PV Micromanaging

story & photos by Kathy Swartz & Kris Sutton

After Kathy Swartz and Kris Sutton bought their 5-acre property in Paonia, Colorado, they realized it needed a coop for future chickens—part of their overall plan for providing some of their own food and living as locally as possible. What they didn't realize was that the chickens would also help "grow" their own energy.

When we first looked at our pastured property with wide-open mountain views near the edge of the North Fork of the Gunnison River, there was a little red shed that we thought would make a great chicken coop. Little did we know that the seller was going to take it with him when he moved. Though we were disappointed at its disappearance, constructing a new coop became an opportunity to explore load-bearing straw-bale construction and passive solar design—as well as make room for a second, 1,750-watt grid-tied PV system.

In 2006, we installed a 1,440 W grid-tied PV system—sized to meet our budget at the time and approximately 50% of our electricity usage. But our goal all along was to produce 100% of our own electricity with renewables. The chicken coop, designed with a south-facing roof and nearly shade-free solar access, was a prime spot for the other PV system.

Mounted parallel to the roof plane, which sits at a 15-degree tilt, the second system takes advantage of the region's long, sunny summer days. The pitch is lower than recommended for optimal production, but the system will only suffer a 5% annual production loss as a result, which we find acceptable. However, the shallow pitch does not shed snow very well. In some parts of Colorado, this would be a problem, but since we experience less snowfall, it was less of an issue. After a heavy snow, we sometimes brush off the array with a broom to hasten melting.

Why Microinverters?

We decided to use ten 175 W SolarWorld modules with Enphase microinverters, one per module. As proponents of buying as locally as possible, it was important to buy U.S.-

Top to bottom: The PV mounting rails, ready to go; detail of the inverter mounting scheme; inverters appropriately spaced between the PV mounting bolts, with the AC wiring neatly tucked away; the modules in place and connected to their inverters (note the ground wires across the inverters, and behind and attached to the modules).

made PV products. Both of these companies are in California and just happen to be the closest manufacturers to us.

Kris is typically very cautious about buying equipment from start-up companies. But because the microinverters are so unique—and potentially industry-changing—we were excited to try this product.

Microinverters are fundamentally different from conventional string or central inverters—they have a one-inverter-per-module design. Individual inverters provide maximum power point tracking (MPPT) for each module in the system, resulting in higher system output overall. Though it doesn't apply to our sunny site, with the microinverters, any shading of one module does not influence another module's output. With a larger, central inverter with multiple modules in series, shading of part of one module can decrease the performance of the whole series string. Because of the individual MPPT, modules can be oriented differently or mounted at various tilt angles without affecting one another. Another benefit to a microinverter-based system is that you can put as many modules as you want or can afford in a system—matching module strings to inverters, as required with string or central inverters, is not necessary. Therefore, you can have exactly the number of modules that fit your roof or your budget—increasing the system size in the future is made easy.

Since modules are not connected in series, the DC voltages of the PV array are no higher than one module's open-circuit voltage, reducing (but not eliminating) the shock hazard for PV technicians. As a safety professional in the PV industry, Kris believes that this design is safer to install and service than most conventional PV systems. Plus, eliminating higher-voltage DC circuits meant that we saved approximately $200 and about one hour of installation time, since we did not have to use a high-voltage DC disconnect. Also eliminated are the fused DC combiner boxes required on larger systems with multiple strings in the array. Using microinverters saves wall space and a few hours of installation time by not having to mount a single, large inverter with accompanying disconnects and conduit.

For the size of our small system (and not including communication systems, other balance-of-system components, or installed labor differences), the Enphase microinverters average about $1.14 per watt retail for a 1,750 W system, offering a tiny bit of savings (about $0.02 to $0.16 per watt) compared to a similarly sized central inverter.

However, Enphase microinverters are not without their disadvantages. The biggest one is that they are a new company offering a product with a short track record in the field, even though the microinverters carry a 15-year warranty. They were introduced to the market in the summer of 2008. We don't know what the performance will be like in five or 10 years. And, of course, if the company were to go out of business, product support would disappear along with the company's Web-based data monitoring. But that's a risk that we take with all companies.

If one of the inverters fails, replacing it could be challenging depending on the accessibility to the back of the modules—for instance, if an array is mounted several stories off the ground on a steep roof. For our application, the modules are easily accessible, and this not a concern.

It can get pretty hot under PV modules in the sun and, in general, inverters and other electronics can fail early if they cannot handle the heat. This is also an issue with mounting standard inverters in direct sun or in contained spaces with no airflow. Enphase recommends a minimum gap of 1 inch above the roof for proper heat dissipation.

Putting the System Together

Our system installation started out like any conventional installation—first figuring out the module layout and then attaching mounting hardware to the roof. However, the step that differed was paying attention to the location of modules on the roof to determine where the microinverters would be mounted so they'd be evenly spaced between the module frames. The inverters must be mounted on the rails, between where the module's frames will lay against the mounting rails.

The inverters were then laid out on the roof to make sure that all of the prewired AC cabling would reach the next inverters' cables. Once their location was determined, we bolted the inverters to the PV mounting rails. The prewired AC quick-connect cables from each inverter were all plugged in together. Once the cables were connected, we secured the extra wire along the mounting rails (see "Installation Tip:

Tech Specs

Overview

System type: Grid-direct solar-electric

Location: Paonia, Colorado

Solar resource: 5.85 average daily peak sun-hours

Record low temperature: -31°F

Average high temperature: 90°F

Average monthly production: 205 AC kWh

Utility electricity offset annually: 100% (includes existing 1.44 kW system)

PV System Components

Modules: 10 SolarWorld, 175 W STC, 35.8 Vmp, 4.9 Imp, 44.4 Voc, 5.3 Isc

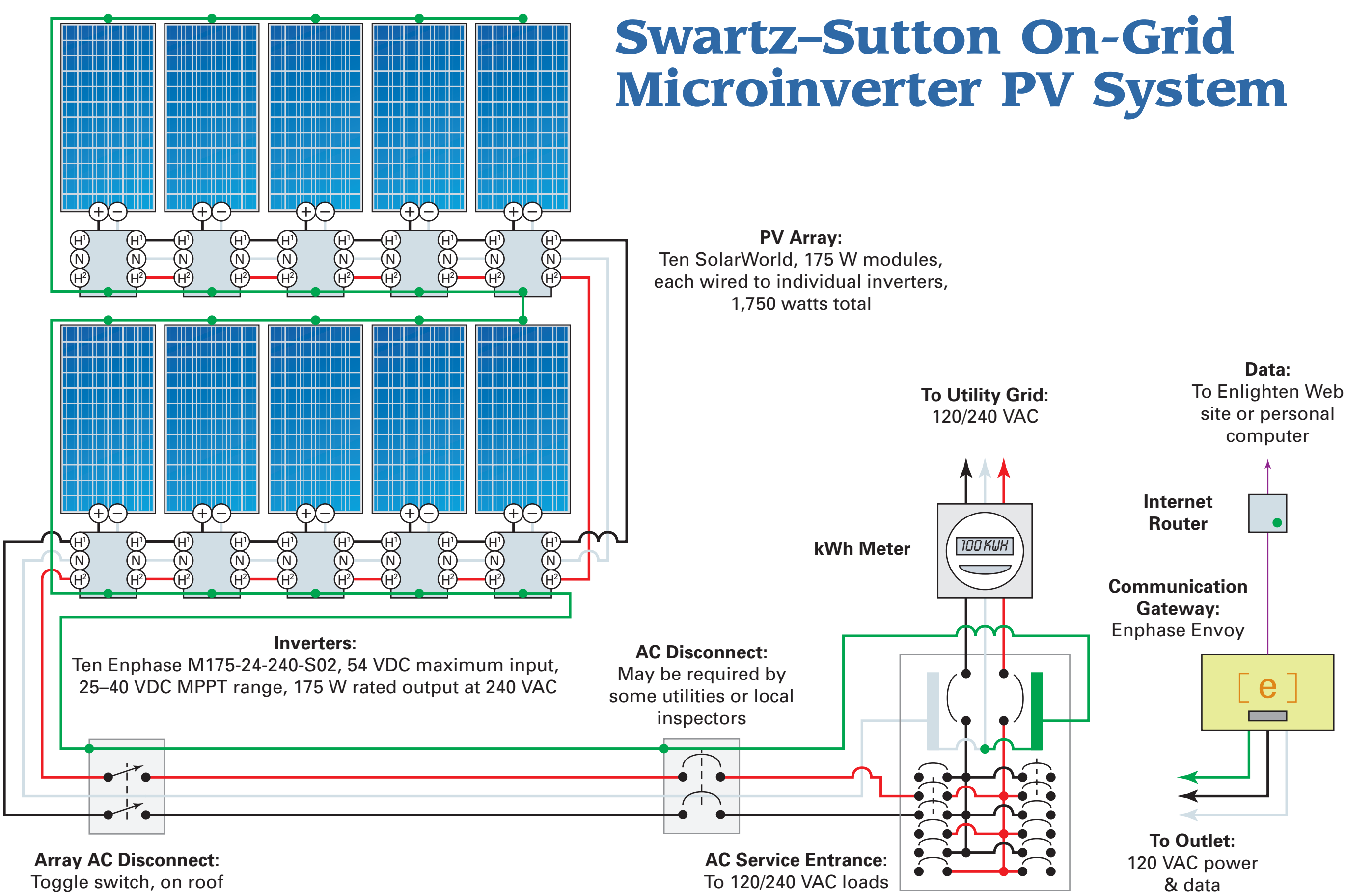
Array: 10 modules, 1,750 W STC total

Array installation: Direct Power & Water mounts installed on south-facing roof, 15° tilt

Inverters: 10 Enphase M175-24-240-S02, 175 W rated output, 54 VDC maximum input, 25–40 VDC MPPT operating range, 240 VAC output

System performance metering: Enphase Envoy monitor with Enlighten Web site

Swartz–Sutton On-Grid Microinverter PV System



Microinverter System Costs

Item	Cost
10 SolarWorld PV modules, 175 W	$10,500
10 Enphase microinverters	2,000
DP&W PV mounts	786
Envoy Internet gateway & 1 yr. Web service	350
Additional 5 yrs. Web service	650
Utility AC disconnect	75
Weatherproof box and AC toggle	30
Misc. wire, connectors, conduit & hardware	590
Total	$14,981
Less 2008 Federal Tax Credit	2,000
Grand Total	$12,981

Wire Ties" sidebar). After securing all the inverters and wire, the continuous bare copper grounding wire was connected to the grounding clip on the top of every microinverter.

We connected an Enphase AC home-run cable to the last inverter. The cable was terminated with a 240 VAC heavy-duty toggle switch in a weatherproof enclosure, as a roof-mounted AC disconnect to shut down the array when servicing. In this box, we switched from the Enphase cable to THWN-2 wire run in electrical metallic tubing (EMT) conduit from the roof to the ground, and then transitioned to PVC conduit for the underground run to the service panel.

We've found that microinverter systems require a bit more time on the roof than standard PV systems, but can save a significant amount of time, space, and money by not mounting and wiring a DC disconnect, inverter, and AC disconnect on the house. A utility disconnect is sometimes still required by the utility or local jurisdiction.

Data Monitoring

Enphase microinverters have a data monitoring system to follow individual module performance. The inverters communicate via the system's 240 VAC output wires to the service panel. We mounted the Enphase Envoy communications module in the house. It picks up the inverters' communication signals through the AC wall outlet that the module is plugged into and exports the data to our network router. From there, the data communicates to Enphase servers for near real-time display on Enphase's Enlighten Web site. No communication wire is needed to the roof or between inverters, making this the easiest Web-based data monitoring system that we've installed. The Web-monitoring system requires a broadband connection, but the Envoy can also communicate through a LAN and information viewed by typing an IP address into an Internet browser.

The data monitoring system shows information common to most other systems: instantaneous power, daily and monthly

The Envoy communications gateway receives data through the AC power lines and sends it to Enphase's Enlighten Web site.

The Enlighten site provides private Web pages for each subscriber that show specifics for individual PV modules as well as the whole system.

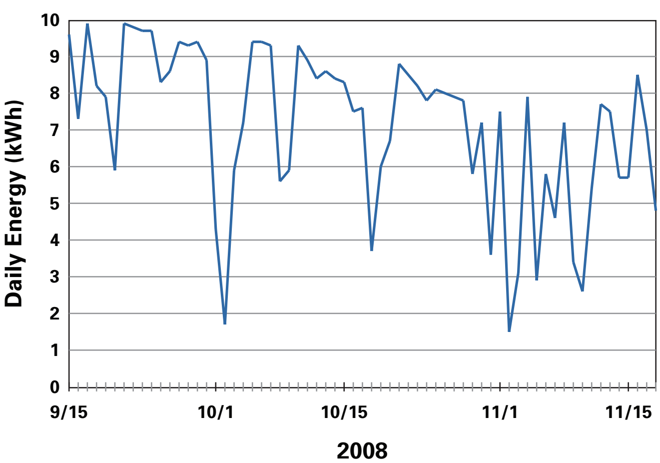
A graph of the array's performance on a partly cloudy day from the Enlighten Web site.

A Web site display quantifying system production.

cumulative kWh generated, and total cumulative kWh generated. What's unique about Enphase's data monitoring is the ability to keep tabs on per-module production, both instantaneous and cumulative. The Web site's graphical layout depicting module placement adjusts the color of the modules to reflect instantaneous power output, ranging from black (0 W) to light blue (at full inverter output). Besides near real-time monitoring, we can review time-lapse graphic displays of the system's daily and weekly production and, if problems arise, easily pinpoint individual module or inverter malfunctions. The monitoring system automatically alerts us to system failure via e-mail. Setting up the monitoring function entailed making a layout map, marking the serial numbers of the inverters on the map, and then sending the map to Enphase.

This monitoring service costs an additional $350 for the Enphase Envoy Internet gateway (including one year of data monitoring) and $650 for five years of additional service. The Enlighten service also includes "rapid replacement" if there are inverter problems, along with financial reimbursement for lost production.

Daily System Production



Alternatively, a computer networked directly to the Envoy allows monitoring of the inverters, but without the sophisticated Enlighten Web site and automated e-mail notification. The system will operate normally without an Envoy connected, but there is no way to track individual inverters.

Maximizing Performance?

After working on PV systems for almost a decade, it amazes us how far the industry has come. Our system is performing well, and we'll be excited to see our first full year of performance in September—and whether or not we truly hit 100% of our energy goal. Comparing our actual system output to the National Renewable Energy Laboratory's PVWatts analysis, our system performed above the monthly projected average for October. So, at this time, meeting our goal seems very likely. And by April, we'll have our first round of chicks, and finally be on our way to eating our own solar-powered omelets.

Installation Tip: Wire Ties

When thinking about PV installations, which may be producing energy for decades, long-term durability should be your guide, down to the wire ties you choose. Stainless steel wire ties and module clips are highly recommended to secure module wires to the module frames and racks. All wires must be secured to prevent them from touching the roof surface. Wiring that comes in contact with the roof can be damaged due to mechanical abrasion by wind or ice, potentially creating fire and shock hazards. In this installation, the installers added a few layers of electrician's splicing tape under the stainless wire ties to prevent abrasion against the ties' abrupt edges.

Access

Kathy Swartz (kswartz@solarenergy.org) oversees the RE education program at Solar Energy International (SEI). She is looking forward to using her chickens' eggs to bake goodies for the SEI staff.

Kris Sutton (kris@suttonsolar.com) has worked in the PV industry since 1999. He currently is a PV instructor at SEI (www.solarenergy.org) and runs a PV consulting business, Sutton Solar Services. He is a NABCEP-certified PV installer, a Certified SEI Affiliated Master PV Trainer through IREC/ISPQ, and on the Board of Directors of CoSEIA.

Many thanks to Matt Harris, Laura Bartels, Dave Clark, and the students in SEI's straw bale workshop for helping us erect and plaster our coop. We couldn't have done it without you!

System Components:

Direct Power & Water Corp. • www.directpower.com • PV mount

Enphase Energy • www.enphaseenergy.com • Inverters

SolarWorld • www.solarworld-usa.com • PV modules