Home Power's 12 Volt System

Richard Perez & Joe Schwartz

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***HP's* bathhouse and power room, with all of the 12 volt PV arrays (and some of the 24 volt arrays).**

In the last issue of *Home Power,* we reported on our new 24 volt system. This issue's report is about rebuilding our 12 volt system. This system has many of the same design details as the 24 volt system. Perhaps the most novel feature of this new 12 volt system is the use of a "booster battery" to solve the problem of voltage loss in a long 12 volt power line.

Re-Using the Leftovers

After we had finished pillaging our old 12 volt system to build the 24 volt system, we assembled a new 12 volt system with the remaining hardware. It became sort of a patchwork job, making do with the leftovers. Fortunately, there were plenty of leftovers.

Revamping our systems here at *Home Power* gave us a renewed appreciation of the modular nature of RE equipment. We were able to break down our original huge 12 volt system, and use the components to make two systems—one 24 VDC and the other 12 VDC. Though we needed to purchase new inverters and batteries for the 24 VDC system, all the major 12 VDC components were reused. Nothing was wasted.

While our 24 volt system currently cycles about 8 KWH per day, the 12 volt system cycles only about half this amount, 4.7 KWH per day. We mostly use the 12 volt system for water pumping and garden irrigation, and to energize our 12 volt appliances.

Photovoltaics

The PVs in the 12 volt system are a motley assortment of modules. We used most of the modules that had identical mates for the 24 volt system, and what remained were mostly our older modules.

The 12 volt PVs are divided into three sub-arrays. 12 VDC sub-array #1 consists of eight Kyocera J-51 modules mounted on a dual-axis Wattsun tracker. In addition, a BP-275, an Arco Super Tri-lam, and a Mariposa concentrator are ground-mounted and paralleled into the tracked PVs. The combined output of 12 VDC sub-array #1 is 545 watts.

Home Power's democracy rack makes up 12 VDC sub-array #2. This ground-mounted array is made up of eleven modules from nine different PV manufacturers. Three ground-mounted Solarex MSX-53s are also

paralleled into this array, for a total output of 580 watts.

12 VDC sub-array #3 consists of a dual-axis Wattsun tracker with six high-voltage, 44-cell Kyocera J-61 modules. A single Solavolt SV8000 is paralleled into this array. Total output of 12 VDC sub-array #3 is 310 watts.

All in all, there are about 1,400 watts of photovoltaic modules in the 12 volt system. Most of these modules are static mounted, so the output is significantly less than a largely tracked system like our 24 volt system. We routinely see around 90 amperes from this system when the sun is shining, and total energy production is around 5 KWH per day.

12 volt PV sub-array #2: The democracy rack and more, 580 rated watts.

Each of the three 12 VDC PV arrays has a separate #1/0 (53 mm^2) copper home run into the power room. The longest run is 60 feet (18 m) from array to battery. We are starting to build a new addition onto *Home Power's* cabin/office. Afternoon shading from this addition will require the ground mounted PVs in 12 VDC sub-array #1 to be moved. When these modules are relocated, separate home runs will be provided for testing small 12 volt charge controllers.

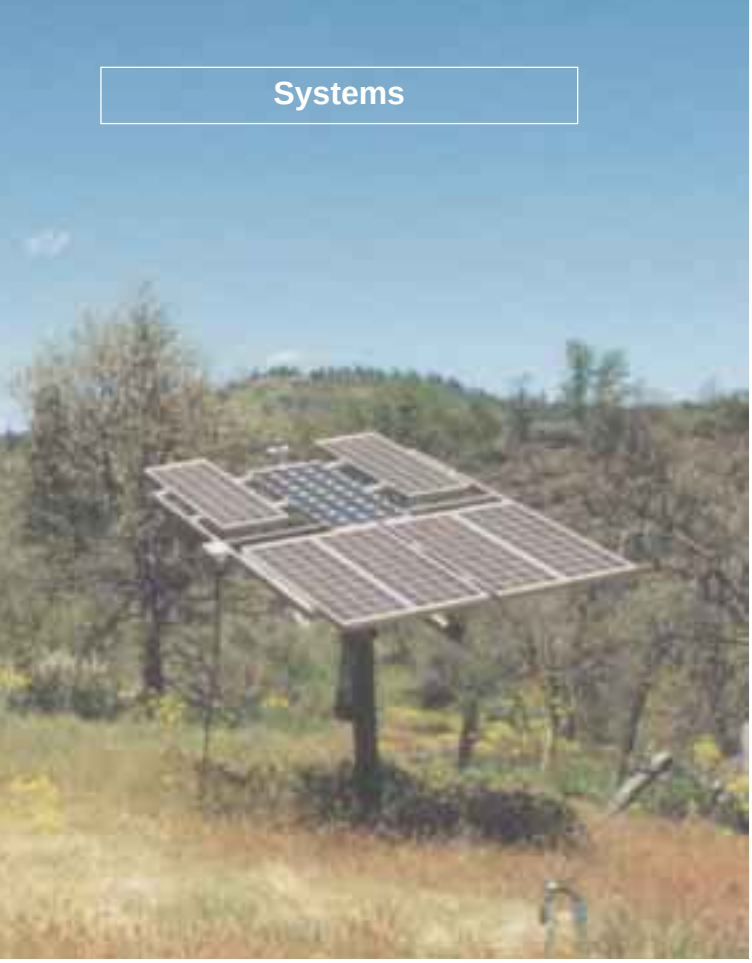
12 volt PV sub-array #1: 545 rated watts.

Controls & Instrumentation

The various PV arrays are regulated by a single Heliotrope CC-120 PV controller. See *HP48,* page 36 for a *Things that Work!* review of this controller. In the past, we seasonally adjusted the regulation voltage of this controller to reflect changes in battery temperature. We would set the controller at 14.9 VDC for winter operation and 14.7 VDC for summer operation. Now that the 12 volt system battery is housed in the hydronically heated battery box, we'll just leave the Heliotrope CC-120 set at 14.7 VDC.

Instrumentation for the 12 volt system is provided by two battery ampere-hour meters. A Cruising Equipment Amp-hours +2 meter is located in the Ananda power center in the new power room. This two channel amp-hour meter measures both net battery current and voltage, and total PV current and voltage. A Cruising Equipment E-Meter is located on the wall in the office.

Even though we check the instrumentation in the power room several times a day, it's convenient to be able to check on system operation without leaving the office. Battery ampere-hour meters are essential items for off-grid PV systems—without them you are flying blind. This is especially true in our case, since we are operating two different systems. We need to know which system is energy rich, so we can use its energy first.



12 volt PV sub-array #3: 310 rated watts.

Inverters

The 12 volt system is currently equipped with three inverters. The main inverter is a Statpower PROsine 2.5 KW, with surge capability to 4 KW, a peak efficiency of 88 percent, and a maximum total harmonic distortion (THD) of 5 percent. See *HP69,* page 60 for a *Things that Work!* review of this unit.

The PROsine 2.5 KW inverter is primarily used for pumping water from our well with a 1/3 hp submersible pump. It also occasionally powers a 1/2 hp centrifugal irrigation pump that pressurizes four Rainbird sprinklers in the vegetable garden. These two tasks use a considerable amount of energy—about 0.7 KWH per day in the winter, and over 5 KWH per day during the summer months when the garden is green and growing.

There are two other inverters in the 12 volt system, a Statpower PROsine 1000 and an Exeltech XP1100. Since we are currently testing the PROsine 1000, it is the active smaller inverter, and operates 24 hours a day. The PROsine 1000 has a surge rating of 1,500 watts, a peak efficiency of 89 percent, and a maximum THD of 3 percent. The Exeltech XP1100 has a surge rating of 2,200 watts, a peak efficiency of 87 percent, and a maximum THD of 2 percent. See *HP75,* page 76 for a *Things that Work!* review of this inverter. The Exeltech is currently off-line during testing of the Statpower 1000.

We're using these particular inverters because they produce high quality power. Because the output is a true sine wave, THD never rises above 3 to 5 percent and is typically below 1 percent. Needless to say, all of our appliances love this clean power. Big motor loads such as the well pump and irrigation pump run cooler and more efficiently when powered by the true sine wave output of these inverters.

The main loads currently connected to the PROsine 1000 are two solar hot water circulating pumps. Each of these pumps consumes about 65 watts, which at first glance might not seem like much power. But these pumps run all day, every sunny day, and between them they can consume over 1.5 KWH per day. The circulation pumps are the third largest daily electrical load at *Home Power* Central.

The solar thermal systems could be much more efficiently driven by smaller, magnetically-coupled DC pumps, and this upgrade is on the project list. Also connected to the PROsine 1000 are the compact fluorescent lighting in the greenhouse/bathhouse, and the Staber washing machine, neither of which are big energy consumers.

Battery

We store energy in four Surrette 6-CS-25PS batteries, each 820 ampere-hours at 6 volts. See *HP75,* page 84, for a *Things that Work!* review of these batteries. We used #4/0 (107 mm^2) copper welding cable (labeled "CU") to series/parallel the Surrettes. Total battery capacity is 1,640 ampere-hours at 12 VDC. These four Surrettes are housed in the solar-hydronically heated battery box described in *HP77,* page 41.

System Connections

RE products we receive for testing are rotated through the system on a regular basis. Because of this, we wanted to keep the system as modular as possible. We followed the same basic design parameters for the 12 VDC system as we did for the 24 VDC system detailed in *HP77.* All hardware is mounted on racks for ease of installation and additional cooling. Conduit and raceways are oversized to simplify modifications or additions to the system.

The hot inputs from the three 12 VDC PV sub-arrays are wired to separate 60 amp, DC-rated breakers in the Ananda. The positive PV input is combined on the battery side of the breakers, routed through a Heliotrope CC-120 charge controller, and terminated at the positive bus in the power center.

The negative leads from the PV arrays each pass through a dedicated 100 mV/100 A shunt for metering of the individual arrays. The PV negatives are then combined and run through a 50 mV/500 A shunt used to

measure total PV input. The PV negative leg then goes to the charge controller, and finally terminates at the negative bus in the Ananda.

The batteries are wired to the Ananda with two pairs of #4/0 (107 mm^2) CU welding cable. All lugs are crimped, soldered, and sealed with heat shrink tubing. DC input to the inverters is routed through Class-T fuses in the Ananda. AC output from the inverters runs through an easily accessed raceway and then to the AC distribution mains.

When the Sun Doesn't Shine

We use a Honda ES6500 120 VAC generator to supply backup energy for both the 12 volt and 24 volt systems. In the 12 volt system, we use a dedicated hot leg of the generator to power the onboard charger in the Statpower PROsine 2.5 KW inverter. This leg also provides AC for a 70 ampere Todd battery charger.

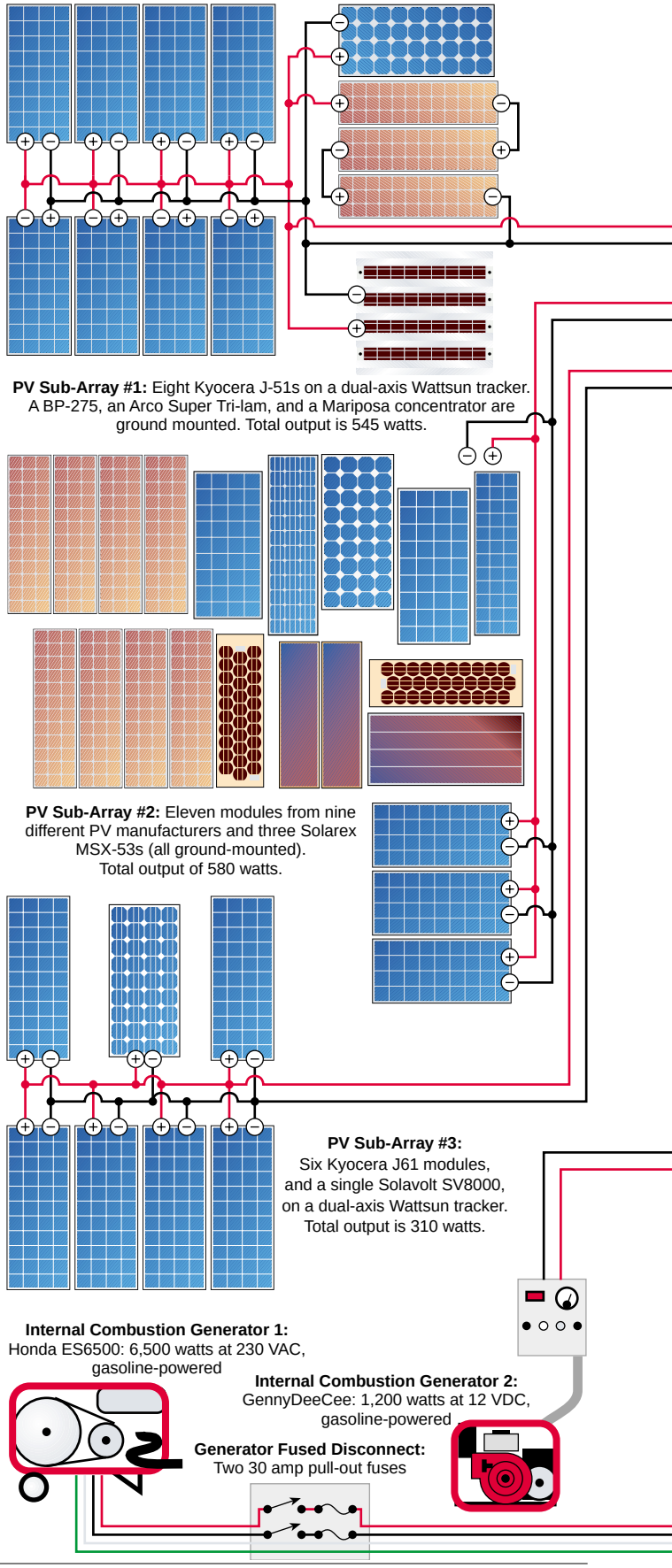
We're totally impressed by the quality of the charger built into the Statpower inverter. It puts over its rated 100 amps (we've measured 117 A) into the battery at 12 VDC. The charger presents a near-unity power factor (0.99 to 1.0) to the generator. This results in less generator run time, fuel consumption, noise, and pollution. The Statpower's AC charger is so effective that we rarely have to use the Todd charger.

The 12 volt system including power center, inverters, controller, and charger.

The Surrette 6-CS25-PS batteries provide 1,640 AH of storage at 12 VDC.

A GennyDeeCee 12 volt engine generator manufactured by Feather River Solar Electric is a second backup charging source. It uses a Honda overhead valve engine to drive a 12 VDC alternator. Our unit has a maximum output of 100 amps at 12 VDC. The big advantage of the GennyDeeCee is that it uses about half the gas per amp-hour into the batteries as a conventional AC generator. Burning fossil fuels is definitely an instance where less is better!

Inside the Ananda Power Center.



12 Volt DC Loads

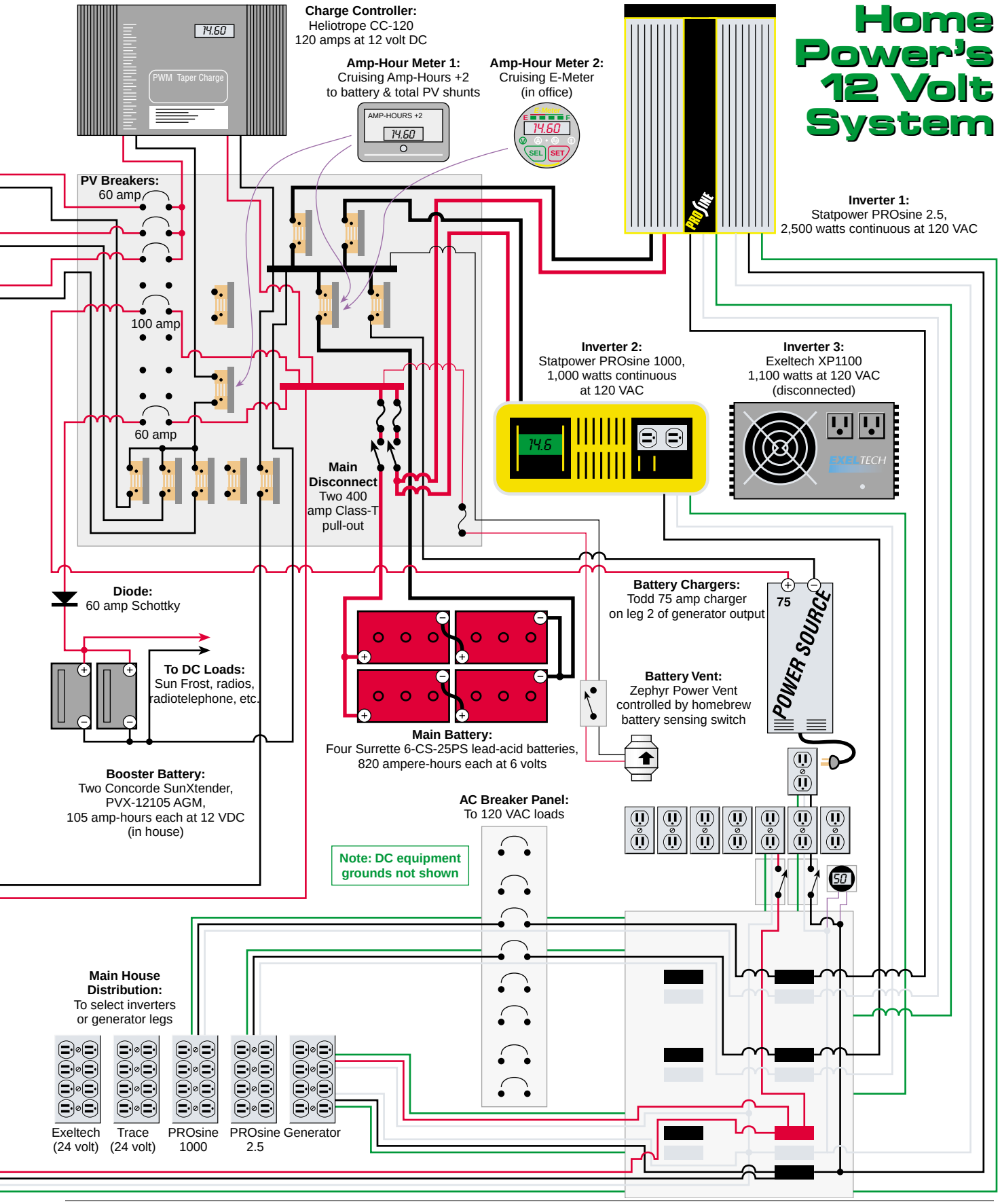
Our AC loads are covered in the inverter section. AC loads are about 61 percent of our total load for this system, while DC loads are about 39 percent. One of the reasons we opted to keep a 12 volt system was our 12 VDC loads, which, while few in number, are still significant energy users. The largest consumer is our Sun Frost RF-19 refrigerator, which uses an average of 960 watt-hours per day. Smaller consumers include our ham radios (242 watt-hours per day) and our radiotelephone (264 watt-hours per day).

These loads consume a total of about 1.5 KWH per day. They are all located in the house, which is about 100 feet (30 m) from the 12 volt battery housed in the power room. The best way to move 12 volt power this distance without excessive voltage drop was the topic of much discussion.

While the average current consumption of a single motor/compressor in the Sun Frost is about 5 amperes, the peak or surge consumption is around 15 amperes. And the Sun Frost has two motor/compressors, one for the refrigerator and one for the freezer. We were concerned about supplying the peak demands of these compressors without undue voltage loss in that long, low-voltage power line.

We installed 110 feet (34 m) of #1/0 (53 mm^2) aluminum (AL) cable between the battery in the power room and the house. With a single Sun Frost compressor operating, voltage loss in this power line averaged 0.5 VDC. With both compressors operating, the peak voltage loss in the 12 VDC power line was over 1.5 VDC—far too high.

Home Power's 12 Volt System



The Missing Wind Generator

Home Power's 1,000 watt Whisper wind generator, manufactured by World Power Technologies, doesn't really have a proper home in either the 24 or 12 volt system articles. When we wrote the 24 volt system article, the wind genny was charging the 12 volt system. Now it is has been switched over to the 24 VDC system. We made this switch because the 24 VDC system is loaded more heavily than the 12 VDC system.

The Whisper 1000 is mounted on a 64 foot (20 m) tilt-up tower located 600 feet (180 m) from the new power room. The generator is wired for 48 VDC to minimize losses in the long wire run. Its output is run through #1/0 (53 mm^2) AL USE wire and stepped down to 24 VDC in the power room using an 80 amp Bobier Electronics LCB. The shift from the 12 V system to the 24 V system means that the LCB runs more efficiently because there isn't as much of a down conversion.

At high output, the LCB is only about 85 percent efficient. But it allows us to transmit maximum wind generator output over a long distance with an acceptable 9 percent voltage drop. The other nice feature of the LCB is that the wind generator's maximum power point can be manually adjusted. During high winds, we dial up the LCB's input voltage, resulting in a higher operating voltage at the wind generator and increased current into the battery.

During nighttime operation when the batteries were not under charge, the compressors in the Sun Frost were getting browned out. They were forced to start and run while supplied with lower than specified supply voltage. (12.0 VDC minimum). This will shorten their life and reduce their efficiency. We were also concerned about feeding too low a voltage to the ham radios, and most especially the radiotelephone (R/T). After a few days of this condition, we opted for plan B. We decided to solve this problem by using a "booster battery" installed in the house, near the Sun Frost.

Booster Battery

We probably didn't invent the concept of a booster battery. We're sure that someone, somewhere, must have tried this before, but we've never heard of it. Here's the basic idea: A small 12 volt battery is located as near as possible to the 12 volt loads. In our case, this small battery is two Concorde AGM batteries, each rated at 105 ampere-hours at 12 VDC. These are wired in parallel with the main 12 volt battery bank.

During the day, the 12 VDC system recharges the booster battery, and also powers the loads connected to it. At night, the booster battery supplies the surge current needed to operate appliances without undue voltage depression. Should the booster battery's voltage ever drop to lower than the main battery's voltage by 0.4 VDC or greater, then the main battery will supply the loads.

We chose the Concorde AGMs for this job because they are sealed, and could easily be housed in a kitchen cabinet. We wired them in parallel for a total of 210 ampere-hours at 12 VDC. This booster battery is connected to the main 12 volt battery, which is over 100 feet (30 m) away.

There is a Schottky diode inserted in series in the positive leg between the main battery and the booster battery. This diode prevents the booster battery from discharging into the main battery, but allows the main battery (and its power sources) to recharge the booster battery. The main idea here is that the booster battery will deliver the surge current required to run the Sun Frost compressors, and thus keep the DC voltage higher in the house.

So far, this booster battery concept is working well. We installed a TriMetric battery ampere-hour meter on the booster battery so we could measure its performance. At night, we discharge the booster battery about 40 ampere-hours, and each day it is refilled by the main 12 volt system. The main 12 volt system regulates at 14.7 VDC. The 60 ampere Schottky diode we used has a forward voltage drop of 0.4 VDC. This limits the charge voltage to the booster battery to 14.3 VDC, which is

***Home Power's* 12 VDC System Loads**

Appliance	*AC or DC*	*WH per day*	*%*
2 Solar DHW circulating pumps	AC	1,200	27.3%
Well pump, 1/3 hp	AC	1,200	27.3%
Sun Frost RF-19 fridge/freezer	DC	960	21.8%
Inverter in standby mode	DC	360	8.2%
2 Ham radio receivers	DC	192	4.4%
Staber washing machine	AC	165	3.8%
Radiotelephone receiver	DC	144	3.3%
Radiotelephone transmitter	DC	120	2.7%
Ham radio transmitter	DC	50	1.1%
Soldering iron	DC	3	0.1%
	Total	4,394	

perfect for the sealed Concorde AGMs. When the batteries receive equalization charges, we will disconnect the booster battery from the main battery system to avoid overcharging the sealed batteries. A 30 ampere Square D QO breaker provides overcurrent protection and a disconnect to the booster battery circuit.

The booster battery picks up the surge current required by the Sun Frost compressors, and keeps the voltage high at night for the ham radios and radiotelephone. While the booster battery is a somewhat roundabout approach to solving voltage loss in long 12 VDC lines, it works. Most systems will not need this approach. It's best to site your battery bank as close as possible to major DC loads, or run only 120 VAC appliances only if this is not possible. But in special cases, it's good to know that a custom approach like this can work.

Other Options

We considered other options to the booster battery. We could have achieved an acceptable voltage drop by running #4/0 (107 mm^2) copper cable from the main battery up to the house. The expense involved didn't make this a very attractive option. A second option was to run 24 VDC to the house and convert it down to 12 VDC using a power supply. The problem with this was noise from the DC to DC converter.

Switching power supplies tend to produce electrical noise, which is in turn transmitted to the various 12 volt appliances, and particularly communications devices. That includes TVs, two-way radios, cell phones, R/Ts, AM radios, FM radios, cordless phones, satellite dishes, etc. Communication is essential, entertaining, and very much a part of our media-drenched lives. Anything that interferes with it must be eliminated!

Our radiotelephone and ham radios are by no means noise tolerant. Even a small amount of DC noise or ripple on the 12 volt line gives us a buzz on the radios. On the ham radios this is merely annoying. On the radiotelephone, this noise can shut down modem communication entirely. A battery has inherent capacitance, which stores charge and can reduce voltage ripple on DC lines. With the added capacitance filtration of the booster battery, we have no noise or DC ripple, so all the radios are happy, and operate without interference.

System Cost

Since almost all of the gear in our new 12 volt system was scavenged from our old system, the cost to us was merely wire, cable, conduit, and such like. That and all of three days of Joe, Eric, and Jason's labor wiring everything up in the new configurations. If anyone were to duplicate this 12 volt system using all new gear, it would cost about US$15,000, and would provide about

Fossil-fuel backup: A Honda ES6500, 6,500 watts at 230 VAC (left), and a Feather River Solar GennyDeeCee, 1,200 watts at 12 VDC (right).

5 KWH per day. That's enough to run an energy efficient home of four people in a deluxe fashion.

Flexibility

One of the main reasons we retained a 12 volt system here was to have the flexibility of two discrete systems. We can draw from whichever system has the most energy at the time. We can also continue to test 12 volt equipment, which is essential for reports to our readers. Overall, we're very happy with two systems. To be sure, it has been some additional expense and lots and lots of additional work (thanks, Joe!), but for us, it's worth it.

The flexibility of our two systems shines in the new plug-and-play center in what used to be our old power closet. We can waltz in there and choose which system and inverter we want to use to power a load or group of loads. This flexibility is greatly reducing our generator operating time, and saving fossil fuel.

Access

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Cruising Equipment, 5245 Shilshole Ave. NW, Seattle, WA 98107 • 206-782-8100 • Fax: 206-782-4336
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E-Meter AH meter

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www.psln.com/frenergy
GennyDeeCee 12 volt generator

Heliotrope PV, PO Box 1053, Fall Creek, OR 97438
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rvsolar@continet.com • PV controller

Kyocera Solar Inc., 7812 East Acoma Dr., Scottsdale, AZ 85260 • 800-544-6466 or 480-948-8003
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Power center

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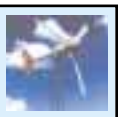

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