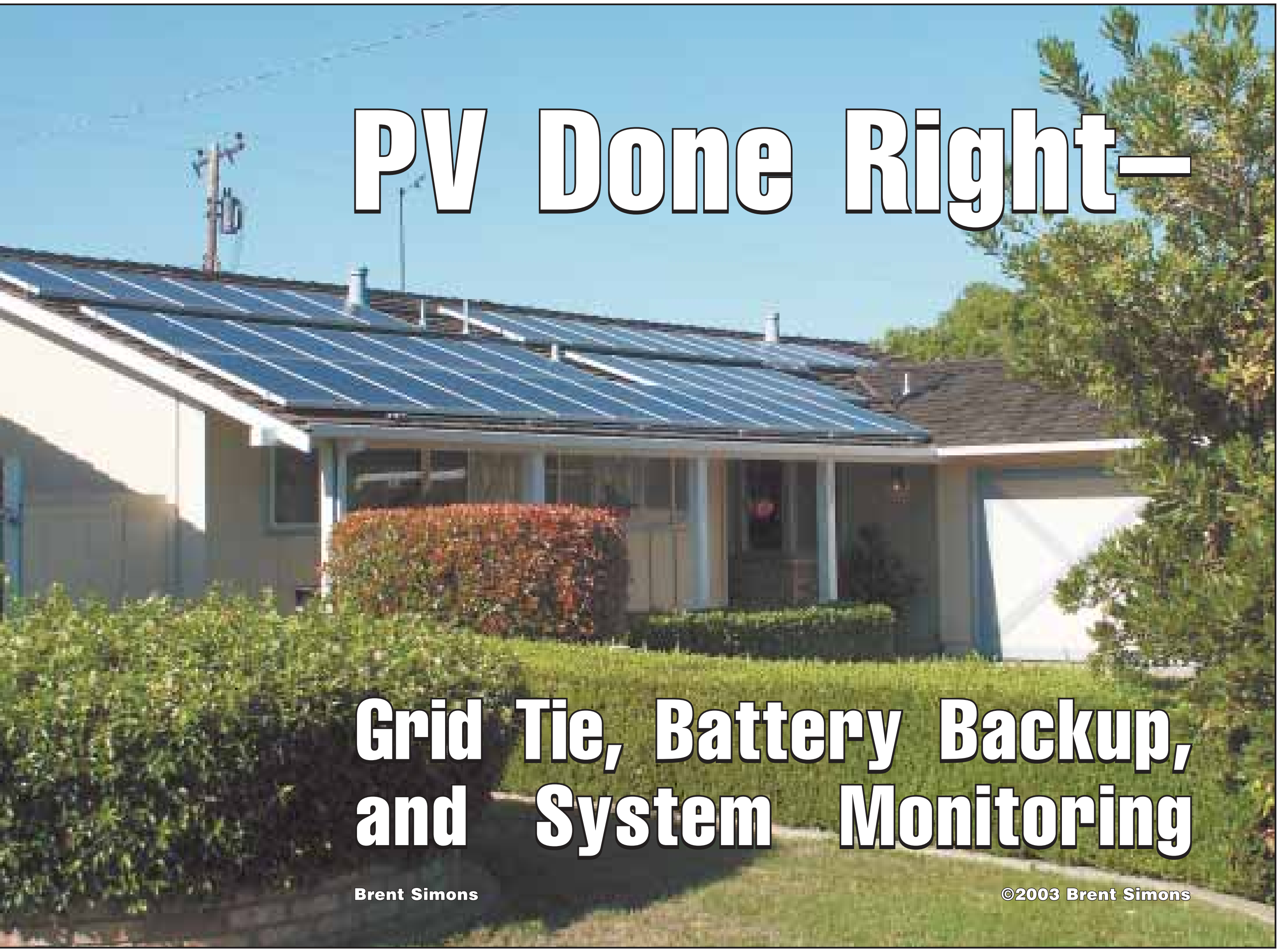


PV Done Right—

Grid Tie, Battery Backup, and System Monitoring

Brent Simons

The Simons family's PV system covers all their loads—with some green-electricity left over to sell back to the utility. A state of the art system monitoring set up allows them to see how their renewable energy system is performing.

Located in the heart of Silicon Valley, my 4 KW solar-electric system provides all the energy needed to service the electrical loads of my home, and generates a healthy, seasonal surplus that is sold to the local utility company.

I installed the system in January 2002. The main motivations were to be independent of the utility if possible, and to take advantage of the rebate program offered by our municipal utility. Silicon Valley Power's program, at the time, offered US$4 per watt up to a maximum of US$16,000. Our total system cost was US$26,000, resulting in an out of pocket cost of US$10,000. Now our utility administers the California Energy Commission rebate program without adding local money.

PV System

After performing a load analysis, I determined that a PV system of around 4 KW would easily supply our needs. After reviewing many different solar-electric panel specifications, we decided to use the BP Solarex SX120, 120 watt panels. The main reason was cost per watt. I wanted panels that are aesthetically pleasing, and I liked the blue color instead of the round grey cells that are available. The performance specs of all the polycrystalline panels that I reviewed were about the same, so that was not a large factor.

The system consists of forty panels mounted on the roof of our house. As luck would have it, the front of the house faces exactly south, and no trees or obstacles block the sun. The slope of the roof is 20 degrees, which is optimal for summer, when our usage is highest.

The 24 volt panels are wired in series in groups of two, providing 48 volts for the Trace SW4048 inverter. Our house has a 7 foot (2.1 m) porch overhang in front. This

Simons System Primary Loads

Load	*Hrs. per Day*	*x*	*Watts*	*=*	*WH per Day*
Fridge/Freezer	8		360		2,880
Lights	4		150		600
TV & stereo	4		350		1,400
Computer	6		250		1,500
Misc.	4		150		600
				Total	6,980

The power panel is installed in the garage.

The Maui Software's system display screen is loaded with system information.

proved to be very convenient for mounting the panels. All roof penetrations were in the front roof overhang, so leakage into our home was not an issue.

We used 2 inch lumber to support our PV racks. Since the roof is heavy shakes, we wanted to keep the bolts a little loose so the shakes could expand. The panels are attached to lumber tracks with $^1/_8$ inch (3 mm) thick aluminum clamps that I had made at a local sheet metal shop. Wiring from the panel junction box is with #10 wire (5 mm^2) in $^1/_2$ inch flexible conduit. Plastic, weatherproof boxes with gasketed lids and 1 inch grey PVC conduit were used to protect the individual panel wires. A flexible 1 $^1/_2$ inch conduit carries the PV cabling through a roof jack to the combiner box located in the garage.

The panels are arranged in two arrays of twenty panels each. The output wires from each array are connected to a standard fused combiner box from Trace. The run from the two combiner boxes to the Trace breaker panel is about 50 feet (15 m). We used #4 (21 mm^2) cable for the run to minimize voltage drop. There is a 60 amp breaker in each positive PV leg.

Power Panel

The power panel consists of a Trace SW4048 inverter, two C40 charge controllers with digital displays, a 175 amp battery/inverter breaker and enclosure, PV breakers, and a GFI breaker. The power panel components are attached to a large section of 1 inch (25 mm) plywood that is bolted to several 2 by 4 studs in an accessible corner of the garage.

The electrical code requires that a GFI breaker be provided when PV panels are mounted on the roof of an occupied dwelling. The metal frames

The battery bank provides ample backup to critical loads.

of the PV panels are bonded together with #8 (8 mm^2) copper wire. All equipment ground wires from the module frames, inverter, and metal enclosures terminate at an isolated wire combiner block. The isolated ground from this block is routed through the GFI breaker to the system's DC negative.

At the power panel, we use two Trace TM500 meters for monitoring purposes—one for battery state of charge, and a second for array output. Both meters are connected to 50 mV/500 A shunts.

All system components were ordered from Arizona Wind and Sun in Flagstaff, Arizona. Special thanks to Lisa for her help in making the procurement process go so smoothly. All of the 120 volt house loads were isolated from the main service panel and connected to a new breaker panel (third panel from left). The power source for the house loads breaker panel can be selected from a switch that allows either the utility or the PV system to run the house (second panel from left). A third switch panel (far left) provides a disconnect for the PV grid tie. The house load panel and grid-tie panels both have 60 amp breakers. If the inverter should fail, it is an easy matter to switch the house loads to regular utility service.

Battery Bank

After investigating various batteries for backup power, we decided to use the Rolls/Surrette S-530, 400 AH batteries. I wanted batteries with a good amp-hour rating that did not weigh several hundred pounds. The Rolls/Surrettes provided the best cost per amp-hour ratio. This system uses eight, 6 VDC batteries in series to provide 48 volts to the inverter.

The batteries provide about 10 KWH of storage at 50 percent discharge. They are housed in a vented wooden enclosure. Two small fans are used to vent hydrogen gas to the outside during bulk charging.

Performance

During the summer months from late April to late August, we have been creating around 24 KWH per day or 720 KWH per month. This has resulted in a surplus of around 150 KWH per month that is sold to the utility.

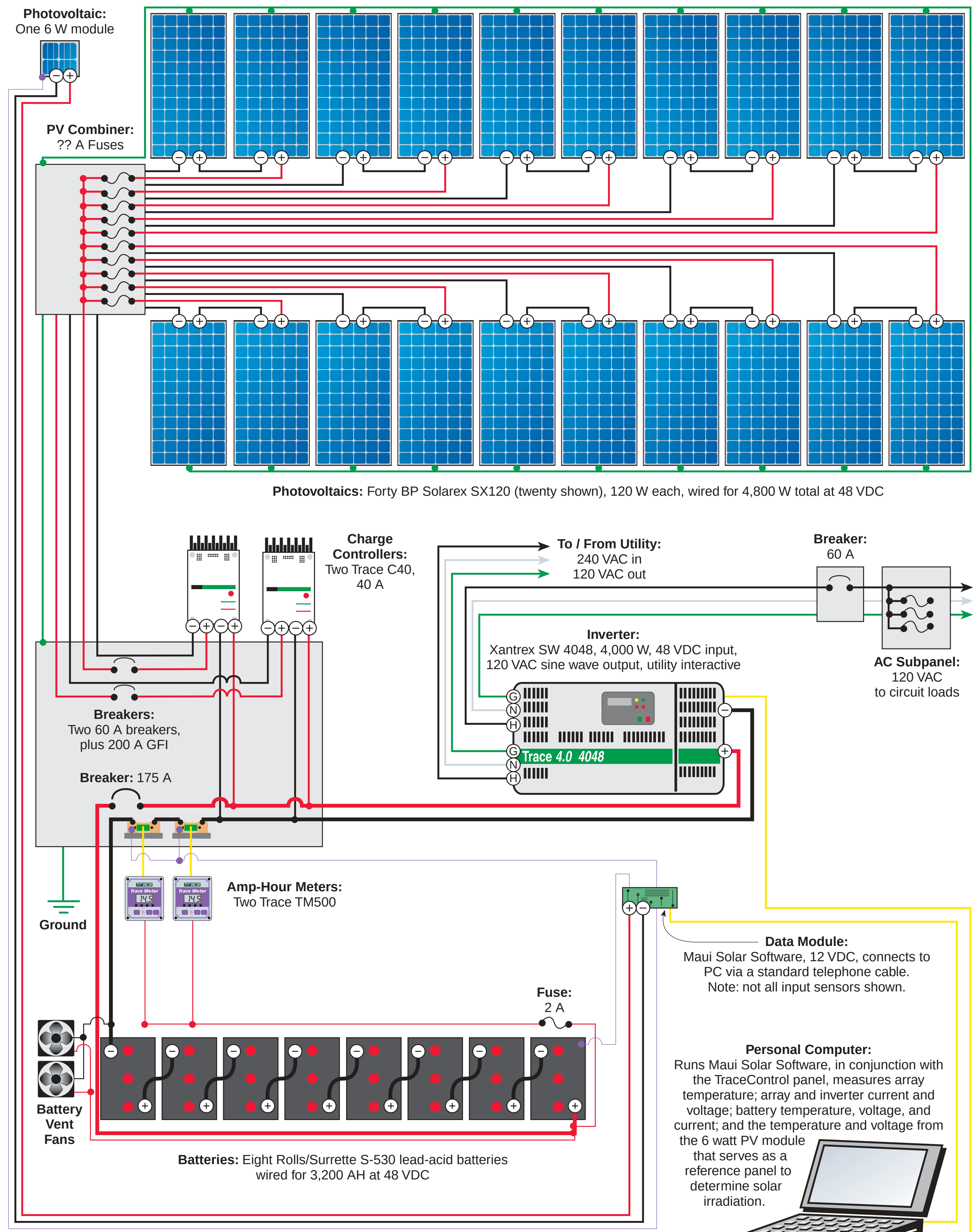
The summer days were warm, which resulted in the PV panels heating up to between 55 to 60°C (131-140°F). Warm temperatures decrease the output of crystalline PV modules. Even with the reduced output of the panels, plenty of electricity is still available for household needs and to sell.

Real Time System Status Monitoring

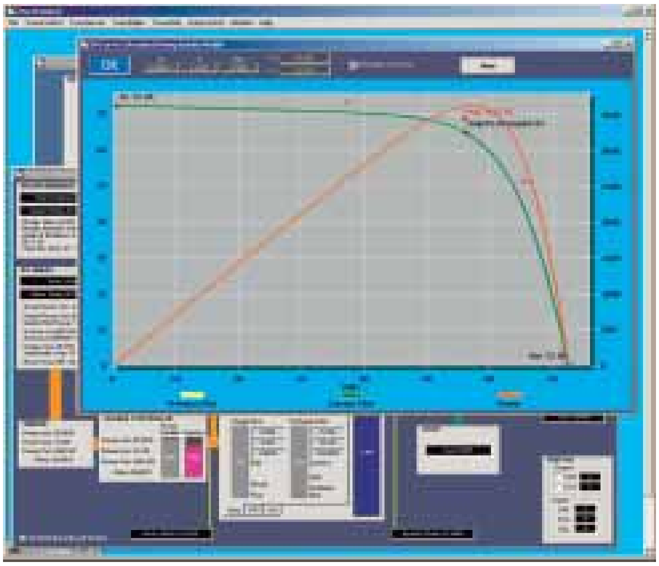
One important feature of our system is the ability to monitor all performance aspects of the inverter and PV system in real time. Using a new product developed by Maui Solar Software, we are able to input information from various sensors to measure array temperature;

The TraceControl screen allow the user to monitor and tweak the inverter.

Simons Family PV System



Note: All numbers are rated, manufacturers' specifications, or nominal unless otherwise specified.

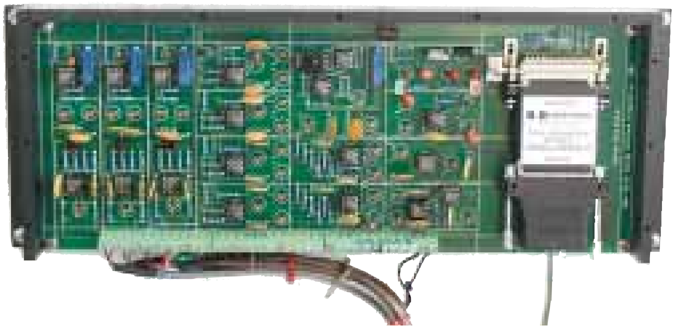


The IV curve screen is based on the system's real-time data.

array and inverter current and voltage; battery temperature, voltage, and current; and the temperature and voltage from a small, 6 watt PV module that serves as a reference panel to determine the exact level of solar irradiation in watts per meter squared (W/m^2).

All of the sensor inputs are connected to a small data module from Maui Solar Software that is located near the inverter and connects to a PC serial communications port via a four-conductor telephone cable. In conjunction with the Trace SWCA communications adaptor, which also connects to an unused PC com port, a real-time display of all operating parameters can be monitored on the PC. A screen shot of the TraceControl and system display is shown .

The system display screen is showing the current system conditions for noon on October 30. Solar irradiation is measured at 729 W/m^2, while the theoretical clear sky irradiation is 740 W/m^2, the difference probably due to a slight haze. It can be seen from the display that the PV arrays are operating at 12.42 percent efficiency. The PV panel temperature is 45.36°C, voltage is 55.38 volts, current is 53.121 amps, and the total output from the PV array is 2,941 watts.



The data module with its cover removed.

The system display screen also shows the wiring loss and charge controller loss values; battery state of charge, temperature, and

Simons System Costs

Items	*Cost (US$)*
40 BP Solarex SX120 modules	$20,000
Trace SW4048 inverter	2,995
8 Rolls S-530 batteries	1,600
Trace TM500 AH meter	396
2 Trace TCB-10 combiner boxes	378
2 Trace C40 controllers	320
Trace PVGFP2 GFI	276
Trace DC175 disconnect	254
Array cables, #4, 120 feet	173
2 Trace C40 digital displays	151
Lumber, 2 by 4s for PV mounts	150
2 Trace DCBB bonding blocks	85
3 Trace BTS-15 batt. temp. sensors	69
2 Trace CD60DC disconnects	63
Battery cables, #2/0 black, 20 feet	40
Battery cables, #2/0 red, 20 feet	40
Total	$26,990
Rebate	16,000
Grand Total	$10,990

voltage; and the amount of capacity remaining in the batteries to 50 percent discharge. Other data displayed includes inverter efficiency, sell power, load power, and grid power. The upper right corner of the screen displays the energy produced and sold for the day.

The screen shot of the TraceControl panel in Maui's software shows the current operating conditions for the Trace inverter. As can be seen on the screen, the system is producing at 2,750 watts. The inverter internal transformer and heat sink temperature are displayed, as well as all fault and status lights.

All inverter set-up values can be entered from the TraceControl program, and they are stored as a profile in memory. The profile may be easily loaded into the inverter from the program settings menu should the inverter operating parameters need to be changed or reloaded. All inverter display functions can be plotted from the "recent data charts" menu.

One of the features of the system display software is the ability to model the PV arrays in the system using the Sandia National Laboratories PV module library. An IV and power curve is displayed in a separate window showing the theoretical IV and power curve for the system PV arrays at their actual operating current and voltage.

The program superimposes the actual array performance on the IV graph (red and green dots) to allow monitoring of real time system performance throughout the day relative to predicted performance. Data setup for the system includes latitude and longitude, and array tilt and azimuth to allow real-time sun position prediction.

The data module board collects the inputs from various external sensors—shunts, system voltages, system temperatures, and solar irradiation reference panel—and conditions them for the analog to digital (A/D) converter module. I have been working with Mike at Maui Solar Software on the testing and debugging of the board and software. My system is the beta site for the monitor board and software. Contact me if you have questions about the system.

Reliability & Independence

After 35 years as an electronics engineer working with military and commercial RF systems, I have had a huge amount of fun designing and installing my own PV system at my home. My wife and I have been operating the PV system at our home for more than twelve months, and it has been great. We may want to move to a mountaintop someday and our experience with this system will allow us to be anywhere we want without worrying about utility service availability.

Since the PV panels are on the front of our house and visible from the street, we have had many people ask what they are for. It is interesting to see the surprised looks when I tell them that we are independent of the grid and supply almost all of our electricity from the sun.

Everyone who has seen the system is amazed that it is possible to do this. I have had several converts who are contemplating installing their own home PV systems. Most people that I have talked to who are nontechnical think that you have to be a rocket scientist to install and operate a PV system for your home. We're trying to show our friends and neighbors that solar electricity is user friendly and attainable.

Access

Brent Simons • b_Simons@pacbell.net

Northern Arizona Wind & Sun, 2725 East Lakin Dr., Flagstaff, AZ 86004 • 800-383-0195 or 928-526-8017 Fax: 928-527-0729 • windsun@windsun.com www.windsun.com • System components

Brent Simons throwing the switch at the AC service panel.

Silicon Valley Power, 1500 Warburton Ave., Santa Clara, CA 95050 • 408-244-7283 • Fax: 408-244-2990 cutcosts@siliconvalleypower.com www.siliconvalleypower.com