SINCE 1987

PRACTICAL DESIGN OPTIONS FOR MICROHYDRO-ELECTRIC SYSTEMS

home power

SOLAR ▸ WIND ▸ HYDRO ▸ DESIGN ▸ BUILD

Electric Motorcycles

For Every Rider

Modern Rooftop Racks

For PV Systems

Minisplit Heat-Pump Installation Tips

Sep. & Oct. 2017, Issue 181
$5.95 US • $5.95 CAN
homepower.com

RE Politics
The Power is Yours

Ironically, while suggesting that PV modules be placed on his proposed border "fence," the president wants to roll back environmental regulations on coal-fired power plants in an effort to restart the coal industry. Besides expressing support for $4.5 billion in federal subsidies for coal power plants in the East, Trump wants more natural gas export facilities, too. Additional gas export will decrease domestic gas supply, making it more expensive—and thus making coal-power more economically competitive in the United States.

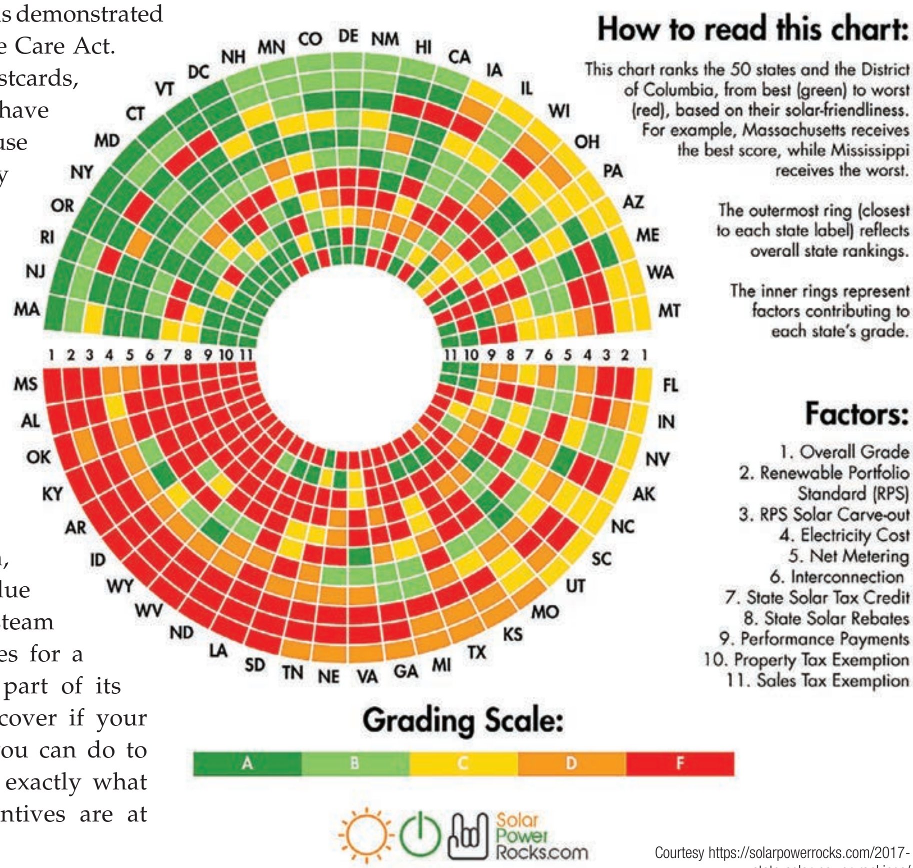
But implementing many of the president's ideas for bolstering fossil fuel use and eliminating environmental regulations is not entirely up to his administration—Congress will be involved. And the pinch-point for Congressional decision-making has been public pressure, as demonstrated by the inability to get rid of the Affordable Care Act. It's been town-hall meeting attendance, postcards, petitions, emails, and phone calls that have kept that legislation in effect. We can use the same tactics to help the RE industry and help keep our air clean by letting our representatives know that we want the solar and renewables industries' pace of building to continue.

While tax credits and other federal encouragement have certainly helped the RE industry, much of the solar revolution we have been experiencing has not been in the hands of the Feds, but rather the purview of state legislation and regulation. After net-metering programs were threatened in Nevada and Florida, both states are making solar comebacks due to public outcry. California is going full steam ahead—and is even considering deadlines for a 100% carbon-free electricity supply—as part of its efforts to beat back climate change. Discover if your state is a solar battleground and what you can do to help at votesolar.org/usa—and find out exactly what your state's RE policies and other incentives are at dsireusa.org.

Support for renewable energy can take many forms, including calls, letters, and emails to your state and Congressional representatives. Check votesolar.org for campaigns that will help your state be a part of the solar revolution. Of course, one of the biggest ways to show support is to install a PV system, whether it's on your rooftop or at your business—it's a visible example to your neighbors and the wider community that solar works, and is ready now.

—Michael Welch, for the *Home Power* crew

2017 State Solar Power Rankings

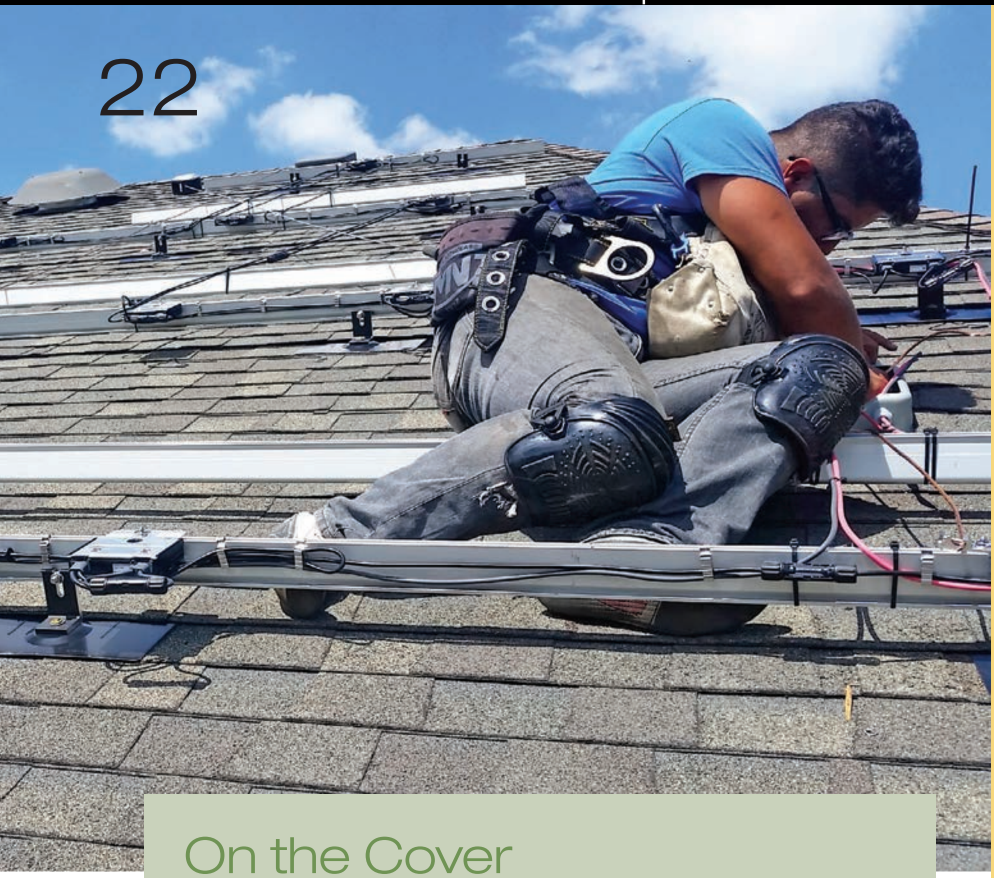


Courtesy https://solarpowerrocks.com/2017-state-solar-power-rankings/

Think About It...

"Solar energy holds great promise as a potentially limitless source of clean energy."

—Richard Nixon, former U.S. president



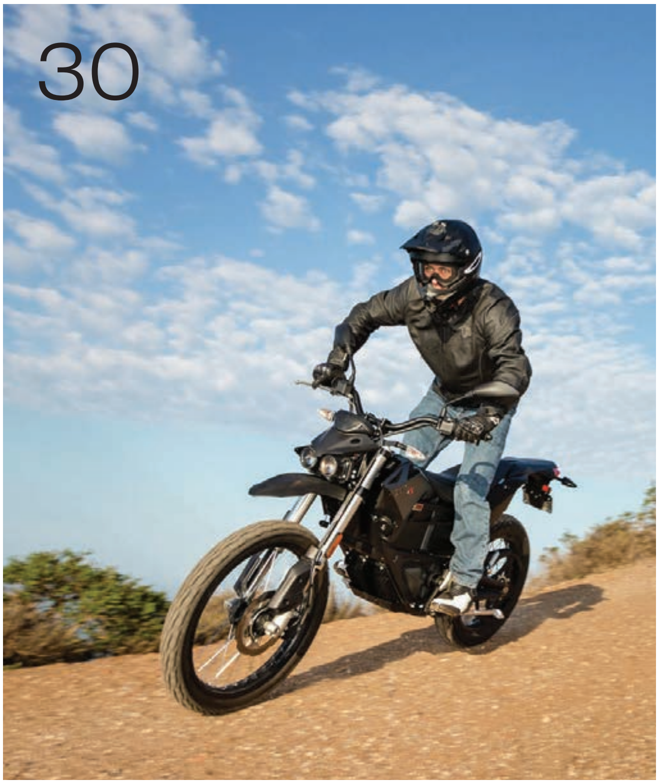
Main Features

continued on page 6

On the Cover

An SR by Zero Motorcycles runs near-silent curves beneath wind turbines that can provide its energy.

Cover photo courtesy Zero Motorcycles



Photos courtesy: Garrison Riegel, Zero Motorcycles, Tim Redshaw


L-Mount Series
Industry's Fastest Just Got *Faster*
Waterproofing | Cost-effective | Single-bolt Installation
Visit us at SPI 2017!
BOOTH#
3339
L-Mount with
Elevated Water Seal Technology®
Works with all leading racks
So you can install solar, *faster*.
Quick Mount PV®
quickmountpv.com | 925.478.8269

contents continued


48

Up Front


15

More Features


12

In Back

Home Power (ISSN 1050-2416) is published bimonthly from offices in Ashland, OR 97520. Periodicals postage paid at Ashland, OR, and at additional mailing offices. POSTMASTER: Send address corrections to Home Power, PO Box 520, Ashland, OR 97520.

Photos: Vaughan Woodruff; courtesy SolarEdge; courtesy Quick Mount PV

HuP® SOLAR-ONE® BATTERIES

HuP® SOLAR ONE®

Highest cycles.

Warranted for 2100 cycles at 80% Depth of Discharge (DOD) (or an estimated 4000 cycles at 50% DOD).

Thickest plates.

Solidly constructed with 0.31" thick positive plates and industrial terminals and hardware.

Longest warranty.

7 year FREE cell replacement. 3 year pro-rated.

Solidly constructed with 0.31" thick positive plates and industrial terminals.

With more usable battery capacity and the longest standard warranty in the industry, the HuP® Solar-One® battery is the clear choice for dependable and resilient solar energy storage. Shipping is FREE in the continental United States to a commercial business with a forklift. To find the right HuP Solar-One battery for your needs, contact your RE professional or Northwest Energy Storage.

Northwest Energy Storage
800-718-8816 • 941-474-0110
www.hupsolarone.com

EnerSys®
Power/Full Solutions

contact us

Home Power—independently published since 1987

Founders	**Richard & Karen Perez**
Publisher & CEO	**Joe Schwartz**
Managing Editor	**Claire Anderson**
Art Director	**Ben Root**
Senior Editors	**Michael Welch, Ian Woofenden**
Senior Technical Editor	**Justine Sanchez**
Building Technology Editor	**Alex Wilson**
Solar Thermal Editor	**Chuck Marken**
Transportation Editor	**Bradley Berman**
Advertising Directors	**Kim Bowker, Connie Said**
Data Manager	**Doug Puffer**

Home Power magazine
PO Box 520 • Ashland, Oregon 97520 • USA

homepower.com

facebook.com/homepower

twitter.com/homepowermag

Subscriptions

To subscribe, renew, change, or inquire about a subscription:

800-707-6585 or **541-512-0201**

subscription@homepower.com

homepower.com/subscribe

Back Issues

Interested in past *Home Power* content beyond the offerings at HomePower.com? Our "Premium Access" subscriptions include download access to *Home Power*'s online archive—more than 160 complete digital back issues in PDF.

Individual back issues are not available for purchase at this time.

Submissions

For inquiries and information related to editorial submissions, write to us at:

submissions@homepower.com

homepower.com/writing

Website

homepower.com

Send your comments regarding the site to:
web@homepower.com

Ask the Experts

To have your technical questions considered for publication, send them to:

asktheexperts@homepower.com

Letters to the Editor

Email your comments and suggestions to us at:

mailbox@homepower.com

or write to the address above.

Marketing

Promotional opportunities and offers:

marketing@homepower.com

Advertising

For inquiries and information related to advertising in *Home Power* or on homepower.com:

Western States:
connie.said@homepower.com
541-326-5773

Eastern States:
kim.bowker@homepower.com
541-858-1791

homepower.com/advertising

Interior paper is made from 85%–100% recycled material, including 20%–30% postconsumer waste.

contributors

this issue's experts

Since 2006, **Ted Dillard** has been converting gas motorcycles to electric and writing for *InsideEVs, Home Power,* and evmc2.com. Ted's book, *Power in Flux: The History of Electric Motorcycles*, is about research, innovation, and the confluence of two-wheeled technologies.

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

Michael Welch, a *Home Power* senior editor, is a renewable energy devotee who will celebrate his 27th year of involvement with the magazine in 2017. He lives in an off-grid home in a redwood forest in Humboldt County, California, and works out of the solar-powered offices of Redwood Alliance in nearby Arcata. Since 1978, Michael has been a safe-energy, antinuclear activist, working on the permanent shutdown and decommissioning of the Humboldt Bay nuclear power plant.

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

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

Brandon Williams founded Iron Edison in 2010 with a passion for high-tech batteries for solar storage in off-grid and grid-backup applications. Brandon has energized thousands of people about using nickel-iron and lithium-iron batteries.

Thirty years ago, **Kathleen Jarschke-Schultze** answered a letter from a man named Bob-O who lived in the Salmon Mountains of California. She fell in love, and has been living off-grid with him ever since. *HP1* started a correspondence that led Kathleen and Bob-O to *Home Power* magazine in its formative years, and their histories have been intertwined ever since.

Garrison Riegel began installing solar in 2005 while completing a degree in environmental studies. Garrison currently manages operations at Solar Service in Niles, Illinois, and also teaches solar design and installation classes with Solar Energy International.

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

Chuck Marken is a *Home Power* contributing editor, licensed electrician, plumber/gas fitter, and HVAC contractor who has been installing, repairing, and servicing SWH and pool systems since 1979. He has taught SWH classes and workshops throughout the United States for Sandia National Laboratories, Solar Energy International, and for many other schools and nonprofit organizations.

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

Home Power senior editor **Ian Woofenden** has lived off-grid in Washington's San Juan Islands for more than 30 years, and enjoys messing with solar, wind, wood, and people-power technologies. In addition to his work with the magazine, he spreads RE knowledge via workshops in Costa Rica, and lecturing, teaching, and consulting with homeowners.

Contact Our Contributors

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


ENDURANCE Plus
Power That Stands Out!
DEEP CYCLE
MADE IN AMERICA
U.S. Battery
Manufacturing Company
Highest initial capacity
Fastest cycle up to full rated capacity
Highest total energy delivered over the life of the battery
AMERICA'S MOST TRUSTED DEEP CYCLE BATTERY SINCE 1926
HANDCRAFTED IN THE USA
VISIT US AT SOLAR POWER INTERNATIONAL BOOTH #1915
WWW.USBATTERY.COM

Courtesy SolarEdge

SolarEdge PV Inverter

with Integrated EV Charger

SolarEdge (solaredge.us) integrated its 7.6 kW HD-Wave inverter with a Level 2 electric vehicle (EV) charger. This product is aimed at the growing "EV with PV" market, in which end users are installing PV arrays to offset their home and EV's utility electricity consumption. Combining both into one package eliminates separate product purchases and installations, and the need for additional breakers. This inverter handles PV system AC output of 7.6 kW but supplies up to 9.6 kW (40 A, 240 VAC) of EV charging by supplementing grid energy with PV output. The EV charger works with SolarEdge's monitoring platform and smartphone app, allowing users to control their EV charging, set charge schedules, and review charging status. This product has a 12-year warranty, extendable up to 25 years.

—Justine Sanchez

Courtesy SolaTrim

SolaTrim ST-055
Barrier

SolaTrim (solatrim.com) added the ST-055 to its line of protective barriers to keep debris and pests from underneath roof-mounted PV arrays. The SolaTrim products provide an air-permeable barrier; a diamond-stamped aluminum panel with a black polyester coating on the outside; and a pre-applied adhesive for a "peel-and-stick" installation to the module frames. The ST-055 is 5.5 inches high to match the array height provided by some rack products and the ST-001 version is 6.75 inches high.

—Justine Sanchez

Courtesy Smappee (2)

Smappee Plus

Energy Monitor

Belgium-based Smappee (smappee.com) released the Smappee Plus energy monitor into the U.S. market. This monitor measures both household energy consumption and PV production. By identifying an appliance's distinct electrical signature, it can also monitor individual appliances with one set of current transformers in the main service panel. For example, a refrigerator has a different electrical usage pattern compared to a toaster. The Smappee matches appliances to their patterns, displaying real-time consumption by appliance, so that users can pinpoint where their energy dollars are being used. Comfort Plugs for 120 VAC appliances work with the Smappee system to provide remote, smartphone-operated load control.

—Justine Sanchez

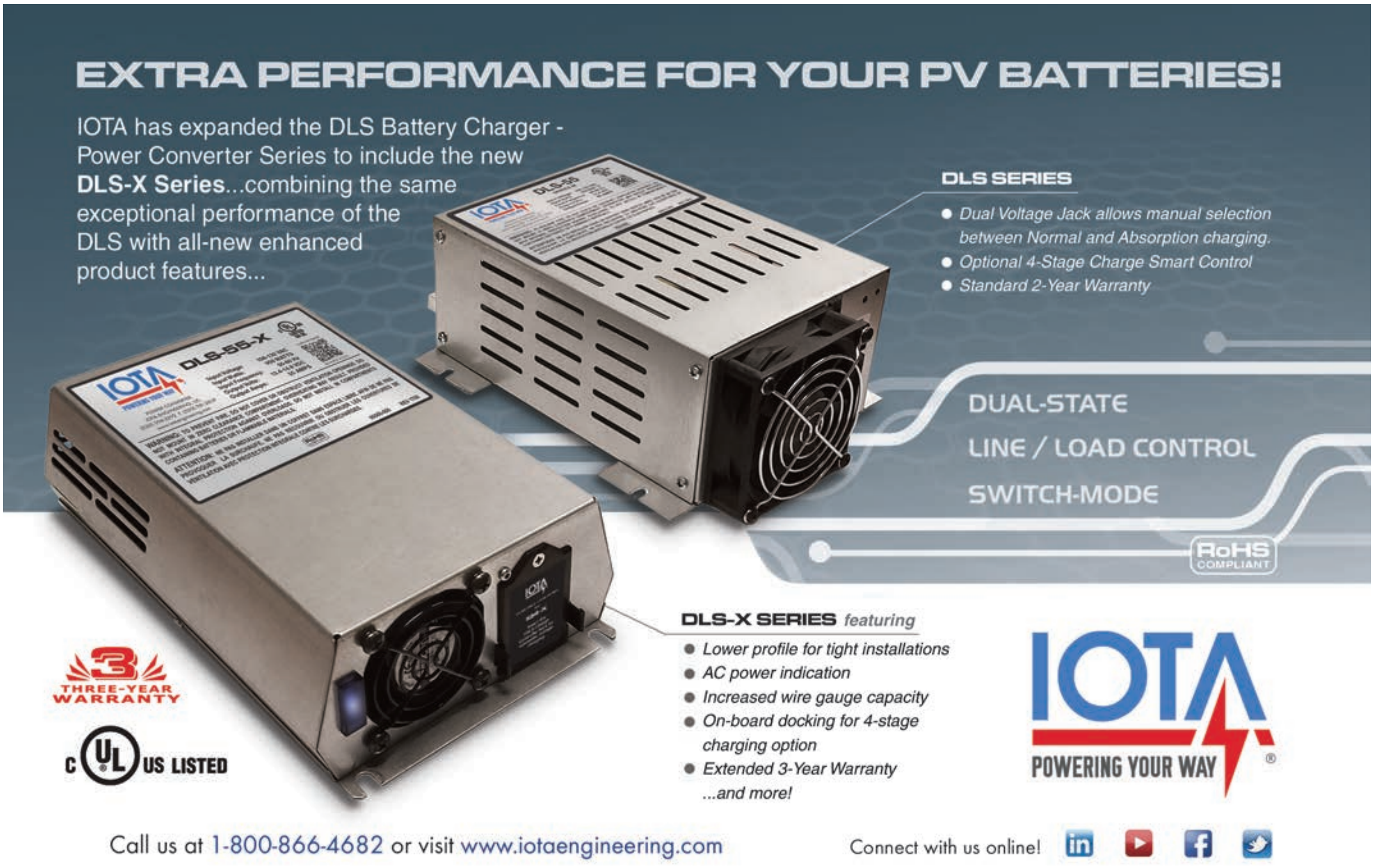
Courtesy Quick Mount PV

Quick Mount PV

L-Mount

Quick Mount PV (quickmountpv.com) released its L-Mount series—an L-foot integrated with flashing—for composition shingle roofs. It is installed with a single lag screw, and an elevated EDPM sealing washer waterproofs the penetration. The L-foot can be rotated 360°, making it versatile enough to be used with almost any rack product. The L-Mount is available in single- or double-slot configurations, in aluminum mill or black finish, and comes with a 25-year warranty.

—Justine Sanchez



Solar Pioneers Party this November!

Home Power is pleased to sponsor the Third and Final Solar Pioneer Party in Mendocino County, California, November 3–5, 2017. Event activities include the debut of the "Solar Pioneer" documentary, a four-hour ride on the historic Skunk Train through ancient redwoods, and a grand finale event in Hopland, California.

If you are a pioneer, a friend of the pioneers, or a solar professional interested in learning more, go to solarpioneerparty.com. Those who need the registration password can contact the organizer through the link on the website.

We look forward to seeing our friends in Mendocino in November to pay tribute to the solar pioneers who paved the way for the growth of this amazing industry.

Students Win in Wind

The Botetourt County, Virginia, high school students had a great year. The wind electricity team not only won first place in a state competition, but also then went on to win first place in the National KidWind Challenge at the annual American Wind Energy Association conference in Anaheim, California. For more info on the Challenge, see kidwindchallenge.org.

This group of high-school kids constructed true airfoil wind blades from wood. I really enjoyed working with the team. It was lots of hard work for them—cutting, chipping, and sanding. Credit also goes to Mark Hanson for teaching how to match their alternator to the load using an MPPT fixed-load resistor for maximum performance in the wind tunnel competition. Their coach and educator, Wendy Grimshaw from the Learning Barn, guided the team to victory. Team members included Jacob Leonard, Jonathan Leonard, Josh Grimshaw, Thomas Laughridge, and Tucker Grimshaw.

Coming up is the U.S. Department of Energy's Collegiate Wind Competition 2018. The 2018 rules are to be released very soon. Maximum blade and rotor size will be defined by the DOE, and students are encouraged, but not required, to make the load visually stimulating by indicating the power being generated in an interesting and creative way. For more info, see bit.ly/CollegeWindComp.

I strongly encourage students to pursue a renewable energy education—it's their future. The Collegiate Wind Competition isn't exclusively for Integrated Science and Technology students—the project spans across departments and allows students to branch into other subjects outside of their majors.

Roger Beale • Evington, Virginia

Right: Roger Beale in his wind workshop with Botetourt County, Virginia, high-school students.

Courtesy Roger Beale

Industrial Battery Redemption

I've had my off-grid system for long enough now that I'm learning about battery-bank life span. I've recently learned how to recognize when batteries are no longer performing at their peak, what can be done to service them, and how some proper care and feeding can resurrect what appears to be a dying bank.

My battery bank is two 850 Ah, 24 V industrial batteries in parallel. These batteries were purchased new in 2010 and placed into service with a 2 kW PV array and a backup generator. Unfortunately, the manufacturer wasn't forthcoming with good guidance about bulk, absorb, and equalization charge levels, so I made some educated guesses based on general battery research.

During the 2016-2017 winter, the generator began running more often, and the charge time (especially the bulk part) was shorter than it should have been. "Probably just a sign that the batteries are aging," I thought. During watering, I also noted that the plate protector in one cell was a dull gray color—the plate protector in all of the other cells was red. I also noted that I hadn't, by my recollection, actually watered this cell in months, but all of its peers were forever in need of topping off.

This is when I realized that there was something more problematic than age at work, and that some real investigation was needed. I used three different tactics to test the battery for relative health:

- I used my voltmeter to test the bad cell relative to the other 11 cells in the battery. Sure enough, this cell, fresh off a generator charge, measured a half-volt below its neighbors (1.6 versus 2.1 V).
- I disconnected the battery from the bank after a charge run, and let it sit idle for five days. In that time, the battery self-discharged from 25 V to 21.2 V.
- I ordered a new hydrometer. Once it arrived, I measured the specific gravity of the cells after letting the battery sit idle for several hours. The neighboring cells measured at about 1.265, but my bad cell measured zero. Yes, zero.

I concluded that this cell had internally shorted between the plates and effectively killed my battery. While all this testing was being done, I also noted that my remaining batteries were not performing well on their

Courtesy Northwest Energy Storage

While a different brand than the reader's, industrial flooded lead-acid cells like these can be removed from their case for individual maintenance or replacement.

own. The bank went through bulk charge quickly, and when drawn down, would get to 23.9 V and then, in minutes, crash to below 23.3 V and start a new charge cycle from the generator. I concluded that the only real option available was to squeeze whatever life was left in the remaining battery while I investigated the state of storage and figured out how I'd free up $7,000 to $10,000 for new batteries. I also investigated whether the manufacturer would replace the failed battery under warranty (seven years for industrial batteries seemed like a premature death).

While there was no warranty coverage, getting the battery serviced and replacing the bad cell was an option. The company referred me to a heavy equipment retailer (specializing in forklifts) about two hours away. The vendor assured me that they would be able to replace the bad cell, would inspect and (if needed) service the others. It would take only a few days and wouldn't cost more than $700. My friends and I wrestled about 1,600 pounds of battery out of the battery room and onto a trailer.

Once we dropped them off, the repair process didn't go quite as smoothly as I'd hoped. Highlights included, "My shop guys say there are three bad cells," and "I have this battery in stock for only $3,800," and "Just to even think about replacing the cell we have to charge a $900 inspection and test fee." At this point, I concluded that unless the repair bill exceeded 50% of the replacement cost, I would proceed. "OK," they told me, "we'll send the battery to the specialist company we work with and won't proceed with any work until after they do their inspection." They replaced the one bad cell; all the other cells tested at nearly their "new" capacity of 850 Ah. The final repair bill was $1,250.

While the bad battery was being tested/repaired, I spoke with the manufacturer about proper charge tolerances on the batteries. All these years, I'd been undercharging them. The remaining battery, after only one solid equalization run, stopped cutting out at 23.9 V. Turns out, it just needed a good stirring of the electrolyte through equalization.

With the repaired battery back in the bank, I'm now back to six days at a time with no generator input. The beasts are performing like they're new again. From this experience, I've learned a few things:

- Industrial batteries can take a lot of abuse and still come back to life—with proper information from the battery vendor.
- You can replace bad cells in industrial batteries!
- If you're going to get batteries serviced, be in direct communication with the repair people.
- Equalize regularly, and to the values the vendor recommends!
- Pay attention to how often you have to water each of the cells in a bank. A cell that doesn't seem to get thirsty may be sucking energy and capacity out of the rest of the battery.
- Pay attention to how often and how long your generator runs. Fast charge and discharge cycles can be a bad sign about your battery bank health.

Thank you very much to *Home Power* for the many informative articles about batteries and their proper care and feeding, and for making themselves available to bounce ideas off of.

Joe McCabe • Napa, California

Off-Grid EV Charging

I very much appreciated *Home Power's* coverage of the electric car market ("The Next Wave of Electric Vehicles" by Bradley Berman in *HP180*). However, I think you should also focus articles on charging an electric vehicle from an off-grid PV system.

I drive a Zero electric motorcycle that recharges with about 15 amps at 120 VAC using a standard Level 1 (slowest) charger, provided by my 3 kW PV system. Larger off-grid PV home systems could possibly accommodate Level 2 charging—up to 30 A at 240 VAC. Or a dedicated stand-alone PV system could be used only for vehicle charging.

There are some important considerations to sizing a solar-electric system to support even minimum charge requirements. For example, to avoid depleting the battery, a 3 kW off-grid PV array with a 15 to 20 kWh battery bank can charge a vehicle battery only during peak sun-hours. At this time, solar energy input is sufficient to charge the vehicle. The battery in an electric vehicle is often the same capacity or larger than a house's system battery. Manually switching on the charger when house batteries are fully charged and the array is in full sunshine makes it all possible.

Courtesy Steve Willey

Elizabeth and Steve Willey charge their Zero S electric motorcycle with an off-grid PV system.

For practicality, we need products that incorporate a timer and relay on the vehicle-charging outlet to limit charging to peak sun-hours. A small insolation-sensing, time-delay circuit could shut off the charging outlet if cloud cover extends past several minutes. Perhaps some charge controllers that offer a diversion signal could delay the start of vehicle charging until the house battery is fully charged. This might ensure that vehicle charging uses energy directly from the array, and avoids depleting the house batteries.

So far, I've found no commercial products that focus on this process. Articles and user reports, ideas, and off-grid EV charging experiences would be cherished by your readers that are already EV users, and could also encourage more EV usage.

Steve Willey • Sandpoint, Idaho

write to:

mailbox@homepower.com

or Mailbox, c/o Home Power
PO Box 520, Ashland, OR 97520

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

AC-Coupling

I have two solar-electric systems at my home in Puerto Rico. One system, installed in 2000, has 26 12-volt, 60 W modules in two subarrays connected to two C-60 charge controllers, with 10 T-105 batteries and a 2,500 W inverter. The other system, installed in 2014, is grid-connected, with 12 24-volt, 240 W modules with Enphase 215 microinverters. I'm wondering if there's a way to use the old system to power the new one when the grid goes down?

Alberto Marty • Lajas, Puerto Rico

The simplest and least expensive way to provide battery backup is an automatic transfer switch between your off-grid inverter and main AC panel. This would power that panel and disconnect the new PV array during a blackout. But if your total loads are close to (or more than) 2,500 watts, you'll need another option.

To avoid the large-loads problem, consider a backed-up loads subpanel to power only your most important loads—such as refrigeration, lights, etc.—from the battery bank. It might reduce your loads enough that the 2,500 W inverter could cover them.

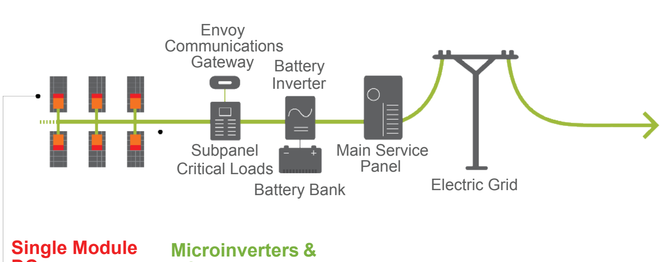
If the loads exceed inverter capacity, you might be able to use AC-coupling. These systems rely on the capability of "multimode" inverters to supplement your battery-based system with AC from the second, grid-tied system when the grid goes down. Unfortunately, it is unlikely that your older inverter has AC-coupling capability, so you'd need to purchase a modern multimode inverter with split-phase 120/240 VAC output to accommodate the microinverters' 240 VAC output.

Another issue is controlling battery charging from the AC-coupled PV array. Your existing controllers can manage charging only from your old array—not from your newer microinverter-based system. When the grid is out, multimode inverters can trigger your microinverters to shut down the new array when the battery bank is fully charged.

However, as a safeguard, Enphase requires a "blackout relay," which completely cuts off the multimode inverter and forces the microinverters to shut down. This results in one-stage charging, with the inverter/charger shutting down for 5 minutes, then restarting for 5 minutes. If grid blackouts are infrequent and short, little or no damage to your batteries is likely to occur under this setup. But best battery life is achieved with three-stage charging. If blackouts are frequent and long-lasting, a standard diversion-load controller that "dumps" extra incoming energy to heating elements when your batteries are full is recommended. However, both the heaters and controllers need to be sized to handle your new array's entire output.

With the advent of new, high-tech battery types and increasing interest in supplying power during outages, AC-coupling is becoming popular and the technology is rapidly becoming more sophisticated and easier to implement. Best of luck with your project!

Dan Fink • Buckville Energy Consulting



Courtesy Enphase

Replacing a Solar Storage Tank

Our Ford solar water storage tank has rusted and is leaking. What can I replace it with? I want to keep our system operational!

Deb Harden • via homepower.com

Although these Ford tanks likely had a lifetime warranty, that division of the company is no longer in business. Ford quit making tanks—heavy, stone-lined, 66-, 80- or 120-gallon metal-clad units with internal heat exchangers—in the late 1980s, so you probably won't find one just like it to replace it. Instead, consider a glass-lined Rheem/Rudd tank with an integrated heat exchanger that's about the size of your present tank—but replace it only if the rest of the system is in good condition.

If other major components in your present system are in poor condition, consider a new system if you have good local, state, or utility incentives to add to the federal 30% solar tax credit. A new installation may be able to use the existing piping system if made of copper tubing—and this should make the system less expensive.

Either way, contact at least two local installers to inspect the system and give you bids for repair or replacement. You can find installers through your local chapter of the Solar Energy Industries Association (seia.org); the American Solar Energy Society (ases.org); or the North American Board of Certified Energy Professionals (nabcep.org).

I've replaced a lot of tanks, and it is usually a half to a full day of work for two people depending on many factors—such as access and installation complexity. In a basement, removing a 120-gallon Ford tank can take three or maybe more people to do it safely; a tank swap in a garage is a snap compared to that.

For more details on solar water heating systems, see the many articles at homepower.com/solar-water-heating.

Chuck Marken • *Home Power* solar water heating editor

Courtesy Rheem

Battery Watering

At which state of charge/depth of discharge (SOC/DOD) is it best to top off flooded lead-acid (FLA) batteries with distilled water?

Ben Aeschbach • via homepower.com

I recommend the following quarterly battery maintenance procedure. Before you start, put on your protective gear—safety glasses and nitrile gloves, at a minimum. And have an acid spill-control kit nearby—this can be as simple as a box of baking soda.

1. Get the batteries to float stage, either by PV input and load shifting or with a fossil-fuel generator.

2. Take and record voltage and specific gravity readings on each cell.

3. Top off each battery cell to the fill line with distilled water.

4. Although you can start the equalization cycle with your PV charge controller or inverter/charger, I recommend using a generator. Equalize cycles are timed, and a cloudy afternoon could make your PV equalization attempt abort until the next day, and the day after that. It's best to get it done immediately—and completely—with the generator.

5. The equalization cycle mixes the electrolyte thoroughly to prevent stratification. After the cycle is over, check each cell's voltage and, if needed, top off with distilled water. Once each cap is back in place, gently clean the tops of the batteries with a damp (not wet!) rag.

6. Check for loose connections and corrosion each time, addressing any problems found.

Dan Fink • Buckville Energy Consulting

Looking down into the cell at the fill level of a Trojan L-16 flooded lead-acid battery.

Dan Fink

Battery Management System (BMS)

I have an off-grid system with a Sunny Island 5048 inverter and a 475 Ah, 48 V FLA battery bank. The system is now about 10 years old. The batteries are down to 80% state of health (SOH), so nearing their end of life.

I'm looking at options for my next set of batteries. I am considering LiFePO4, 300 to 400 Ah at 48 V. It looks like I could bottom-balance the batteries and use a simple constant-current charge to around 90% without the complexities of a battery management system (BMS). Does this all sound reasonable, or am I missing something obvious?

Alistair Ward • via homepower.com

A BMS's primary function is to prevent cells from overcharging by controlling a physical disconnect (a contactor) located on the battery. This monitoring and disconnect system can also help protect the battery from overdischarge, helping to extend its life, and prevents damage from charging when the battery temperature is 0°C or less.

When lithium batteries are charged, it's common that one cell in the pack reaches full charge before the others. Without the BMS and under a heavy charge, this one full cell will jump from 3.45 V to 4 V almost immediately. Above 4.2 V, there is irreparable damage to the cell. This process can happen on the very first charge cycle of a new lithium battery's life no matter how well the cells are pre-balanced.

Nominal cell voltage for lithium batteries is about 3.2 V per cell, and 100% state of charge happens at about 3.45 V per cell. If you set a charge controller or inverter's charger to 3.45 V per cell times 16 cells (55.2 V for bulk and absorb), we would expect that all the cells would come up together to 55.2 V. The charger would hold 55.2 V during the absorb cycle for the predetermined time before transitioning to float. However, with the one errant cell, this is what happens:

Cycle 1
3.35 V × 15 cells = 50.25 V
3.45 V × 1 cell = 3.45 V
Pack voltage = 53.7 V
Target voltage = 55.2 V

At 53.7 V, that one cell at 3.45 V is about to run away. The charge controller is still in bulk, delivering maximum current to the battery. The higher impedance results in a cell's voltage rapidly increasing, and it will accept even more energy from the charging source. This is where things get bad. The PV array will keep charging the battery until the pack reaches 55.2 V, the bulk/absorb transition point. That means that the battery will have to come up an additional 1.5 V before it begins the absorb countdown timer. During the absorb stage, the charging source will continue to push a good amount of power into the battery for at least an hour before it's time for float.

Without a BMS, that one lithium cell previously at 3.45 V will climb to 4.9 V and hold that voltage for the entire absorb cycle. After that one charge cycle, the overcharged lithium cell will be damaged beyond repair. Its voltage will drop quickly as the battery begins to discharge. The next cycle will be worse, because this damaged cell will charge slower than the rest of the pack. A different cell will run away on this second charge cycle, and its overcharge will be even worse because of the damaged cell from the first cycle that may be holding 2.8 to 3.0 V.

Courtesy Iron Edison

Cycle 2
3.0 V × 1 damaged cell = 3.0 V
3.35 × 14 cells normally charged = 46.9 V
Subtotal = 49.9 V for 15 cells
Target voltage for solar charging = 55.2 V

That leaves room for the one overcharged cell to achieve 5.3 V. This is the point at which a lithium cobalt or lithium manganese battery will catch fire.

The BMS has the ability to control this overcharged cell though passive or active cell balancing. Resistors are used for passive cell balancing. Under charge, when one cell rises to about 3.3 V, the balancers activate and look for a voltage differential greater than 50 mV or 0.05 V per cell. If one cell starts climbing faster, the balance resistor begins to bleed a small amount of energy from that cell. On a high current charge like we see at 48 V, the balance current should equal 1% of the maximum charge rate. High-amperage resistor packs, sometimes 6 amps per cell, are used to keep big batteries from overcharging.

Beyond the BMS, consider that lithium iron phosphate chemistry is intrinsically much safer than other lithium chemistries. Lithium cobalt and lithium manganese are both volatile and prone to thermal runaway.

Brandon Williams • Iron Edison Battery Co.

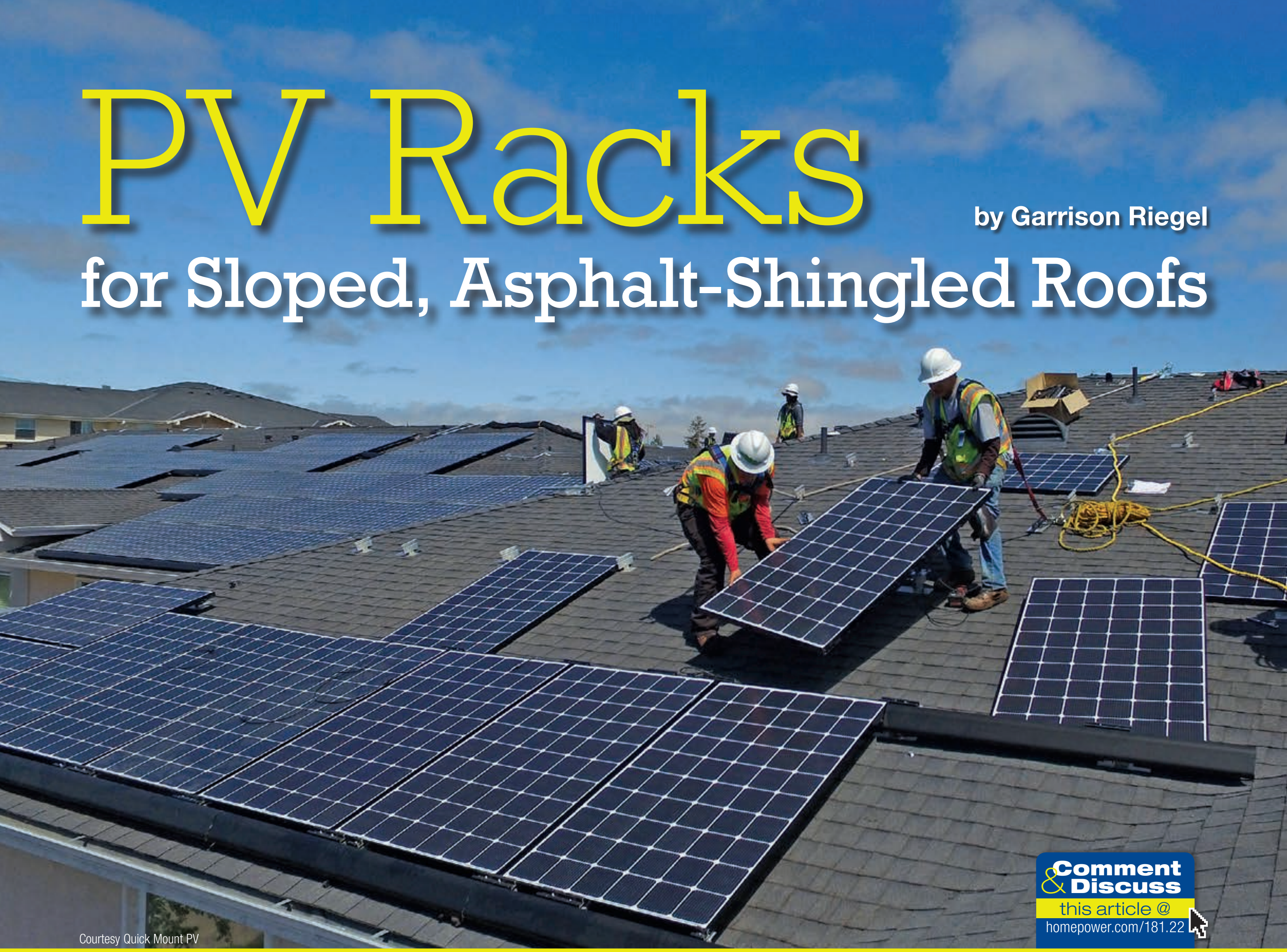
write to:

asktheexperts@homepower.com

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

PV Racks for Sloped, Asphalt-Shingled Roofs

by Garrison Riegel

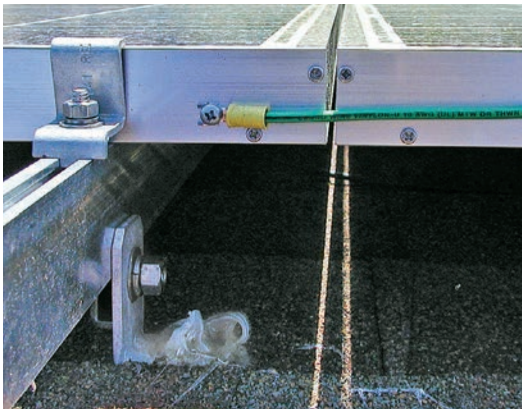


Courtesy Quick Mount PV

A rack system has the simple job of supporting the modules in a PV array. While that's straightforward, options available may make choosing a manufacturer or method more complex. As installed costs for PV systems continue to decrease, racks become a larger portion of the cost, making it important to select racks that will install quickly and easily, be durable and reliable—and will not result in unexpected costs before, during, or after the installation.

In the early days of PV systems, rack system requirements were much simpler—there were no relative UL standards, no permits that needed to be pulled, and rarely were inspectors questioning materials and installation methods—PV systems weren't covered in the *National Electrical Code (NEC)*. Structures to support an array were custom-built from whatever materials were available. Most roof-mounted systems were tilted to capture every possible watt-hour from a handful of expensive PV modules.

Many of these early installations have lasted decades without problems, but that is not always the case. One of the issues with early systems is that the racks' connection to the roof rarely included flashing to create a waterproof seal



Early rack solutions often included poor grounding techniques and inadequately protected roof penetrations.

Ryan Mayfield

Rail-based racks provide an easy way to level and align PV modules, as well as attaching module-level inverters and optimizers.

and maintain the roof warranty. Wind and snow loads can result in hundreds of pounds of force on this connection, and thermal cycling adds stress from expansion and contraction. Commonly, sealant was applied under and around a piece of angle aluminum, L-foot, wood block, or whatever anchor was used to hold the system in place. This method is not acceptable, as it will void the roofing warranty. Plus, it does not meet *International Building Code (IBC)* requirements or the National Roofing Contractors Association best-practice recommendations for sealing roof penetrations.

Another issue common in early rack systems was grounding and bonding. Since the rails and hardware to secure the modules did not necessarily create an effective ground path, a separate wire was needed to bond the modules together. A lay-in lug was typically used to bond the modules to the bare wire, but the installation methods for these lugs were not well understood by all installers, so it was common to see improperly bonded modules, or incorrectly rated parts and hardware used to make this connection.

As array voltage increased from 12 to 600 V, and as PV systems increasingly came under the scrutiny of the authority having jurisdiction (usually, the local electrical inspector) and the National Fire Protection Association, custom racks fell out of favor. With higher voltages, greater importance was placed on ensuring that the modules and rack were properly bonded, so that ground-fault protection systems in the inverter would function properly and shock and fire hazards would be reduced.

The lay-in lug method eventually evolved into the use of a washer electrical equipment bond (WEEB) to bond the modules to the rack system. At the time, this was revolutionary, as it dramatically decreased the installation time. However, with this method came unique issues, as properly locating the WEEB between module frames can be difficult. Plus, the sharp points on the washer that pierce the anodized module frame to create the bond wear out very quickly if the module needs to be unclamped and shifted during installation or maintenance. And, since the WEEB is hidden under the module frame, it is difficult for the installer or the inspector to verify that a reliable bond has been formed between the module and the rail.

Rails run vertically for PV modules mounted in landscape orientation.

Garrison Riegel (2)

Top-down racking, like this system by RBI Solar, involves clamps that grip the module frames from above and supporting rails beneath.

There are a variety of extruded rail configurations and clamping attachment systems.

Courtesty RBI Solar (2)

Modern Racks

In most systems, extruded aluminum rails support each row of modules, and clamps hold the PV modules in place. A flashed post, L-foot, or metal block elevates the rails; and a lag screw secures the system to the framing below. The main change is that roof racks have been simplified and are now available as complete systems with all components and hardware included, which can be adapted to most roofs.

Two rack system types dominate for parallel-mounted, sloped-roof applications: rail-based and rail-free. Whether rail-based or rail-free, each has benefits and disadvantages. Variations exist between manufacturers, and quality is a key consideration for selecting a rack system for a sloped roof. Some of the hallmarks of a quality product include manufacturer longevity and their support during the design, permitting, and installation phases of the project. Post-installation support and the rack's accompanying warranty are also important considerations.

Rail-Based

Rail-based racks have been the mainstay of the industry for decades. This system is simple, reliable, and can be adapted to most roof pitches and roof types. In most systems, there are two rails per module row; top-down (installable from above) clamps between modules hold them in place. These rails make it easy to connect to the roof surface with various attachment methods like L-feet, tile-hooks, or standing-seam clamps, and integrate easily into the waterproofing system with flashings from the rail manufacturer or a third-party supplier.

Another benefit of a rail-based system is they do not need to be precisely placed in relation to the module frame. This is helpful because courses of shingles are almost never in a straight line, and flashings are limited to where they can be installed and still maintain water-tightness. As long as the rail supports the module within its manufacturer-specified clamping zone, then the rail can be placed where it's most convenient. Installing the rail to closely follow the shingle line will help ensure a leak-free penetration.

Rail systems also provide a mounting place for module-level power electronics (MLPEs). Microinverters and DC converters are capturing an increasing share of the market. These are typically installed one per module, but with some systems two or more modules are connected to a single rack-mounted microinverter or DC converter. Rails also help conceal and secure MLPE wiring.

If installing under the 2014 or 2017 *National Electrical Code,* you may need to mount equipment for rapid shutdown (RSD) at the array. If not using RSD-compliant MLPEs, a separate device is needed at the array. This can be rail-mounted. Even without RSD requirements, most installations transition at the roof from outdoor-rated wire to less-expensive THWN-2. Here again, the rail provides an easy place to mount junction boxes, saving the need to cut or drill more holes in the roof to flash or secure a junction box.

Rooftop PV systems require some maintenance and most rail-based systems make this straightforward. Since the modules are secured with top-down clamps, removing a module from the array—while leaving the others in place—is uncomplicated. With most modern systems, the ground path is maintained through the rail, so no additional bonding jumpers are required when a module is removed for service or replacement.

Rail-Free

A disadvantage to rail-based systems is the expense of the rails and their transportation—long, heavy pieces of metal can be expensive to ship. Most modules are also encased in an aluminum frame, similar to a rail, so it's material redundancy to add an external rail where one already exists.

Rail-free racks were first popularized by Zep Solar. This system has modules with specially grooved frames that were connected with a splice bar, which fit into those grooves. The system's flashed leveling feet also attached to the grooves.

Rail-free rack systems like this Quick Rack by Quick Mount PV use top clamps that integrate with mounting-foot locations.

Courtesy Quick Mount PV

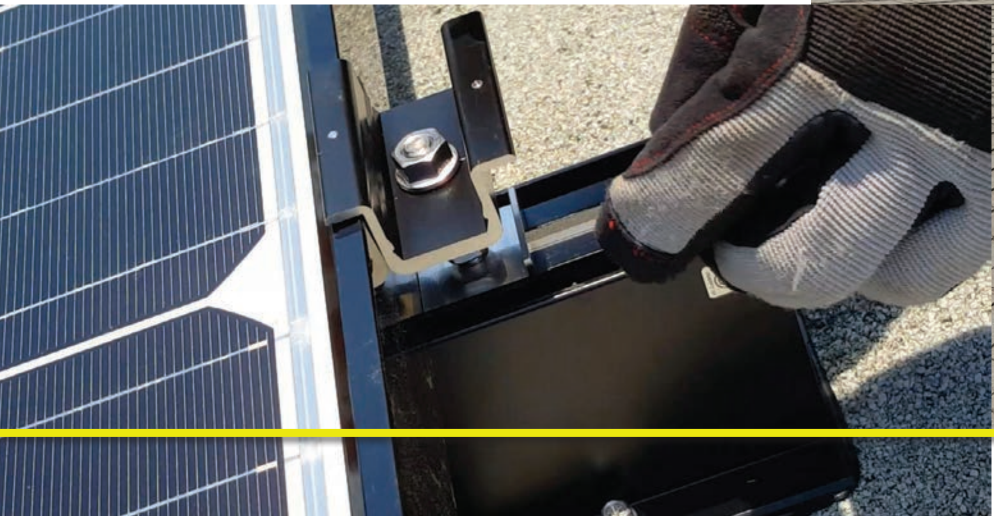
These systems required PV modules with proprietary grooved frames, plus specialty tools and parts, which added cost but saved installation time.

Other manufacturers have since created a variety of "rail-free" systems (although, in most, a small section of rail or channel structure supports the modules and allows for some adjustability). This lets the attachments follow the shingle line and the roof surface, which often dips and rises due to wood framing inconsistencies below.

Most of these newer rail-free systems do not require a special module frame, so they can be used to support almost any PV module. Most rail-free racks use a top-down clip or clamp similar to those used in rail-based racks. The difference is that this clamp is part of a bracket assembly that also elevates the module off the roof, and connects to the roof frame with a lag screw and integrated flashing. Typically, only one attachment kit is needed per module at the upper and lower sides of each row. If more than one row is installed, then there will be a shared bracket assembly between module rows. With many systems, a coupling then connects adjacent modules at their corners to create a rigid support structure.

This greatly reduces the number of attachments needed to support an array—especially if modules are installed in a landscape layout, since only one connection is needed per 66 inches or so for a typical 60-cell module. If modules are in a portrait layout, then one connection may be needed every 40 inches or so.

Material and shipping costs may be reduced by choosing rail-free systems. However, some systems may require more roof attachment points and more critical alignment. Below: Like others of its kind, this Roof Tech system allows subtle adjustment of horizontal and vertical alignment.



Courtesy Roof Tech (2)

Right and below: Clamps at the module corners of this rail-less system by Quick Mount PV secure the module frames to the roof attachments.

The gray rail is actually a trim strip, providing an aesthetic finish for the bottom of the array.

Courtesy Quick Mount PV (2)

With fewer attachments and no rails, the entire rack system can sometimes ship in a single box—saving several hundred dollars in freight costs, and reducing time spent on the roof.

The downside to fewer attachments is that all of the dead and live loads are transferred to fewer points in the roof supports. In snow country, this could result in hundreds of additional pounds per connection, which could necessitate adding connections or even structurally reinforcing the roof. With support in fewer places on the long side of the module, the frame's ability to resist wind and snow loads is decreased, which means these rack systems are not deployable in all areas, with all modules.

Usually, wire management is easier with modules installed in a portrait layout. In this orientation, there is always enough wire length to securely clip the leads to the module frame while avoiding drooping wires. For the same size array, there are also usually fewer rows of modules in a portrait layout than in a landscape layout. This decreases the number of jumpers needed between rows as modules are wired into source or output circuits. Most rail-free systems, then, are at a disadvantage, since they encourage modules to be installed in landscape orientation. The addition of MLPEs, which have even more wiring to deal with, makes this more complicated. With rail-free systems, MLPEs need to be connected to the module frame with an accessory bracket, which adds time and cost, but can be done on the ground before the modules are lifted to the roof. Even with the unique challenges of rail-free racks, the material cost and time savings can outweigh the potential disadvantages. This is especially true for lower-sloped roofs and in locations where heavy snow loads are not a significant factor.

Technical Considerations

When deciding what type of rack system to use and from which manufacturer, there are a number of considerations that can help ensure a smooth project from start to finish.

Compatibility. The rack system needs to fit the specific site characteristics and the PV system's electrical design. If you're installing many systems, a rack preference should be versatile enough to work with many roof types, pitches, and module manufacturers. It is not uncommon to design a system for a specific module and then have that model no longer available by the time the permit is approved and parts are ordered. The more universal the system, the easier it will be to accommodate changes without a major system redesign. With rail-free systems, it is critical to verify that the modules are compatible, as some PV module frames' clamping zones may be too small for many rail-free systems.

Quick Mount PV's online design tool.

Courtesy Quick Mount PV

PV Racks Comparison

Manufacturer	Rail-Based	Rail-Free	Compatible with Standard Module Frame	Online Design Tool Available	UL 2703 Listing	Fire Class A*	Integrated Wire Management
Ecofasten ecofastensolar.com		√	√		√	√	
Ecolibrium ecolibriumsolar.com		√	√	√	√	√	
Everest everest-solarsystems.com	√		√	√	√	√	√
IronRidge ironridge.com	√		√	√	√	√	
Magerack magerack.com	√	√	√		√	√	
Mounting Systems mounting-systems.us	√	√	√	√	√	√	
Orion orionsolarracking.com	√		√	√	√	√	
Polar Racking polarracking.com	√		√	√	√	pending	
Preformed Line Products preformed.com	√	√	√	√	√	√	
ProSolar prosolar.com	√		√		√	√	√
PV Racking pvracking.com	√		√		√	√	
Quick Mount PV quickmountpv.com		√	√	√	√	√	
RBI Solar rbisolar.com	√		√	√	√	√	
Rooftech roof-tech.us		√	√	√	√	√	
Schletter schletter.us	√		√	√	√	√	√
S:Flex sflex.com	√		√		√	√	
SnapNrack snapnrack.com	√	√	√	√	√	√	√
Spice Solar spicesolar.com		√			√	√	
SunModo sunmodo.com	√		√	√	√	√	√
UniRac unirac.com	√	√	√	√	√	√	
Zilla zillarac.com	√	√	√		√		

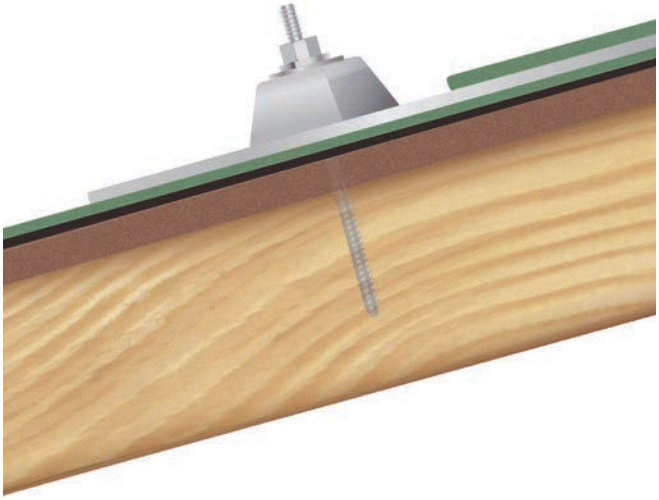
*Roof pitch, module type, and racking model specific. Verify with manufacturer based on project-specific details.

Design support. Many rack manufacturers offer online tools to assist with the system design and verify module compatibility. The best tools allow you to design a virtual system.

With a few site-specific inputs like location, module model, roof height and pitch, and attachment spacing, the design tool should provide an engineering report that can be used to verify that the structure can support the live loads specific to that area, based on local code requirements. This report should provide uplift and shear forces on the attachments, which can be used to help select the appropriate lag for the project.

More sophisticated online tools provide drawings that define array area, rail lengths, and attachment locations, and provide custom views of the module layout and array height above the roof. These can help expedite engineering and permit review. If the drawings are accurate, they can also be referenced during installation. Some tools also provide a complete “balance of materials” report for the entire rack installation.

Attachment methods. Most rack manufacturers have an attachment method and compatible flashing designed for asphalt shingles—but not all flashings are created equal.



A solid structural attachment directly to the roof rafters is ideal. However, attachment to blocking or even sheathing is possible with the proper product choices and engineering.

A typical flashing for a rack's foot.

Courtesy Quick Mount PV (3)

Post feet can be installed prior to roofing material, allowing reroofing without compromising the structure.

Small, thin flashings can bend easily when lag-screwed into the framing, creating a concave shape that encourages water to run toward the penetration. The best flashings are wide, not too flexible, and elevate the mounting hardware above the roof with a raised base so that water flows around the penetration.

If coordinating the PV installation with installing a new roof, consider preinstalling posts and suitable flashing before the roofing material is laid down. Post-and-base installations are compatible with several different shingle types, and most roofers are familiar with flashing these, since they are similar to working around a vent pipe. The posts also allow for later reroofing while leaving all the rack attachments in place, which maintains the integrity of the roof framing and the lag-screwed posts.

Materials. Rack systems should be suitable for the environment in which they are installed, which means most are made from anodized aluminum with stainless steel hardware. However, as manufacturers try to be cost-competitive, more coated steel products are entering the market. Few, if any, of these steel racks have been in the field for the length of their warranty, so only time will tell how well this material will perform over the long term.

Wire management. Various third-party clips are available to help secure the PV module leads, home-run wiring, and MLPE cable assemblies. Some rack manufacturers have integrated wire management, which can help expedite the installation and protect the wiring. Good wire management helps ensure successful inspections, and prevents ground faults that are expensive to troubleshoot and can be a hazard to life and property.

Grounding. *NEC* Section 690.43(A) requires that any devices and systems used for mounting PV modules that are also used for bonding module frames be listed, labeled, and identified for such purposes. To meet this requirement, most rack systems include integrated grounding. The clamps and rails (and, sometimes, attachment hardware) are now listed to UL 2703 standard for "Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels." UL-listed hardware then connects the components together to form an electrical bond by cutting into the rack material and module frames. If UL 2703-listed racks are not used, then a ground wire needs to be connected to each module frame and, possibly, to each rack component in the system.

Fire classification. In 2012, the *International Building Code* stipulated that rooftop-mounted PV systems carry the same fire classification as the roof assembly. Previously, although PV modules had a fire class rating, the system, which includes the rack, did not. Based on this requirement, UL 1703 and 2703 standards include testing and fire classification for PV rack systems. If installing in a jurisdiction that enforces this *IBC* requirement, it is important to select a rack system that is code-compliant.

Various options for wire management can be integrated with racks, including clips, zip ties, and tucking wires into rail cavities. No matter what method is used, care must be taken to protect the wire's insulation.

Garrison Riegel

Choose Wisely

When selecting a rack system for a sloped-roof PV installation, there are many factors to consider and many rack manufacturers to choose from. The right rack system should be cost-effective and install quickly, but should also help decrease the soft costs associated with design, engineering, permit approval, and procurement. As the pressure to decrease BOS costs continues, installers are looking more closely at these ancillary benefits, selecting rack systems that support the PV modules and ease the installation process from start to finish.

MODERN ELECTRIC MOTORCYCLES

Courtesy Energica

by Ted Dillard

Dream of hitting the highway on two wheels, with no tailpipe pollution? An electric motorcycle could meet your needs for fun, exhilarating transportation.

Over the last 10 years, the electric motorcycle (EM) market has developed, yet only a handful of products have emerged that are available to the ready buyer. "Concept" bikes, custom builders, and what can only be called "startup vaporware" ventures have clouded the market with products that were either unavailable or unwise purchases. At this point, only a handful of electric motorcycles have proved to be reliable, supported, and viable.

We've set a few criteria for inclusion in this guide. The most important is that of homologation (the process of designing a vehicle that meets state and federal safety and environmental standards)—a daunting, expensive, and ongoing process. It's prohibitively expensive to homologate any vehicle after it has been designed; it's the reason you don't see many (if any) custom-designed, one-off machines making it into production.

The next criterion is having a traditional dealer network. When you're considering buying a vehicle for tens of thousands of dollars, you'll want to be able to visit a dealership and test-ride (or at least sit on!) the bikes. You'll also want after-sales support—for service and warranty repairs. While many companies tried creative alternatives to traditional dealer support, like marketing out of a big-box electronics store, the industry has settled on a more conventional strategy of dedicated electric vehicle dealerships or selling alongside gasoline motorcycles.

Only three brands meet these two criteria: Alta, Energica, and Zero. Alta has two models and has about 25 dealers signed up so far. Energica covers the "superbike" category (a type of production street motorcycle capable of being modified for racing) with three 150 mph models based on essentially the same drive-train—the Energica EGO, EGO 45, and the EVA. Zero has six models based on two main platforms, covering everything from fun-in-the-dirt bikes and supermotos to the SR, which compares to most midrange sport cycles.

Out of all the electric motorcycle companies, Energica and Zero Motorcycles have established a solid development curve, conventional sales and service support, and protections for customer loyalty in a fast-evolving technology. The risks of buying into this technology are far less daunting than even a few short years ago.

We're also including several electric motorcycles available that don't necessarily meet these criteria, yet are available to an interested buyer—either built-to-order or one-off designs. They include the Brutus, Johammer, Lightning, and Lito Sora. While some, like the Lito Sora, have earned homologation, there is no solid dealer network yet. Others, like Brutus, are in the process of developing a fully homologized machine.

Electric Tech

The most common motor in use today is a brushless, high-rpm AC design, yielding an almost maintenance-free power plant, low weight, and a remarkable degree of speed and power control. Most EMs use the relatively new lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$; NMC) chemistry for their batteries—the same used in electric cars like the Nissan Leaf. These batteries have set the standard due to their ability to provide sufficient power and high energy density—lots of kWh in a small, lightweight package.

The current range hovers around the 100-mile mark. With the previous chemistries used only a few years ago, expanded range was an elusive target. Of course, your motorcycle's actual range will vary, since it depends on riding style, speed, and the weight of the rider and cargo.

Charging solutions have evolved as well. While any of these vehicles can be recharged with a standard wall plug, several bikes feature the Level 2, J1772 standard—a 240 V, up to 30 A option standard on most car-charging stations that cuts the charge time by more than half (see "Charging Times" table).

Alta Motors

Alta's marketing campaign focused on why we like to ride (because it's FUN!) with some clever videos and ad work, capturing the imagination of the motorcycle world. In 2016, the company started delivering bikes. While there's a limited dealer network, they cover the United States in traditional gas motorcycle dealerships focused on off-road riding. They've maintained interest in the Redshift, their base model, for nearly a decade, partly due to the leadership of Tesla's cofounder Martin Eberhard (in 2013) and some serious financial backing.

Alta's two basic models are the Redshift MX, an off-road motocross version; and the Redshift SM, a supermoto (see "E-Motorcycle Terminology" sidebar) configuration, with similar specs. As off-road recreational machines, these models are an almost-perfect application of an electric drive-train—lightweight with enormous torque and an interchangeable battery pack, and are ideal for pits and tracks.

Courtesy Alta Motors (2)

Comment & Discuss this article @ homepower.com/181.30

Above: The Alta Redshift SM.

Left: The Redshift MX.

The Energica EVA.

Courtesy Energica (2)

Energica

Energica offers three variations of the EGO, its 150 mph, 600-pound, 0-to-60 mph-in-less-than-3-seconds core model. The EVA is a slightly tamer, stripped-down bike with a lower saddle height and with a lower (limited) top speed. It's a bit more comfortable and easier to handle for those with shorter legs. The EGO 45 is a richly appointed model with essentially the same specs as the base EGO, but a more hand-built fit and finish. The EGO 45 is a limited edition, and includes, with the purchase, a factory tour (in English or Italian), and an exclusive Olmo watch by Lowell, made entirely out of wood.

The bikes debuted in 2015 with a few tweaks (such as ABS braking, promised in the final models and ultimately delivered), but have largely remained unchanged. They are fully homologated worldwide, with dealer networks in Europe and North America. The EVA and EGO base models are $34,544; and the EGO 45 (if available), retails for a starting price of $40,000, depending upon customization. One of the more notable features of the design is the vehicle control unit (VCU), which takes full advantage of the electric drive-train's power, includes regenerative braking and suspension control, and results in possibly the most comfortable and controllable throttle response I've experienced. Once the bike is rolling, its mass fades into a memory, and it's as light and agile as any 150-mph-capable bike I've ridden.

The bikes have a 3 kW onboard charger, accepting 120 and 240 VAC, and are compatible with SAE J1772 and IEC 62196-2-equipped charging stations. Energica also launched a Tesla Supercharger-like limited network of proprietary DC fast-charging stations in Italy and California—dedicated 20 kW DC chargers (DC technology, Combo CCS standard plugs).

The EGO and EGO 45 are true superbikes, at an 150 mph top speed and 0-to-60 mph acceleration in 3 seconds.

E-Motorcycle Terminology

ABS
An antilock braking system (ABS) is used on most modern motorcycles.

Battery Pack
Battery pack specs indicate the nominal capacity (expected typical use) and the maximum capacity (estimated "best-case" capacity, often not a "real-world" number).

Several models provide battery capacity options. A larger pack may provide greater range, but with more weight and a longer recharge time. Optional on-board and off-board charging is common. Several manufactures have hot-swap battery packs, which are good for track use.

Chassis, Suspension & Brakes
Many electric bikes use suspension components supplied by third-party manufacturers, either off-the-shelf parts or built to spec for the bikes. This includes front and rear suspension, brakes, wheels, and tires.

Dimensions
A bike's dimensions include the wheelbase (which indicates the bike's agility and responsiveness); the seat height (an important metric for both long- and short-legged riders); carrying capacity; and the weight—perhaps most significant to the overall handling of the bike.

Drivetrain
In all current models, the "transmission" reference is moot—an electric bike is direct-drive, with no gears. The "final drive" is a belt or chain between the motor and the rear wheel. While a belt is maintenance-free and nearly silent, a more traditional chain-drive is more versatile, adjustable, and arguably stronger—but requires oiling and cleaning.

Electronics & Displays
Electronics and displays on electric motorcycles are remarkably sophisticated, since the motor control allows easy and precise integration with the vehicle control unit. Smartphone integration may include charging information and controls.

Monocoque Frame
A monocoque (French for "single shell") frame can refer to a car, motorcycle, or even an aircraft where the vehicle body is designed to be part of, or entirely, the structural support. In cars, it became popular in the '80s as "unibody" construction.

Motor
Motor specs include torque (an indication of "off-the-line" performance) and power (watts or hp), which indicates the top speed and load-carrying capability of the motor.

Range
Range estimates often are a combination of riding at city speeds, plus highway speeds (70+ mph), and lower speeds (55 mph).

Pack Life
Pack life estimates the years of expected life of the battery pack under normal use.

Power & Energy
Power and energy are two key concepts in understanding electric vehicles, and are often confused. Power is the ability to perform work over time. It is also known as a rate of energy consumption or production, and is discussed in terms of horsepower (hp), watts (W), or Joules per second (J/s). For example, pushing a cart slowly requires a certain amount of power. Pushing it faster, or pushing it uphill, requires more power. In a motorcycle, the power a battery pack can deliver will determine its acceleration and top speed. While power is a rate, energy is a quantity—power used or available over a period of time. For example, pushing a cart at 5 mph for 15 minutes requires a certain amount of energy. It is one way to describe battery capacity, which, in turn, is one of the factors determining the range of the vehicle. In an EV, it's generally described as kilowatt-hours (kWh). One kWh is equal to 1,000 watts for a period of one hour. (See homepower.com/power-vs-energy for more information.)

SAE J1772
SAE J1772 refers to a North American standard electrical connector used in electric vehicle charging stations. The J1772 standard includes two basic charging levels:

	Voltage	Phase	Peak (A)	Power (kW)
AC Level 1	120	Single	16	1.92
AC Level 2	208	208Y 3-phase	30	6.24
AC Level 2	240	Split	30 32 (2001) 80 (2009)	7.20 7.68 19.20

via Wikipedia

Stressed Members
Stressed members (battery box): A stressed member is an engineering term for any part of a design that acts as a mechanical support for the machine. In the motorcycle world, it commonly refers to the engine and transmission which, rather than simply being cradled in the frame, is part of the frame's structure and lends strength and rigidity to the chassis. A few electric motorcycle designs have experimented with a stressed battery box, including Brammo's Empulse and Enertia, and the Amarok—a Canadian-built race bike.

Supermoto
The supermoto bike evolved out of a 1970s race that included three courses in one race—flat-track, a dirt oval in which the rider spends most of the ride in a high-speed, controlled slide; motocross, again a dirt track, but with hills, bumps, ruts and jumps; and a paved road race course. The bikes have evolved to resemble the off-road design of a pure motocross bike, but equipped with street-capable tires. Recently, they've become a popular style of commercially available bike.

Vehicle Control Unit (VCU)
The VCU is an electronic control that handles much of the vehicle's functions. Originating in fuel-injected, gasoline cars, it is a natural fit for electric vehicles, incorporating speed, acceleration, regen braking, and power curve controls, as well as antilock braking and suspension balance.

Zero Motorcycles

Zero Motorcycles offers models with different battery capacity options. The lineup starts with the FX and FXS as the lightest and most affordable. The FX is an off-road, but street-legal bike and the FXS is a supermoto but equipped with street tires. They both come with 3.3 or 6.5 kWh battery options, and for chain-drive traditionalists there's a conversion kit available.

The S and SR are strictly for street use and, in the case of the SR, with impressive performance even for gas-bike enthusiasts. The DS and DSR are "dual-sport" EMs for street and limited off-road use. For both the S/SR and the DS/DSR, the "R" indicates higher performance, with a 52 kW (70 hp), 116-foot-pounds motor—a slight increase over the 45 kW (60 hp) non-R version. Both the 2017 models sport a 6.5 kWh standard battery. An optional 13 kWh pack is available. All models support adding the Power Tank ($2,695), which at 3.3 kWh, boosts battery capacity to 16.3 kWh and range to about 200 miles.

Charging is via the onboard 120/240 VAC charger or the $2,000 dealer-installed Charge Tank option that uses a Level 2, J1772 charging standard and triples the charging rate from the base charger. The Charge Tank and the Power Tank won't fit the bike simultaneously. Off-board Quick Chargers are available that work in conjunction with on-board chargers, and increase charge rates by 1 kW each.

The Zero FX.

The Zero DS, dual-sport.

The Zero SR.

Courtesy Zero Motorcycles (3)

Built-to-Order E-Motos

Brutus Motorcycles

The initial, circa 2010 Brutus one-off custom bike spawned a lineup of variations—the Brutus V2 Rocket, Brutus V9, Brutus 2, and Brutus 2 Café. Under the original name Bell Custom Cycles, the small team put together a few contracts for custom projects, attracted investors, and is in the process of developing a new homologated model.

The bikes fill a void in electric motorcycle availability—the large cruiser, suiting riders who want a comfortable machine with longer range (a little more than 200 miles). Bell has a handful of bikes on hand, and is ready to custom-build on demand.

In today's world of mass-production, the chance to buy a custom-built product is rare. The Bell bikes can be tailored to a rider's tastes, even to the point of custom-designing the fit of the chassis to the rider's physique. Like any handmade product, the fit and finish reflects the builder's care and craftsmanship. The downsides? It's not something you can buy on-demand, and you'll pay a premium for it.

The Brutus 2.

Courtesy Brutus Motorcycles (3)

The Brutus V9.

The Brutus V2 Rocket.

Johammer

An interesting aspect of the electric motorcycle industry's evolution was the rethinking of motorcycle design. The electric drivetrain presented an opportunity to start from scratch, covering everything from front suspension and vehicle control strategies to basic frame design. Many never made it past the concept stage. Several, built as prototypes, remained as one-off prototypes like the MissionR (only one powered bike existed) and the Vectrix Superbike. Among the oddest bikes built have persisted and are available through a limited European dealer network—The Johammer J1.150 and J1.200.

Designed around a stressed battery box (but just short of a monocoque frame), an in-wheel motor and controller combination, and a unique front suspension and body design, the performance is modest, at best. The Johammer in either configuration is probably more for the rider looking to turn heads and possibly own a bit of history, than a biker looking to replace their gas machine.

Courtesy Johammer

The Johammer J1.150 & 200.

Lito Sora

Canadian Lito Sora is positioning itself as the "first luxury electric superbike"—with a fully homologated product yet no apparent dealer network in Canada nor the United States. The $77,000 price for the base model and $104,000 for its Signature Series bikes certainly put them in the luxury market, but the machines' specifications and performance don't really back that up. Nor do the bikes qualify for superbike status. With a 120 mph top speed and a 120-mile claimed range, the bikes would be hard-pressed to hold their own against the 2017 Zero SR with the optional Power Tank. The site claims a delivery list due to an overwhelming response (to the higher-priced Signature Series model, no less) and an order requires a $10,000 deposit.

The Lito Sora.

Electric Motorcycles

Manufacturer	Model	Range (Miles)	Top Speed (MPH)	0 to 60 MPH (Seconds)	Battery Capacity (kWh)	Weight (Lbs.)	Price (Base)	Warranty (Battery/ Bike— Yrs.)	Dealer Network	Availability
Alta Motors altamotors.co	Redshift MX	3 hrs. (continuous)	65	3.0	5.8	267	$14,995	2/1	Yes	Yes; ltd.
	Redshift SM	50	80	3.0	5.8	275 (Race), 283 (Street)	$15,495			
Brutus brutusmotorcycle.com	V2 Rocket	150	200+	4.1	12.8, 17.8, or 21.7	545	$75,000	Bike: 1 yr./ 12,000 mi.	No	Yes; order
	V9	225	125	5.1	18.8 or 33.7	784 or 886	$85,000			
	2	150	135	4.7	10.0	485	$65,000			
	2 Café	150	135	4.7	10.0	460	$65,000			
Energica energicamotorusa.com	EVA	100 - 130	125 (limited)	< 3	11.7	621	$34,544	3/2	Yes	Yes
	EGO	90 - 120	150 (limited)	< 3	11.7	621	$34,544			
	EGO 45	90 - 120	150 (limited)	< 3	11.7	621	$40,000			
Johammer johammer.com	J1.150	93	75	7.0	8.3	350	$25,600	Info N/A	Yes	Yes
	J1.200	124	75	8.0	12.7	390	$27,900			
Lito Sora soraelectricsuperbike.com	Base	62 - 124	118	4.7	12.0	573	$77,000	Info N/A	No	Order
	Signature Series	62 - 124	118	3.9	12.0	573	$104,000			
Zero zeromotorcycles.com	S ZF6.5	50 - 60	91	4.8	6.5	313	$10,995	3/2	Yes	Yes
	S ZF13.0	108 - 120	98		13.0	408	$13,995			
	SR ZF13.0	108 - 120	102	3.3	13.0	414	$15,995			
	DS ZF6.5	47 - 55	91		6.5	317	$10,995			
	DS ZF13.0	95 - 110	98	5.7	13.0	413	$13,995			
	DSR ZF13.0	95 - 110	102	3.9	13.0	419	$15,995			
	FX ZF3.3 MODULAR	24 - 31	85	4.3	3.3	247	$8,495			
	FX ZF6.5	49 - 62	85	4.0	6.5	289	$10,495			
	FX ZF6.5 MODULAR	49 - 62	85		6.5	289	$10,495			
	FXS ZF3.3 MODULAR	26 - 34	85	4.1	3.3	251	$8,495			
	FXS ZF6.5	52 - 68	85	3.8	6.5	293	$10,495			
	FXS ZF6.5 MODULAR	52 - 68	85		6.5	293	$10,495			

Courtesy Energica

Carving up the twisties with the EGO 45—a true Italian superbike.

In 2017, we're witnessing the results of a remarkably short, 10-year gestation of electric motorcycles. The major bike manufacturers—BMW, Ducati, Honda, KTM, Polaris, and Yamaha—are watching closely, and in some cases have dabbled with their own prototypes. The bikes you can buy today, though, are the result of a few companies sticking to the basics—getting significant backing, offering reliable and upgradable products, and backing up their dealer and customer base with credible support. Most importantly, for a buyer, the costs have stabilized, and in some cases, dropped. In addition, electric motorcycles may qualify for financial incentives, such as tax credits and rebates.

Courtesy Alta Motors

The Alta MX charges up for another run in the dirt.

Electric Motorcycle Charging Times

Manufacturer	Model	Charge Time (Hrs.)
Alta	Redshift MX	2.5 (240 VAC) / 4.0 (120 VAC)
	Redshift SM	4.0 (240 VAC) / 6.0 (120 VAC)
Brutus	V2 Rocket	2.0
	V9	2.0
	2	2.0
	2 Café	2.0

Manufacturer	Model	Charge Time (Hrs.) 100%, Mode 2 or 3	Charge Time (Hrs.) 85%, Mode 4 DC Fast Charge
Energica	EVA	3.5	0.5
	EGO	3.5	0.5
	EGO 45	3.5	0.5

		Charge Time (Hrs.)
Johammer	J1.150	2.3
	J1.200	3.5
Lito	Sora	9.0

Manufacturer	Model	Standard	Charge Time (Hrs., for 100% / 95% Charged): With Charge Tank Accessory	With One Accessory Charger	With Max Accessory Chargers
Zero	S ZF6.5	4.7 / 4.2	1.9 / 1.4	2.9 / 2.4	1.6 / 1.1
	S ZF13.0	8.9 / 8.4	3.4 / 2.9	5.2 / 4.7	2.6 / 2.1
	S ZF13.0 + Power Tank	11.0 / 10.5	N/A	6.4 / 5.9	3.1 / 2.6
	SR ZF13.0	8.9 / 8.4	3.4 / 2.9	5.2 / 4.7	2.6 / 2.1
	SR ZF13.0 + Power Tank	11.0 / 10.5	N/A	6.4 / 5.9	3.1 / 2.6
	DS ZF6.5	4.7 / 4.2	1.9 / 1.4	2.9 / 2.4	1.6 / 1.1
	DS ZF13.0	8.9 / 8.4	3.4 / 2.9	5.2 / 4.7	2.6 / 2.1
	DS ZF13.0 + Power Tank	11.0 / 10.5	N/A	6.4 / 5.9	3.1 / 2.6
	DSR ZF13.0	8.9 / 8.4	3.4 / 2.9	5.2 / 4.7	2.6 / 2.1
	DSR ZF13.0 + Power Tank	11.0 / 10.5	N/A	6.4 / 5.9	3.1 / 2.6
	FX ZF3.3 Modular	4.7 / 4.2	N/A	2.1 / 1.6	1.5 / 1.0
	FX ZF6.5	8.9 / 8.4	N/A	3.8 / 3.3	1.7 / 1.2
	FX ZF6.5 Modular	8.9 / 8.4	N/A	3.8 / 3.3	1.7 / 1.2

Microhydro Equipment & System Design

by Hugh Piggott

A hydro-electric system uses the flow of water down a slope to create electrical energy. The amount of energy depends on how much water is flowing, and on the height difference (head) between intake and turbine. This article covers selecting the necessary equipment, from the intake to power electronics.

Courtesy Tim Redshaw

Courtesy Michael Wallford

1 Intake

An **intake** is required to channel water into the hydro system. A reservoir of water is an ideal microhydro source, but it's not essential and most sites don't have one. Instead, water is diverted from a flowing stream or creek into an intake that must be robust enough to withstand floods. Build a small weir or choose a natural constriction in the stream where you can catch the water.

2 Screen

A **screen** of sufficient area prevents things like vegetation, pebbles, and fish from entering the penstock—the pipe that carries water to the turbine. If placed deep in a very large body of static water, this screen may not need much maintenance. It may just need occasional scrubbing with a long-handled brush. Fast-moving water brings debris that must be cleaned off the screen frequently. The best solution is a sloping screen on top of a box or tank that feeds the penstock. Smooth, perforated stainless steel plate or even mesh is suitable screen material. Aquashear (Coanda-effect) screens are virtually maintenance-free if the approach velocity of the water is correctly engineered.

Divert the flow so it spills over the screen, or embed a collection tank in the bottom of the stream or at the edge of a fall. The mouth of the penstock must be large enough and deep enough in the water that it does not create a vortex and draw air.

Brent Summerville

3 Vent Pipe

A single, vertical **vent** downstream of the screen near the top of the penstock helps bubbles escape, prevents damage to the intake from suction if it gets blocked, and removes any trapped air from the penstock, when it is filling up. A **valve** is essential at the bottom of the penstock to shut off the turbine, but rarely needed at the top. If you fit a valve at the top of the penstock, put it upstream of the vent, so you can drain the penstock if desired. Valves at the turbine end of the penstock should be a type that closes slowly, to avoid pressure surges.

4 Penstock

The **penstock** is the engine that drives the turbine, and is the most important part of the hydro system. This pipe doesn't just deliver water—it also provides pressure (see "Penstock Example" sidebar). The longer the penstock is, the larger its diameter must be, or friction will reduce the pressure, decreasing the energy available. Choice of pipe is a compromise between cost and efficiency—a long pipe often makes the penstock more costly than the turbine.

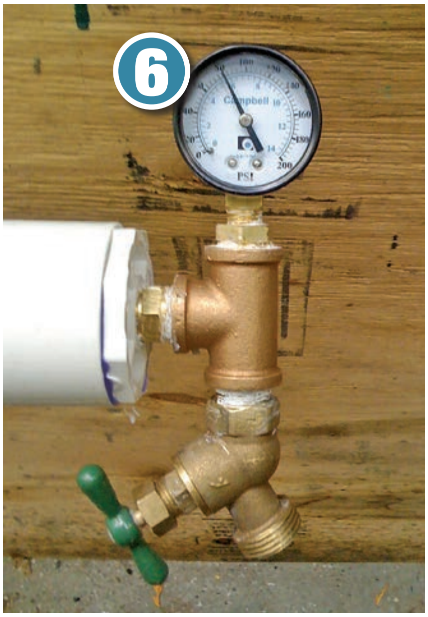
To make the best of limited water, try to keep penstock pressure losses below 20%. There are many online pipe friction tables and calculators for different pipe materials, but few that will factor in friction increases as pipes get older and dirtier. Oversizing the pipe is a good investment for the future.

5 Manifold

You'll need to figure out how to connect the penstock to the turbine using valves, tees, and elbows to construct a **manifold** (used for multiple nozzles on a turbine). It's important to avoid or limit tight bends with small-diameter pipe or there will be additional friction loss.

6 Pressure Gauge

A **pressure gauge** is key for troubleshooting any hydro system—include one in the manifold. Position it upstream of the nozzle control valves so that the static (gross) head as well as the operating (net) head can be measured. If there is not enough water entering the intake, the pipe will begin to draw in air. Head will drop and demand must be reduced. Don't partially close a valve to restrict flow, because it will reduce the pressure at the nozzle. Close valves fully (but slowly) if you do not want a nozzle in operation.



Ian Woofenden (3)

web extras

"Methods: Hydro Measurements" by Ian Woofenden in *HP170* • **homepower.com/170.14**

"Microhydro Turbine Buyer's Guide" by Hugh Piggott & Ian Woofenden in *HP174* • **homepower.com/174.28**

"Harvesting Surplus Energy, Off-Grid" by Hugh Piggott in *HP179* • **homepower.com/179.46**

"Microhydro Intake Design" by Jerry Ostermeier in *HP124* • **homepower.com/124.68**

Penstock Example

This typical example illustrates how the losses in a penstock are affected by flow rate.

Penstock data:
1,000 feet long
2 inches internal diameter
100 feet of vertical fall

We used a pipe friction calculator to determine the net head (shown in green) over the range of possible flows. This line also represents the pipe efficiency (in percent). We then used the rule below to estimate the available power in watts. This is shown in blue.

Power (W) = Net Head (ft.) × Flow (gpm) ÷ 12

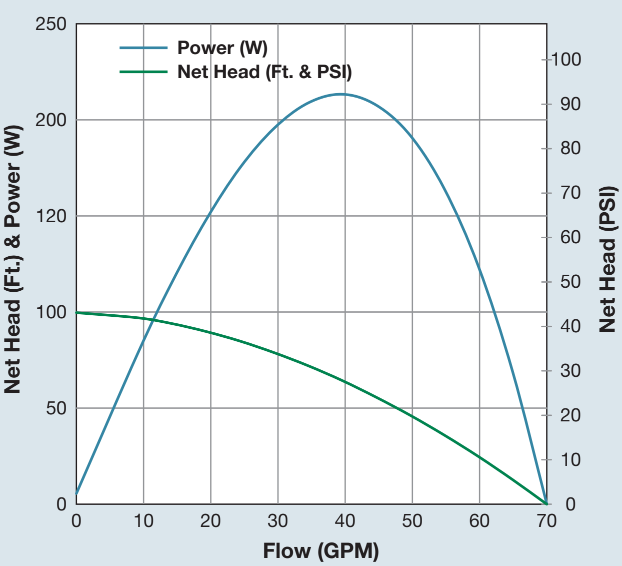
At this site—with 100 feet of head and the valves closed—the pressure gauge should read 43 psi. The flow is controlled by the nozzle sizes fitted in the turbine. If all constrictions are removed so that the pipe runs "full-bore," there will be no pressure on the gauge, and we will see about 70 gpm flow, but no power.

Maximum power for this penstock is achieved by using nozzles that reduce flow to 40 gpm. This coincides with a net head of 66 feet (the gauge will read 28 psi).

However, this 2-inch-diameter pipe may not be the best choice for a 40 gpm flow because the efficiency is only 66%. If 40 gpm is available for enough of the year then it's worth considering the cost of larger pipe; this diameter is a good choice for a site with 20 to 30 gpm flows. Observe how the efficiency is much higher at these slightly lower flow rates.

Your choice of pipe diameter will be governed by the sizes that are available and by how much the pipe costs relative to the pressure loss it incurs. In most cases, a target of 80% to 90% efficiency is cost-effective. But if the pipe is the major cost, or you wish to benefit from short-term high flows, then 66% efficiency could be the right choice.

Maximizing Penstock Efficiency



7 Turbine

The **turbine** must suit the site conditions, matched to the alternator in a package that works for your specific site's head, flow, and operating voltage. A Pelton turbine works well at high heads, or for low flow. For high flow on very low-head sites, a propeller (aka low-head—LH) turbine that sits at the top of a vertical draft tube (see photos on pages 38 and 43). Turgo and crossflow turbines are options for intermediate site conditions. The ranges of all these turbines overlap and are well-documented by manufacturers.

Reliability, efficiency, and cost are important criteria for choosing a turbine. In cases where the rest of the system is very expensive, efficiency is more important than cost. It makes no sense to spend thousands on large pipes and cables, and then sacrifice performance to save a few hundred dollars on the turbine. Look for good technical support, and learn how to do the maintenance.

Pelton

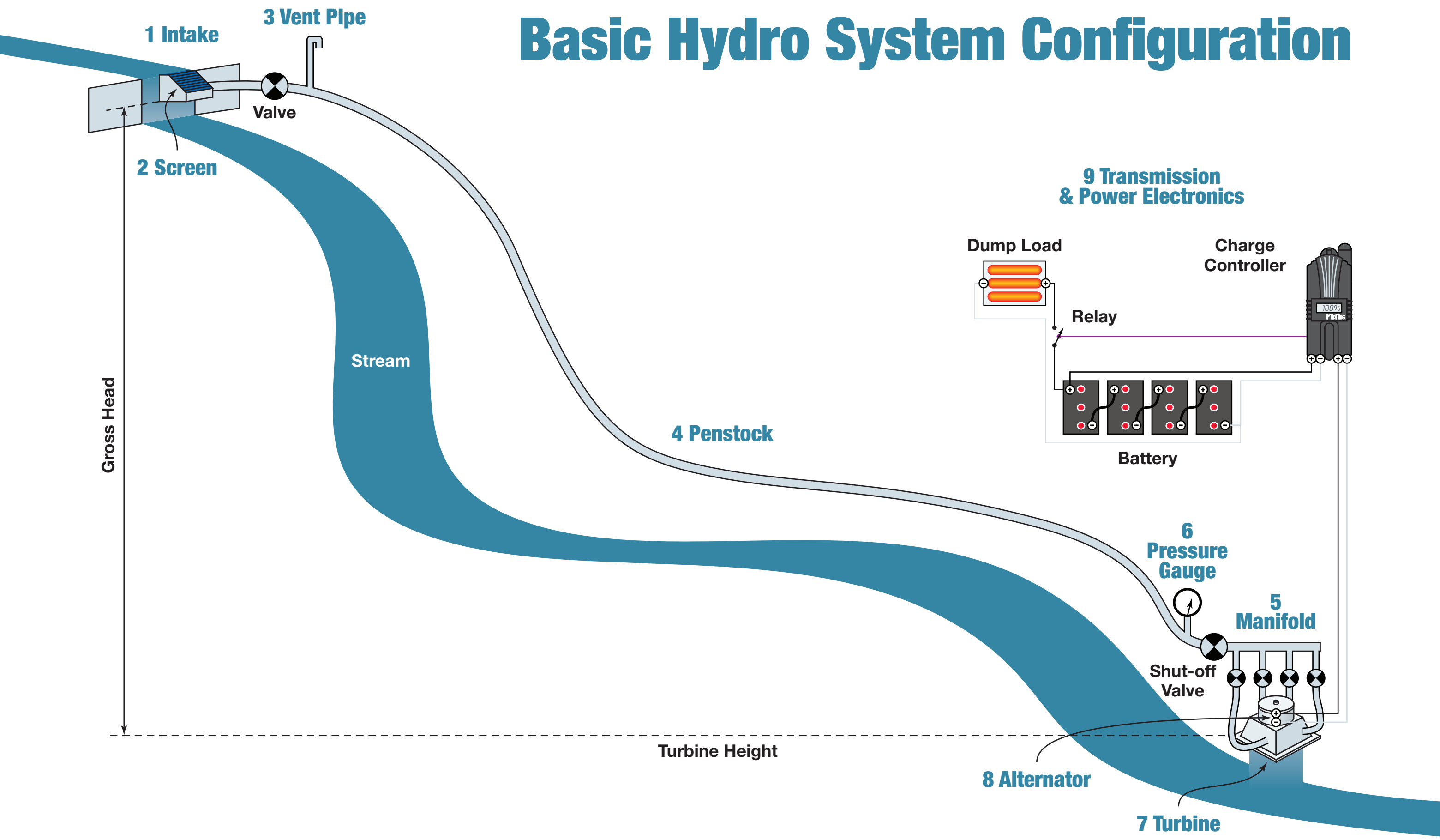
Turgo

Courtesy PowerSpout (2)

Hugh Piggott

Propeller

Basic Hydro System Configuration



8 Alternator

Almost all domestic-scale microhydro turbines are supplied with **permanent-magnet alternators (PMAs)**. The turbine's output is converted to DC and fed to battery/inverter systems or to grid-tied inverters. Some manufacturers custom-build their alternators, but others find mass-produced brushless PM motors a cost-effective solution because they are low-cost, efficient, and reliable.

On larger systems, induction motors are sometimes used instead of PMAs for the same reasons. Induction motors can produce off-grid AC. Larger turbines that produce AC for direct use are more often supplied with brushless alternators with wound-field coils and automatic voltage regulators.

Permanent-magnet alternator (PMA)

Ian Woofenden

Induction motor as alternator

Courtesy Hi Power Hydro

9 Transmission & Power Electronics

The farther the turbine is from where the electricity is used, the more expensive it may be to run **wire**. As with the penstock, you must weigh cost versus the energy loss. Wire used at common battery voltage is heavy and expensive—not because it is DC**,** but because low voltage has greater wire loss. For example, you'll need 16 times more copper in a cable for a 12-volt microhydro turbine than you would for a 48-volt turbine of the same power. It is common to use even higher DC voltages—like 200 VDC—feeding a maximum power point tracking (MPPT) charge controller or a grid-tied inverter. (High voltages can be lethal. Stop the turbine and isolate the wiring before working on connections.) The only advantage of AC for power transmission is that you can use transformers to easily step the voltage up at the turbine and back down at balance-of-system electronics. MPPT devices (controllers and inverters) now make this unnecessary.

Most small off-grid hydro systems are **battery-based**, so the accumulated energy can be stored and used when needed. The battery will not cycle as much of the energy as it would in a PV system, but it still needs to be suitably chosen to maximize its service life. You will need to program the charge controller with the correct voltage settings for your chosen battery type. Larger hydro systems may be able to be used off-grid without batteries, but there will need to be a lot of surplus water power available.

Power electronics—**charge controllers and inverters**—for microhydro systems have evolved rapidly in recent years, becoming more sophisticated and useful, and less expensive. They can:

- Convert power. A high DC voltage in the transmission wire is stepped down to battery voltage or converted to grid AC.
- Maximize power output with MPPT by adjusting operating voltage. Solar controllers and grid-tied inverters can often work as well for microhydro turbines as they do for PV modules. MPPT software finds the best operating speed for the flow conditions. Make sure the equipment is compatible with your turbine and warranted for microhydro use.
- Charge controllers limit the charging current during most of the battery's recharging cycle, based on voltage settings for your battery type.
- Energy diversion serves two functions. First, it protects against turbine overspeed, which can produce noise, wear, and possible damage. Turbines become unloaded when charge controllers limit the flow of energy from the turbine to the battery. Similarly, grid-tied inverters delay connecting the turbine during startup, resulting in overspeed. Diversion of energy to a heating load avoids these issues by keeping the turbine under load.

The second reason for diversion is to maximize your turbine's value by using all of the available energy. A well-designed battery system has regular energy surpluses. Rather than using a "dump load," it's better to take the opportunity to heat water or even your home.

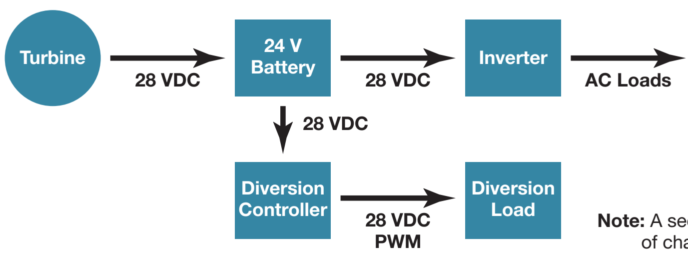
Courtesy MidNite Solar

Direct or MPPT?

It is possible to connect a turbine's PMA directly to batteries via a simple rectifier, but you will need a pulse-width-modulated (PWM) diversion controller, such as Morningstar's TriStar, to control your battery charge rate. Be aware that this is not a fail-safe method. If it cuts out on overload, the battery can be overcharged, which can cause expensive damage and even explosions. To protect against dangerous overcharging, the *National Electrical Code (NEC)* requires the diversion load to be oversized in relation to all of the charging sources. For safety, the *NEC* also requires a second independent means of charge control.

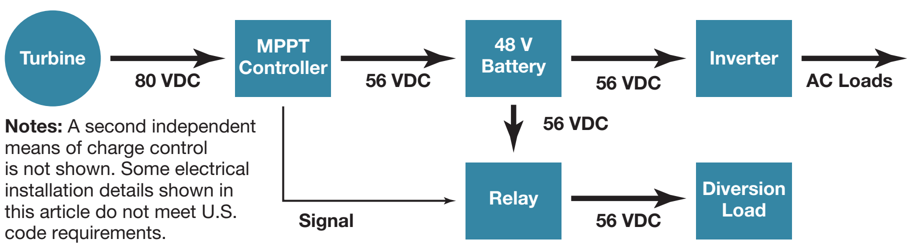
Sometimes, MPPT charge controllers have auxiliary ports that make diversion easy, to prevent turbine overspeed or to harvest surplus energy. Or you may use a diversion controller alongside your MPPT. Set the MPPT controller's battery voltage setpoints slightly higher than the diversion controller, and it will serve as a safety net in case the diversion control fails. In the "Direct Diversion" illustration below, the diversion controller plays a critical role for safety, so redundant capacity is recommended. In the case of MPPT, there is no danger of overcharge.

Direct Diversion



Note: A second independent means of charge control is not shown.

Relay Diversion



Notes: A second independent means of charge control is not shown. Some electrical installation details shown in this article do not meet U.S. code requirements.

Case Studies

Low-Power Turbine with Hot Water Diversion

Andrew has a vacation house on an island that he visits when he has time. He had been using an old diesel generator with batteries and an inverter for lighting and small appliances. Then he decided to tap the nearby stream that runs past the house. The stream has a fall of 80 feet; its flow varies depending on rainfall.

Andrew put in a Harris turbine that has four nozzles of various sizes, each controlled by a valve on a manifold. During the rainy season, the turbine can generate 300 W (7.2 kWh of energy per day). When the house is unoccupied, he adjusts nozzle choice to leave the turbine running at 80 W (nearly 2 kWh per day) to keep the 400 Ah battery charged. A TriStar controller diverts surplus energy to heat the top of a 30-gallon tank-style water heater. Even 80 W of heat can produce 10 gallons of hot water over a 12-hour period. When the water in the tank reaches 120°F, a relay switches the diversion to an air-cooled dump resistor in the battery shed.

Andrew runs the diesel generator to power his washing machine and for battery charging. During this time, the inverter/charger raises the battery voltage, which triggers the water heater—even though the inverter can control its own charging cycle. But the heater is only a small load for the generator, and hot water is useful for clothes washing.

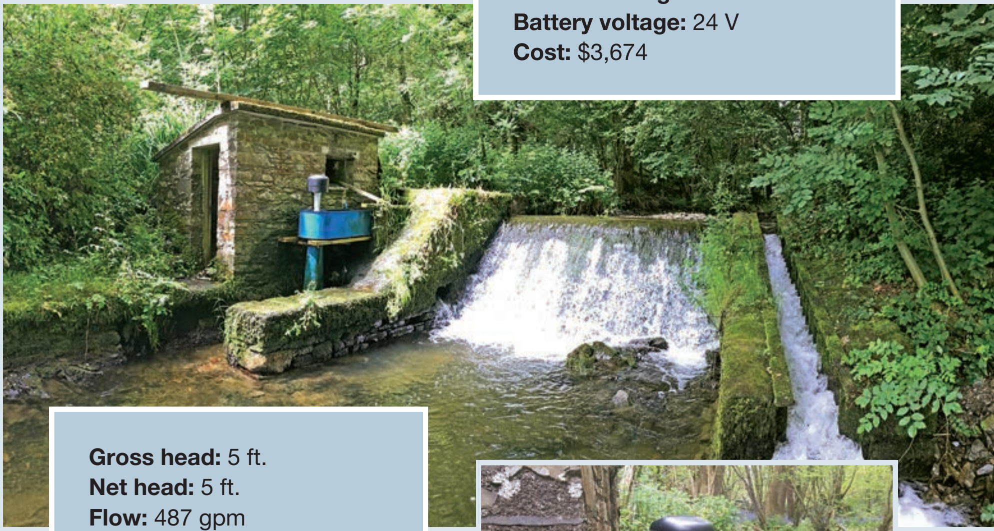
Hugh Piggott

Gross head: 80 ft.
Net head: 66 ft.
Flow: 42 gpm
Penstock length: 400 ft.
Penstock diameter: 2.0 in.
Turbine power: 0.30 kW
Turbine type: Pelton
Turbine make: LoPower Harris
Generator: PMA
Turbine voltage: 24 VDC
Battery voltage: 24 V
Cost: $3,674

Low-Head Grid-Tied Upgrade

Tim has an old mill site with a 5-foot head. He can't increase the head easily because of the need to maintain fish passage, which also diverts some of the flow from the turbine. He installed a PowerPal LH turbine with a Mastervolt grid-tied inverter, but recently upgraded to a PowerSpout LH with Ginlong Solis Mini inverter. The PowerSpout unit fit the existing spiral flume, but its output could be improved by a straighter flume, which could also include more turbines for use in wet weather.

The inverter communicates with Tim's router by WiFi and a "powerline" ethernet adapter, enabling him to view his system's energy production online. The turbine produces a steady 300 W most of the time, adding up to more than 2,000 kWh each year. Tim has a feed-in tariff contract whereby this energy is metered and he is paid 10 cents per kWh in addition to offsetting his utility bill.



Gross head: 5 ft.
Net head: 5 ft.
Flow: 487 gpm
Penstock length: 5 ft.
Penstock diameter: 8.0 in.
Turbine power: 0.30 kW
Turbine type: Low-head
Turbine make: PowerSpout
Generator: PMA
Turbine voltage: 200 VDC
Battery voltage: None
Cost: $2,003

Courtesy Tim Redshaw (3)

Hybrid System with Direct 24 V Battery Charging

When Nigel bought a large off-grid house on the Scottish west coast, he installed a 16 kW diesel generator; six OutBack VFX3024 inverters; and a 3,000 Ah, 24 V battery. Nigel's 500 feet of 5-inch pipe gives up to 323 gpm at 100 feet of head from the stream (with 10% loss). Three ES&D Stream Engine turbines charge the battery, and ES&D helped him configure the turbines for the site. The turbines were connected to the battery with wiring suitable for the 100 A combined output current, and two TriStar PWM controllers in diversion mode regulate the charging voltage. Metering in the house enables Nigel to monitor power and energy from the systems, along with battery voltage and water pressure.

When there is enough water, the system produces 2.5 kW, and there is no need for the diesel generator. To protect the battery from overcharging, surplus energy is diverted to an air-heating diversion load. A relay in one of the OutBack inverters also sends surplus energy to a 40-gallon water heater and acts as an "independent means" to control voltage.

The stream's flow rate is volatile. When the rain stops, Nigel has to close valves at the manifold, which reduces the flow and avoids drawing air into the penstock. At times, there is not enough flow to generate any power, so Nigel added a 5 kW PV array to the system for the drier periods, which are often sunny. The array is more than 100 feet from the battery, so he wired the modules at 90 V through TriStar MPPT controllers to reduce the required wire diameter for a long wire run.

Hugh Piggott (3)

Gross head: 100 ft.
Net head: 80 ft.
Flow: 323 gpm
Penstock length: 500 ft.
Penstock diameter: 5.0 in.
Turbine power: 2.70 kW
Turbine type: 3 Turgos
Turbine make: ES&D
Generator: PMA
Turbine voltage: 24 VDC
Battery voltage: 24 VDC
Cost: $64,500

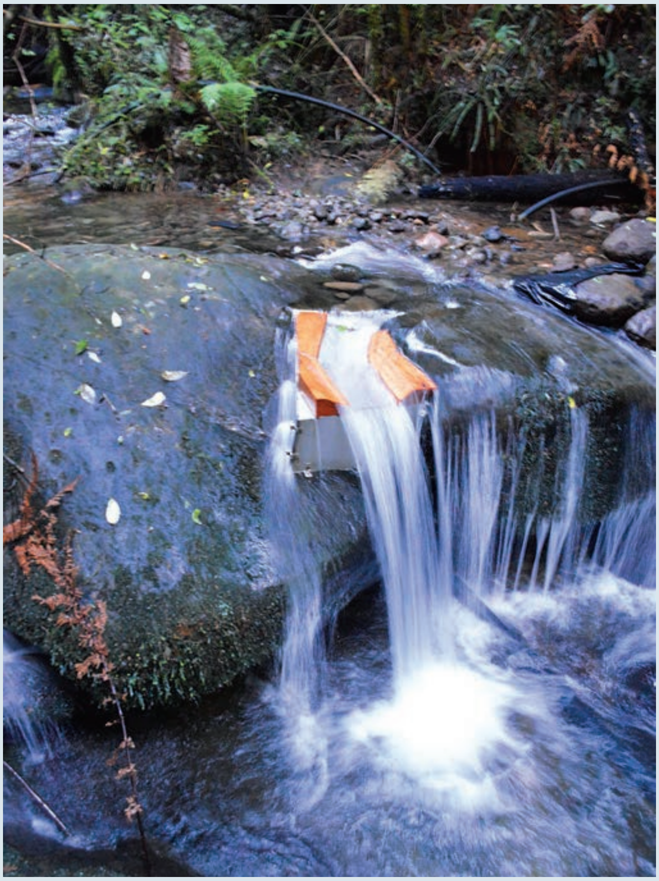
Off-Grid Home with MPPT-Controlled Hydro

Kane built his house at the edge of the New Zealand bush, far from the grid. A stream flows through his property, and an early priority was to install a microhydro system to provide electricity for running the builders' power tools.

Permitting requirements were extensive and expensive. Stipulations included ensuring a minimum flow in the stream, which he accomplished by deliberately diverting some water. In the summer, when the stream's flow drops, he may need a small PV system.

Kane fitted a custom tank onto the sloping faces of two boulders at the top of a low waterfall, cutting the rock faces to accept the edges of the stainless-steel tank, secured by a dozen rock-bolts. A fine screen on top filters debris from reaching two PowerSpout Pelton turbines. A MidNite Classic MPPT controller connects them to a 48 V battery and a pair of OutBack VFX inverters. The microhydro system was designed using the manufacturer's online calculation tool, but produces 15% more than the estimated 2,050 W output. The MPPT controller optimizes the turbine speed, by tracking to the best voltage, to obtain maximum power. This is the default configuration for PowerSpout off-grid systems.

When the batteries initially reached full charge, the Classic started to taper down the current to prevent battery voltage exceeding the absorption-charge setpoint, and the unloaded turbines started overspeeding. Turbine voltage rose dramatically, but this had been foreseen and remained within the 250 V controller's wide operating window. But it was noisy and put excessive load on the turbines' bearings.



Courtesy Kane (3)

Kane consulted with PowerSpout, who advised him to divert current from the battery side of the controller. One of the Classic auxiliary ports has a "waste-not" mode that can drive solid-state relays (SSRs) in PWM to regulate battery voltage (similar to a TriStar). Kane connected two solid-state relays (SSRs) to the inverter's DC buses and the problem was solved. The SSRs divert up to 60 A into resistor dump loads (located outside the shed) to prevent overspeed. Later, Kane will use the other auxiliary output in the Classic to drive a water heater relay so he can use the surplus enerMgy. Living off-grid has not forced him to do without the normal appliances of a modern New Zealand home, and the system generates enough surplus to charge an electric car.

Gross head: 215 ft.
Net head: 195 ft.
Flow: 104 gpm
Penstock length: 2,180 ft.
Penstock diameter: 3.8 in.
Turbine power: 2.35 kW
Turbine type: 2 Peltons
Turbine make: PowerSpout
Generator: PMA
Turbine voltage: 80 VDC
Battery voltage: 48 VDC
Cost: $40,511

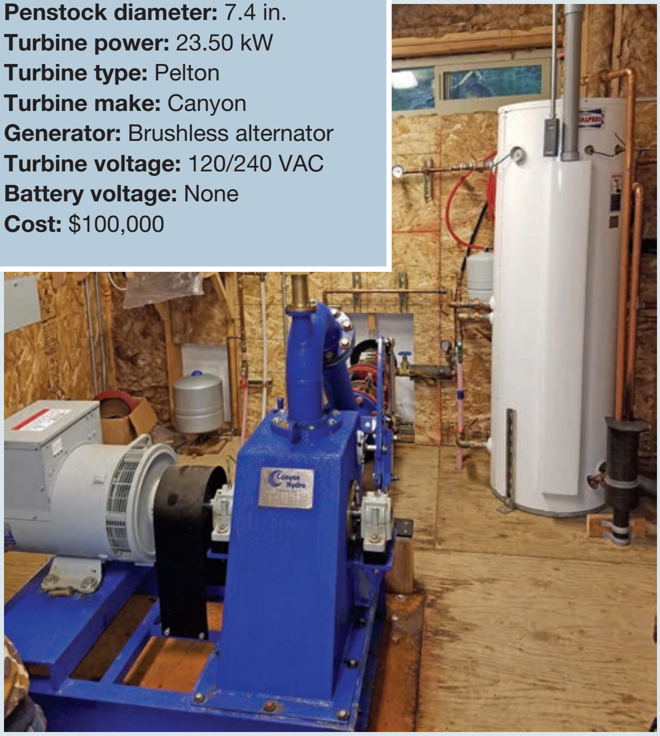
Direct AC Turbine on a Remote Island

Aurora Power & Design had already installed a successful 5.5 kW battery-based triple Turgo microhydro system at a fishing lodge, saving the owners hundreds of thousands of dollars in generator operating costs. When the time came to add a 25 kW turbine at a nearby site, they chose a stand-alone "islanded" direct AC Pelton turbine from Canyon Industries. With so much power, there was no need for batteries. The turbine can meet peak loads easily. Much of the surplus is stored in hot water.

The power quality is excellent, as the turbine speed and frequency are controlled by a Thomson and Howe load-control governor. A custom water tank was built with 1,500 W and 2,500 W elements that are turned on in succession as needed, to maintain constant turbine speed despite the changing demands of the fishing lodge's electrical loads. The controller makes fine adjustments by PWM switching one heater. A second (optional) controller is given priority over this basic one. It harvests excess energy for heating water in the lodge when needed, intervening before the heat is dumped to the large tank. Heat stored in the large tank next to the microhydro turbine is also pumped to a radiant heating system in the lodge to reduce heating costs and use all of the energy produced.

Courtesy Aurora Power & Design (3)

Gross head: 275 ft.
Net head: 261 ft.
Flow: 601 gpm
Penstock length: 1,500 ft.
Penstock diameter: 7.4 in.
Turbine power: 23.50 kW
Turbine type: Pelton
Turbine make: Canyon
Generator: Brushless alternator
Turbine voltage: 120/240 VAC
Battery voltage: None
Cost: $100,000



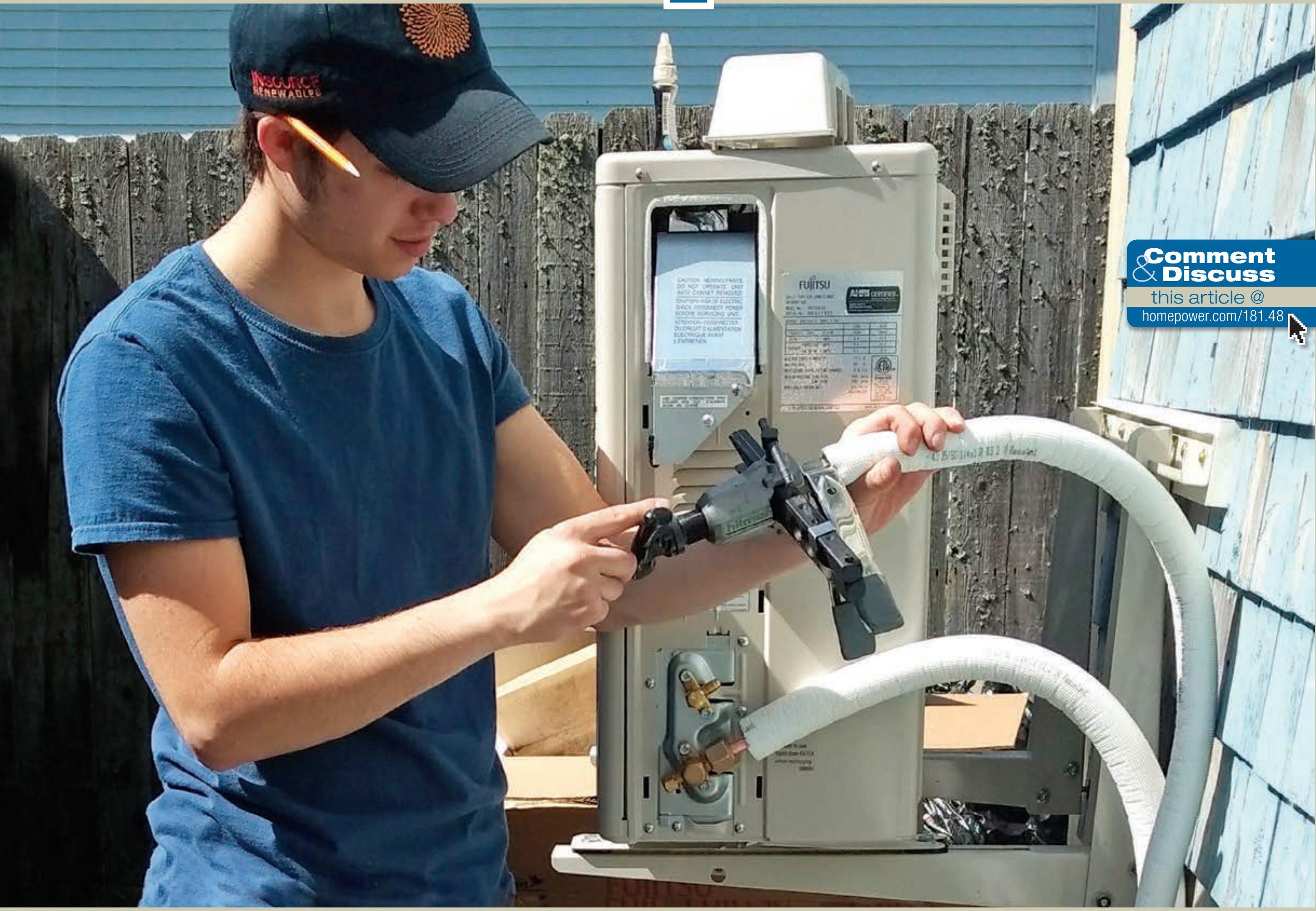
Go Ahead & Do It!

These are just some examples of successful microhydro systems. There are hundreds more possible features and permutations, including automatic flow control, AC coupling, crossflow turbines, and reservoir intakes.

Because every site is different, some problem solving is inherent in designing a custom system. But with a good basic design and responsive technical support, the system can be easily tuned. If you have a suitable site, a microhydro system is very worthwhile, providing consistent clean energy.

Installing Minisplit Heat Pumps

Story & photos by Vaughan Woodruff



Comment & Discuss this article @ homepower.com/181.48

Installing a minisplit heat pump (MSHP) requires skills in carpentry, electrical wiring, and working with refrigeration equipment. Before you jump in, here's what you need to know.

MSHP DIY?

Occasionally, a skilled homeowner will install an MSHP. Installation requires work with 240 VAC circuits and involves refrigerant that has greenhouse gas implications, so it is important to understand the requirements and safety factors. Many jurisdictions require MSHP contractors to have an electrical contractor's license and certification from the U.S. EPA for handling refrigerants.

System installation requires common hand tools, such as drills, drivers, wrenches, screwdrivers, levels, caulk guns, knives, multimeters, and pliers. There are also specialty tools and materials that are required, including tube flaring tools, gauges, refrigeration manifolds, a vacuum pump, torque wrenches, and a nitrogen tank and regulator. For most DIYers, it makes sense to let an electrician complete that aspect of the installation, and to use a refrigeration technician to make those hookups and charge the system.

This article explores some of the common and critical tasks associated with installing MSHPs. This isn't meant to be a substitute for technical training but to help readers understand the scope of an installation and to avoid common pitfalls.

Structural Installation

A MSHP system consists of an outdoor unit and at least one indoor unit (see "Efficient Heating with Minisplit Heat Pumps" in *HP180*). The outdoor and indoor unit are connected by electrical wiring and insulated refrigeration tubing. These units need to remain fixed in specific locations.

There are three common methods for supporting an outdoor unit:

- on a mounting frame connected to the home's exterior wall;
- directly on a concrete or composite pad;
- atop a frame that sits on a pad.

The outdoor unit contains a compressor and fan, and each causes vibration. To accommodate this vibration, the outdoor unit is typically mounted on a structure that uses rubber dampers or one that isolates the outdoor unit from the house.

In areas where the ground is prone to frost-heave, installing the outdoor unit on a wall-mounted frame can be most practical. Mounting frames are attached to the structure, either with lag screws into wall studs or bolts anchored into concrete on a foundation wall. The size and weight of some outdoor units—multizone units might weigh about 300 pounds—may dictate a more robust mounting solution such as a stronger wall-mount or a ground stand.

The integrity of the wall is important. In a well-built, conventionally framed home, an outdoor unit may be supported by two wall studs. A home with lightly framed walls or one that utilizes challenging details—such as a timber frame with structurally insulated panels—may not be suitable for a wall-mounted MSHP.

Right: A stand provides an alternative to mounting the unit on a wall, while keeping the unit above snow level.

Below: A wall mount is easy to install and adequate for most structures.

If the outdoor unit is mounted on a separate pad or ground frame in areas subject to frost heaving, care must be taken to reduce the incidence and impact of heaving on the integrity of the refrigeration connections. A pad needs to have adequate drainage and an appropriate subbase, such as crushed stone, that is less susceptible to frost heave.

Minisplit Heat Pump Outdoor Unit Anatomy

1 Fan that pulls outdoor air through a heat exchanger

2 Rain cap

3 Mounting bracket

4 Electrical disconnect

5 240 VAC input

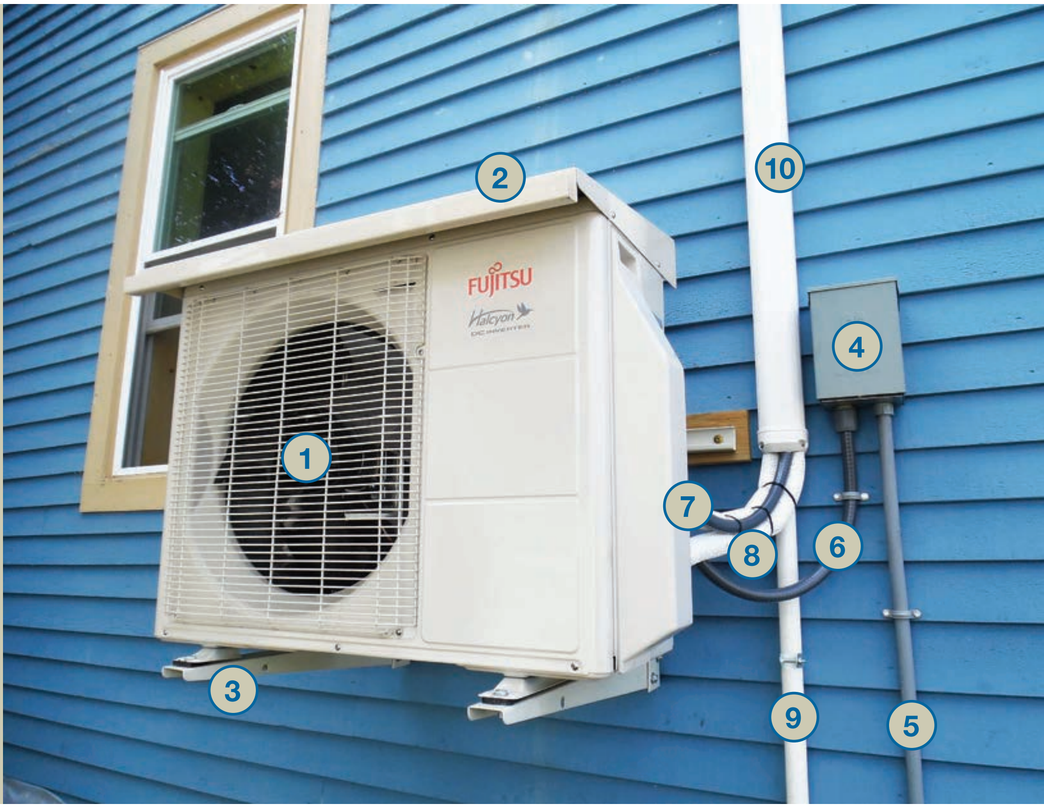
6 240 VAC to outdoor unit

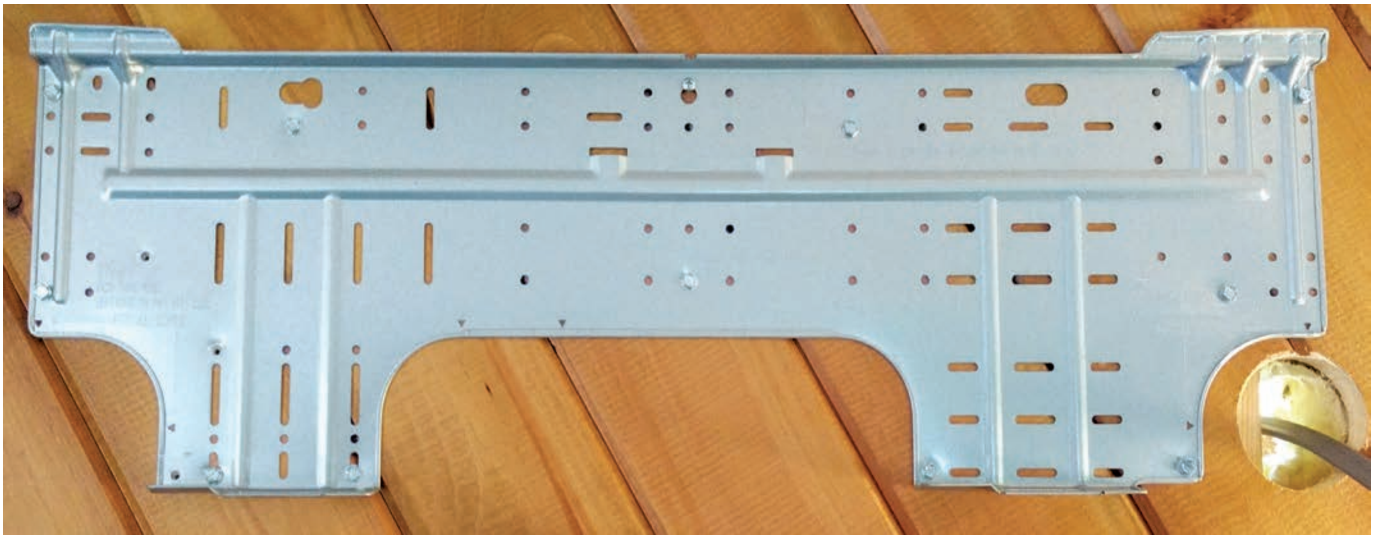
7 Power and control wires to indoor unit(s)

8 Refrigeration lines to/from indoor unit

9 Condensate drain line

10 Line-set channel and cover





A wall bracket for the indoor unit. Notice the wall penetration for a right-side connection and the small cutout triangles on the mounting bracket that indicate the proper location for the center of the hole.

Indoor Unit Details

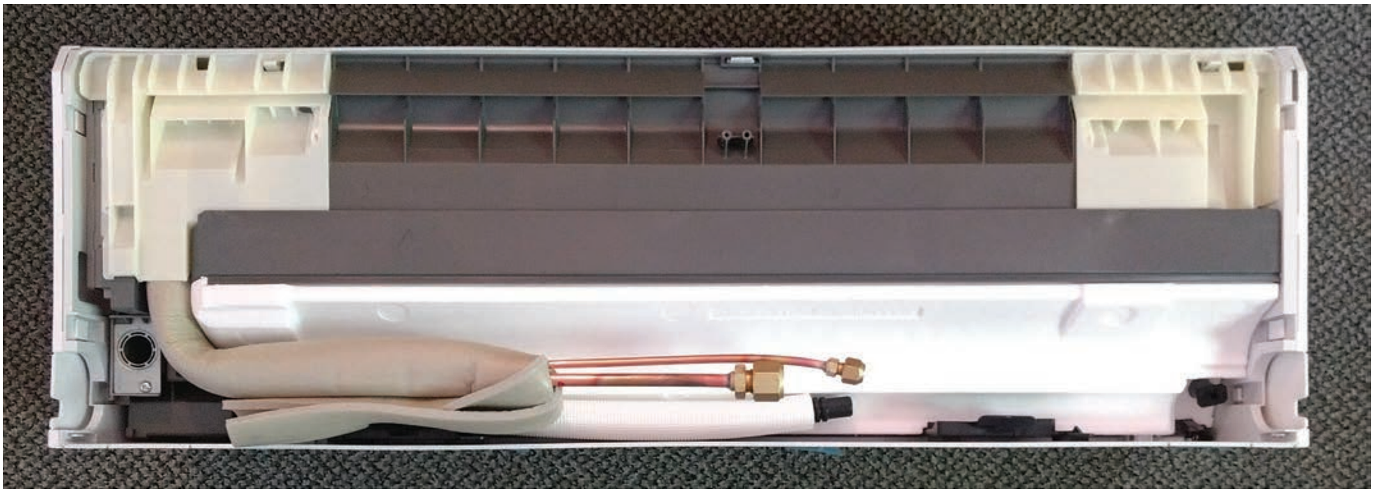
The indoor unit also contains a fan, but it runs at a much lower speed that limits vibration effects. So wall-mounted and floor-mounted units are commonly secured with metal mounting plates supplied by the manufacturer. These plates can be secured to wall framing with screws or to the wall sheathing with appropriate hardware, such as drywall anchors. Simply screwing into drywall won't hold up over time.

Ducted units and ceiling cassettes are typically hung from threaded rod or chain. MSHP manufacturers provide installation details that incorporate a number of considerations, including vibration impacts and minimum clearances for service and operation.

Once the bracket is installed, a 2- to 2.5-inch hole is drilled to accommodate two insulated refrigeration lines; the condensate line; and the wiring between the indoor and the outdoor units. For wall-mounted units, the mounting bracket will indicate the center of the hole. For installations where the indoor unit is on the interior surface of an exterior wall and the refrigeration lines will pass through the wall and be attached to its outside surface, the hole is typically drilled by the right side of the unit. With this approach, the connection piping on the indoor unit passes through the wall and the flared connections take place on the exterior of the building.

If the wall is thicker than the length of the unit's connection piping or if the refrigeration lines are installed in the partition during new construction, the hole is drilled by the left side of the unit. The connection piping is kept parallel to the wall to keep the flare fittings on the interior side of the wall, where they will remain accessible. Left piping requires more work and can be particularly challenging when a system requires 1/2-inch or larger refrigeration tubing. Large tubing is more susceptible to kinking and requires a bending radius that can be prohibitive in the confined space between the indoor unit and the wall.

The back of the indoor unit, with the two refrigeration lines and the condensate drain at the bottom center.



Electrical Installation

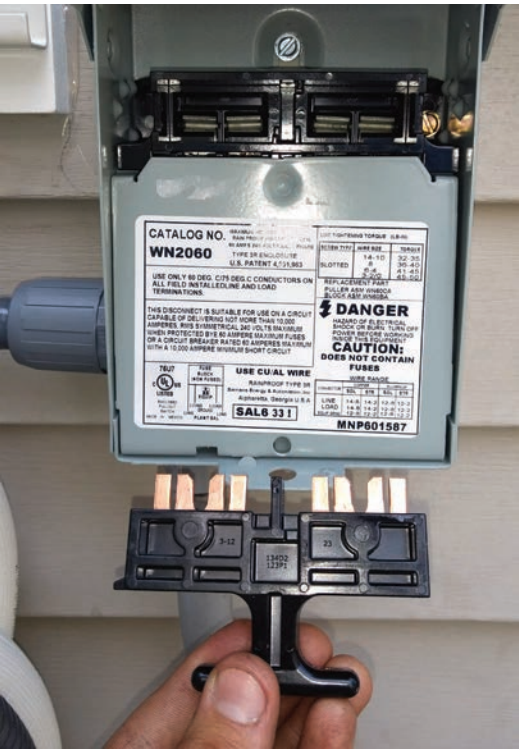
Most MSHPs require a 240 VAC power source to the outdoor unit. The indoor unit is powered by a cable that connects it to the outdoor unit. Installing a 240 VAC branch circuit for the unit is similar to wiring other 240 V appliances—with a few exceptions. The required size of the two-pole breaker is specified by the MSHP manufacturer. A small single-zone unit may require a 15 A breaker, while multizone units could require 40 A overcurrent protection. The electrical code requires a disconnect within direct sight of the outdoor unit per the 2017 *National Electrical Code's* Section 440.14. Common MSHP disconnects include a blade-type or one with integrated overcurrent protection, such as a circuit breaker.

Section 210.63 of the 2017 *NEC* requires an outdoor GFCI be located within 25 feet of the outdoor unit for future servicing, which commonly requires electrical equipment such as recovery units and vacuum pumps. When an MSHP is installed at a home without a nearby GFCI, a disconnect that includes a GFCI can be used. This will require a separate 120 V circuit to power the outlet, but streamlines the installation by allowing both the MSHP circuit and the GFCI circuit to use the same conduit and enclosures from the service panel to the disconnect.

Since these units are located outside and contain sensitive electronics, it is advantageous to include surge suppression in the branch circuit. This minimizes the opportunity for static electricity to accumulate and damage the printed circuit boards housed in the outdoor unit. If the outdoor unit is far enough from the electric service to result in a voltage drop of 2% or more, the wire size needs to be increased to avoid damage from low voltage.

The cable between the outdoor and indoor units also provides communication between them. This typically requires three conductors plus a ground. Two of the wires carry AC and the third carries low-voltage DC. The conductors need to be rated for outdoor use and need to satisfy the requirements of carrying DC and AC. One solution is heat-pump cable, which features flexible coated aluminum to protect the copper conductors.

Many *Home Power* readers may find the electrical wiring the easy part of an installation. Routing and connecting the refrigerant tubing can be more complex.



The *NEC* requires a disconnect at the outdoor unit. In some cases. this may provide overcurrent protection as well.

Installing the cable between the indoor and outdoor units typically occurs while mounting the indoor unit. The cable is fed from outside through the hole. The wire is terminated at the indoor unit, commonly with ring terminals (as specified by the manufacturer). Many units have cable clamps to provide strain relief.

Ceiling cassettes, ducted units, and floor-mounted units typically remain in place as they are being wired and connected to refrigeration tubing. Wall-mounted models vary. For a common wall-mounted installation that uses "right piping" and results in the connection piping passing through the wall to the outside of the building, the indoor unit can be set once the electrical wiring is complete. For a wall-mounted unit that requires "left piping," the indoor unit is hung temporarily after it is wired and cannot be set permanently until the refrigeration tubing is connected to the connection piping. With multizone units, it is important to label the wiring for each unit to ensure that the indoor units are connected to the correct terminals at the outdoor unit.

A tubing cutter provides a clean, even cut in the tubing. The cut should then be deburred.

Before flaring the end, put the flare nut on the tube. Flares provide a sealed connection on the refrigerant line.

Line-Set Installation

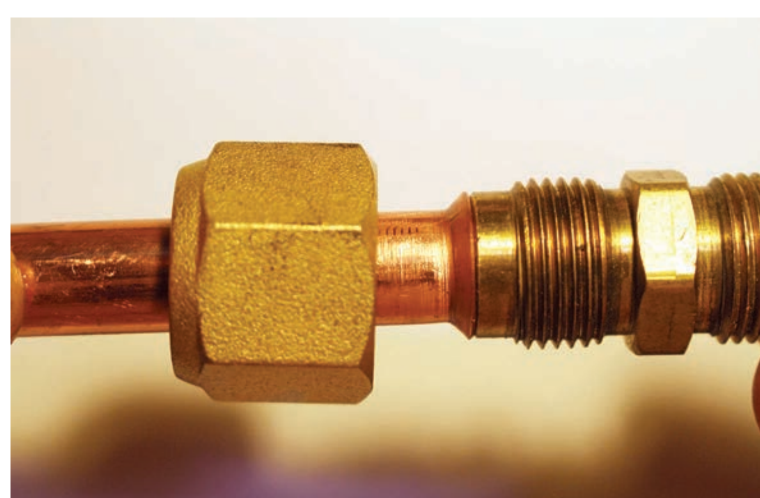
The most common installation mistakes are poorly made and poorly attached flare fittings. These connections require craftsmanship, care, and attention to detail. Due to vibration and the swing in system operating temperatures, a poorly flared fitting will eventually leak. This renders the system inoperable and leaked refrigerant can have a dramatic impact on our climate. If released into the atmosphere, the quantity of R410A refrigerant that is precharged into a standard single-zone MSHP has the greenhouse gas potential of burning almost an entire 275-gallon tank of home heating oil.

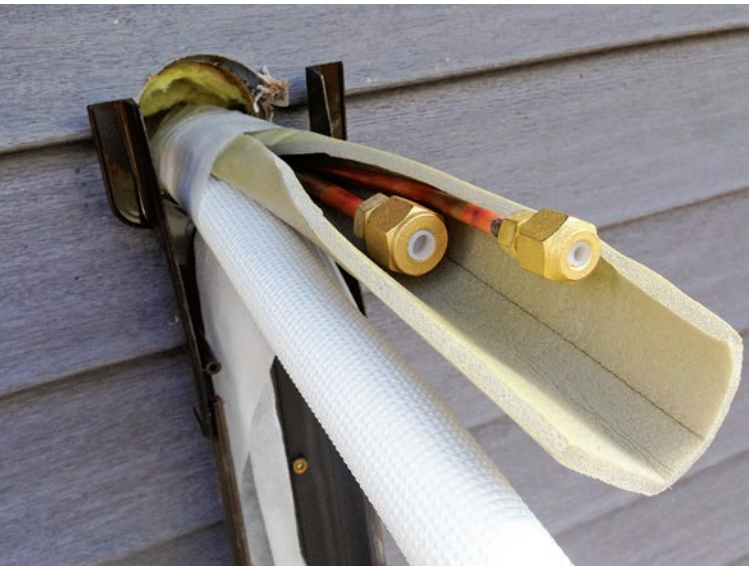
Refrigeration line sets come preinsulated in rolls of various lengths. Installation companies that do this work regularly buy long rolls (e.g., 50 meters), while others commonly purchase shorter line sets on a job-by-job basis. Some rolls come already flared at each end, while others require on-site flaring.

Line sets are typically installed in a line-set cover, which is a two-piece PVC product. The channel is attached to the structure with screws and the cover is snapped in place to conceal refrigeration tubing, the condensate line, and the wiring. The channel is installed before the refrigeration tubing to give it support. There are a variety of cover fittings—couplings, 90° elbows, 45° elbows, tees, offsets, etc.—that are used to extend the line-set cover and allow it to change direction.

Since the line-set cover often contains the condensate drain from the indoor unit, care should be taken to ensure that the condensate can drain by gravity, avoiding uphill traps for the water. Once the channel is in place, the refrigeration tubing is shaped into it. A tubing bender helps maintain an appropriate bend radius and avoid kinked tubing.

Flaring provides a wide surface area that seals the joint when the flare nut is tightened.





The connection piping for an indoor unit with "right piping" commonly passes through an exterior wall. The flare fittings for the smaller liquid line and the larger vapor line are made outside and concealed in a line-set cover.

Care must be taken with the refrigeration tubing to avoid contamination from moisture and particles, such as copper shavings and dirt. To properly flare the tubing, a sharp tubing cutter must be used. Once cut, the tubing should be lightly deburred with the end of the pipe pointed downward to keep the shavings outside the tubing. The fittings are slid onto the tubing and the end is placed in the die of a flaring block. Before tightening the flaring tool to shape the copper, it is useful to apply vacuum-pump oil—the oil used in the pump that will later be used to evacuate air and moisture from the system—to lubricate the flare tool. This helps reduce the chance of cracking in the copper tubing while shaping the flare.

The flare should be checked to ensure that it covers the entire face of the male flare fitting and be checked for small cracks or chips. This is done both for the larger refrigeration line that transports the gaseous refrigerant and for the smaller line that transports the refrigerant as a liquid. For each indoor unit, four flare fittings are required—two at the indoor unit and two at the outdoor unit.

Commissioning

Once the units have been secured and wired, and the tubing has been connected, the system needs to be filled with refrigerant. Most MSHPs come with precharged refrigerant that is released into the system once system testing and evacuation are complete. Additional refrigerant is added if the line-set length exceeds the maximum specified by the manufacturer. Adding refrigerant requires a number of additional tools—a refrigerant scale, R410A tank, gauges, hoses, etc. These specialty items are pricey and could drive up your project expenses significantly. This is yet another reason that it is worthwhile to have a refrigeration professional involved in your installation.

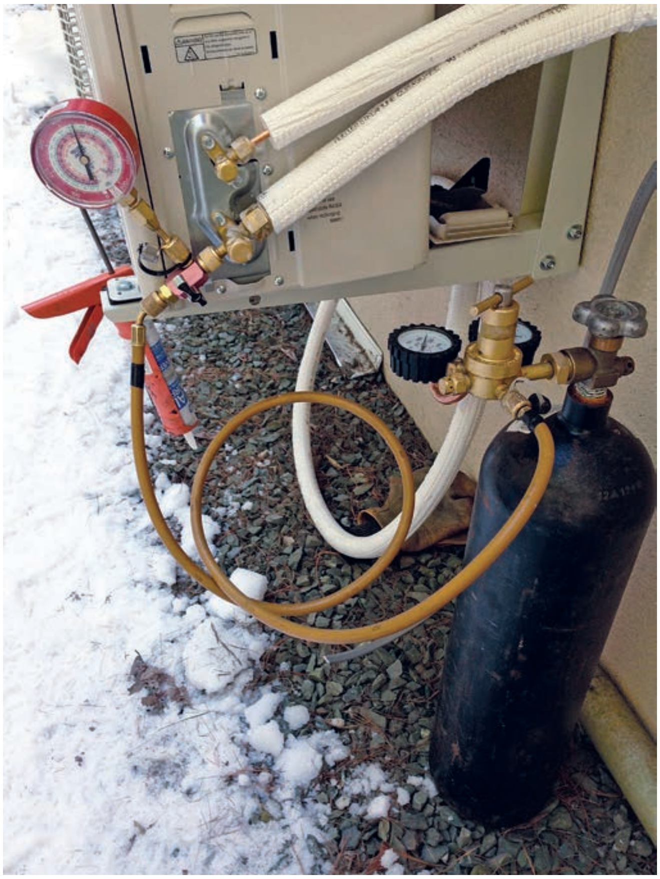
Proper pressure testing and system evacuation are critical to long-term system health and performance. Pressure-testing verifies the system's integrity, and evacuation removes contaminants, such as moisture and air, to maintain the refrigerant's integrity.

Nitrogen is commonly used to check pressure, as it is an inert gas. The outdoor unit contains service valves for each zone in the system. Using an R410A manifold containing hoses, valves, and gauges, nitrogen from a high-pressure tank is introduced into a system zone. One flare is opened momentarily so the nitrogen can purge small particles from the system. The flares are then tightened to the proper torque specification; the system is pressurized to 400 psi and left to sit for at least an hour to ensure it holds pressure.

If the system maintains pressure, it is time to evacuate air and moisture with a vacuum pump and a vacuum gauge. The nitrogen is released from the system and the vacuum pump turned on. The goal is to evacuate the system to a vacuum of 250 microns or less. In a dry system with new oil in the vacuum pumps, this takes less than 30 minutes. In systems where moisture is present or an old vacuum pump is being used, this process can take hours. This is a critical process, as contaminated refrigerant will have a shorter life, and can lead to unneeded wear and tear on system components, including the compressor.

Once a zone has been tested and evacuated, the refrigerant can be released into the system by opening the zone's three-way valve. If this valve is not loosened all the way, it won't backseat and may eventually leak. Once the system is filled with refrigerant, the power can be turned on and the system operated.

A technician carefully works the line set into its channel.



Nitrogen is used to pressure-test the system. If the system passes the test, the nitrogen is purged, and a vacuum pump is connected to the system to remove air and moisture.

Getting it Right

Given the environmental consequences of releasing refrigerant into the atmosphere, great care needs to be taken to ensure that the refrigeration work can withstand the vibration, expansion, and contraction that is common to an MSHP system. Get it wrong, and your system will be inoperable and you will have contributed significantly to climate change. Done right, you can expect 10 to 15 years of high-efficiency heating and cooling.

web extras

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

“When Passive Strategies Aren’t Enough” by Kathy Kelly in *HP154* • **homepower.com/154.90**

“Solutions: Reducing Energy Use, One Load at a Time” by Ian Woofenden in *HP165* • **homepower.com/165.16**

Comment & Discuss
this article @
homepower.com/181.56

Energy Storage Systems: Article 706

by Brian Mehalic

Most energy storage for PV systems has been comprised of lead-acid batteries. Newer technologies and applications—flow and lithium-ion batteries; all-in-one storage plus power conversion "appliances;" peak load shaving; and grid stabilization—are changing the face of energy storage. Article 706, "Energy Storage Systems," addresses this in the 2017 *National Electrical Code (NEC)*.

What's Covered

Article 706 addresses permanently installed energy storage systems (ESSs) that operate over 50 volts AC or 60 VDC. An ESS could be a battery connected to separate power conditioning equipment—all of the configurations in Figure 690.1(b) that include an ESS show it located after the PV system disconnect. (The line between PV and ESSs is clearly defined—a PV system isn't included, ever, although a PV system may be installed at the same location.) Or it could be a "self-contained" system, such as an AC-coupled ESS. There are many options and applications, and Section 706 applies to stand-alone, interactive, and multimode systems.

To comply with Section 706.5, an entire self-contained ESS can be (but does not have to be) listed by a nationally recognized testing laboratory (NRTL) as a complete system. Otherwise, individual components (charge controllers, overcurrent protection devices, power conversion and energy storage equipment, etc.) must be listed. The only exception to this listing requirement is lead-acid batteries.

This can be confusing, as products and systems may be listed to the same standards, but have different functionality. Sections 706.3 and 706.8 refer to Article 705 for ESS interconnection with primary sources, such as the grid. Stand-alone systems have specific requirements, and must also comply with the new Article 710—the rules are taken from the 2014 *Code* Section 690.10.

Some of the language in 706 was, and still is, in other articles, including Article 480, "Storage Batteries." In future *Code* cycles, some shared definitions will be moved to Article 100, but expect Article 480 to continue to be relevant for battery installations.

Types of ESSs

Sections 706.2 and 706.4 define three categories of ESSs.

- **Type 1. Self-contained** ESSs are assembled, installed, and packaged into a single unit. Typically, this type of ESS is manufactured and sold as a product and listed to UL 9540. The Enphase Model B280-1200-LL-I-US00-RF0 consists of a UL 1973-listed stationary battery packaged with a UL 1741-listed inverter, with the entire system listed to

Enphase is one of several manufacturers offering self-contained energy storage systems. Its AC Battery products have received UL 9540 certification.

Courtesy Enphase

Courtesy Cape Fear Solar Systems

sonnenBatterie's eco series ESS is made up of individual NRTL-listed components designed to work well together.

UL 9540. Tabuchi and JLM Energy also manufacture UL 9540-listed ESSs. Typically, self-contained ESSs use lithium batteries.

A listed, self-contained ESS is a box with internal components that are not field-assembled and thus are not subject to field inspections. However, input and output wiring, overcurrent protection, and disconnect(s) connected to a listed ESS are subject to inspection by the AHJ.

- **Type 2. Pre-engineered of matched components** ESSs are field-assembled, but the components are from a "singular entity" and are intended to be installed together on-site. Components in these systems are either NRTL-listed individually or as an assembly. An example is the sonnenBatterie eco series (an OutBack Radian inverter with Sony lithium batteries).

- **Type 3. Other** ESSs are not self-contained or pre-engineered, and consist of various components that are individually listed to relevant NRTL standards, designed to work in a system, and field-assembled. Any system comprised of various components, likely from more than one manufacturer, that together allow for energy storage, would fall into this category. This category includes most of the batteries installed with PV systems until recently, and many of the ones still being installed.

Connection Requirements

While self-contained ESSs aren't subject to AHJ inspections, items connected to a listed ESS—disconnects, input and output wiring, and overcurrent protection devices (OCPDs)—are. Disconnecting means are required for ungrounded conductors. When controlled remotely, they must be able to be locked open. Labeling requirements include voltage and maximum short-circuit current for the ESS. For self-contained and pre-engineered ESSs, an Informational Note in 706.7(D) allows using manufacturer-provided labeling.

Article 706 specifies additional requirements (including location, a second disconnect, and directories) if the ESS's input or output terminals are more than 5 feet from connected equipment, or pass through a wall or partition. Depending on the ESS type, its input and output terminals could be AC, DC, or both.

Sections 706.11(A) and (B) contain similarities to Article 690, specifying that there must be a directory at the service disconnect and at all other power sources for grid-tied systems. A directory is also required for stand-alone systems indicating the location of the ESS disconnect.

Conductor and OCPD requirements in Part II of Article 706 are similar to PV system requirements. Maximum circuit current for ESS types 1 and 2 is indicated by the nameplate rating of the ESS; the same is true for inverter and DC-to-DC converter output circuits. Maximum current on inverter input circuits is based on full rated power output at the lowest input voltage (when current will be the greatest).

OCPDs must be sized to handle at least 125% of the maximum circuit current, rated for the current and voltage, and have the correct interrupting rating. Current-limiting OCPDs must be installed adjacent to the ESS for each DC output circuit. Note that some ESSs may already provide this current-limiting capability. Much like a combiner box in a PV system, there are likely to be fuses that are energized in both directions in an ESS—means such as switches or pullouts must be provided in the event that an ESS needs servicing.

Electrochemical Systems & Charging

Part III of 706 contains the rules for installing and maintaining batteries in an ESS. However, these rules apply only to electrochemical batteries that are not components in a listed product.

Per 706.30(A), unless live parts are inaccessible during service, the voltage limit between any ESS conductors and ground is 100 V in dwelling units. This can be confusing because an ESS may have an AC output at a typical service voltage—but again, note that Part III does not apply to batteries that are part of a listed product like a self-contained ESS. Alternately, the AC side of the ESS may be the output of a UL 1741-listed inverter, which then may exceed and be in conflict with the 100 V limit.

The rest of the provisions in Part III apply mainly to DC circuits, and are similar to requirements in Article 480. A possible interpretation is that 706.30(A) should also only apply to DC circuits, so as not to limit the installation of listed ESS with a 120/240 VAC output.

Part IV addresses ESSs with flow batteries. "Similar to fuel cells," these include dual-electrolyte technologies, such as zinc bromine and vanadium redox. Article 692, "Fuel Cell Systems," is specifically referenced, which has many of the same requirements as Article 706. Flow battery electrolyte must be identified by name and chemical composition on a readily discernable sign, and there must be spill containment for the electrolyte. Part V literally is "Other," essentially a placeholder and catch-all for new and different types of ESSs that may be forthcoming.

Section 706.23 addresses charging, and stipulates some form of charge control. If the charge controller is adjustable, the Section specifies limiting access to qualified persons. A diversion controller is not allowed as the sole means of regulating charge on the ESS. Although a common method to regulate charge is to divert energy from a PV system to the utility grid when the ESS is full. When grid-tied inverters are used, a second, independent method of control for the ESS charging process must be provided.

Location

Not all ESS technology requires ventilation—consult the manufacturer for guidance. Be aware that, like with PV systems, building and fire officials can be cautious with new technology, and may also rightly enforce relevant parts of other codes and standards, such as the *International Building Code* and NFPA 1.

Workspace clearances around an ESS must comply with Article 110, and there are additional requirements regarding spacing in Article 706 similar to ones in Article 480. Designating a room as an "ESS room" means that it must have doors that open in the direction of egress, with listed panic/fire exit hardware in accordance with 706.10(D).

Comment & Discuss this article @ homepower.com/181.60

Tributary Tribulation

by Kathleen Jarschke-Schultze

While off-grid hydropower is our preferred option, we are only able to harvest that energy when our seasonal creek is flowing—usually around the middle of December to the first weeks of July. Most of that time, the 24-volt system supplies us with 9.6 kilowatt-hours a day, meeting most of our electricity needs. While we get some winter sun on our PV system in our small canyon, and storm winds crank our wind turbine on occasion, the creek provides the main winter input.

Over the years, my husband Bob-O has improved the microhydro intake at the head of the pipe to maximize the turbine's output. For instance, the pipe has been enlarged, from 2-inch PVC to 6-inch PVC. He has designed and built several intakes—the last, of course, being the best so far. But it is the unexpected but inevitable maintenance that throws us a curve ball. Early last winter, I was driving across our bridge and saw that a huge boulder had broken loose from the creek bank and was laying on top of the pipe. The rock had not broken the pipe; it had somehow gently deposited itself right across it. We made plans to remove it in the late summer when the creek was dry.

Last January, we came home from traveling to find the turbine a quarter-mile downcreek. A small flash flood had torn it loose from its wiring and separated the valves from the main pipe. Thankfully, Bob-O keeps a spare turbine, so he soon had the system producing energy again. We sent the tumbled turbine to Denis Ledbetter at LoPower Engineering for repair and rejuvenation, and it is now our spare.

Come Hell or High Water

Until this past February, we had a wonderful water year. Lots of rain, with snow on the mountain at the head of our canyon—everything was looking rosy. Then it got warm and started raining. It rained for days. It rained on the mountain and melted the snow there.

On February 7, 2017, our creek was swift, brown, and rising fast. Within its path, the microhydro turbine was sitting under an inverted blue-plastic tub on its wooden base. This protected it above from rainwater, but not from the turbulent water below. Because of this erratic flow, turbine output was down by half. We set a timer for 30 minutes to remind us to check on the creek, but I couldn't help looking out the window every few minutes. Before the 30 minutes were up, we determined it was time to rescue the microhydro turbine from the rising water.

We suited up—Bob-O in his work pants underneath hip waders, and me in rubber boots and zebra-print leggings (if you are going to get soaked anyway, go for style and range of motion). We donned hats and our cheap glasses rather than

risking our prescription eyeglasses. Just as I had my hand on the doorknob to leave the house, we heard our smartphones' simultaneous calls of "One Love" and the "Firefly" theme. It was a small-stream flood-watch alert from the National Weather Service. Duh!

By the time we waded in, the water was already thigh-high. In the creek, we started clearing away the flotsam that was accumulating above the turbine, sending it on down through the brown, rushing torrent. In the process, our blue turbine cover took a hit from one of the branches we had untangled and disappeared downstream in a flash. Upstream, a large log had jammed, causing smaller flotsam to gather above the turbine. It took both of us to turn the log into the current, but the flow only partially moved it—right alongside the turbine. At this point, the water had risen too high to pull the turbine, and the hose connections were under water. It was going to have to ride out the flood.

What the Morning Revealed

By morning, although the creek had receded and the muddy brown color had disappeared, it was still a very loud torrent of hydraulic power. Our turbine had held on—but only by a wire. The pipe had broken at one junction. Its loose length was carried across the creek, and water was flowing over and under it. Luckily, most of the flotsam had been flushed from the creek during the night.

continued on page 62

homepower.com/subscribe

SUBSCRIBE or RENEW

Digital Edition Only	
1 Year (6 issues)	$14.95
2 Years (12 issues)	$24.95
1 Year (6 issues) + Premium Access	$39.95
2 Years (12 issues) + Premium Access	$49.95

Digital+Print Edition (U.S.)*	
1 Year (6 issues)	$34.95
2 Years (12 issues)	$54.95
1 Year (6 issues) + Premium Access	$59.95
2 Years (12 issues) + Premium Access	$79.95

Print Edition Only (U.S.)*	
1 Year (6 issues)	$29.95
2 Years (12 issues)	$49.95
1 Year (6 issues) + Premium Access	$59.95
2 Years (12 issues) + Premium Access	$79.95

***Premium Access** subscriptions include download access to our complete online archive—over 175 digital back issues in PDF!*

** Print edition subscribers with non-U.S. postal addresses please add US$11 for postage & handling.*

ONLINE homepower.com/subscribe (whether new or renewing)

PHONE 800.707.6585 or 541.512.0201, mon–thu, 8am–4pm pacific

MAIL print our order form from homepower.com/subscribebymail

home power

Courtesy Nunatak Alternative Energy Solutions

QUESTIONS ?
subscribe@homepower.com
homepower.com/faq

continued from page 60

We suited up again. My insulated muck boots were wet inside, but still kept my feet warm. Bob-O waded in, tied a rope around the turbine, and heaved. I stood on the bank, braced against a boulder, and also heaved on the rope to move the turbine to the bank. Despite our efforts, it wouldn't budge. We would have to wait until the water level went down before we could retrieve it or the attached pipe section.

After the water had receded later that day, Bob-O was able to pull the turbine and the pipe section up onto the muddy bank. After unclamping the turbine from its hoses and removing the wires, he spent the rest of the day cleaning the debris from the turbine and checking its wiring. He also prepped the pipe for "in-the-creek" repairs, shutting a valve near the intake to stop the flow of water through it and then cleaning and drying it as much as possible. Around dusk, I helped him jockey the pipe into position and then reglue it in two places. After the glue set, he opened the valves to run water through the pipe. Everything checked out.

The next morning, he reinstalled the turbine—this time, a little farther downstream and a little higher. The added elevation, although slight, lost us an amp. As frugal as we are with electricity, this didn't bother us. It was worth it to have some added storm-water security. That big boulder sitting on the pipe a little farther upstream (which we'd planned to remove in the summer) anchored the pipe at that point and kept us from losing a longer section of pipe. By the time the creek dries up, we will have added a length of pipe right upstream from the turbine and will have moved it to an easier-to-access, creekside outcrop of granite.

Our microhydro system can be high-maintenance or trouble-free; it all depends on the wet season's weather. We do not underestimate the hydraulic force of our small creek. And we practice safety first, always. After all, you have to be able to walk away from a problem to be able to return to it.

Our water turbine is a key piece in our homestead's energy generation—and we are willing to spend a lot of time and energy making it the best we can. As with so many aspects of our off-grid life, it is a hands-on, sometimes harum-scarum adventure. We really wouldn't have it any other way.

Comment & Discuss this article @ homepower.com/181.64

Comparing Ratings of Energy Sources

How much does a 1-kilowatt (kW) PV array produce compared to a 1 kW wind turbine? And how does that compare to a microhydro turbine? These are common questions that make poor assumptions about how electricity generating devices are rated. Let's sort out the tech—and the misinformation.

Starting with nonrenewables, if you buy a **fossil-fueled generator** that is *accurately* rated at 1,000 watts, it will be capable of that level of production continuously—as long as you keep supplying it with fuel and until it breaks down. An honest rating for a device defines its continuous operating output. Over a 24-hour day, that fueled generator will produce 24 kilowatt-hours (kWh)—its actual power output times the number of hours of operation.

One hundred feet of head and 120 gpm of flow could produce 1 kW continuously with the right hydro turbine. With only 10 feet of head, it could take 1,200 gpm of flow (and a different turbine design) to generate the same 1 kW.


Ian Woofenden

A 1 kW **microhydro turbine** is quite similar. If supplied with sufficient water power (head and flow), it can kick out 1 kW continuously, and therefore produce 24 kWh per day. A well-designed system will endure many years of continuous operation.

How about a 1 kW **PV array**? Unlike a fossil-fueled or microhydro generator, it does not receive a continuous supply of power (sunshine). It gets no sun at night, and optimum sun for only a small part of each sunny day. The solar resource in a particular area is measured in "peak sun-hours." The San Juan Islands in Washington (where I live) average 4 sun-hours per day, or the equivalent of one-sixth of a day. If the rating was accurate and there were no other losses, a 1 kW PV array here should produce an average of 4 kWh per day. Not accounting for losses, a 6 kW PV array would be needed, then, to produce 24 kWh per day at my location.

Wind-electric generator ratings are even less predictable and calculable. To get to kWh, we need to either make a prediction based on the turbine's swept area and average wind speed (the wind equivalent of sun-hours), or use test or predicted numbers from real-world sites or manufacturers' calculators. We cannot predict wind energy output in any simple and accurate way from a wind turbine's peak rated output.

Several factors contribute to this problem. A 1 kW wind turbine refers to the turbine's production at the peak wind speed. But wind turbines only witness that speed—and therefore rated production—a very small portion of the time. Manufacturers may also choose different wind speeds to rate their machines. Because wind is a cubic resource, a small drop in wind speed means a dramatic drop in output. So, in the wind world, "1 kW" is just a shorthand for a turbine's general size—it's not a number that's used to predict energy (kWh) output.

In the end, since you want to generate and use energy from the generating source, getting hard production numbers for each technology is the goal. Comparing microhydro, PV, and wind by rated power (kW) is not sensible. It's all about energy, so cut to the chase and get accurate energy numbers (kWh)—and then compare.

—Ian Woofenden