Let The Midnight Special Shine Its Light On Me...

Blackout Protection for Your On-Grid Home

Joe Schwartz
& Richard Perez

Which one of these houses is yours? Blackout protection lets you decide when the lights go out.

Rolling blackouts have become a regular occurrence for many electric utility customers in California. Drought conditions in much of the Pacific Northwest have radically reduced hydroelectric generation utilized up and down the West Coast. As a result, the states of Oregon and Washington face a steadily increasing probability of being dragged into California's energy debacle. Lack of both transmission and generation capacity in Illinois, Michigan, Delaware, and New York may plague the residents of these states with blackouts in the near future.

An inverter/battery-based uninterruptible power supply (UPS) will provide blackout-proof power to your home. This system will keep your electric appliances up and running during utility blackouts caused by acts of nature such as storms, or by acts of man such as utility irresponsibility. This article provides all the specifics for a basic UPS system. We call this blackout buster the "Midnight Special."

The system is both modular and expandable—a larger capacity battery bank or renewable energy inputs can easily be added to the system. The basic Midnight Special costs about US$6,000, and that includes professional installation.

System Overview

We chose a Trace SW series inverter as the central component of this UPS system. An inverter-based grid backup system uses utility power, when it's available, to charge a battery bank. When a blackout occurs, selected loads are automatically transferred to the inverter. The inverter's main job is to take a battery's linear DC waveform and create a digital representation of an AC sine wave. This is the waveform that your household appliances are designed to run on.

During a power outage, the inverter uses the energy stored in the batteries to power household loads. When the grid comes back online, the loads are automatically transferred back to grid power. Then the inverter's battery charger goes to work and recharges the batteries, so the system is ready to go when the next blackout rolls around.

The Midnight Special's system components—sealed Concorde 6 volt, 220 amp-hour, absorbed glass mat (AGM) batteries (left); TriMetric amp-hour meter (center); and Trace SW4024 sine-wave inverter with AC disconnect/bypass box (right) and DC disconnect box (far right).

The Loads

The load table (page 36) lists the appliances we selected to be powered by this UPS system. Both essential and desirable loads have been included. The system is designed to support up to a 4 KW continuous load. It will supply about 6,500 watt-hours of energy per day in a normal appliance usage scenario. This system will keep the lights on, the fridge/freezer operating, the communication gear running, and still have power left over to vacuum the floors and do the wash.

The system is designed to power these loads for a period of 24 hours—far longer than the average utility blackout. For power outages lasting several days, an engine-generator or photovoltaics (PVs) can be added to the system to recharge the batteries and energize the system.

This system is not compatible with large thermal loads powered by electricity. It is not designed to run electric stoves, electric water heaters, electric space heating, heat pumps, or central air conditioning. All these loads are very big energy consumers, and beyond the capabilities of this system.

The Parts

This system uses standard off-the-shelf renewable energy equipment—the same inverter, batteries, instrumentation, and safety gear found in many off-grid homes. The renewable energy equipment selected for this system has been proven to be efficient and reliable over years of use in thousands of off-grid homes in the U.S.

The specified components are UL listed for fire safety—just like the rest of the appliances in your home. The cost table (page 38) gives a list of the equipment used in this UPS system. Estimated prices for the equipment and professional installation are included.

Inverter/Battery Charger

A Trace SW4024 inverter creates standard 120 VAC, 60 Hz electricity from the energy stored in the battery bank. Trace SW series inverters are the most commonly used inverters in off-grid and grid backup systems. The model specified for this system is the SW4024. It has a 24 VDC input and a 4,000 VA AC output.

Two other 60 Hz Trace SW series inverters are available—the SW4048 and the SW5548. These inverters have a 48 VDC input voltage and 4,000 VA and 5,500 VA output respectively. The surge capacity of all three models is 78 amps at 120 VAC. Export models are also available with 230 VAC, 50 Hz outputs.

Trace SW series inverters have an onboard, 60 amp AC transfer switch. When grid electricity is present, the transfer switch routes utility power directly to household loads. When a power outage occurs, the loads are automatically transferred to the inverter/battery system. Depending on the nature of the grid failure, this transfer may be noticeable—the lights may momentarily dim. But the transfer time is typically fast enough to keep computers running during most grid failures.

A Trace SW4024 inverter uses three transformers to create an AC waveform to run your appliances. The SW4024 is also designed to run these transformers backwards to charge your batteries. In this mode, the transformers are capable of producing 120 amps at 24 VDC for charging your batteries. The charge rate is user programmable, and the inverter automatically reduces the charge rate as the batteries become full.

This inverter interfaces gracefully with grid power, and is equally at home on the grid or off. And best of all, renewable energy sources can be added to this system. PVs, a wind generator, or a microhydro turbine can supply all the power your home needs. The SW series

Typical Load Table (From Energy Master Spreadsheet)

INVERTER SUPPLIED 120 VAC APPLIANCE POWER CONSUMPTION ESTIMATE

Midnight Special
Your House
Sunny, California USA

Date: 08/01/01

AC Watt-hrs. Used Daily 6512

Please note: this is an estimate and is only as good as the information supplied.

All Appliances on the list below are powered by 120 VAC from the inverter

No.	Inverter Powered Appliance	P?	Run Watts	Start Watts	Hours /Day	Days /Week	W-hrs/day	%
1	19 cu ft refrigerator/freezer	1	140	240	10.00	7.00	1400.0	21.11%
1	Computer monitor	1	90	200	8.00	7.00	720.0	10.86%
1	Solar DHW system	1	75	75	8.00	7.00	600.0	9.05%
1	Computer	1	60	120	8.00	7.00	480.0	7.24%
6	Fluorescent lights	1	15	15	5.00	7.00	450.0	6.79%
1	Laser printer	1	700	1200	0.50	7.00	350.0	5.28%
1	Television set	1	75	200	4.00	7.00	300.0	4.52%
1	Stereo	1	25	25	9.00	7.00	225.0	3.39%
1	Washing machine	1	250	500	1.25	5.00	223.2	3.37%
1	Microwave oven	1	800	1200	0.25	7.00	200.0	3.02%
1	Vacuum cleaner	1	1350	2700	0.50	2.00	192.9	2.91%
1	Video cassette recorders	1	40	40	4.00	7.00	160.0	2.41%
1	Fax standby	1	5	5	24.00	7.00	120.0	1.81%
1	Cordless telephone	1	4	4	24.00	7.00	96.0	1.45%
1	Ni-Cd battery recharger	1	20	20	6.00	3.00	51.4	0.78%
1	Fax/Copier	1	40	40	1.00	5.00	28.6	0.43%
1	Sewing machine	0	80	160	4.00	1.00	45.7	0.69%
1	Blender	0	350	700	0.05	7.00	17.5	0.26%
1	Coffee grinder	0	50	150	0.05	7.00	2.5	0.04%

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Inverter AC W-hrs Consumed Daily 5663 w15% Invert Ineffic.= 6512.2
Largest Appliance Wattage 1350
Largest Appliance Surge Wattage 2700
Inverter Priority Wattage 3764

inverter is even designed to spin your utility meter backwards and place your surplus renewable energy (RE) on the utility grid for your neighbors to use.

Trace SW series inverters require programming once they're installed. The settings table shows recommended set points for the 440 AH battery bank specified for the Midnight Special. Regulation set points for both sealed AGM and flooded lead acid batteries are included.

Batteries

We selected 6 volt, 220 amp-hour, sealed Concorde absorbed glass mat (AGM) batteries for this UPS system. Sealed batteries are becoming more and more popular, especially in on-grid systems where the batteries are typically kept at a full state of charge.

Sealed batteries are very user friendly compared to standard flooded lead-acid cells. They are maintenance free, so you never need to add water. All batteries experience self-discharge, a gradual loss of energy within the battery. But different battery types experience different rates of self-discharge. New sealed batteries have about one tenth the rate of self-discharge (between 1 and 3 percent a month, depending on temperature) of flooded lead-acid batteries.

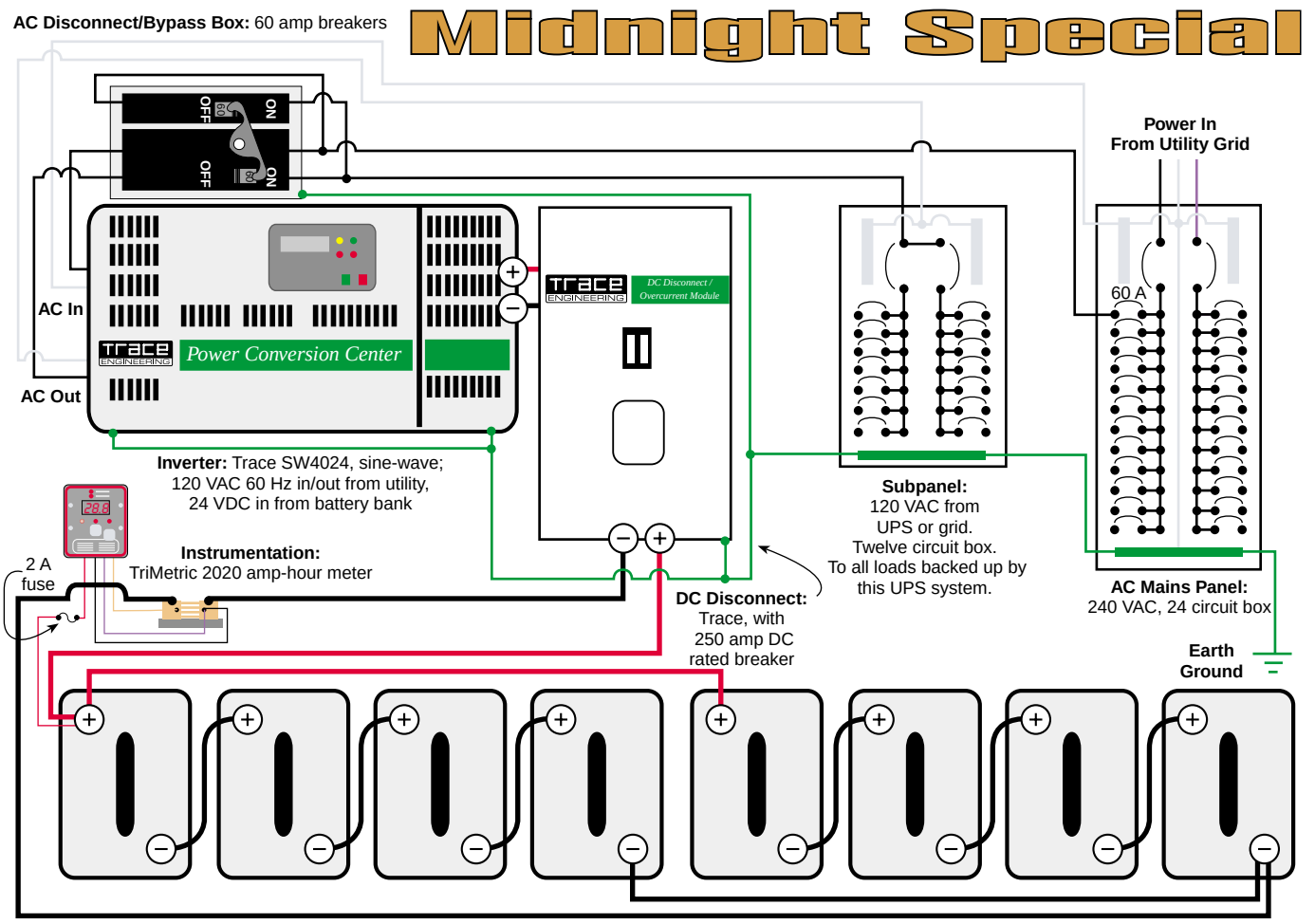
Sealed batteries are safer. They do not produce large quantities of hydrogen gas like flooded lead-acid cells. So they don't need to be vented to the outside. But they should still be located in a containment. You never want to leave battery terminals exposed to kids, dropped wrenches, etc.

No maintenance, no gassing, low self-discharge—why use anything else? Well, Concorde AGMs cost roughly 40 percent more than flooded lead-acid cells. But if you have the cash, Concorde AGMs are a great way to go.

It's important to note that sealed batteries may be permanently damaged by battery voltages higher than manufacturer specifications. Concorde specifies voltages no higher than 14.4 VDC for a 12 VDC nominal system. So the batteries in our 24 VDC UPS system should never be charged higher than 28.8 VDC. The SW4024 inverter allows you to set both bulk and float voltages, so you can maintain the batteries at the proper regulation voltage.

The 440 amp-hour battery bank for this system is sized for the intermittent use of the appliances listed in the load table. This is a minimal battery bank compared to the full output capabilities of the SW4024 inverter. As the inverter powers these selected loads, battery voltage will sag. This will happen when loads with a large startup surge (like the vacuum cleaner) are turned on.

Most modified square-wave inverters are not voltage regulated. So as the battery voltage drops, so does the AC output voltage. This isn't the case with SW series



Battery Bank: Eight sealed Concorde 6 volt, 220 amp-hour, absorbed glass mat (AGM) batteries. Wired series/ parallel for 24 volts, 440 amp-hours.

inverters, which regulate AC output voltage (120 VAC +/- 3%). SW series inverters have a user programmable low battery voltage cut-out. They also have an adjustable low battery cut-out delay. This keeps the inverter online when battery voltage dips with the startup of motors with a large surge.

The smaller the battery bank, the greater the voltage depression, and the harder the batteries are worked. A small battery bank also means deeper discharges when the grid fails and the batteries are cycled. But in UPS systems, small battery banks are common. The batteries spend most of their lives at a full state of charge, and are only cycled intermittently.

In an off-grid system, the batteries are cycled on a daily basis. A 700 to 900 amp-hour battery at 24 VDC is a good minimum off-grid battery capacity in relation to the output of an SW4024 inverter. The standard battery bank supporting an SW4024 in an off-grid system is 1,000 to 1,200 amp-hours at 24 VDC. A larger battery bank means higher voltage under load. And because of the increased capacity, the batteries are cycled less deeply, increasing battery longevity.

Battery longevity is directly related to how well the batteries are maintained. The major causes of early battery death are chronically undercharging or overcharging them, deeply discharging them, and not adding water if you're running flooded lead-acid cells. A set of properly maintained batteries, adequately sized for a given system, can be expected to last ten years in a grid backup application. Depending on how often the batteries are cycled, a significantly longer battery lifespan can be expected.

Instrumentation

A critical piece of equipment for any battery-based system is an amp-hour meter. This meter compares the amps coming into the battery from the charging sources to the amps going out to the loads. An amp-hour meter is the only accurate way to monitor the state of charge (SOC) of your batteries. It is also very convenient, and accessible to non-technical users. The meter displays battery SOC as a percentage of total capacity. Just like the fuel gauge in your car, a quick glance at the meter tells you your batteries' SOC.

Typical Midnight Special Costs (From Energy Master Spreadsheet)

RENEWABLE ENERGY SYSTEM HARDWARE COST ESTIMATE

Midnight Special	Date: 08/01/01
Your house	
Sunny, California USA	

Initial Cost Estimate $5760.00

Power Consumption 6632.204 Watt-hours/day

No.	Item Description	Type	Unit Price	Item Total	% of Cost
1	Trace inverter	SW4024	$3,495.00	$3,495.00	54.69%
8	Concorde batteries	B-PVX6220	$179.00	$1,432.00	22.41%
8	Installation labor per hour	estimate	$50.00	$400.00	6.25%
1	Inverter/battery disconnect	DC250	$329.00	$329.00	5.14%
1	Battery amp-hour meter	TriMetric	$200.00	$200.00	3.12%
10	Battery/inverter cables		$180.00	$180.00	2.81%
1	Misc. wire and fittings	estimate	$100.00	$100.00	1.56%
1	Trace SW conduit box	SWCB	$94.00	$94.00	1.47%
1	AC subpanel	8 circuit	$80.00	$80.00	1.25%
1	Inverter bypass switch	Sq. D	$80.00	$80.00	1.25%

Total Initial Hardware Cost Estimate $6,390.00

Three different brands of amp-hour meter are available: Bogart Engineering's TriMetric, Xantrex's Link 10, and the Trace TM500. All three of these meters display battery SOC and other system information.

In this intermittent, grid backup application, an 80 percent depth of discharge (DOD) is acceptable. We never recommend discharging your lead-acid batteries by more than 80 percent (20% SOC). Doing so will greatly decrease your battery bank's longevity. Without a battery amp-hour meter, you won't know how deeply you are discharging your batteries.

In an off-grid system, batteries are cycled on a daily basis. In that case, a 25 percent daily depth of discharge is good threshold to shoot for. Remember, batteries like to be at a full state of charge. The less deeply you cycle them, the longer they'll last.

DC Safety Gear

Your battery bank has the potential to deliver tens of thousands of amps if a direct short ever occurred. This is a fire hazard and a potentially life-threatening situation. So just like the circuits in your house, you want to make sure to have a fused disconnect or breaker between the battery bank and the inverter. Since this breaker is on the low voltage DC side of the system, a high current DC-rated breaker is required.

Trace manufacturers a DC250 enclosure that houses a 250 amp DC-rated breaker. This provides overcurrent protection between the inverter and batteries. It also makes it possible to electrically isolate the inverter from the batteries if inverter servicing is ever required.

Interfacing with the Grid—The Subpanel

The maximum continuous output current from a Trace SW4024 is 33 amps at 120 VAC. Your home's mains panel is probably a 100 amp, 200 amp, or even larger service. So it's quickly apparent that a single inverter can't handle all the loads in a typical, on-grid household.

Usually, only certain loads are deemed important enough to require a backup power source. You need to survey the appliances in your home and decide which ones you want dedicated to your UPS system. The total appliance load must be within the inverter's output rating. In this case, that limit is 33 amps at 120 VAC (4,000 watts) continuous.

The next step is to identify the circuits that power the appliances requiring backup power. Circuit locations are usually listed on the inside of the cover of your mains panel. Once these circuits have been identified, they are pulled from the AC mains panel and rerouted to a new AC subpanel. Now you have a dedicated breaker panel for loads requiring an uninterruptible power supply.

In our case, the output of the inverter is run through a 60 amp breaker and on to the subpanel. In addition, grid power for battery charging must be run via a 60 amp breaker from your mains panel to the inverter. Both of these 60 amp breakers are included in the inverter bypass switch, which is housed in a separate enclosure, typically mounted above the inverter.

Inverter Bypass Switch

You always want to include an inverter bypass switch in a battery based, utility intertied system. You recall that in this UPS system, when grid power is available, it is routed directly to the dedicated AC loads by way of the inverter's internal transfer switch. Very occasionally, an inverter needs to be removed for service. When the inverter is removed for repair, so is the onboard transfer switch. This isolates the dedicated subpanel from the mains panel. That blacks out all the loads powered via the subpanel, which is definitely not the desired effect.

Without the inverter bypass switch, you would have to temporarily rewire the subpanel directly to the mains panel. Then you would have to switch the wiring back

again when the inverter was re-installed. If you're not doing the work yourself, this would mean two trips by a local electrician. A bypass switch eliminates this potentially expensive headache.

A three circuit Square D load center (model number QO403L60NS, with butterfly switch), one single pole 60 amp QO breaker, and one double pole 60 amp QO breaker are the parts that make up the bypass switch. At retail, this setup costs about US$80. The bypass switch allows you to throw one switch and route AC power from the mains panel directly to the subpanel. The breakers in the bypass switch also serve as overcurrent protection between the mains panel and the inverter, and between the inverter and the subpanel.

Non-Grid Power Sources

The local utility isn't the only source of electricity. As many off-grid *HP* readers can testify, there are many ways of making electricity that don't involve the utility. The Midnight Special is designed to handle them all.

AC Generators

If a utility blackout begins to stretch out for days, you need to come up with another power source to recharge the batteries and energize the system. The most common option is an engine-powered generator. Trace SW series inverters are designed to simultaneously manage both utility grid and engine-generator inputs. User programmable setpoints allow the use of most common generators.

Trace SW series inverters can also be programmed to automatically start generators based on either time of day or battery voltage. This sample system does not include a generator, since it's designed to power the specified loads for 24 hours. The majority of grid failures can be weathered by an appropriately sized battery bank.

Off-grid homes powered solely by an engine generator will also benefit greatly from the addition of an inverter/battery system. Generator-to-loads direct systems are extremely inefficient to run. Electricity produced by an engine generator costs about US$0.60 KWH.

More often than not, the generator will be operating at a fraction of its full output. Running a 10 KW generator to power a couple of lights and a TV is a tremendous waste of fuel. And you have to listen to the blasted thing whenever you want to turn on a light! Adding an inverter and batteries to the system will reduce generator run time, noise, and fuel costs by 80 to 90 percent.

Photovoltaics, Wind, & Microhydro

Since the gear used in this system is standard stuff, it can switch from a steady diet of grid power to a pollution-free diet of renewable energy. You can add PVs, wind power, microhydro, or a combination. This will make the system (and your home) energy self sufficient. Of course, RE resources are site specific. Most suburban homeowners don't have a stream cascading down their back yard, and wind turbines are tough to site in town.

If you have any surplus RE generated at your home, it can be placed on the grid for others to use. We

Need a Larger UPS System? Or a Smaller One?

Sometimes backup power demands are higher than the rated output of a single inverter. With the addition of an interface cable, two Trace SW series inverters can be stacked in either a series or parallel configuration for increased output.

For example, two series-stacked SW4024 inverters have a 120/240 VAC split phase output. The waveforms of the two inverters are 180 degrees out of phase—like the utility lines coming into your house. This configuration gives you two 4,000 VA legs, and allows you to run 240 VAC appliances. Two SW inverters can also be stacked in parallel for 8,000 VA of single phase, 120 VAC output.

Larger systems will require a larger battery bank. Always start with a survey of the loads you need to back up, and the number of minutes or hours you need to run them. In a grid backup application, your battery bank should be sized for a maximum discharge of 80 percent.

Just want to back up your computer? Off the shelf computer UPS systems may be your best bet. Want to back up your computer, a couple of lights, and your stereo? Calculate the total load you want to power and how long you want to power it. Then choose an appropriate battery bank capacity based on an 80 percent depth of discharge. Exeltech manufacturers small true sine-wave inverters. Several models are available with AC outputs from 125 watts to 1,100 watts. These inverters supply higher quality power than the utility grid. And you're the one to decide when they get shut down!

Midnight Special Inverter Settings

Menu Heading	*Menu Item*	*Recommended Setting*
For 8 Concorde Sealed AGM Batteries, 440 AH at 24 VDC		
Inverter Mode - 1	Set Inverter	SRCH (search)
Time of Day - 6		Set Hr/Min/Sec
Inverter Setup - 9	Set Grid Usage	FLT (float)
	Set High Battery Cut-Out VDC	29 VDC
	Set Search Watts	16 watts
Battery Charging - 10	Set Bulk VDC	28.8 VDC
	Set Absorption Time	1:00 Hr.
	Set Float VDC	26.8 VDC
	Set Max Charge Amps AC	20 Amps AC
	Set Temperature Compensation	Lead-Acid
For 8 Flooded Lead-Acid Batteries, 700 AH at 24 VDC		
Inverter Mode - 1	Set Inverter	SRCH (search)
Time of Day - 6		Set Hr/Min/Sec
Inverter Setup - 9	Set Grid Usage	FLT (float)
	Set High Battery Cut-Out VDC	32 VDC
	Set Search Watts	16 watts
Battery Charging - 10	Set Bulk VDC	29.6 VDC
	Set Absorption Time	1:00 Hr.
	Set Float VDC	26.8 VDC
	Set Max Charge Amps AC	20 Amps AC
	Set Temperature Compensation	Lead-Acid

estimate that about US$8,000 worth of PV and a larger battery will make this system capable of delivering about 6 KWH per day. This will run the loads listed in the table, on a site with 5.3 average sun hours per day.

A System with a Future

Considering the increasingly unreliable nature of utility grids, this system offers you a future where the lights are always on. If a storm brings down the power lines and puts out the lights, this system can bring them back. If the local utility gets irresponsible and shuts off the power because they can't make a profit or supply the demand, your lights will still be on. And then there is the tantalizing possibility of adding solar, wind, or microhydro energy to this system. The Midnight Special is a blackout buster with a clean and green future.

Access

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The Energy Master Spreadsheet is available for free from the Download section at www.homepower.com or on the *HP* Solar CD-ROMs

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