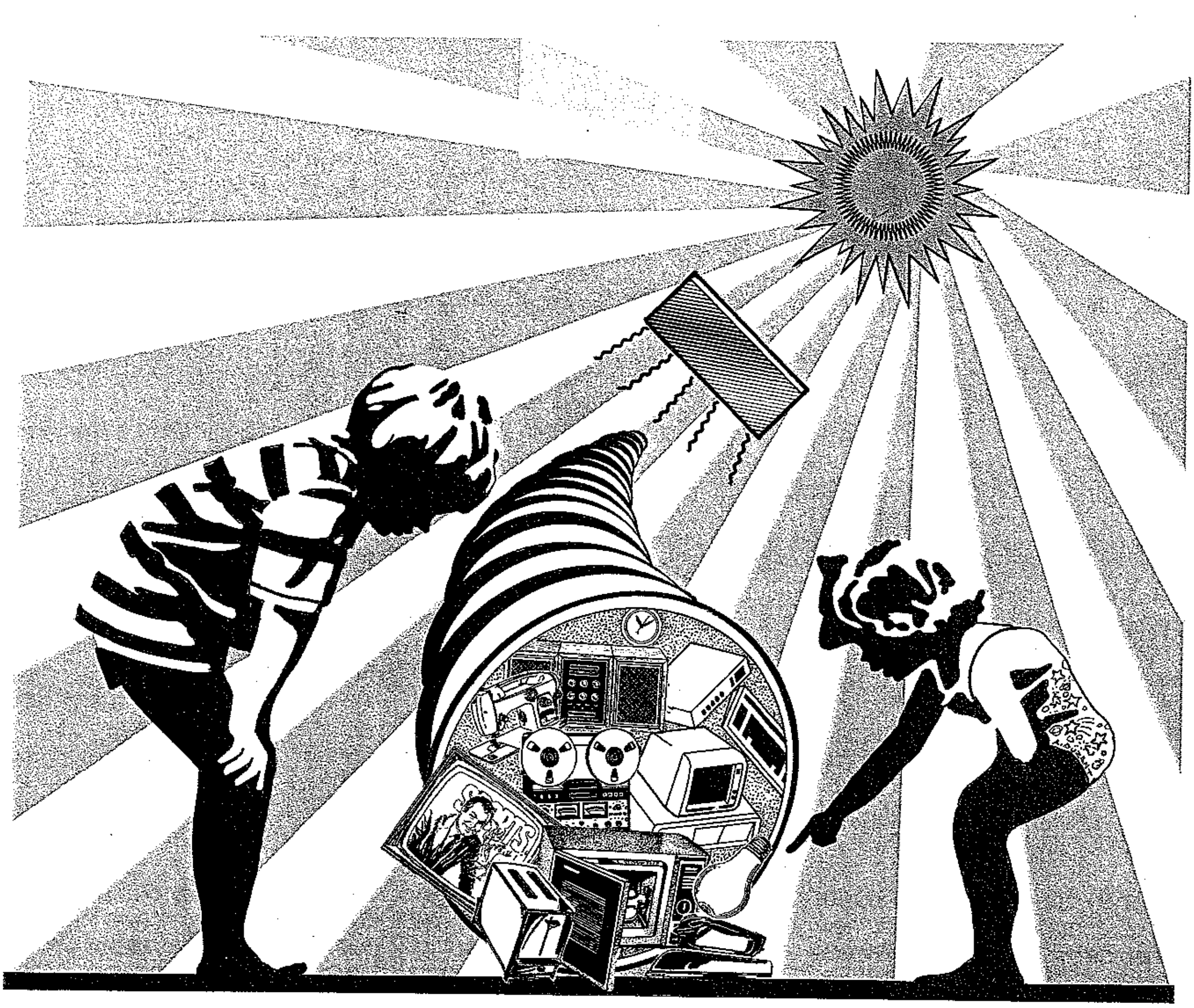


BUILD A SOLAR-CHARGE CONTROLLER

Harness the sun's energy to charge batteries with this easy-to-build controller.

BLAKE REED

With energy costs continually rising, using photovoltaic panels to get "free" electricity from the sun has become an intriguing concept. However, the cost of setting up such a system can be high enough to cancel out any potential savings. The most costly part of a system is the solar panel itself. Other than shopping around for good used or surplus panels, there is not much that can be done in the way of lowering costs in that area.

Just buying a panel and connecting it to a load is the simplest way to set up a solar power station, but that arrangement will not work very well. The more traditional way is use the panel to charge a battery and draw energy from that battery. That will compensate for any fluctuations from the panel's output, which can occur from passing clouds or the changing angle of the sun as it crosses the sky during the day. Storing the sun's energy in a battery will also let you use power at night.

If we study how a storage-type photovoltaic generating system is designed, some cost-cutting methods might be incorporated, making such a system affordable to the average person.

Designing a Solar-Energy Station. Surplus and used panels are in-

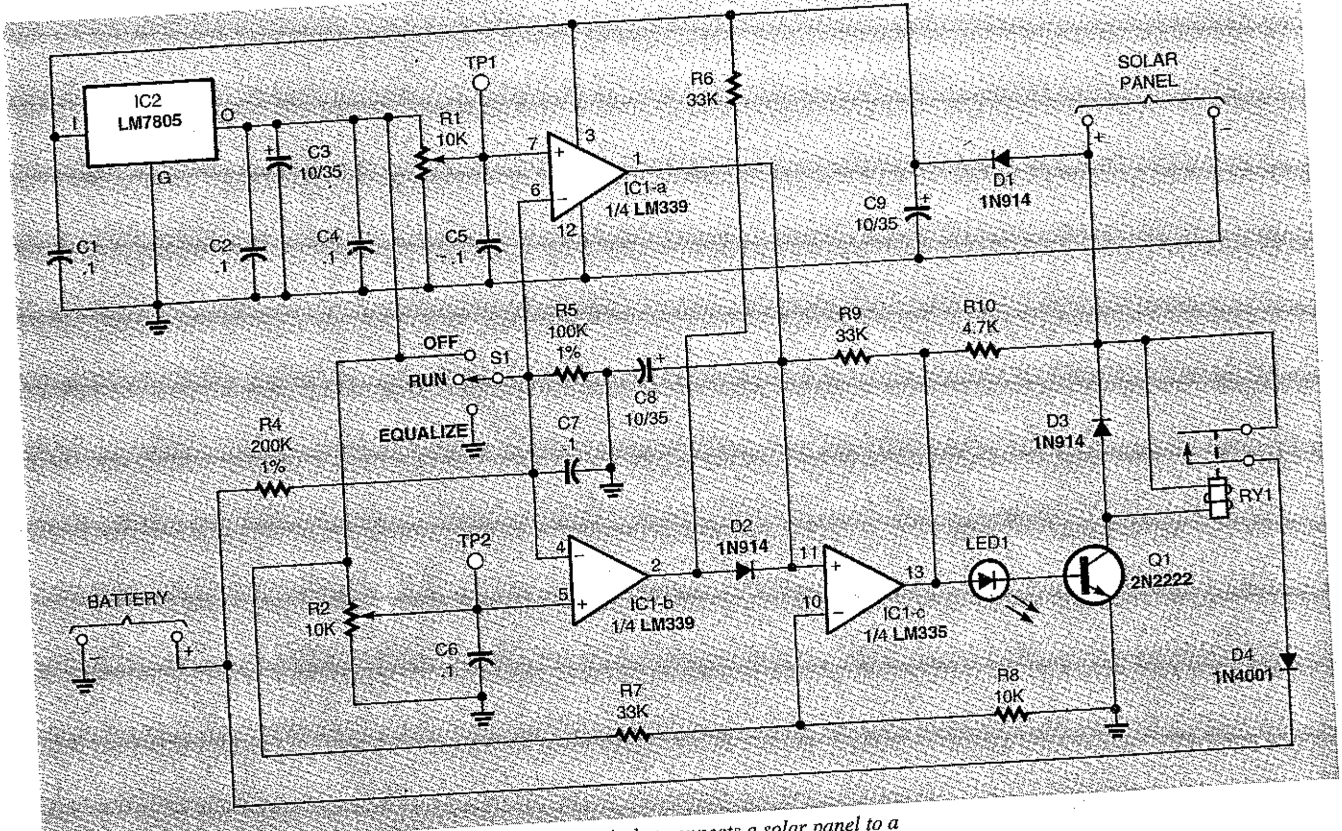


Fig. 1. The Solar-Charge Controller is a simple comparator circuit that connects a solar panel to a battery when it senses that the battery voltage is getting too low.

creasingly appearing on the market at reasonable prices. Often, new panels are "seconds" from the manufacturers. Those panels usually work fine but don't quite meet all of the manufacturer's specifications. Used panels, on the other hand, often come from solar-electric power stations. When the panels have dropped to 80% of their original rated output, they are replaced. Although the panels no longer put out their rated power, they can still put out plenty of energy and will continue to do so for many years. The power loss on panels is a logarithmic function, so it is unlikely that a decrease of power would be noticed by the average home user, even after 20 or 30 years of service. Those panels are often very reasonably priced and have the best "bang for the buck."

As we've said previously, the output of the panels will fluctuate during the day depending on the amount of sunshine falling on the panel. Solar panels are typically designed to put out about 16 volts. The output voltage can run as high as 28 volts on an extremely bright day, depending on the particular panel used. Those types of panels will work well when charging a 12-volt battery system while allowing for some losses.

Using a charge controller when charging batteries from a solar panel is required to keep the batteries from being overcharged. Overcharging batteries, especially gel cells (which cannot tolerate any amount of overcharge), will greatly shorten their life. The charge controller monitors the battery's condition and connects the solar panel when the battery needs charging and disconnects the panel when the battery is full.

There are many types of controllers available with different features such as keeping the batteries at their best "float-charge" voltage or the ability to compensate for temperature changes. Such controllers are often very expensive—over $200 for a fancier high-current unit. Spending a small fortune on a controller is probably the last thing someone wants to hear after shelling out big bucks on a panel and batteries.

The charge controller presented here is a very basic unit that will meet most needs. In fact, it can be used to maintain a battery from just about any power source so long as the charging voltage is less than 30 volts DC and the charging current is within the capability of the controller. In addition to running a photovoltaic generator, the controller is very handy for keeping an RV battery up to snuff over the winter or for keeping the ham-shack battery ready at all times. In those cases, a wall transformer can be used as the power source instead of a solar panel.

The charge controller is designed to handle charging currents up to 1 amp. By changing three components, currents up to 20 amps can be handled. All components are available at any RadioShack for about $26. That cost will rise to about $46 if the controller is modified to handle 20 amps. If the unit is hard wired into a photovoltaic generator station, a case and terminal block might not be needed, lowering the cost a bit.

Drawing a small amount of

power over a long period can easily drain a battery, especially if it has a small capacity. Powering the controller from the solar panel will not drain any power from the battery. Besides, if there is no sun, there is no reason to turn on the controller. The modified 20-amp controller, on the other hand, uses up to 100 mA when the panel is charging the battery. Because of that amount of current draw, it makes no sense to use the high-power version in a low-power station. The high-power controller would use up a majority of the panel's output current, leaving little or no energy to charge the battery. For any panel with more than a 1-amp capacity, the 20-amp controller should work well.

Solar-Panel Ratings. Most solar panels are rated by the power they can produce. Unfortunately, a wattage rating is very deceiving and doesn't tell what the actual useful power will be. The reason for that is that solar panels are constant-current devices. Their output current remains about the same as long as the load voltage is below what the panel can produce. An average solar cell can produce about 0.45 volt, which drops as the panel gets hot. As the voltage drops, the total wattage will drop since the current remains the same. Therefore, a 12-volt panel will always have considerable overhead, typically running 16 volts or more. That will compensate for the voltage drop on very hot days. It also guarantees that full charging current will be available for a battery pack, whose voltage can vary from 12 to 16 volts.

The panel rating is usually the total power available at the maximum current (which is constant) and the maximum voltage under ideal conditions. To show how those ratings work in the real world, let's look at the author's setup: The panel is rated at about 87 watts, producing about 5.27 amps at 16.5 volts. The battery pack being used runs on average at about 12.6 volts while charging. That means that the actual useful power produced by the panel to charge the batteries is a bit over 66 watts. The 22-watt difference is lost by the voltage drop across the charge controller's diode (3.7 watts), the resistance of the cables, and heating on the panel itself (which reduces its output voltage).

TABLE 1

Battery Type	Float Voltage	Turn-off Voltage
Deep-cycle lead acid (single)	13.4	14.6
Deep-cycle lead acid (two in series)	13.3	15.0
Gel cell (single)	13.5	14.1
Gel cell (two in series)	13.7	14.4
PbCa (lead calcium)	13.2	14.3
NiCd (single)	14.0	16.0
NiCd (two in series)	14.5	16.0

The power lost in the diode and cables is not much of a concern as removing those losses will not result in more useful power, only more heat across the panel. The only limitation to the losses is that they must be low enough to keep the overall system voltage (battery + cable + diode) less than the solar panel's output voltage under worst case conditions. To calculate the useful power of a panel, take the current of the panel times the voltage of the battery used and multiply that by the sun hours each day. That will give the number of useful watt-hours a day from the panel.

Batteries. The type of battery used for a solar power system is very important. Although there are many inexpensive automobile batteries available, they are not suitable. The reason for this is that they are designed to supply high current for a very brief period and then to be recharged right away, such as what happens when starting a car. If they are discharged and not recharged until the next day, they will fail very rapidly. A better choice is an RV or a marine trolling-motor battery. Those batteries are designed for many discharge and recharge cycles. One of the best batteries for a solar station is a golf-cart battery. They are designed for a high capacity and very heavy discharge/recharge cycles. As those batteries are 6-volt devices, two should be wired in series to make 12 volts.

Although the internal construction of those batteries is somewhat different, they are all variations of lead-acid battery technology. They all require periodic maintenance such as adding water and cleaning the terminals. Lead-acid batteries have a habit of generating hydrogen while being charged. Hydrogen in a great enough concentration and a spark can easily cause a very nasty explosion. The acid itself can cause severe burns or damage if any is spilled or a leak develops. It is a good idea to put lead-acid batteries into a sealed box that is resistant to acid and is vented to the outdoors if the batteries are kept indoors, which is the preferred setup. Here's why:

The best place to keep a battery is in a stable temperature environment. A battery's output capability drops considerably when the temperature drops. As much as 70% of a battery's power capability can be lost in extreme cold. The capacity will return when the temperature returns to normal. Extreme heat can greatly shorten the life of the battery. The other problem with having the battery outdoors is that the voltage at which the battery is fully charged changes with temperature. That could cause the battery to either be under- or overcharged when very cold or hot. An advantage to having the battery indoors is to keep losses in the wiring to a minimum. As with the solar panel wiring, the losses in the power cables can be significant. That is even more of a problem for the battery cabling as the currents used by the loads are often many times greater than those of the solar panel. It is therefore best to have the batteries as close as possible to the loads in a weatherproof environment.

For indoor use, it is best to use sealed batteries like gel cells. Those types of batteries do not generate enough hydrogen to cause any problems, unless they are overcharged, in which case they will be destroyed quickly. They have no liquid acid that can spill or leak. In addition, their terminals do not corrode and they work well together when there are several in a pack. Unfortunately, gel cells are very expensive unless they can be found on the surplus market. Great care must be taken when buying surplus batteries as it is very easy to get bad ones.

Gel cells often can not take a charge current of more than $^{1}/_{10}$ of their rated capacity. A 50-amp-hour battery, for example, should not be charged with more than 5 amps. Doing so may cause the battery to dry out and fail in a short period. It is best to have a battery amp-hour capacity that is greater than 10 times the maximum output of the solar panel.

There are also other types of batteries that can be used, such as NiCd and lead-calcium. The voltage characteristics of those batteries are slightly different from those of the standard lead-acid batteries. Be aware that there are even minor differences between lead-acid and gel-cell batteries. Some of those differences are shown in Table 1. Because of those differences, use only one type of battery in a system. Do not mix batteries—even mixing manufactures of batteries can cause problems. It is best to use batteries that, after having a full charge and sitting for awhile, have the same voltage and have the same rated capacity.

Most deep-cycle batteries are useful for a defined number of cycles. That is the number of times the battery can be taken down to the fully discharged state (about 1.8 volts per 2-volt cell for most lead-acid batteries) and recharged before having to be replaced. That can vary from less than 500 to over 1500 times depending on the battery's construction. In most solar applications, the battery is discharged throughout the day and night and then recharged the next day. If the battery is fully discharged each time, it can be expected to last only as long as specified by the manufacturer. Even though a cycle number such as 500 may seem good, cycling the battery once a day will mean the batteries will have to be replaced about every 16 months—a very expensive procedure. Fortunately, the cycle life of the battery increases logarithmically as the depth of the cycle decreases. Discharging the battery by only 30% of its total capacity greatly increases its life. Most manufactures recommend discharging only to the 30% level so a 100-amp-hour battery is effectively only useful for 30 amp-hours. It is even better to cycle the battery to only its 15% level. That allows for some slop in the load usage, a couple of cloudy days, and much greater battery life.

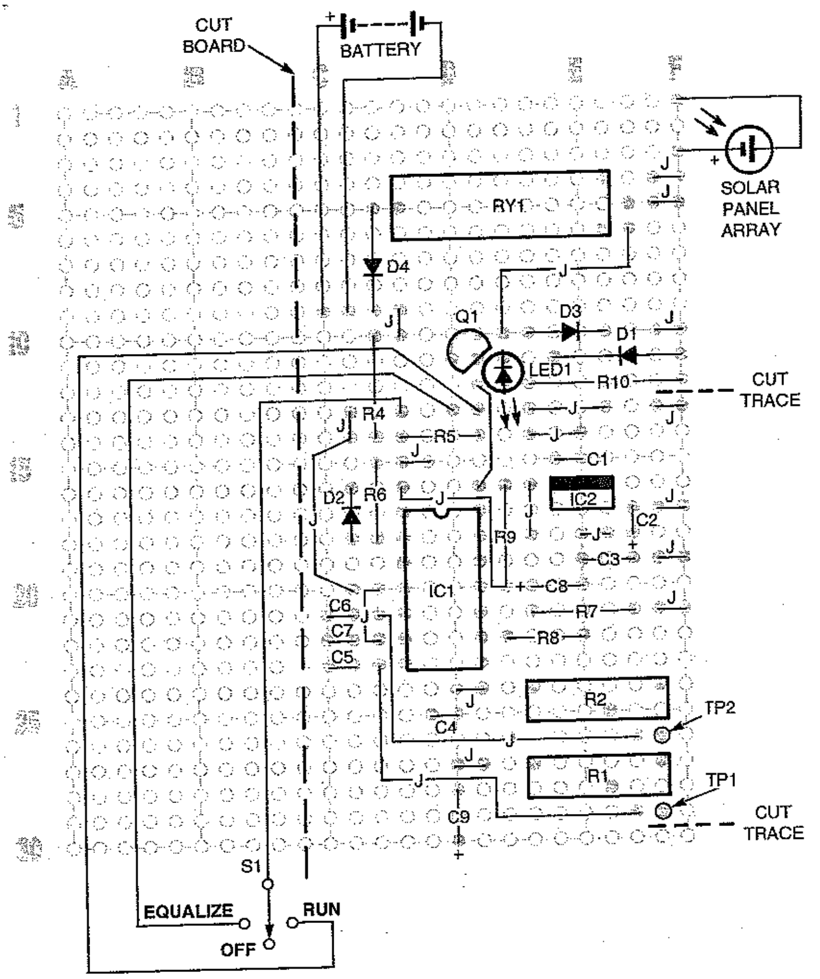


Fig. 2. The controller circuit is simple enough to lay out on perfboard. This layout is the author's design. Based on RadioShack's 276-168 universal breadboard, the unused portion of the board can be cut off if it is not needed. Don't forget to cut the trace that runs along line "F" at the two places shown.

The total capacity of the battery required for a solar system must take into account several factors, such as discharge factor, solar panel output, average sun-hours per day, and battery load (whether it is an everyday load or only occasional). If the power is to be used every day, it is best to be sure that the load doesn't use any more than the solar panel's daily output. A 5-amp panel that gets 5 hours of full sun a day means up to 25 amp-hours of power can be used every day. At that rate, the battery capacity should be at least 83 amp-hours for a 30% discharge rate, or preferably 167 amp-hours at a 15% rate. That will allow for a day of no sun without discharging the battery too much.

Circuit Description. The heart of

the schematic diagram in Fig. 1 is a set/reset flip-flop circuit. That flip-flop is made from the comparator gates in IC1. When the battery voltage drops below the turn-on trip point set by R2, RY1 is turned on. That connects the solar panel to the battery, charging it up. The relay remains on until the battery voltage gets to the turn-off point set by R1. At that point, the battery is fully charged. The relay is then turned off and remains off until the battery voltage drops back down to the turn-on point.

The controller is powered from the solar panel through D1. Filtering of the power supply is done by D1, C9, and C1. However, drastic voltage variations might occur each time RY1 connects or disconnects the panel from the battery. It was found on early prototypes that high-frequency pulses from the switching of RY1 caused IC1 to latch.

Power for IC1 comes directly from the solar panel. A 5-volt regulator, IC2, is used as a voltage reference for the trip points. The components associated with RY1 (R10, Q1, D3, and D4) are connected directly to the unfiltered solar panel instead of the filtered power on the board after it has gone through diode D1. Those components don't need a clean power supply.

Battery voltage is divided to ${}^{1}/_{3}$ of its actual voltage by R4 and R5. The turn-on and turn-off points can be set as high as 5 volts, so the maximum battery voltage that the controller can handle is 15 volts. All voltage comparisons occur within the range of the reference (5 volts) which is well within IC1's common-mode voltage range. The battery input is filtered by C7 to keep noise from affecting the circuit.

The charging cycle is centered on IC1-c. When the battery is not being charged by the solar panel, the output of IC1-c is low. No voltage flows through LED1 or Q1, so RY1 is off, disconnecting the solar panel from the battery. Feedback resistor R9 holds the input to IC1-c at a low level, keeping the circuit in an off state.

While the battery voltage is above the turn-on level set by R2, IC1-b remains grounded. When the battery voltage drops below that voltage, the output of IC1-b goes high. The voltage from pull-up resistor R6 flows though D2 to the non-inverting input of IC1-c. The ground signal from R9 is overridden, and pin 11 of IC1 is pulled above the reference voltage set by R7 and R8. The output of IC1-c goes high, letting current flow through R10 to LED1 and Q1. That, in turn, closes the contacts of RY1. The solar panel is then connected to the battery through the relay contacts and D4. The purpose of D4 is to prevent cur-

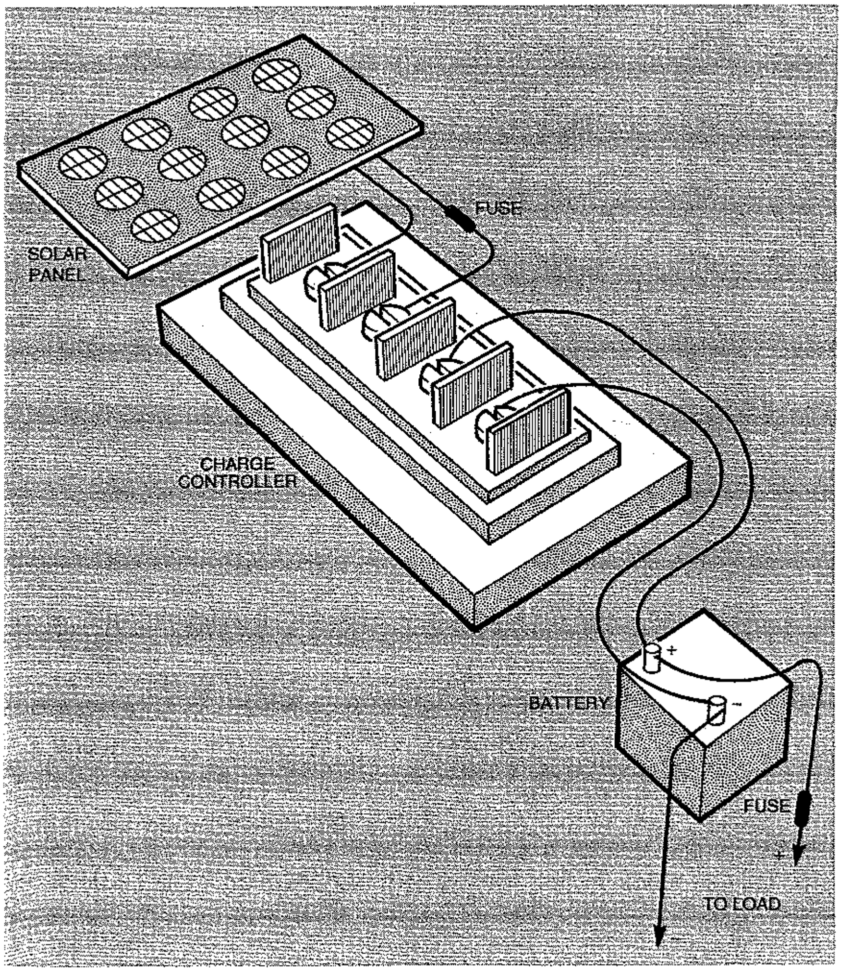


Fig. 3. Wiring up a solar-panel generator is quite straightforward. It's always a good idea to put fuses between a source of power and its load.

PARTS LIST FOR THE SOLAR-CHARGE CONTROLLER

SEMICONDUCTORS

IC1—LM339 quad comparator, integrated circuit
IC2—LM7805 5-volt regulator, integrated circuit
Q1—2N2222 NPN transistor
D1–D3—1N914 silicon diode
D4—1N4001 silicon diode
LED1—Light-emitting diode, red

RESISTORS

(All resistors are ¼-watt, 5% units unless otherwise noted.)
R1, R2—10,000-ohm, 15 turn trimmer potentiometer
R3—Not used
R4—200,000-ohm, ¼-watt, 1% (see text)
R5—100,000-ohm, ¼-watt, 1%
R6, R7, R9—33,000-ohm,
R8—10,000-ohm
R10—4,700-ohm

CAPACITORS

C1, C2, C4–C7—0.1-µF, ceramic-disk
C3, C8, C9—10-µF, 35-WVDC, electrolytic

ADDITIONAL PARTS AND MATERIALS

S1—Single-pole, double-throw, center-off toggle switch.
RY1—12-volt relay, single-pole, single-throw, 1-amp contacts
PC board, terminal strip, double-sided foam tape, enclosure, wire, hardware, etc.

rent flow from the battery back to the solar panel and controller. That keeps the battery from powering the controller at night and eliminates the danger of a short circuit.

As the battery is charged, its voltage increases. Once the voltage rises above the level set by R2, the output of IC1-b returns to a low state. The state of IC1-c is held on by R9. The battery will continue to charge until the battery voltage reaches the turn-off point set by R1. At that point, IC1-a goes low. That pulls the input to IC1-c low, turning off IC1-c. Current stops flowing though LED1 and Q1, so RY1 switches off. The solar panel is disconnected from the battery and stops charging it. Diode D3 suppresses the voltage spikes generated by the relay coil when it is turned off. Resistor R9 holds IC1-c in a low state again, and the cycle repeats. Capacitor C8 helps keep RY1 from chattering due to any transients caused by the switching.

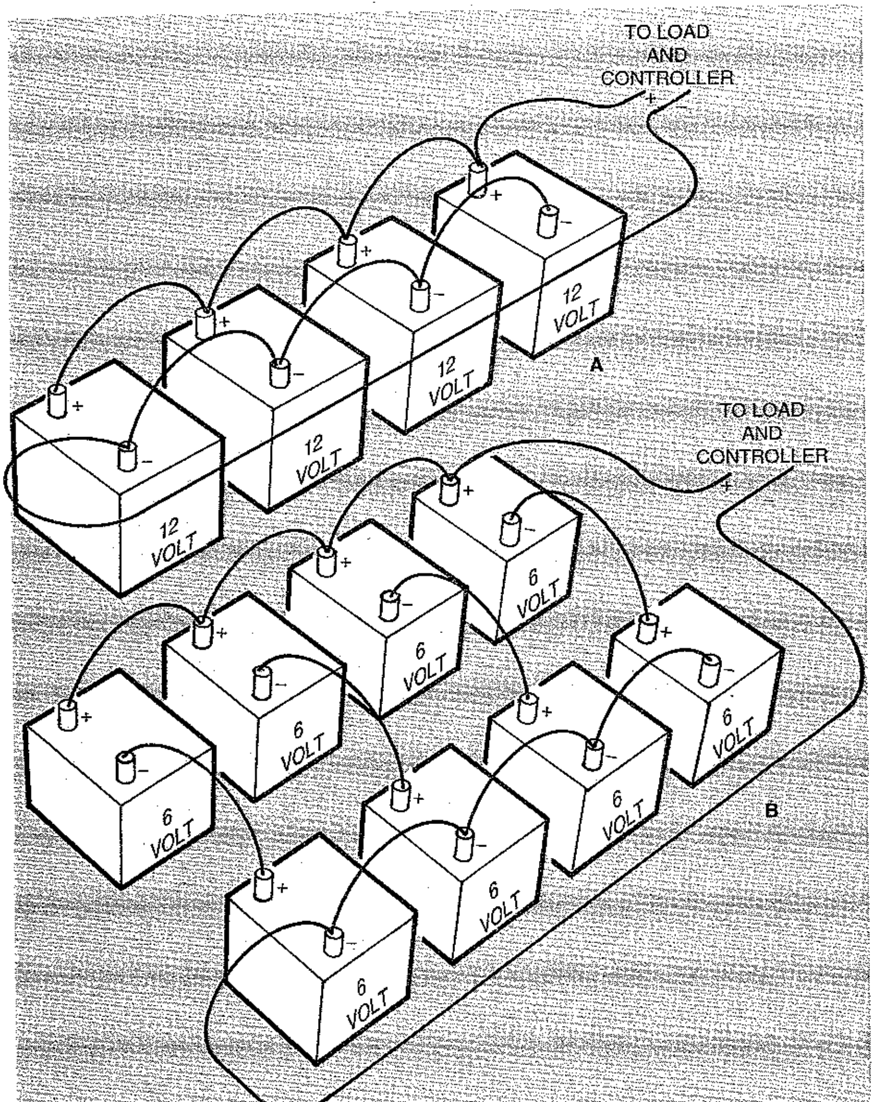


Fig. 4. If you want to use several batteries wired together in a pack, these diagrams show how to hook them together. For 12-volt devices, simply wire all the positive and negative terminals together (A). If you are using 6-volt batteries, connect pairs together to make 12-volt assemblies that are paralleled (B). In either case, don't connect the load to both terminals of one battery, or that battery will work too hard and fail first. Instead, use the terminals at opposite corners of the pack to spread the load evenly across all of the batteries.

The control switch S1 is a single-pole, double-throw switch with a center-off position. When the switch is in the center position, the controller operates normally. When it is set to the grounded position, the circuit will always see the battery's voltage as zero. The controller will then try to continuously charge the battery. That is used on occasion to briefly overcharge the batteries in a multi-battery pack to equalize them. Equalizing the batteries will make sure they are all at the same state of charge. Equalizing should only be done occasionally and with great care in order not to damage the batteries. Setting the switch to the equalizing position briefly and then returning it to the center-off position will start the charging cycle. That can be used to "top off" a partially discharged battery that is not low enough to trigger a full charging cycle. When S1 is set to the other position, the circuit will always see the battery as being fully charged. That will prevent the controller from charging the battery. That allows the battery to be disconnected from the circuit without having the relay oscillate or having any unconnected battery leads laying around with power on them. Depending on the solar panels used, severe shocks or fire hazards could result otherwise.

PARTS LIST FOR THE 20 AMP UPGRADE

R10—2,200-ohm, 5%, ½-watt resistor
RY1—12-volt relay, double-pole, double-throw, 10-amp contacts
BR1—Bridge rectifier, 25-amp, 50-volt
Wire, solder, etc.

Construction. All components for the solar-charge controller are available at RadioShack. No special parts or PC boards are needed. The circuit can be built easily on a perfboard with trace patterns, making assembly easier. A suggested component-placement diagram is shown in Fig. 2. That placement diagram is based on RadioShack's 276-168 universal perfboard.

The layout in Fig. 2 also allows the unused portion of the perfboard to be trimmed down, making it easier to fit in an outlet box. If the board is going to be used that way, it is best to trim the board down to size before installing any components. To do that, place the board in a vise with the desired breakpoint at the top of the vise jaws. The portion of the board that will be used for the circuit should be between the vise jaws. That will protect the usable part of the board if the board does not snap cleanly. Put pressure on the board just above where it comes out of the vise jaws and the board should break cleanly along the desired line. Be sure to make the two trace cuts shown in Fig. 2 before adding any components.

Placing IC1 on the board first will act as a reference for placement of the other components. Using a socket for IC1 is not necessary. In fact, if the controller is placed outdoors or in an unheated area, a socket might cause intermittent problems after several years. After confirming that IC1 is installed in the correct direction, fold pins 3 and 12 of IC1 over so that they touch the traces running between the legs of IC1 before soldering it in. That will connect the power and ground lines to the IC.

Install the fixed resistors next. The lead of R8 that connects to pin 9 of IC1 should be folded over so that it also connects to pin 10. Save the leads clipped off the resistors after soldering them in. They will be used for the jumpers later.

When installing the capacitors, place them as shown in the parts-placement diagram. Pay attention to the polarity of C3, C8, and C9. If those components are installed backwards, the board might fail or the capacitors could explode. Again, save the clipped-off leads. The polarity of D1–D4 and LED1 should also be double-checked before installing them. The lead from the cathode (band side) of D2 is folded over to make a connection with pin 1 of IC1.

The flat side of LED1 is installed facing toward Q1. If it is installed backward, RY1 will not be able to turn on. If you want, LED1 can be connected with leads and mounted on the case for easier viewing. Install Q1 and RY1 as shown.

Use the leads clipped off the installed components for the jumpers that connect straight from hole to hole without any bends. The jumpers that must bend around components or corners should use any convenient insulated wire, such as 26-gauge wire or wire-wrap wire. Two jumpers share connecting points with a resistor and another jumper. It is best to use small gauge wire, like 30-gauge wire-wrap wire, for those connections. When installing the jumpers that go to R1 and R2, be sure to route them so they don't get in the way of installing the pots. Use a short piece of component lead for the test points at the pots. Adding the test points will be necessary if the board is being installed in an outlet box, otherwise it will be difficult to calibrate the controller.

SUPPLIERS OF SOLAR PANELS AND ACCESSORIES

Caleb Wholesale Products
8015 Carrisa Hwy.
Santa Margarita, CA 93453
(805) 475-2128

Jade Mountain
P.O. Box 4616
Boulder, CO 80306-4616
(800) 442-1972
(303) 449-6601

Sierra Solar Systems
109 Argall Way
Nevada City, CA 95959
(800) 517-6527
(916) 265-8441

At this point, the trimpots are installed. Fold the lead on each pot closest to the board edge so that they connect with the power trace. Fold the center leads so they connect to the trace the jumper wire connects to before soldering in the pots. Finally, install IC2 as shown.

Use 5-inch lengths of insulated wire to connect S1 to the board as shown. If you only need to force the controller either on or off, you may substitute a single-pole switch for S1. A push-button switch can be used to the ground connection in place of a center-off switch if you only want to top off the battery charge as discussed before. If you can find one, a center-off toggle switch with a momentary position would make a good combination switch for both disabling the controller and topping off the battery charge with one control.

If you are mounting the controller in a case, use 5-inch lengths of at least 22-gauge wire to connect the circuit board and the connector together. If the board is going to be hard-wired into the system, it is best to use wire as short and as heavy as possible. It is especially important to keep the leads between the board and the battery as short as possible. The controller will see any voltage drop developed across those leads as a part of the battery's voltage, causing it to turn off too early.

Verify that all the solder connections are properly made and that all polarized components are installed correctly. Check that the wiring on the board matches the schematic diagram. Once that is done, the controller is ready for testing and installation.

Testing. For testing the controller and setting the turn-on and turn-off points, it is best to use a 12-volt, low-current (100 ma to 1 amp) power supply instead of a battery. If there is a problem with the circuit, a battery can supply enough current to cause significant damage.

Set S1 to either the on or off position and connect the power supply to the connector for the solar panel leads. Connect a voltmeter to the circuit ground—the tab on IC2 works well. Measure the voltage on TP1 and adjust R1 for a reading of 4.7 volts. That sets the controller to disconnect the solar panel when the battery voltage reaches 14.1 volts. Connect the meter to TP2 and adjust R2 for a reading of 4.15 volts. That sets the controller to turn on at 12.45 volts, which is just below the point at which a gel-cell battery sits when fully charged. If you are using batteries of a different technology or different voltages, it is easy to calculate the values for TP1 and TP2—just take the values desired and divide by 3.

When S1 is set to the equalize position (always on), LED1 and RY1 should turn on. Measure the voltage at the battery leads on the terminal block; it should be about 0.7 volts less than the power supply voltage. With S1 in the off position, there should be no voltage on the battery connections.

If you also have a variable power supply available, connect i to the battery leads. As the variable supply is adjusted up and down

RY1 and LED1 should turn on at 12.45 volts and off at 14.1 volts. If the controller passes all tests, it is ready to be permanently mounted in whatever box you will be using.

The board is best mounted on the inside of the box lid and a terminal block mounted on the outside. Either screws or double-sided foam tape can be used to hold the board in place. Be sure to allow enough clearance between the board and the lid if a metal box is being used. Two layers of foam tape will give plenty of clearance if that method is being used. Once the board is mounted, wire it up to the terminal block and close the box. The controller is now ready to be put into operation.

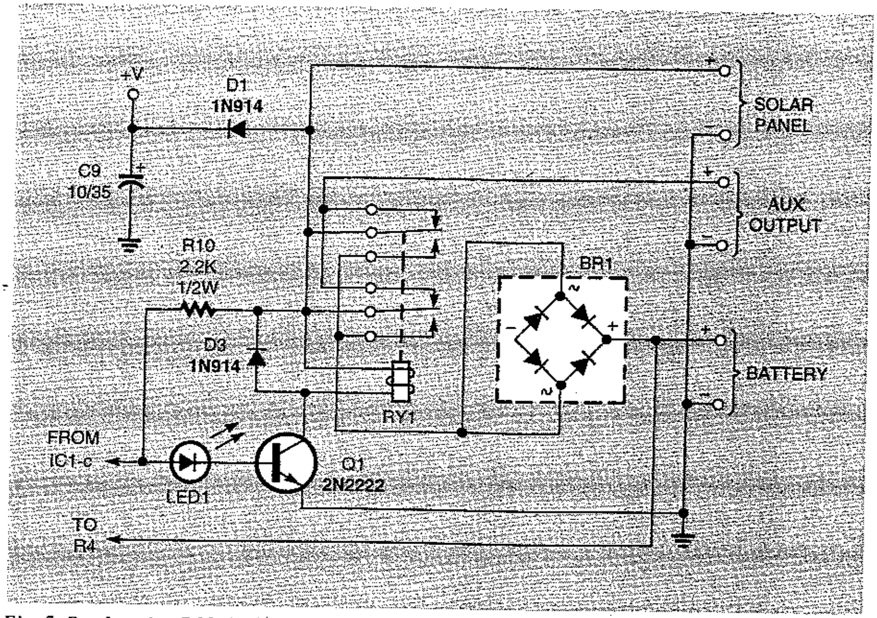


Fig. 5. By changing R10, RY1, and D4 to the components shown here, the controller will be able to handle currents up to 20 amps. Diode D4 is replaced by BR1. An extra set of contacts on RY1 let the solar panel drive an additional load when it is not recharging the battery. Of course, that load will be disconnected when the battery is being charged.

Installation. A few things need to be said about the wiring between the controller, the solar panel, and the battery, especially if high currents are going to be used. Those wires should be as large and as short as practical in order to keep losses to a minimum. As current flows through a wire, a voltage drop is developed across it due to the wire's resistance. Higher currents yield greater voltage drops. The controller will see the voltage drop as being part of the battery's voltage and turn off the charge current too soon. It is easy enough to limit the voltage drop between the controller and the battery if both items are mounted near each other. With a shorter wire, the voltage drop will not be as great.

The wire coming from the solar panel, on the other hand, is more likely to be a much greater length, so the losses will be more significant. There is no sense in losing power in the cable if it is not necessary. The size of the wire required depends on the length as well as how much current is going to be run through it. For example, a 12-gauge wire has a resistance of 0.001619 ohms per foot. In a 50-foot cable, the total resistance will be 0.1619 ohms—50 feet for the positive wire and 50 feet for the negative wire. A 10-amp load will create a voltage drop of 1.619 volts, which comes out to 16.19 watts of wasted power—quite a considerable amount. It should be noted, however, that solar panels are designed to put out extra voltage to allow for some cable loss. Even so, it is always good engineering practice to keep losses in any power-generating system to a minimum. Therefore, the smallest wire size recommend is 12 gauge for runs up to 50 feet and currents up to 5 amps. The author's installation uses 8-gauge wire. If your particular setup will be using more than one solar panel, a multi-conductor AC cable from a hardware store or RV supply house will allow one cable to be used with a bank of panels. Each panel can be wired to its own individual wire pair, or the wires can be connected in parallel for less voltage drop.

The general arrangement for a solar generating station is shown in Fig. 3. The controller is simply connected between the solar panel and the battery. As an added safety precaution, fuses should protect the positive wires between the solar panel and the charge controller, and between the battery and whatever load will be connected to the system.

For more storage capacity and charge current capacity, several batteries can be connected in parallel. Figure 4 shows the preferred way of wiring them together. Again, note that the wires between the batteries should be as large in diameter and as short as possible to keep losses to a minimum. For most applications, it is best to use a minimum of 8-gauge wire, especially if a 120-volt AC inverter that is larger than a couple hundred watts will be used. Keep the cables short enough so that they can not touch the opposite polarity terminal on any of the batteries when disconnected. That allows a battery to be replaced without the potential for a direct short across the batteries. Also, be sure the positive and negative cables do not cross over each other anywhere. This is for additional safety. If the wires get hot enough to melt the insulation if there is too high a load, the batteries will not be able to become directly shorted through the cables. Not allowing the positive and negative cables to cross could prevent a bad situation from turning into an even worse one.

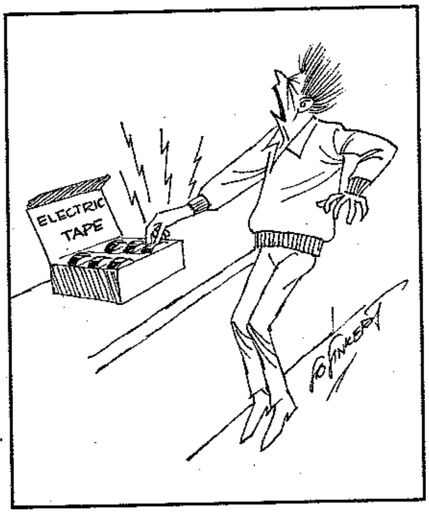
The positive and negative connections that go to the controller and the load should not be connected to the same physical battery. One lead should connect to the first battery while the other connects to the last battery as shown in Fig. 4A and Fig. 4B. That wiring technique, called *reverse return*, keeps all of the batteries in the pack balanced. If both output wires are connected to one battery's terminals, the other batteries will not work as hard. Those batteries will receive less of a charge, and those that are closer to the connections will fail prematurely.

Modifications. As shown, the charge controller can accommodate about any battery with the exception of the NiCd type. For that type of battery, replacing IC2 with a 7806 will allow the controller to function up to 18 volts, allowing its use with NiCds. When using a different type of battery, set the turn-off voltage of the controller according to the recommendations obtained from the manufacturer. If that is not possible, the values in Table 1 can be substituted if you know the type of battery. If neither of those methods can be used, the turn-on set point can be found experimentally. Charge the battery pack to its turn-off point and let it sit for awhile before measuring the voltage again. The turn-on point should be set just below that reading.

If a 20-amp controller is desired, simply replace R10, RY1, and D4 as shown in Fig. 5. The diode is replaced with a bridge rectifier, which is less expensive than a pair of 25-amp diodes. Using a double-pole relay allows an auxiliary output to be connected directly to the solar panel when the battery is not being charged.

For more information on solar and other alternative energy parts and equipment, getting a catalog from one of the suppliers listed is recommended. The catalogs are full of solar devices, wind generators, water-turbine systems, batteries, and inverters. They also contain many products that can be run directly off a 12-volt system with no inverter required. Some companies carry such items as fluorescent lamps, refrigerators, and even washing machines. The catalogs often have a great deal of information on setting up a system such as tables and work sheets for determining the size of solar panel and battery pack for running the loads desired. Those catalogs are well worth the $4 or $5 that is charged for them. Most times, the catalog price will be refunded with the first purchase.

The Solar-Charge Controller is a great project for maintaining the charge on batteries whether they are used in a solar panel station or elsewhere. You might not be able to thumb your nose completely at the monthly electric bill, but you can certainly put a dent in it! Ω



FUEL CELLS

(continued from page 58)

gas can be operated almost any place in the world without the complications that arise in transporting hydrogen.

A Fuel-Cell Power Plant. On June 3, 1996, the Santa Clara Demonstration Project (SCDP) formally dedicated the world's largest direct fuel cell power plant. The Santa Clara Demonstration Project represents a unique collaborative effort between the public and private sector. The fuel cells themselves were manufactured by the Fuel Cell Manufacturing Corporation, which is a wholly owned subsidiary of Energy Research Corporation. (ERC).

Most fuel cells require the hydrogen from natural gas to be extracted in a separate process. The ERC fuel cell can process the fuel inside the fuel cell itself, where the fuel is immediately consumed to generate electricity. The two approaches are compared in Fig. 3. It is believed that the direct system offers the potential for a simpler and more efficient power plant as compared to other types of fuel cells.

The power plant in Santa Clara is rated at 1.8 megawatts net (it actually reached 1.9 MW AC net). It contains more than 4000 individual cells, grouped into 16 stacks, each capable of producing approximately 1.25 kW of DC power. The direct current from the fuel cells is converted to AC in a power conditioning unit prior to being fed into Santa Clara's distribution system. A block diagram of the SCDP system is shown in Fig. 4, and a photograph appears at the beginning of this article.

The SCDP system is just the first utility-scale demonstration of a direct fuel-cell power plant. The next generation power plant will be a 2.85 MW packaged unit that is expected to be available by the turn of the century. By increasing the size of the fuel cells in the stacks, as well as the height of the stacks, and compressing the plant layout, the overall space will be decreased by 90 percent, yet the proposed power plant will produce an additional megawatt of power. Ω