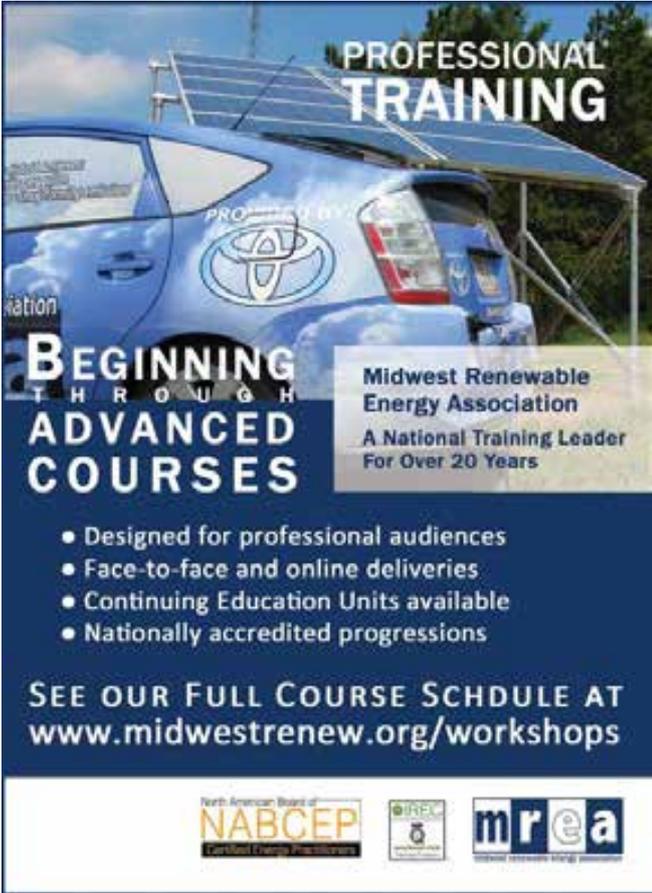
These two *Code* articles, 200 and 240, set the foundation for PV installations. Be sure to read through to the end of Article 240, as it covers the various types of OCPDs. As with nearly all of the *Code*, I suggest you read and re-read these articles. You'd be surprised how often something new jumps out at you and changes your thinking.

## Access

Ryan Mayfield (ryan@renewableassociates.com) is the principal at a design, consulting, and educational firm with a focus on PV systems in Corvallis, Oregon. He is an ISPQ Affiliated Master Trainer.



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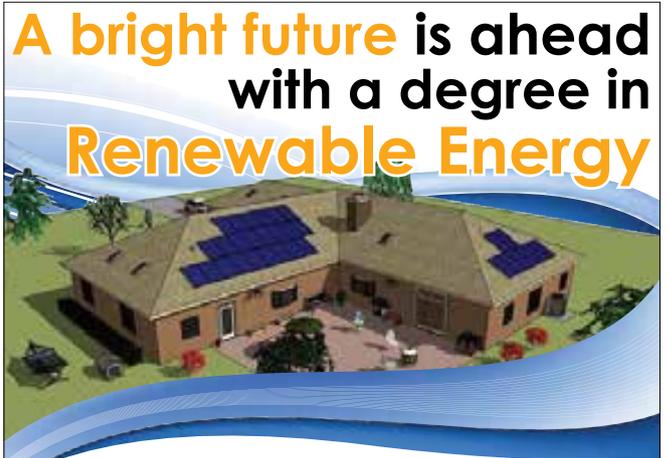
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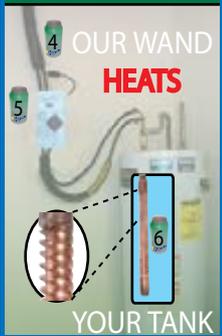


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# Tankful

by Kathleen Jarschke-Schultze



When my husband Bob-O and I moved to our homestead 21 years ago, we rented a trencher for a day and dug trenches for water pipe to all the places we could think of where we might garden some day. The largest part of this water system was the 1,350-gallon polyethylene water tank we located on the hillside to gravity-feed our agricultural watering system.

Within the first couple of years we added another tank next to the first. Using our small tractor on the slanted hillside, Bob-O graded a flat area for the tanks. Empty, they are not terribly heavy, so we pried them up and set a long redwood board under their fronts for stability. Our adobe clay soil can become slimy mush when wet, so the plank provided a sturdy edge and distributed the weight of the full tanks.

## Tanked

Every time I return home from a trip, I take stock of our surroundings—shop, greenhouse, garden, chicken coop, woodshed. All are usually good. Several years ago, Bob-O and I were assessing the homestead after being away. This time, though, the hillside looked different. There was only one big, black tank instead of two. Our eyes immediately dropped farther down the hill, where we spotted the second tank.

The big board we had placed under the front bottom of the tank so many years ago had finally rotted through. Soil erosion caused the board to give way, dropping the full 1,350-gallon tank over the edge and down the hill.

The first debris we came to was the 2-foot-diameter lid, which was ripped loose and propelled all the way to the

bottom. The rush of more than 5 tons of gushing water left a trail of mud and flattened weeds for us to follow. The tank itself only made it one-third of the way down. It was lying on its side, looking like a big black toothpaste tube squeezed in the middle. All of the connecting pipe had broken off.

We righted the tank and pushed the dented side back into round. Bob-O assessed the damage. A crack in the side about halfway down was the injury that ended the tank's life.

### Raised Bed from the Dead

Bob-O used a reciprocating saw to cut the tank into sections about 2 feet wide. The corrugated walls were great for marking the cuts. This left us with four round, plastic rings; a wide, shallow, open tub; and the roof of the tank.

We hauled the rings down into our main garden. Standing on either side, we pushed the rings into ovals. Using our legs to hold their shape, Bob-O then hammered in several short pieces of rebar on each long side as anchors.

These ex-tank raised beds have turned out to be better than any of my seven other beds, which are edged with rock, cinder blocks, or wood. The black poly oval beds heat up earlier in the spring and hold moisture very well. Like any raised bed, they are easy to weed, easy to plant, easy to work and amend the soil, and easy to cover in case of a late frost. Another plus is that they are almost impervious to the ravages of time.

I've been growing huge carrots, better beets and onions, and larger potatoes. Any root crop that does not have to fight our adobe mud does wonderfully well in the raised beds.

I'm sold on reclaimed poly water tank raised beds. The only problem is that we would never cut a good tank to pieces. We put an ad on Craigslist for leaking unwanted tanks but, so far, no leads.

### Think Tank

We still had the tank's short, open tub and its top. The fall of 2011, I finally found out why we had been saving the top.

I needed a rain cover for my chicken feeder that was big enough to shelter the feeder and the chickens while they eat. I needed to use components I could salvage from the yard. A power drill and tape measure would be my main tools. I wandered the boneyard looking for anything that might spark some sort of design plan.

My chicken feeder is round, so when my eye caught the flash of a chrome hoop I swooped in. I found two heavy chromed hoops 30 inches across. They used to be the base for a round glass table—the glass had become our coffee table. The rickety legs that had joined the two hoops are long gone.

I had the plan. I needed to find lumber to make four sturdy legs to join the hoops into a round base that would fit over the feeder. I searched all the woodpiles hither and yon. I was pondering the point that the four legs would have to be exactly the same length for my design to work. This was worrisome. My goal is always to find a piece so close to what I need I don't have to do much, if any, sawing (not my best skill).

**This innovative recycling/reuse project now provides some weather protection for feeding chickens.**



I suddenly realized I had the perfect legs. I had taken apart an old redwood hot tub a couple of years ago (see *HP136*) and the wood was still stacked, untouched. Each board was exactly the same length and had the slightest curve, which fit the hoop circumference perfectly. The hoops already had bolt holes, so in a matter of minutes I attached the legs with deck screws.

### Tank Top

Now I needed a roof. I was walking back to the boneyard, thinking "plywood," when I spotted the old tank top. It was sitting on the hillside, just a yard or so from where the tank fell. I measured it. Round black poly and 69 inches in diameter seemed like just what I needed. Although it was unwieldy, I picked it up and carried it to the hen yard.

It was, seriously, the crowning touch. The feeder sits inside the center of the bottom hoop, with access between the upright wooden legs. The poly roof resting on the top hoop keeps it all dry. The lid is domed so it sheds rain and snow. An L-shaped piece of thick rebar, pounded into the ground, pins the bottom ring for stability.

I am inordinately proud of my chicken feeder structure. Not only did I scrounge all the parts (except the deck screws), but I didn't have to saw anything. The bonus is that I find it very attractive; its sculptural quality is appealing. There is a deep satisfaction and feeling of accomplishment when Bob-O and I can repurpose materials of all sorts, especially when it takes thinking outside the box, er, tank.

### Access

Kathleen Jarschke-Schultze ([kathleen.jarschke-schultze@homepower.com](mailto:kathleen.jarschke-schultze@homepower.com)) is on the hunt for a good springtime manure source at her off-grid home in northernmost California.



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# Safety Labeling



More than 30 years ago, I had a memorable experience with a local electrical inspector concerning listing agencies and labels. I was a new electrical contractor on a home-construction job. The owners had purchased some of their electrical fixtures in Mexico—great for aesthetics, but bad for inspections. “Where’s the UL label?” was a question I couldn’t answer at the final inspection. No slack was given and a correction notice (red tag) was issued. Underwriters Laboratories (UL) was the only label we knew of back then, so the homeowners bought new UL-labeled fixtures and the inspection passed.

Safety labels come from what are commonly known in the construction trades as listing agencies. Code books often refer to acceptable products as “listed” devices. The listing agencies are laboratories that are recognized by the Occupational Safety and Health Administration (OSHA).

Underwriters Laboratories was established in 1894 by insurance underwriters in an effort to make products safer—and reduce claims and premiums. The UL label offers consumers and workers assurance that products meet standards set by UL and other organizations. Today, manufacturers have additional choices for laboratories to test their products.

OSHA maintains a nationally recognized testing laboratory (NRTL) program (see [www.osha.gov/dts/otpc/nrtl](http://www.osha.gov/dts/otpc/nrtl)). The program recognizes organizations as NRTLs, as having met the necessary qualifications. The NRTLs test products submitted by manufacturers to ensure that they meet standards that are published by various organizations.

UL still dominates the safety testing community and the many standards under which products are tested carry a UL designation. But it’s the National Fire Protection Agency

(NFPA), the National Electrical Manufacturer’s Association (NEMA), the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and other organizations that publish the standards that NRTLs use.

Other NRTLs, such as Canadian Standards Association (CSA), TUV Rheinland North America (TUV) and Intertek Testing Services NA (ITSNA, formally ETL), along with UL, routinely test solar and solar-related products using the following standards:

- **ANSI/UL 1703.** Flat-Plate Photovoltaic Modules and Panels.
- **UL 1741.** Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources.
- **UL 2703.** Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels.
- **UL 873.** Temperature-Indicating and -Regulating Equipment.
- **UL 1261.** Electric Water Heaters for Pools and Tubs.
- **UL 834.** Heating, Water Supply, and Power Boilers—Electric.
- **ANSI Z21.10.3.** Water Heaters—Circulating Tank, Instantaneous, and Large Automatic Storage-Type Water Heaters.

Labels from a “qualified testing agency” (NRTL) normally satisfy safety concerns of the local authority having jurisdiction (AHJ), aka the building official or inspector.

—Chuck Marken

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