Practical Battery-Back-Up Power for Amateur Radio Stations—*Part 1*

Many radio amateurs use batteries only in low-power, portable/mobile applications. Here's how to use batteries to keep a ham station going when commercial ac power fails.

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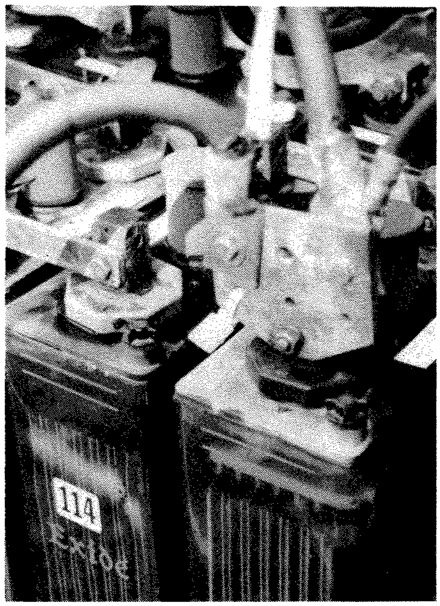
Heavy-duty back-up power is readily available for many—perhaps most—Amateur Radio stations, and it need not be expensive. Virtually all modern amateur gear is designed to operate from 11 to 14 or 15 V dc, making operation possible from highly reliable, heavy-duty batteries. Yet, battery backup is underappreciated and underutilized by amateurs—probably because of a lack of familiarity and the supposed difficulty or expense of obtaining suitable batteries. Surplus commercial or industrial heavy-duty lead-acid cells often can be obtained for the asking, however, and frequently they come in batches big enough to supply several stations at once.[1]

Besides superb back-up against failure of commercial ac power, batteries provide other benefits. One of these is surge protection: A power-line spike big enough to demolish a regulated dc power supply probably won't get past a battery to damage solid-state electronics. In addition, batteries:

- Are clean and safe.[2]
- Require very little maintenance.
- Offer considerable overvoltage protection if a power-supply regulator fails.
- Can accumulate dribs and drabs of energy from alternative power systems, such as solar energy, water or wind power, and deliver it when needed.

As useful and versatile as batteries are, however, building a battery back-up system requires care and planning. Many hams believe that an old automobile battery, stuck under the operating desk and put on a charger every so often, constitutes battery back-up. 'Tain't so!

This three-part article describes how to get a practical battery-back-up system up and running. In this article, Part 1, we'll discuss back-up-battery types, chemistry, construction and procurement, and the basics of housing and installing a power-back-up system. In Part 2, we'll cover battery chargers and charging. Part 3 will cover back-up-battery monitoring, maintenance and safety, and how to dispose of unusable batteries safely and responsibly.



Part of the author's 12-V back-up power system, these 2-V, 300-Ah, lead-acid float cells—obtained free of charge from a local telephone company—help keep W4MLE on the air when commercial power fails. *(W4MLE photos)*

Components of a Battery-Back-Up System

In its most basic form (Fig 1), a battery-backed-up power system consists of a back-up battery, its load, a charger, and interconnecting wiring. A practical system—Fig 2 outlines mine—may include more than one storage battery, and also includes fusing and instruments (or points for connecting instruments) to monitor voltage and current in the system.

Suitable Batteries for Back-Up Power

Automotive batteries are unsuitable for station back-up power except as a last resort.[3] Intended *to start cars,* they are designed to provide several hundred amperes for the few seconds needed to crank an engine. From a back-up-power standpoint, though, their weakness is that they don't like to be discharged very far. You

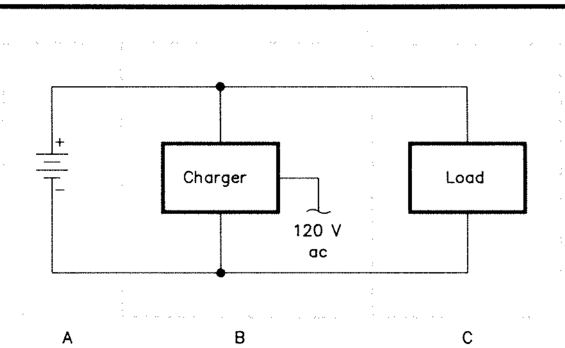


Fig 1—A basic battery-based power system consists of a back-up battery, A, a charger, B, the system load, C, and interconnecting wiring. This article, part 1 of 3, focuses on back-up-battery topics and the basics of housing and installing a power-back-up system. Chargers and charging topics are discussed in Part 2.

[1]Notes appear on page 37.

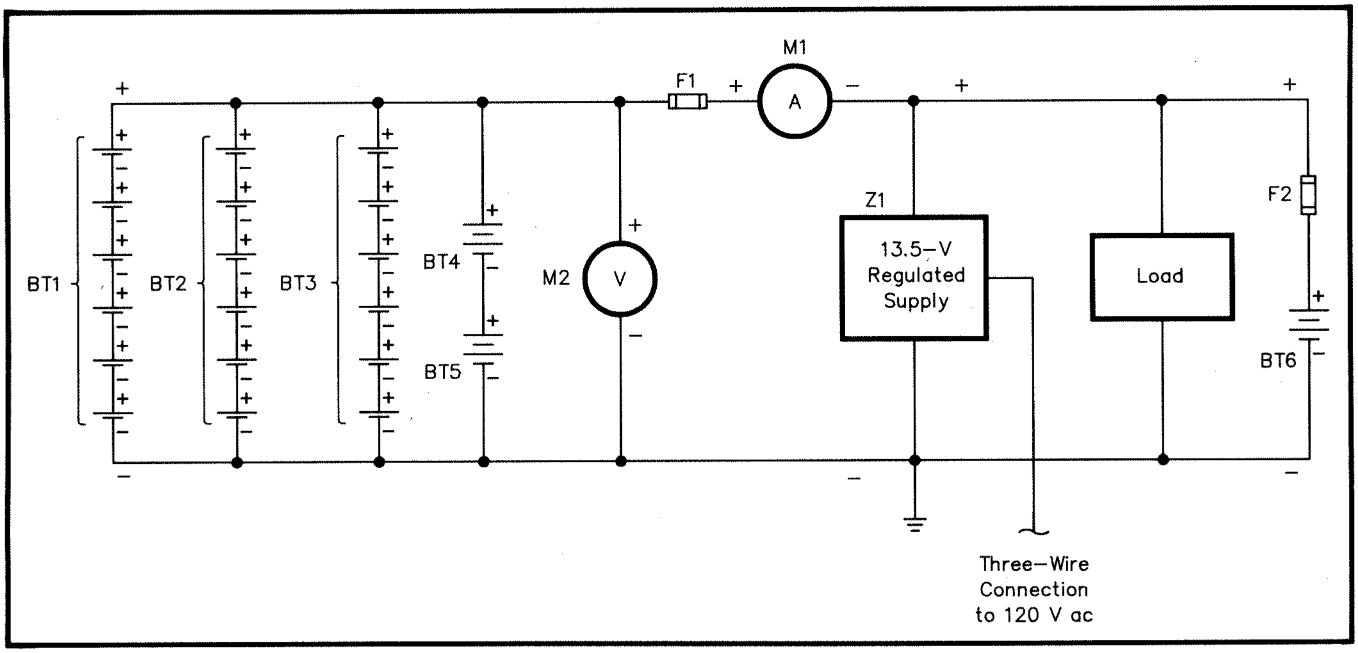


Fig 2—A practical battery-backed-up power system may include more than one storage battery, and also includes fusing and instruments, or points for connecting instruments, to monitor system voltage and current. This drawing, which depicts the author's system, illustrates how batteries of varying types and capacities can work together to provide solid back-up power. *Stock regulated power supplies usually must be modified before they can be used for charging service at Z1; see below and Part 2 of this article—to appear in a subsequent issue of* QST*—for more information.* A simple battery voltage/current monitor (M1 and M2 serve this function in this diagram) will be described in Part 3.

BT1, BT2, BT3—Battery consisting of six 2-V, 300-Ah float cells.
BT4, BT5—6-V, 100-Ah deep-cycle batteries.
BT6—Optional deep-cycle battery to handle peak current demand in cases of high-voltage drop in station-to-battery wiring; see text.
F1, F2—32-V fuse of a current rating no greater than that necessary to handle the system current demand with a margin of safety (for example, 20 to 25 A for the ≈15-A load presented by a 13.8-V, 100-W MF/HF transceiver). F2 is used only if BT6 is present.
M1—Zero-center ammeter; range dependent on battery capacity and load.
M2—Meter capable of measuring voltages from 10 to 15. A 0- to 15-V meter will work, but a 10- to 15-V, expanded-scale meter is better.
Z1—Regulated power supply, modified for protection against reverse voltage as described in Part 2 of this article. *Do not use a supply that has not been modified for reverse-voltage protection.*

may have already discovered this the hard way: Kill your car battery two or three times by leaving your headlights on, and you'll probably have to replace it.

Three other types of rechargeable lead-acid battery, readily available to radio amateurs, can be deeply discharged and recharged:

• *Deep-cycle batteries* are used in recreational vehicles and by boaters and fishermen to operate boat trolling motors, lights, pumps and electronics. Industrial deep-cycle batteries are often fully discharged every day and recharged every night.

• *Gelled-electrolyte batteries,* manufactured both for float and deep-cycle service, are usually intended for portable use and can be quite small. In most respects, they can be managed either as conventional deep-cycle batteries or, in light-duty applications, as float batteries. I won't discuss gelled-electrolyte batteries specifically because they behave much like their liquid-electrolyte counterparts.

• *"Float-service" batteries,* used in uninterruptible power systems[4] for telephone and large computer systems, should not be discharged and recharged more frequently than necessary. They are kept on a regulated charging source all the time—the same source that normally powers the load.

Properly applied, deep-cycle, gelled-electrolyte and float-service batteries are well-suited for back-up service even though their chemistries are similar to that of automotive batteries. They can replace your station's commercial ac power so completely during an outage that your rig may not notice that the power is down!

Back-Up Battery Chemistry

Selection, use and care of lead-acid back-up batteries requires knowledge of their chemistry and construction. Most such batteries consist of a case, or tank, divided into compartments—one compartment per cell—each of which is filled with dilute sulfuric acid (H_2SO_4). Immersed in this acid are *plates*—actually latticework frames—made of lead alloy. Half of the total number of a given cell's plates are filled with lead peroxide (PbO_2); these plates serve as the cell anode (+ electrode). The remainder of the cell's plates are filled with *spongy* metallic lead (Pb)—lead that's finely divided to expose maximum surface area to the electrolyte. These spongy plates serve as the cell cathode (− electrode).

Deep-cycle cells generally differ in construction from automotive cells in that their plate-support grids consist of a lead-antimony alloy that stands up well to repeated cycling.

Float cells usually contain lead-calcium plates that tend to respond to repeated cycling by swelling, cracking and falling apart, eventually creating short circuits between adjacent plates.

With no load connected to a fully charged battery of any of these types, a voltage—about 2 V per cell—appears between the anode and cathode of each cell. When a load is connected, the battery releases stored chemical energy by causing electric current to flow through the load. The transformation of chemical to electrical energy occurs as a result of several chemical reactions in the battery, with the final results represented by the equation:

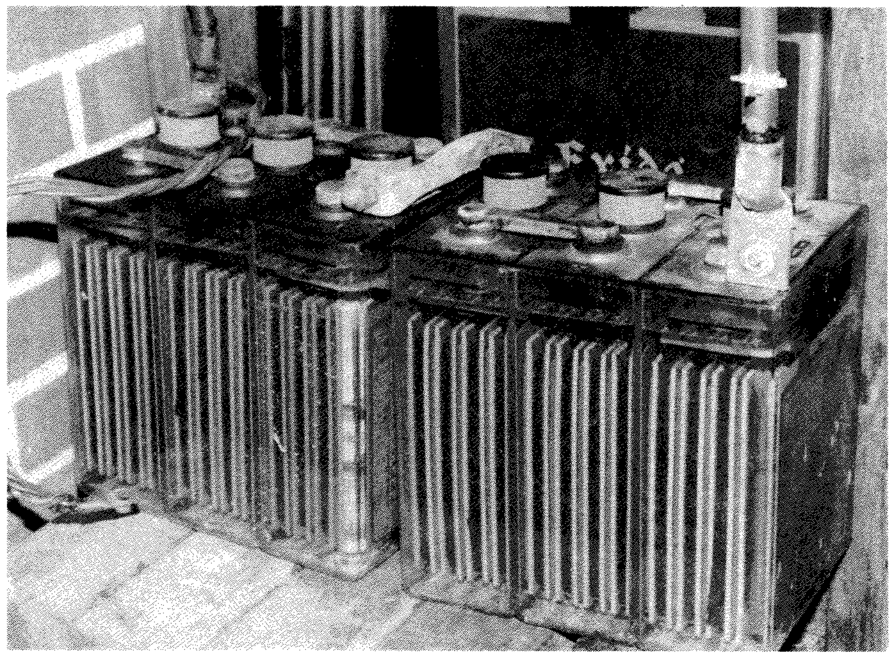
$$PbO_2 + Pb + 2H_2SO_4 \rightleftarrows PbSO_4 + 2H_2O \quad \text{(Eq 1)}$$

Translated, this means that the lead peroxide and spongy lead react with the sulfuric acid to release energy and produce two new compounds—lead sulfate ($PbSO_4$) and water. This reaction is indicated by the right-pointing arrow in Eq 1. As the discharge continues, more and more acid is converted, causing the specific gravity of the electrolyte to decrease.[5] When all the lead peroxide (PbO_2) is used up, the battery is "dead." Because the electrolyte normally contains a surplus of acid, its specific gravity usually doesn't fall all the way to 1.0.

When the battery is charged, the reaction reverses (hence the left-pointing arrow in Eq 1), converting the charging electrical energy into stored chemical energy. Now, lead sulfate on the positive plate is converted back to lead peroxide, releasing sulfuric acid. Lead sulfate on the negative plate is converted back to spongy lead, producing still more sulfuric acid. When all the sulfuric acid has been released, the battery is fully recharged and the specific gravity of the electrolyte is back at maximum.

The chemical process is the same in lead-calcium and lead-antimony cells (including gelled-electrolyte cells). But the design and application of these two types differ in detail, such as the optimum electrolyte specific gravity, the normal open-circuit voltage for a single cell at full charge, and the optimum float voltage. Lead-calcium cells, usually used in float-charged systems, require and produce a slightly higher voltage per cell, lose less energy through internal leakage and take less maintenance, than their lead-antimony counterparts. These design differences are important in Amateur Radio applications.

Since back-up batteries are seldom, if ever, called upon to deliver short bursts of extremely high current, their electrolyte is not as acidic as that in automotive batteries, and they contain fewer plates.[6] On the other hand, back-up-battery plates are thicker and more densely packed with material than those of automotive starting batteries. And the plates of float batteries are usually immersed in larger quantities of electrolyte than other lead-acid battery types.



These 6-V, 100-Ah, float batteries, also part of the W4MLE back-up battery, consist of three cells each.

An Overview of Available Back-Up Batteries

Float-service batteries are the vice presidents of the battery world. Their functions are to wait for a main power system to fail, to be ready when it does, and to not complain when it doesn't. They are electrochemical couch potatoes, luxuriating in a light but continuous flow of current—just enough to replace their internal leakage losses—from a regulated power supply.

Float cells are sold in many forms. They range from 6-V, 100-Ah batteries of three cells each, to individual 2-V, 100- to 300-Ah cells weighing as much as 85 pounds each. Cells of much higher capacities are manufactured for industrial uses, but their size usually precludes their use in ham stations.

Most manufacturers, such as Gould, Exide and C&D, warrant their float cells for *20 years* under strenuous industrial use. Used for power back-up in Amateur Radio stations, industrial float batteries may be virtually immortal, with industrial preventive-maintenance discards probably lasting more than 10 years even after a hard working life. Remember, though, that float cells don't like deep discharges. One manufacturer[7] warns that

> if occasional discharges are experienced, battery life will decrease in proportion to the frequency and depth of these discharges...
>
> It is customary that a stationary battery will not experience any more than 200 discharge cycles evenly distributed throughout its useful life. Frequent or greater depths of discharge can shorten service life to 10 years or even less, even with proper maintenance and operating conditions.

Two hundred cycles may sound like a lot, but remember that many industrial applications—golf-cart service, for instance—require full discharge every day and complete recharge every night. In such service, 200 cycles amounts to less than a year of business days!

Deep-cycle batteries can tolerate frequent discharges to about 11 V, and can withstand such use every day for years if well-maintained. But they also perform quite well in float service. The most useful deep-cycle batteries for Amateur Radio Service consist of six 2-V cells, connected in series, in a single, compact case. Deep-cycle batteries intended for use on boats and recreational vehicles are typically rated at 60 to 100 Ah, compared to 40 to 50 Ah for car (starting) batteries. And deep-cycle batteries are designed to operate at 13.8 V *while charging*. Industrial deep-cycle batteries may be designed for slightly lower voltages.

Deep-cycle fishing and recreational-vehicle batteries are normally warranted for 18 months because they tend to be abused by forgetful sportsmen who top them off by fast charging after leaving them discharged for long periods. Properly nurtured and used in stationary service at a ham station, however, deep-cycle fishing batteries can last much, much longer than 18 months.

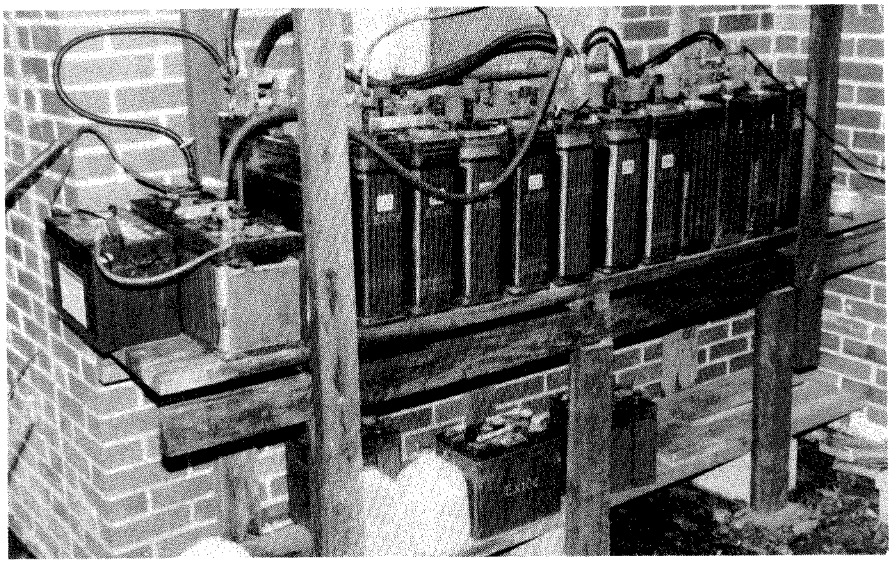
Obtaining Back-Up Batteries

Where can you find suitable back-up batteries? You could buy float cells from a manufacturer for something like $1/Ah per 2-V cell. That amounts to maybe $300 for a 2-V, 300-Ah cell—$1,800 for a 6-cell battery! Surprisingly, however, float cells are often available gratis.

Used batteries are seldom retained when float-cell-backed power systems are upgraded. Old float cells are generally hauled off to a toxic-waste dump or to a salvage house, where the cells' lead, and polycarbonate plastic cases, are reclaimed. Often, an Amateur Radio club, or even individual amateurs, can arrange to get these discarded cells for hauling them away.

The Tallahassee Amateur Radio Society has a written agreement with the local telephone company (Centel) to accept discarded batteries on behalf of club members. About 75% of the cells the club has received from the company were in good health. Similar arrangements have been worked out between industrial battery users and other Amateur Radio clubs nationwide. My own station has a 1000-Ah float-cell bank, some cells of which once powered the city police department's telephones. Other cells powered a monster computer at Florida State University!

Of course, deep-cycle batteries can be purchased off-the-shelf at most boat dealers, fishing-tackle shops and automotive stores. Price, warranty and rated capacity are the important considerations in a new-battery purchase.



W4MLE's main battery—BT1-BT5 in Fig 2—consists of deep-cycle *and* float cells, connected in series-parallel and housed outdoors.

Housing a Battery-Back-Up System

Back-up batteries can be kept indoors, since they do not sputter electrolyte as automotive batteries do, *but they must be ventilated.* Charging generates oxygen and hydrogen—gases that form a highly explosive mixture if allowed to collect in an enclosed area. With back-up batteries, safe ventilation is generally assured if you follow a simple rule: *Don't put them in a closet or enclose them in a box.* Small batteries can be stored in a corner or under a desk; a room's ordinary air circulation will suffice for ventilation in most cases.

Back-up batteries can be kept outdoors in most climates; fully charged, they freeze at about −95 °F.[8] Completely discharged —when their electrolyte is least acidic—their freezing point is quite close to that of water (32 °F). To protect the battery from sunlight, rain, snow, trash, insects and accidental short circuits, the cells should be provided with a housing or cover. You may be able to obtain a suitable plastic-coated steel battery rack from the supplier of your back-up cells. Such racks can usually hold two sets of six cells each. Or you can build a rack of your own, as I did the rack shown in the photo above. If you build your own rack, be sure it can take the weight of your back-up batteries; my rack consists of 2 × 4 and 4 × 4 lumber.

The porous, explosion-proof caps in the tops of back-up-batteries' cells are normally covered by plastic lids. If these lids get lost, don't leave the caps open; trash, rain and insects can get in. (Mud-dauber wasps, for instance, love to build nests in the necks of the funnels—and mud contains no known vitamins beneficial to battery cells.) Ordinary glass marbles, placed in the cap necks, are a good substitute for the lids; they can be easily removed when water must be added to the cells.

Back-up batteries need protection from direct sunlight. The polycarbonate plastic cases of float cells can be damaged by ultraviolet light; they develop cracks, and leak. If you store your cells outdoors, keep them off the ground and out of the sun, where you can eyeball them frequently to check their electrolyte levels. At nontropical latitudes in the northern hemisphere, the north side of a building receives little or no sun throughout the year; if that's where you live, the north side of your house is a good location for battery storage, when it's available.

Minimizing Voltage Drop in Battery-to-Station Wiring

Wire is resistive, and resistance dissipates useful power as heat. Because of this, be sure to install your back-up battery as close as possible to its heaviest load—no more than 10 to 15 ft away, and the closer the better. A 200-W load, such as a 100-W-output MF/HF transceiver, draws at least 15 A at 13.5 V; a 300-W load draws 22 A at this voltage. The wire resistance between battery and load causes a voltage drop; for example, a resistance of 0.1 Ω in a line carrying 22 A causes a drop of 2.2 V! The resistance of the system's positive *and* negative leads must be taken into account. Moral: Use *heavy-gage* wire.

Automotive battery cables are a good source of such wire. Welding cable is another. Or, you can try flexible, three-conductor, house-wiring cable: Double it and connect all six of its no. 10 solid conductors in parallel. Use one such six-conductor cable for the positive connection, and another for your system's negative load-to-battery lead. (You may be able to find some suitable discarded cable at a building site, or obtain "reel ends" from a building-materials supplier.) Make sure that every connection is well soldered and mechanically tight. You may have to use a propane torch to heat the joints sufficiently to solder them. Connect the main-battery negative lead to the power supply and the rig.

Assuming that the battery is sufficiently close to its load, most of the resistance in a back-up system occurs at its connectors. Measure the system voltage at the battery, at the power supply and at the load. If you measure a drop of more than half a volt at full load, you have a problem. (Monitors for in-line current and voltage at the battery terminals should be located where you'll see them every time you enter the room. Part 3 of this article will describe battery monitoring in detail and describe a circuit designed for this purpose.)

In cases of excessive voltage drop, such as those with long runs of wire (15 feet or more), another solution is possible. Put a small (100 Ah) battery under your operating desk, within two or three feet of the system's heaviest load (usually your MF/HF transceiver). Hang this additional battery—BT6 in Fig 2—across the 12-V line by connecting it directly—through a suitably rated fuse in its positive lead—to the rig terminals, in parallel with the line from the outside batteries and power supply. This battery will keep the system voltage from sagging during the relatively brief periods of heavy load and then recharge itself from the main battery during intervals of light load.

Notes

1. A *cell* is a single electrochemical unit capable of generating electricity by means of two electrodes and an electrolyte. Depending on its chemistry and design, a cell may be classed as *primary* (non-rechargeable) or *secondary* (rechargeable). A battery consists of two or more cells connected in series, parallel or series-parallel to combine their voltage and/or current capacities. (In popular usage, *battery* can mean a single cell or a battery of cells. For clarity, battery is used to mean "a battery of cells" throughout this article.) The batteries used in commercial and Amateur Radio back-up service are invariably rechargeable and, in heavy-duty, full-station back-up service, are nearly always based on *lead-acid* chemistry. Thus, throughout this article, back-up battery is used to mean *"lead-acid back-up battery."*
2. But reasonable safety precautions must be taken when handling and installing back-up batteries because they contain caustic and highly corrosive sulfuric acid.
3. "Standby Power: Will the Automotive Battery Do?" *Telephone Journal,* Jan-Feb 1975.
4. Uninterruptible power systems are designed to be just that: power-supply systems capable of taking over, or continuing to operate, when regular ac power fails.
5. The *specific gravity* of a substance is the ratio of its density to the density of another substance, with both densities measured in air. The specific gravity of back-up-battery electrolytes uses that of pure water—1.0—as a referent. The specific gravity of the electrolyte in fully charged float cells typically ranges from about 1.2 to 1.275; for deep-cycle cells, the specific gravity is slightly higher.
6. Float-service cells usually contain approximately 6-molar sulfuric acid; this is, six *moles* (molecular weights, measured in grams) of H_2SO_4 per liter of electrolyte. The molecular weight of sulfuric acid is 98, so a mole of sulfuric acid is 98 grams.
7. *C&D Stationary Battery Installation and Operating Instructions,* pub in 1981 by C&D Batteries, 3043 Walton Rd, Plymouth Meeting, PA 19462.
8. If you store your batteries outside, be sure they are inaccessible to unauthorized personnel.

Practical Battery-Back-Up Power for Amateur Radio Stations—*Part 2*[†]

Obtaining and installing a back-up battery is the first step toward assembling your own back-up-power system. Next, you've got to charge that battery—and *keep* it charged.

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Acquiring a float-service battery is only half of the process of putting your Amateur Radio station on back-up power. The other half is keeping the battery fully charged at all times without overcharging it. Float-service batteries are intended to be connected to their charging system continuously, except during power failures. Recharging energy can come from almost any source of electricity that provides dc.

Chargers

In an automobile, an alternator begins supplying current to the battery as soon as the engine starts. Occasionally, an automotive battery must be recharged by putting it on a charger for a few hours, letting unfiltered dc—merely rectified commercial-power-line ac, do the job with questionable current and voltage limiting. Whatever you do, *don't rely on an automotive charger to maintain back-up cells and batteries.* Although *temporary* use of such a charger to restore a depleted back-up battery is acceptable in an emergency, an automotive recharger will overcharge, and likely damage, a back-up battery designed for float service.

The best charger for Amateur Radio float systems is an ordinary, stiffly regulated 12- to 13.8-V power supply capable of sourcing 15 A or more. A home-built supply is fine, or you can use the supply that powers your existing 12-V MF/HF transceiver.[9] Ideally, the charging power supply should be capable of handling the entire system load without assistance from the battery, and the battery should be able to power the entire system without help from the power supply. See the sidebar "A Closer Look at Charger Capacity" for more on choosing the right power supply for the job.

Many off-the-shelf commercial regulated power supplies work well as float service chargers, so this article will not discuss building a charger. The standard 18- or 20-A supply usually required by a 100-watt-output transceiver needs only a minor modification or two as discussed in the sidebar "Protecting the Charger When Commercial AC Power Fails."

Charging Rate

When charging voltage is applied to a depleted battery, the initial current drain is quite heavy. How much current flows depends on the battery's terminal voltage and the charging voltage applied. The greater the difference between the charger-output and battery voltages, the greater the charging current.

As the battery charges, its terminal voltage rises. The effect of this depends on the charger in use. Nickel-cadmium batteries, for example, are usually charged by *constant-current* power supplies that let the applied charging voltage rise as the battery's demand falls.

Lead-acid batteries, however, prefer to be charged by *constant-voltage* chargers—and the output voltage of the stiffly regulated power supplies commonly used with

A Closer Look at Charger Capacity

A float-system charger should be adjusted to provide just enough charging current to replace the battery's internal losses. Typically, this amounts to about 1 mA per ampere-hour of battery capacity. Thus, a 100-Ah battery typically requires about 100 mA of float current at room temperature. (The required charging current increases with temperature, as discussed in the text.)

This doesn't mean you can use a 1-A float supply to keep a 1000-Ah battery topped off! Remember, the ideal power supply/charger should be able to handle the entire system load without aid from the battery (you can fudge on this just a little; see below). Of course, the system battery should be able to handle the entire load without aid from the power supply.

If you're running, say, a 100-W transceiver, a 25-W 2-meter rig, a desk lamp, a small 12-V fan and a few other accessories from your dc line you might pull a maximum load of about 30 to 35 A at 13.5 V, *if* all of your back-up-powered transmitters are keyed simultaneously at full power.

Because all of your transmitters operate key-down simultaneously only rarely—and, if at all, for only a few seconds at a time—you can expect a normal momentary maximum load of, say, 25 A. A 20-A continuous-duty supply should handle this nicely, with the battery handling the small momentary overload.

That said, however, resist the temptation to try to get away with a lower-capacity supply—say, a 10-A unit. Without the battery, it can't handle the system's normal peak load. Even a 15-A supply is marginal at best, because recharging a deeply discharged battery—likely necessary after a lengthy commercial-power failure—may strain even a 15-A supply because of the heavy initial current needed to charge the battery.—*W4MLE*

[†]Part 1 of this article appeared on pp 34-37 of March 1990 *QST*.
[9]Notes appear on page 35.

Protecting the Charger When Commercial AC Power Fails

A back-up system is intended to take over when commercial electricity fails. When the lights go out, your back-up battery continues to apply about 12.5 V dc to the output connectors of your power supply—and to the output terminals of the regulator IC in that supply. At the same time, the absence of commercial ac reduces the regulator's input voltage to zero. Most voltage-regulator chips deeply resent this reverse-voltage condition and respond by committing suicide. Simple cures are readily applied. Which cure you use depends on which voltage-regulator IC your supply uses. Most regulated power supplies use either a 723 regulator—a 14-pin DIP IC in its most common form—or a three-terminal regulator, such as an LM317 (adjustable output) or one of the 7800-series (fixed output) ICs.

Protecting 723 Regulator ICs

Most commercial supplies, such as those in the popular Astron series, are based on the 723 regulator IC. The 723 fails under reverse-voltage conditions because 0 V at the chip's **V+** pin causes too much current to be forced through the base-emitter junction of Q12, the 723's inverting-input transistor.† A solution, devised by Ted Zateslo, W1XO,†† involves installing a resistor in the base lead of Q12 (that is, between pin 4 of a 14-pin-DIP 723 and its associated components). This pin is connected to the voltage-adjustment-control wiper in Astron supplies (and probably many others); you need only lift the control's wiper lead and insert the resistor—a 6.8- to 10-k Ω, ¼-W unit is sufficient; the exact value is not critical. The resistor protects the 723 by limiting Q12's forward base-emitter current to a safe value.

One other quirk of 723 regulators comes to light less often, but has the same cause. The problem arises when a power supply has been unpowered and disconnected for some time, allowing its filter capacitor(s) to discharge completely. If the power supply is connected to the battery before being turned on, the filter capacitor tries to charge through the base junctions of Q12 and Q14. Since uncharged capacitors act as momentary short circuits, the instantaneous current can be quite large, resulting in destruction of the 723, *even with the 6.8- to 10-kΩ series resistor in place.*

The cure is simple: *Turn on the power supply before attaching the battery.* This allows the rectifier to charge the supply's filter capacitor.

Protecting Three-Terminal Regulators

Three-terminal regulators are even simpler to protect. Connect a 1-A silicon diode, such as a 1N4004, between the IC's INPUT and OUTPUT pins, with the diode's cathode (banded end) to the INPUT pin. As long as the regulator's input-to-output differential exceeds the diode's contact potential (0.7 V or so)—no current flows through the diode because it is reverse-biased. But when the regulator input voltage drops during a commercial-ac-power failure, and the system battery keeps the regulator output voltage higher than the regulator input voltage, the diode conducts strongly, virtually short-circuiting the regulator IC and protecting its innards.

Watch Out for Crowbars

Crowbar circuitry protects a power supply's load from overvoltage by blowing a fuse. Usually, a crowbar consists of an SCR connected across the supply's OUTPUT terminals, and trigger circuitry set to *fire* (turn on) the SCR if the supply voltage exceeds a predetermined value. When the SCR fires, it shorts the supply's OUTPUT terminals and blows the supply's ac-line fuse.

Snag: A battery connected across the supply's OUTPUT terminals may dump hundreds of amperes into the fired SCR. Unless a fuse is interposed between the battery and SCR, the results tend to be spectacular! The wires between supply and battery heat quickly, often setting fire to their insulation. Unless the wires melt through, the battery electrolyte may boil, and the battery may explode.

Crowbar-caused system meltdown can be avoided by (1) disconnecting the crowbar circuitry entirely or (2) by installing a fuse between the battery and power supply *in addition to the fuse already present between the battery and its load.*

Solution 1 is acceptable because the battery itself clamps the supply's output voltage to a value that may not damage your gear. *Warning:* This overcharges the battery, and prolonged operation under this condition may damage your gear or your battery, or both. Don't substitute the battery's clamping ability for power-supply repair!

Solution 2 requires a power-supply-to-battery fuse with the same current rating as F1 in Fig 2 (in Part 1 of this series). Be sure to connect the fuse between the supply and the battery, not between the battery and its load. (Your system should already include a battery-to-load fuse [F1, as mentioned above].) The resistance of another battery-to-load fuse may noticeably degrade system voltage regulation.
—W4MLE

†See the LM723 schematic in National Semiconductor's *Linear Databook 1*, 1988 ed (Santa Clara: 1988, National Semiconductor Corp), p 1-194.

††Ted Zateslo, W1XO, 1540 Chuli Nene, Tallahassee, FL 32301.

100-W transceivers is constant. Sourced by such a supply, a charging voltage of 13.5, applied to a battery with a terminal voltage of 11 (fully discharged), causes an initial charging current of 1 to 30 A or more, depending on the battery's capacity.

If the charging voltage is maintained at 13.5 for several hours, the charging current slowly decreases as the battery's terminal voltage rises to meet the charging voltage. If the charging voltage is held constant for a long period of time—days or weeks—the charging current gradually tapers to whatever the battery requires to maintain itself in good health. This is the *float current.* This tapering effect complicates calculating the time required to bring a battery back to full charge.

The time required for a full recharge can be estimated, however. As a general rule, you must restore at least as much energy to the battery as you've drawn. If, for instance, you've drawn 5 A from the battery for 5 hours, you have depleted the battery's capacity by 5 A × 5 h, or 25 Ah. This is how much capacity you must restore. You can do this at the rate of 10 A for 2.5 hours 2.5 A for 10 hours, or any combination of rate and time that equates to 25 Ah. Recharging is not 100% efficient, however, so you must increase this figure somewhat. As a rule of thumb, recharge requires about 140% of the ampere-hours you deplete—in this case, 35 Ah to restore 25 Ah. A constant-voltage charger eliminates the need for calculation: Just set the charging voltage and let the regulated power supply do its thing.

Stiff charge-voltage regulation—and setting the charging voltage accurately in the first place—is important for another reason: Float current rises *very steeply* with small float-voltage increases. For a string of six cells, for instance, charging current about *doubles* for every 0.06 V increase in charging voltage. This overcharging increases the rate at which the battery loses electrolyte and, if allowed to continue for a long period, shortens cell life. Mild undercharging is not harmful; it merely reduces the total amount of energy that can be taken

Alternative Charge Sources

The commercial ac power line is certainly not the only source that can be used to charge a battery. Alternatives include automotive alternators and generators driven by windmills, water wheels or pedal cranks; 120-V ac gasoline generators; solar panels; other batteries and just about any energy source that can produce 14 to 15 V dc at more than a few hundred milliamperes. The purity of the direct current applied to a back-up battery is immaterial; the battery itself functions as a huge capacitor, swamping ripple and producing pure dc.

The alternator mounted in the family chariot can quite effectively recharge a depleted battery when necessary; after all, that's what such alternators are intended to do. Be wary, however: Like an automotive-battery charger, an automotive alternator can quickly overcharge a float battery.

An automotive alternator can be driven by a lawn-mower engine quite effectively. If the engine shaft is vertical, as is true of most lawn-mower engines, the necessary pulleys and belt can be mounted below the platform that supports the engine and alternator. Or, a small engine with a horizontal shaft can be mounted atop the platform.

The battery must energize the alternator's field coil; the alternator's output voltage depends on how much current flows in the field coil. The field-coil current can be set by a resistor or rheostat in series with the battery, or by an adjustable three-terminal regulator IC powered by the battery. Even a heavily-loaded alternator should not require more than a few amperes of field current. Any regulator circuit designed to be driven by a bridge rectifier should work well as a field-current regulator. In this case, however, the system battery, connected in parallel with the rectified alternator output, drives the regulator (Fig A). The regulator output, adjustable from 1.4 V up to nearly the battery voltage, feeds the field winding.

Many portable gasoline generators, like those used on Field Day, also have 12-V dc outputs for charging batteries, though the current-handling capacity of these may be less than that necessary for maintaining a back-up-battery system.

Of course, an ac-powered 13.5-V-dc supply can be powered by a 120-V ac gasoline generator.

Various mechanical contrivances can use the energy of the wind or a waterwheel to rotate an alternator. Articles describing such systems have appeared in Amateur Radio literature over the years.

Solar cells, an increasingly important source of alternative energy, come down in cost as photovoltaic technology improves and the market expands. A system using solar panels to charge batteries was described by Mideke in a two-part *QST* series in 1987. The Bibliography (to appear at the conclusion of Part 3 of this series) points the way to this and other sources of information on back-up-battery topics.—*W4MLE*

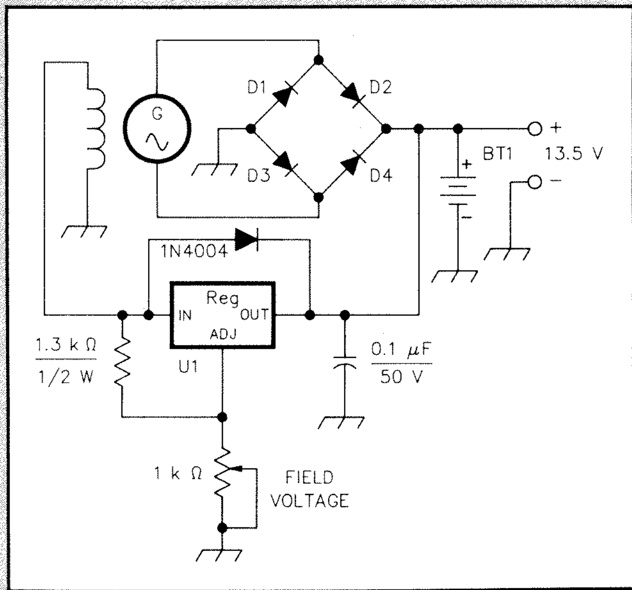

Fig A—Field control for a back-up-battery-powered alternator by means of an adjustable three-terminal regulator (U1). BT1 is the back-up battery; D1-D4 are diodes, or a bridge rectifier, capable of handling the system current; U1 is an LM317T (field currents up to 1.5 A), LM350 (3 A), or LM338 (5 A).

from the battery before full discharge occurs, and increases the frequency with which equalizing charges[10] must be applied.

Adjusting the Charger Voltage

The optimum float voltage varies with battery type, and different manufacturers of a given type may recommend slightly different float voltages for their batteries. As a general rule, however, set the power-supply voltage initially at 13.50 for lead-calcium cells, 12.96 for lead-antimony float cells, and 13.80 for deep-cycle marine and RV batteries. If necessary, cells of various types can be mixed or matched in float service, although it's better not to do so. If you do this, set your power supply to the float voltage suitable for the *lowest-rated* cells. For example, charge a mixture of lead-calcium float cells (13.5 V) and RV batteries (13.8 V) at 13.5 V. A mixture of RV and industrial deep-cycle batteries should be floated at 12.96 V.

After a deep discharge—as can occur when a battery provides back-up power during a commercial-ac-power failure—a high-capacity battery may draw a charging current higher than the charger can supply at the optimum charging voltage. In such a case, you can protect the supply by limiting the charging current with a series resistor, or by setting the supply's current-limiting circuitry—if the supply has it—to limit at a suitable level. If only the initial charging current is excessive, reduce the supply's output voltage until the current falls to a manageable level, then gradually raise the voltage to the float value as the battery charges and draws less charging current.

The Float-Current/Temperature Connection

Float current varies dramatically with temperature. The current through a fully charged battery nearly doubles for each 15 °F increase in electrolyte temperature.[11]

At room temperature, a battery requires about 1 mA of float current per rated ampere-hour of capacity. Thus, a room-temperature string of six 300-Ah cells would probably take a float current of about 300 mA.

If your battery is located outdoors, temperature-related float-current variations will be very noticeable on your system current monitor, with summertime float currents being much higher than those in the winter. The stiff regulation of the system charger automatically takes care of these changes without help from you. A back-up-battery system takes anywhere from several days to a couple of weeks to stabilize at a given temperature.

Equalizing Charge

After a battery has been in use for some time, especially if it is often subjected to shallow discharges, its cells may tend to develop small differences in voltage and specific gravity. (Such differences also occur when the average system charging voltage is too low, resulting in chronic undercharging. This can occur if the system voltmeter is miscalibrated to indicate higher-than-actual float voltage.) An affected battery can be rejuvenated by means of an equalizing charge.

Lead-calcium batteries generally don't require equalizing very often, but lead-antimony cells may need an equalizing charge every three months, or even more frequently. The need for equalization is indicated when the cell voltage falls more than 0.04 V below the float voltage.

To calculate the nominal float voltage per cell in a given battery, divide the float voltage by the number of cells. For example, in a series battery of lead-calcium cells floated at 13.5 V, the voltage across each cell should be 2.25. If the voltage across one or more of the cells in such a battery is 2.21 or less, an equalizing charge should be applied. To do this, raise the float voltage to about 2.4 per cell (14.4 V for a battery of six cells).

This raises the string's charging current dramatically. Maintain the equalizing charge until all the string's cells test at almost the same voltage—less than 0.04 V difference between the highest- and lowest-voltage cells in the string. Then, reduce the float voltage to its normal 13.5.

For lead-antimony float batteries, apply 13.98 V to equalize a string of six cells. The cells should equalize at around 2.33 V per cell after 8 to 24 hours. Then reduce the charging voltage to the normal 12.96.[12]

A battery can be recharged at the equalizing voltage provided your charger can supply the current; this is especially useful after the deep discharge that long power failures can cause. Be sure to readjust the charger to the proper float voltage as soon as the charge is restored and equalization is complete.

Back-Up-Battery Care

Lead-acid back-up batteries require *some* care: they are not black boxes. Here are the basics.

Disconnected from its charger, a single float-service, lead-calcium cell produces about 2.05 V at full charge. Such a cell is considered to be completely discharged when its terminal voltage falls to 1.8 (10.8 for a battery of six cells).[13] *Further discharging can damage the cell.* At full charge, and disconnected from its charger, a "12-V" lead-calcium float battery (six cells in series) exhibits an open-circuit voltage of about 12.3. By comparison, the open-circuit voltage of a fully-charged car battery is about 12.6.

Back-up-battery electrolyte must be kept at the proper level by adding distilled water to replace that slowly lost by electrical decomposition (electrolysis) during charging. Keep the electrolyte somewhere between the top and bottom lines marked on the cell cases for that purpose. *Never let it fall below the tops of the cell plates.*

Discharged batteries should be recharged as soon as possible. The C&D manual says:

> both lead-antimony and lead-calcium batteries should be recharged as quickly as practical following an emergency discharge.... This can be done by raising the bus voltage to the maximum allowed by the other circuit components, but not to exceed the values listed....If charging at equalize voltage is impractical, recharge at float voltage.

If a discharged battery is allowed to stand, it becomes "sulfated" and harder to recharge to normal capacity. Sulfation occurs when the finely-divided lead sulfate formed on the cell plates during discharge changes its crystalline structure to a form that resists recharging.

Disconnected from the charging system, fully charged cells can last several months before going back on charge. Backup-battery manufacturers generally recommend leaving lead-calcium cells off their float supply for no more than six months at a time without a restorative charge. Lead-antimony cells must be recharged at least twice that often.

In Part 3, the conclusion of this series, we'll discuss back-up-battery monitoring, maintenance and safety, and how to safely and responsibly dispose of unusable batteries.

Notes

[9]Even well-regulated power supplies tend to change voltage just a bit when the load or the power-line voltage changes, so it's a good idea to make the output voltage adjustable within narrow limits. Most commercial supplies allow such adjustment. Those that don't can usually be modified to allow it. (Caution: If you raise the output voltage of a 7800-series regulator by lifting its ADJUST pin above common, do so with a resistor, *not a diode or diodes.* Diodes placed between ADJUST and common can cause three-terminal regulators to fail. A 500-Ω pot, inserted between ADJUST and common on a 7812, and connected as a rheostat, usually provides an output-voltage of 12 to 14 or so. The output voltage increases as the inserted resistance increases.

[10]An *equalizing charge* is a charge applied at a voltage higher than the optimum float-charge value. This is usually done to correct cell-to-cell variations in voltage and specific gravity, as described later.

[11]R, Smeaton, Ed., *Switchgear and Control Handbook* (New York: McGraw-Hill, 1977).

[12]See Note 7.

[13]See Note 7.

Practical Battery-Back-Up Power for Amateur Radio Stations—Part 3†

Now that your back-up power system is in place and operating, you need to keep it there. Back-up-battery monitoring, maintenance and safety round out this three-part series on how to keep your station up when commercial power goes down.

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Together, *maintenance* and *monitoring* are *essential* to keep your back-up-power system running efficiently for years. Maintenance includes checking the specific gravity (SG) of the electrolyte in your back-up battery at regular intervals.

Specific gravity is a ratio—the weight of a volume of electrolyte compared to the weight of the same volume of pure water. Pure water has an arbitrary specific gravity of 1.0. The electrolyte is a dilute solution of sulfuric acid in water. Pure sulfuric acid is much heavier than water. Therefore, the more sulfuric acid in the electrolyte, the higher the specific gravity.

Discharging a battery takes sulfuric acid out of the electrolyte and converts it to lead sulfate. Charging a battery reverses this process, restoring acid and raising the specific gravity; when continued charging no longer increases the specific gravity, the cell is fully charged and further charging only electrolyzes water and generates heat. You can estimate the percentage of discharge of a cell quite closely by comparing its specific gravity to its fully charged value.

Typically, lead-calcium float cells use electrolyte with a specific gravity in the range of about 1.22 to 1.28. By contrast, electrolyte in a fully charged automotive battery may read 1.275 or higher. Because of this, measuring back-up cell specific gravity with an automotive hydrometer results in low readings—"fair" or "discharged" even for fully charged back-up cells. So, *be sure to use a hydrometer calibrated in actual values of specific gravity—not just "good," "fair," and "recharge."*

Several factors can make a hydrometer less than ideal for checking cells. For one thing, its calibration may be accurate only near a specified temperature. Cold electrolyte may cause falsely high SG values; warm electrolyte may cause falsely low SG readings. The pointers in some hydrometers tend to stick, giving readings that are hard to interpret. Even a hydrometer using a small glass float in a larger glass cylinder can be a problem: The float may stick to the walls of the cylinder, rather than float free. This destroys the accuracy of the reading. (Take float-hydrometer readings at the *meniscus*—the lowest point of the concave surface of the liquid in the hydrometer tube. Reading calibrations on the float at the meniscus can be difficult because they're obscured by the liquid surface.)

The state of a cell's charge can also be checked by measuring its terminal voltage several hours after the system charger has been turned off. A reading of 2.1 V per cell is about right, depending on the cell type. With the charger turned on and set to apply 13.5 V to the battery, the terminal voltage across each cell in a lead-calcium float battery should be 2.25.

Cells frequently deviate slightly from this value, however. All six cells in a battery rarely test at exactly the same value. If the values diverge too much, the battery needs an equalizing charge, discussed in Part 2 of this article.

Replacing Lost Electrolyte

Most cells lose some liquid over time. This is due partly to evaporation, and partly to the decomposition of water into its constituent hydrogen and oxygen gases by electrolysis. Replace lost cell liquid with distilled water, readily obtainable from grocery stores. *Don't use tap water;* the minerals it contains contaminate the electrolyte and eventually interfere with battery performance.

Occasionally, you may spill some electrolyte from a cell. (If you do, *safety*, not the battery's state of charge, is your first concern! See below.) In that case, the cell loses sulfuric acid *and* water. If not much liquid is spilled, it may be replaced by swiping small amounts of electrolyte from other cells in the battery, then bringing all the cells up to full volume with distilled water.

Considerable electrolyte spills must be replaced by new electrolyte made by mixing sulfuric acid with water in the proper proportion to produce electrolyte of the same specific gravity as that of the electrolyte already in the cell. This process involves handling strong, highly corrosive acid that can burn the skin almost instantly and create sores that are painful and very slow to heal. *Unless you really know what you're doing, don't mix your own electrolyte; go to a battery shop and get replacement electrolyte of the correct specific gravity.*

Safety[14]

Warning: Heavy-duty lead-acid cells are potentially very dangerous. Each cell contains fairly strong sulfuric acid, which can cause injury when in contact with the skin and blindness when in contact with the eyes. Handle the cells with great caution and respect. A 300-Ah float cell contains about three gallons (12 to 13 liters), more or less, of 6-molar sulfuric acid. This means that each healthy, fully-charged cell contains about 15 pounds (6.8 kg) of concentrated sulfuric acid—wicked stuff.

Whenever you handle these cells, as in installing them or moving them, wear liquid-proof safety goggles and acid-resistant rubber (or plastic) gloves. *Keep a*

†Part 1 of this article appeared on pp 34-37 of March 1990 *QST*; Part 2 on pp 32-35 of April 1990 *QST*.

[14]Notes appear on page 27.

A Simple Battery Monitor

Monitoring a battery's electrical performance frequently, or even continuously, is highly desirable. You should at least monitor the system battery voltage; an ammeter for measuring battery charging current can be informative, too. Preferably, a monitor for battery current and voltage should be located where you'll see it every time you enter the shack. The circuit in Fig A, a simple voltage/current monitor, can indicate load and charging current, and battery voltage.

M1 is a zero-center meter capable of indicating 50 or 100 μA, full-scale. It displays the current flowing into or out of the battery by measuring the voltage drop across F1, which serves as a meter shunt.

The fuse exhibits a resistance of a few hundredths of an ohm; the system load and charging currents cause a voltage drop across it, making M1 deflect. How much M1 deflects depends on the voltage drop and M1's internal resistance. If the resistance of F1 equals, say, 0.05 Ω, and the internal resistance of M1 is, say, 1 kΩ, a current of 20 A through the shunt (a voltage drop of 1.0) drives 1 mA through M1. That much current would damage a 50- or 100-μA meter, so switchable multipliers (R2, R3 and R4) are included to reduce this current and set M1's full-scale deflection. Adjusting R2 for an indication of 20 μA for a 20-A load current turns a 50-0-50-μA meter into a 50-0-50-A instrument, for instance. R3 can be adjusted for a full-scale current of 5 A. R4 provides a third range for the current monitor. The 1N4001s across M1 protect it from overvoltage by limiting the voltage drop across M1 to approximately 0.6 V. The meter is further protected by F2, a 500-μA instrument fuse.

The voltmeter circuit (M2 and its associated components) features an expanded scale; that is, it indicates 10 to 15, instead of 0 to 15, volts. (Like M1, M2 is protected against overvoltage by 1N4001 diodes.) If possible, use a 0- to 50-μA meter at M2; then, a reading of 50 μA represents 15 V, with 10 μA corresponding to 11 V. The voltmeter circuit works as follows: The full battery voltage appears across the series string consisting of the 510-Ω resistor, D1 and R6. R6 is adjusted until the voltage drop across D1 and R6 is exactly 10 V, as measured on an accurate digital voltmeter. Then, the voltage drop across the 510-Ω resistor is the difference between the battery voltage and 10 V. R5, **V CAL**, is then adjusted to make M2's reading agree exactly with that of the digital voltmeter. (For example, if the digital voltmeter indicates a float voltage of 13.50, adjust R5 for a reading of 35 μA on M2.)

With its scale thus expanded, M2's low-end readings are somewhat inaccurate because of D1's nonlinear conduction curve, but this is immaterial. Calibrated at your system's normal float voltage, M2 will be accurate at the voltage most critical to proper operation of your system. Any deviation from this voltage can easily be read in tenths of a volt, and estimated to hundredths. If you have any cause to doubt M2's calibration accuracy, you can always recheck it with the digital voltmeter.—*W4MLE*

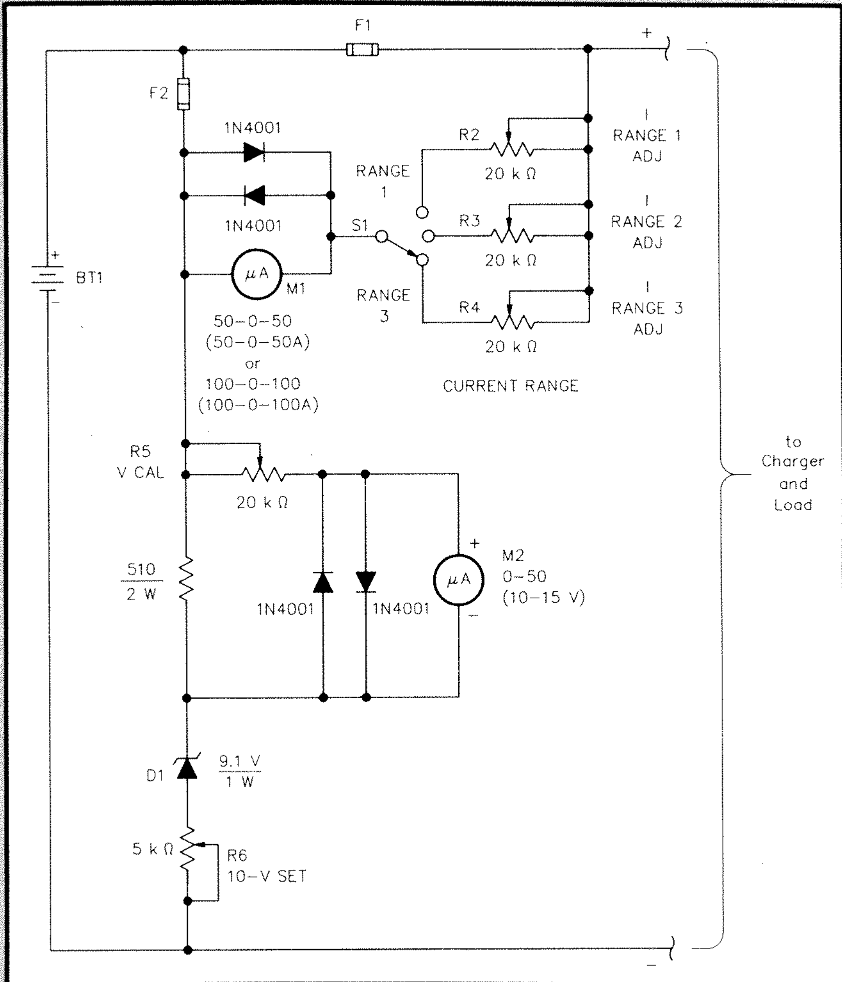

Fig A—Monitoring voltage and current in your back-up-power system is easier with a specialized voltage and current monitor like this. See the text for how to adjust the **V CAL**, **I RANGE ADJ** and **10-V SET** trimmers. Component designators contained in the text but not called out below serve to illuminate the text.

BT1—System battery; see Fig 2 (in Part 1 of this article).
F1—System fuse; see Fig 2.
F2—Instrument fuse, 500 μA.
M1—50-0-50- or 100-0-100-μA (zero-center) meter; see text.
M2—0- to 50-μA meter; see text.
R2-R5—20-kΩ trimmer pot.
R6—5-kΩ trimmer pot.
S1—Rotary switch.

garden hose handy, with water turned on. Keep a supply of sodium bicarbonate (also known as bicarbonate of soda, or baking soda) at hand to neutralize acid that may get on your skin. Have another person standing by to help if something goes wrong.

If any electrolyte makes contact with your skin or clothing, safety experts[15] recommend taking the following measures *immediately:*

• Hose down the affected part of your body. While you're under the hose, quickly remove and discard any clothing splashed with acid.

• If you get acid on your skin, flood the spill with water *immediately,* rinse thoroughly for several minutes, then dust the affected area with sodium bicarbonate.

If electrolyte splashes into your eye(s), the recommended immediate treatment is to:

• *Immediately* flush your eyes with water for at least 15 minutes, including under the lids. Speed in starting the flushing is *critical.* While your eyes are being flushed, *call medical help.* A 911 call is appropriate.

Flushing with large quantities of water is also the proper treatment for electrolyte spills on skin. Elderly people and young children's skin is especially vulnerable to acid, but 6-molar electrolyte causes itching and stinging even in healthy young adults within a few seconds of contact. (Broken or irritated skin reacts quicker, and more strongly.) If the electrolyte is flushed away with water and neutralized with baking soda, chances of serious injury are minor.

The polycarbonate-plastic cases of back-up batteries and cells are extremely strong and acid-resistant, but they must be treated with respect. A 300-Ah float cell weighs about 85 pounds. If you drop it and its case cracks, you have a very dangerous mess on your hands (or feet)!

Dust and gunk of various kinds tend to accumulate on the cases and must be cleaned off periodically. The best cleaner is a damp cloth or paper towel. But if acid is spilled on the outside of the case, it should be neutralized so it won't damage other materials or injure skin that comes into contact with it. Battery manufacturers recommend a dilute solution of baking soda. This extremely mild alkali neutralizes the acid *without damaging the plastic.* (Baking soda fizzes because it reacts with the acid to produce sodium sulfate and carbon dioxide gas.) Don't use stronger alkalis, such as lye (sodium hydroxide) or ammonia (ammonium hydroxide) on back-up batteries. These chemicals damage the cases, causing cracking that may lead to leaks. Also, don't use organic solvents such as alcohol or carbon tetrachloride.

When Batteries Go Bad

Typically, a healthy new cell can be completely discharged and recharged several hundred times before old age sets in. If the discharges are shallow, the cycle can be repeated many more times—perhaps 600 to 800 times. A cell is considered dead when it can deliver no more than about 30 percent of its original capacity after being fully charged.[16]

A cell may die for various reasons. One of them is poisoning by foreign substances, such as copper or iron ions from foreign materials. Another is a gradual buildup of lead sulfate that refuses to convert back to lead peroxide and spongy lead. This happens because lead sulfate tends to form larger crystals over time, and the larger particles don't react as readily to the charging current. Another reason for cell failure is that solid materials, slowly flaking off the plates, fill the small spaces between plates, causing internal short circuits or blocking circulation of electrolyte.

Disposing of Unusable Cells

Batteries are considered by environmental agencies to be hazardous materials. Don't leave discarded units lying around the yard or send them off to the city dump. Safety experts recommend the following procedure to render back-up batteries harmless:

1. Take the safety precautions mentioned earlier. This includes wearing the proper protective gear, and keeping a running hose, baking soda and an assistant nearby.

2. Dump the electrolyte into a corrosion-proof container. A large plastic bucket works fine. Pour as much liquid out of the battery as possible. (Careful: Back-up cells and batteries are *heavy.* Lift them safely. Don't splash electrolyte on yourself or your clothing!)

3. Using a plastic scoop, add small quantities of slaked lime (hardware and garden-supply stores sell it) to the acid in the bucket while stirring the mixture vigorously with a wooden or plastic tool, like an old broom handle. The resulting chemical reaction generates a great deal of heat! Do not just dump lime into the liquid! (Danger: Like the electrolyte, slaked lime is highly caustic. Do not touch it or breath its dust.)

4. After the lime stops reacting with the acid, add a teaspoonful or two of baking soda to the mixture. If it fizzes, some acid remains. Continue to add lime until baking soda no longer fizzes.

5. The resulting mess in the bucket consists mainly of water and calcium sulfate—the material of plaster of paris and gypsum. This mixture is harmless and may be disposed of by washing it down the drain or putting it out in the garbage, enclosed in plastic bags, for sanitation pickup.

Discarded cell carcasses, with lead plates, can sometimes be sold to salvage dealers. Dealers may take cells that still contain electrolyte, but check before you transport the cells: They're messy and dangerous to move.

Summary

Back-up power for Amateur Radio stations is useful, and need not be expensive. Heavy-duty batteries *intended for float service* are available to do this job well. A battery-back-up-power system may be just what you need to keep your station going when emergencies arise and commercial power fails.

Notes

[14]*Material Safety Data Sheet* No. 9, Revision B, Oct 1980, Corporate Research & Development, Schenectady, NY 12305.

[15]Material Safety Data Sheet, Corporate Research and Development, Schenectady, NY 12305, © 1980 by General Electric Company.

[16]C&D Batteries, *Stationary Battery Installation and Operating Instructions,* C&D Batteries, 3043 Walton Rd, Plymouth Meeting, PA 19462.

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G. Thurston, "Designing Low Voltage Power Supplies," *ham radio,* Mar 1985, pp 46-49, 51-54, 56-59. (Note: This article contains several errors: [1] Fig 9A, p 57, shows the base of driver transistor Q3 connected to the bases of the pass transistors, Q1 and Q2. Delete this connection and connect Q2's base to R7 and the Q3's collector. [2] In the parts list on p 57, C5 is 120,000 μF or greater, 50 V [not 0.1 to 2.0 μF, 50 kΩ]. [3] The diode in Fig 6, p 51, is reversed. Its cathode (banded end) should be connected to the 78XX input. [4] Also on p 51, below the equation in the right-hand column, change the sentence to read "...E = 1.4 volts.")