

\$4.95



AMPLE POWER  
PRIMER

**AMPLE POWER**

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## Information you can Count on!

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### Why Ample Power?

Ample Power products exist for a simple reason ... to provide that extra level of performance that separates us from the pack. As an engineering directed firm, we know how hard it is to compete against glossy literature filled with *feel good* scenes, and a host of retailers selling commodity level performance.

### An Educational Approach

Rather than attempt to gloss over the real electrical system issues, we have elected to supply as much useful information as possible. This information should enable you to sort through the confusion that surrounds electrical systems.

Our educational program is supported by sales of our products. We hope that you will become a faithful reader and a satisfied user of Ample Power products. Let us know what questions you have.

## The Power Equation

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### Batteries are Complex Mechanisms

If deep cycle batteries were as simple as the car battery, you could leave the dock with the standard automotive electrical system supplied by most boat builders and enjoy all the power you desire. The fact is, deep cycle batteries are constructed differently than car batteries and require specialized monitoring and charging equipment to operate efficiently for long periods. Expensive batteries are no solution to the power equation ... even the best batteries can be easily ruined by mistreatment.

### Proper Battery Monitoring

Voltage indicators such as LEDs are worse than no indicators because they imply a sense of correctness, when in fact they are incapable of reporting battery state of charge. A simple voltmeter, and ammeter are not adequate as monitoring instruments unless you are willing to spend most of your on-board time staring at them and logging conditions. The fact that these instruments are

### Judging Electrical Components

With all the hype, what's a user to do? There are very few articles in publications that do a respectable job of evaluating electrical system performance. Since it takes a skilled engineer to design fully functional equipment perhaps it takes one to do a comprehensive evaluation of it.

So, what should you do?

We've assembled this Primer as a starting point to gathering knowledge that will help you make a better decision on electrical system design. Browse our Products section for specific Product details and uses. Consider our two books, *Living on 12 Volts with Ample Power* and *Wiring 12 Volts for Ample Power*, which cover more specific topics and details of electrical systems. Read the information provided by others.

widely used is testimony to the widespread misinformation about battery characteristics.

Ignorance, it's said, isn't what you don't know, but what you think you know, that isn't true.

### Battery Experts

Some of the worst people to ask about batteries are people who work in general electronic disciplines. Before anyone can claim to be a battery expert, a comprehensive study program is required. General electronic knowledge just isn't sufficient. Even those working in battery distribution channels can't be relied upon to dispense correct and meaningful battery information.

Since deep cycle batteries are complex mechanisms, no short article about them will make you an expert. The following information hits a few of the high points. Maybe you'll recognize some

of the ways you're killing batteries. As we point out, there are ways to enjoy reliable energy.

## Limit Battery Discharges

The further a battery is discharged, the greater the mechanical stresses on its plates. Therefore deep discharges shorten the life of a battery. To avoid frequent replacements, you need to limit the depth of discharge. As a rule, it is best not to discharge batteries more than about 50% of their rated Amp-hour capacity. If you disobey this rule, expect to have battery problems including sudden death . . . failure without warning. Most of us are painfully aware that things go wrong at the worst possible times, and battery failure isn't an exception.

## Battery Capacity and Voltage

During discharge, battery terminal voltage is not a valid indicator of remaining capacity. This fact rules out the voltmeter as an accurate gauge that tells you when to stop discharging and start charging. Only when a battery has not been charged or discharged in the last 24 hours, can voltage be related to state of charge. A fully charged battery will show a voltage of about 12.8 after being rested for 24 hours. A battery with a 50% state of charge will exhibit a voltage of about 12.2. These values are general and do vary somewhat from manufacturer to manufacturer.

With only 0.6 Volts between a fully charged battery and one 50% discharged, it should be apparent that inexpensive analog voltmeters are not accurate enough to be meaningful.

## Battery Capacity Measurement

Since the voltmeter isn't sufficient to indicate state of charge as the batteries are being used, Amp-hour instruments have been designed. Amp-hour instruments continuously measure the current into and out of the battery bank and compute the Amp-hours extracted. As the battery is being charged, Amp-hours extracted declines. While this sounds simple in principle, implementation methods differ significantly, and as a result, some instruments are much more accurate than others. The best Amp-hour instruments not only indicate Amp-hours extracted, but also display Amp-hours remaining. Measurement of Amp-hours remaining is a complex operation requiring computation of an exponential equation discovered by Peukert in 1897. Recent tests confirm the accuracy of this important equation. Some Amp-hour instruments try to fudge a solution without solving the equation, but such devices provide poor accuracy.

## Prevent Battery Overcharges

While excessive discharge is a major cause of battery failure, overcharge is another significant killer. Batteries that are perpetually overcharged corrode their positive plates. As the plate gets weaker and weaker it becomes susceptible to damage from high current. Sooner or later, a load draw will snap the plate connection open and the battery fails. Overcharge seems like a simple problem to cure. Rather than run the risk of overcharge, why not just undercharge?

## Avoid Battery Undercharges

If all you lost by undercharge were a few Amp-hours of capacity, then undercharge would be a solution. Undercharge destroys batteries in a different way, however, by a buildup of lead sulfate. Only a correct charge will obtain maximum life from batteries.

Many people are completely unaware of the loss of capacity from their batteries due to undercharge. Even worn-out batteries will start an engine, the test used by many to gauge life left in their batteries.

## What is a Full Charge?

To fully charge a battery requires that its terminal voltage rises to about 14.4 Volts. If permanently applied, this voltage would boil all of the electrolyte from the battery and might even cause a condition called thermal runaway. With thermal runaway, the battery gets extremely hot and may even explode, spewing acid everywhere.

## Use Multi-Step Regulation

While 14.4 Volts is required to fully charge batteries, a voltage under the gassing potential of 13.8 Volts is necessary to prevent overcharge. Low cost regulators, such as those found in automotive alternators produce a voltage of about 14 Volts. This isn't quite enough to fully charge a deep cycle battery. On the other hand, it isn't high enough to immediately cause overcharge, but it does extract its toll. Did you ever notice water loss after long hours of motoring?

## Use Temperature Compensation

Proper voltage regulation is only part of the charge characteristic required by a battery. Temperature compensation over a wide range is a *must-have*. At low temperatures, increased internal resistance and reduced chemical activity require a higher charging voltage. High temperatures have the opposite effect. To prevent thermal runaway, applied voltage must be decreased. Thermal runaway is a problem seen with fast charge regulators which don't use temperature sensing at the battery.

## The Ample Power Solution

Since it takes a high voltage to fully charge a battery, and a lower voltage to maintain it after a full charge, multi-step regulators and chargers have come into existence. Such devices are a vast improvement over conventional single setpoint regulators. Ultimate performance is offered by regulators which sense battery temperature and compensate output as a result. Temperature compensation may be your only insurance against thermal runaway.

To enjoy electrical energy, you must have instruments computing Amp-hours remaining to warn you of deep discharges before damage can result. You also need to charge batteries correctly with multi-step regulation. To borrow a famous equation, we might say that the Power Equation is  $E = mc^2$ . That is, Energy equals Monitoring and Charging Correctly.

While solutions to the power equation are simple in concept, a significant and complex engineering effort is needed before devices which optimize battery performance can be produced. Ample Technology has gained an international reputation by offering microcomputer based products which provide ultimate battery care in the harshest of conditons . . . life at sea, and under the hood of an RV touring the desert. Specific performance, accuracy and reliability of Ample Power products is unequalled.

## Design Considerations

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When contemplating an upgrade to an existing electrical system, or starting from scratch to assemble one, there are several important considerations to be made. Take a moment to review each of the following issues before you decide on your next electrical system.

### Battery Capacity

Generally, daily power consumption should only be about 25% of the available battery capacity. The general rule is to avoid discharges much below 50% of rated capacity. If daily loads are only 25% of available capacity, then charging can take place every other day. In an emergency, you'll be able to go four days without charging. Note that the term *available capacity* is used. For liquid electrolyte batteries, and some gel units, available capacity is only about 80% of rated capacity. Some gel batteries can tolerate repeated discharges of 100%, so it's safe to equate available capacity and rated capacity.

Another useful rule about capacity states that the maximum load on the batteries should only be 25% of battery capacity. That is, if you have an inverter that draws 100 Amps, then battery capacity should be 400 Amp-hours.

Often, there is not sufficient room for all the batteries desired. When space is limited, the need for top quality instrumentation is paramount. An undersized battery system can only be managed with such instrumentation. Many people mistakenly believe that systems with small batteries don't warrant extensive instrumentation . . . needless to say, they are always out of power, and blame it solely on the batteries. The closer daily consumption is to available capacity, the greater the need for accurate Amp-hour instrumentation.

### Battery Configuration

A single house bank with a dedicated starter battery is preferred. For more information about this important concept, refer to the section in this *Primer* titled 'The Preferred System'.

### Alternator Sizing

The main engine alternator should be 25–40% of the rated battery capacity. Liquid electrolyte and some gel batteries won't accept a high rate of charge, so an alternator about 25% of the rated battery capacity is most appropriate. When batteries have low acceptance rates, as do thicker plate liquid electrolyte units, they reach absorption voltage long before they're charged. Consequently, water loss is greater, as is corrosion of the plates.

Many engines won't accept large frame alternators without extensive engine modifications. For that reason, many systems don't have as much charging capacity as they might. Often boat designers limit space around the alternator, preventing upgrade to a large frame alternator. Consult an Ample Power dealer about your specific requirements. Ample Power alternators are made for just about every engine.

Don't make the mistake of looking only at the maximum output an alternator produces. Is the output produced at a usable RPM? Alternators can be made to produce high output at low RPM, or high RPM, but not both (except for some large frame units). When you motor for several hours at a high RPM, alterna-

tor capability isn't as important as when you want a fast charge at anchor. Here, the alternator that has good low RPM output will be more appropriate.

### Alternate Charging Capability

Wind and solar energy have a definite place in the energy mix aboard any boat or vehicle, and there are Ample Power products to intelligently integrate those energy sources into the system. We have equipped engineless boats with enough solar and wind power to live completely from the environment . . . even with refrigeration!

We suggest that you supplement your energy needs from the sun and the wind. As much as 25% of your daily consumption is recommended . . . more if you have the space.

Regulation of solar panels and wind generators is required, despite the claims otherwise. Like any regulation system, the solar and wind regulator should provide battery temperature compensation, and be adjustable or programmable to suit your battery system. The Energy Monitor II includes solar and wind generator control capabilities as a standard feature.

### Alarms

An alarm may save your life. If your electrical system is on the verge of collapse, wouldn't you want to know? Battery system alarms may be the most underrated safety device onboard. No one has time to continually monitor the electrical system . . . without alarms, conditions may deteriorate until recovery isn't possible.

How are alarms useful? A high voltage or high battery temperature alarm indicates a runaway regulator. A low voltage or low capacity alarm indicates a need to charge. A high current alarm detects a system short circuit.

Alarms that can't be programmed and individually enabled or disabled can be a nuisance. Perhaps this is why alarms are so often omitted from the electrical system. Choose an alarm system that is easily adjusted, and simple to enable or disable any specific alarm. Don't let a disaster sneak up on you! Make sure your electrical system has sufficient alarms.

### Amp-Hour Instrumentation

Amp-hour instruments are available in a wide range of capability and price. Not everyone needs the same level of capability, but many people select a less expensive unit because they don't understand battery capacity, and think that a simple meter may suit their needs.

The opposite is true. A true battery expert can usually manage a system quite well with just a voltmeter and ammeter. Adding a simple Amp-hour meter to such a system may seem like a luxury to the expert. On the other hand, a user not intimately familiar with battery characteristics needs an Amp-hour meter that not only displays linear Amp-hours consumed, but also Amp-hours remaining, which compensates for the rate of discharge.

The more expensive Amp-hour meters often include regulation and control options, alarms, and other features that makes their higher price warranted by the value they offer.

Before purchasing a monitoring system, look at the package. Is it

watertight? Does it use mechanical switches that will wear out or get knocked apart? Are signals terminated on terminal blocks, or just left dangling? Can it be mounted easily? Will you be able to read it day and night, with adjustable backlighting?

## Alternator Regulation

Standard automotive regulators do not charge deep cycle batteries properly. The reason is the fact that deep cycle batteries require a multi-step charging procedure. Many people have heard this explanation in the last few years, and, not understanding the issue, have purchased *two stage* regulators.

A regulator that makes an alternator supply full output until the battery rises to an adjustable setpoint and then holds that voltage on the battery is a two stage regulator. A standard automotive regulator is a two stage regulator, and some of the expensive regulators sold in marine catalogs are *two stage*. If the regulator isn't three or more steps, don't bother considering it for your electrical system.

Naturally, the alternator regulator should be temperature compensated. The only way to do this is to measure temperature at the battery, and change the regulation setpoints automatically. Some regulators come with a temperature chart and instructions for manual adjustment as the temperature changes. Do you really want to be bothered tweaking the regulator several times a day?

There are other considerations. Do you have halogen lights? The life of halogen lights is shortened by the higher voltages used to charge deep cycle batteries. The regulator should have a means of limiting voltage whenever the halogen lights are on.

Is the rated horsepower of your engine below 30 HP? You may want to install a regulator with current limiting ability so that precious power can be diverted from charging to propulsion in an emergency.

Will you have liquid electrolyte batteries? Your alternator regulator should allow you to equalize them periodically.

## The Preferred System

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The Preferred System consists of a single house bank, and a dedicated starter battery for all engines. A separate generator battery is sometimes present.

### Support for Two House Banks

Ample Technology supports multiple house bank systems because there are so many of them installed. With the accuracy and reliability of Amp-Hour instruments, and the improved charging performance offered by our regulators and chargers, however, a two house bank system is no longer necessary. In fact, the more battery banks in use, the less reliable the system will be, while also increasing cost and management problems.

### The Preferred System

The preferred system is a single house bank of parallel or series/parallel batteries and another battery or bank solely to start the engines. The reasons for this system to be preferred over multiple house bank system are many. First, there is the initial cost. The total battery capacity, and hence battery costs will stay the same, however, the wiring costs will be reduced along with instrumentation costs. Instead of a 1-2-both switch, a simple par-

## Installation

Very few people are trained to install electrical equipment. Despite the lack of training, some people can do well at installation. Others need professional assistance.

Over the years, we've seen many installations. Those who report the most problems with the *equipment* invariably have the worst wiring. Here's a sample list of problems we've seen too often.

- improper wire sizes
- terminal to wire size mismatches
- wire exposed beyond crimps
- lugs crimped over insulation
- unsealed butt splices
- wire strands dangling outside lugs
- severed wire strands
- unsecured wire bundles
- unlabelled wires
- wires joined by household wire nuts
- solid wires instead of stranded
- untinned wires
- wires mounted to screws without lugs
- burned or knicked insulation
- vibrating wires lashed to metal surfaces.
- wires shorted across terminals

Not long ago we observed a boat that needed \$20,000 of interior work done after an electrical fire. The alternator wire had been cut a few inches too short . . . to reach the batteries it had to pass under the engine. It was held in place by nylon ties on either side . . . unfortunately, it rubbed against the oil pan. The system worked for a couple of years, but ruined plans for a world cruise.

The electrical system is vital. If you aren't positive you can do a first rate installation, seek help from a qualified installer . . . one who has been trained on the equipment to be installed.

allel switch can be used to start the engine from the house bank if needed. That switch is only used in an emergency.

### Failures of the 1-2-Both Switch

What is perhaps the most failure prone part of a typical electrical system? The 1-2-both switch! There are a lot of ways that particular switch causes problems. It can fail, of course. It can also be turned off with the alternator charging, destroying the alternator and electronics. The good old 1-2-both switch can also be left in the both position, flattening both batteries and leaving you in the lurch. We've even forgotten to put the switch in both to charge and only luck saved us from losing our boat. By tossing the 1-2-both switch overboard, you can increase system reliability by an order of magnitude.

### The Savings Begin to Add Up

So far we've tossed out lots of wires used to wire two house banks instead of one, and the selector switch to choose which bank. We did add back into the system a parallel switch, but since it is only used if the starter battery dies, the potential for human oversights has been greatly reduced. But isn't a single house bank risky?

What happens if a cell fails in a battery . . . isn't the bank out of service?

## What About Cell Failures?

If you made the house bank out of a single battery and you get a cell failure, you do indeed have a problem. Likewise if you make the house bank out of two series connected 6-Volt units a cell failure is a problem. But, if you make the house bank from parallel batteries a cell failure in one only knocks out that battery. The remaining batteries are still available. With proper maintenance cell failures are very rare. With proper instrumentation, cell failures are easily detected. Even if you don't immediately spot a cell failure, it takes a long time before a bad cell adversely affects the other batteries. In a properly instrumented and managed system, parallel batteries are not only appropriate, they are preferred.

## The Positive Benefits

There are other positive benefits of a single house bank versus two. As reported in *Power News*, November 1991, and August, 1992, a gain in effective capacity results because the rate of discharge relative to battery capacity is reduced. That is, since the relative discharge rate is less, the losses due to Peukert's law are less. Peukert's law is a well known equation that relates battery capacity to the rate of discharge. The faster a battery is discharged, the less total Amp-hours it will yield.

In contrast to the preferred system, a dual house bank system is also used for engine starting. As the house banks wear out, they have a higher and higher probability of failure. That means a higher probability that the engine won't start when needed. The preferred system keeps the starter battery reserved just for start-

ing the engine, and with proper care, the probability of failure remains lower for a longer period of time. See *Power News*, January 1993, for more details about electrical system reliability.

The single house bank is easier to charge, particularly if the Eliminator is used to maintain the starter battery. The battery charger is less expensive and the regulation circuits can be tuned just for the house bank, rather than compromised to account for two banks which are in different states of charge.

## In Review

To recap, the preferred system;

- Costs less to instrument and wire
- Is easier to manage
- Is less prone to human mistakes
- Provides a capacity gain
- Achieves better charging performance
- Has a more reliable starting battery due to less stress

If you're retro-fitting an older boat, or building a new boat consider the preferred system. Even on an existing boat, conversion to the preferred system is easily done with very few wire changes. Properly implemented, operating the system is as easy as operating the electrical system in an automobile. When you want to start the engine you only need the ignition key. No more hassles with the 1-2-both switch. When you run the engine, you're charging. No one can turn off the selector switch underway and blow up the system. When you get to your favorite anchorage, shut off the engine and relax . . . you don't have to worry about the selector switch being in the both position. Enjoy Ample Power!

# Instrumentation

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An Amp-hour is the product of Amps times time. One Ampere for one hour is one Ah. Five Amps for two hours is 10 Ah. This apparent simplicity is mis-leading, since the amount of Amp-hours that a battery can provide is dependent on the rate of discharge. The faster the rate of discharge, the less total Amp-hours will be provided.

To account for rate of discharge, Peukert's exponential equation must be used. This is hard to do with a small microcomputer, and only Ample Power has been able to accomplish the task at this date. For more information about this critical subject consult the book *Wiring 12-Volts for Ample Power*.

## Amp-Hour Instruments

There are two different Ample Power instruments that measure Amp-hours consumed. One of these, the Energy Monitor/Controller also display Amp-hours remaining, which requires the use of Peukert's exponential equation that relates battery capacity to rate of discharge.

Not all instruments are created equally. There are many different ways to measure Volts, Amps, and Amp-hours, but there is only one right way . . . the Ample Power way. We take pride in offering the highest resolution and the highest accuracy of any meters presently available. Here's some of the techniques we use to assure that we provide correct readings, and they will remain correct over temperature variations and the many years we expect

our instruments to survive.

- Extensive input filtering of the analog signals is done to avoid errors caused by electrically noisy power conductors, radios, fluorescent lights, chargers, pumps, radars, and many other typical onboard devices.
- At least 256 measurements per channel are taken every second and digitally filtered to remove errors produced by slow sampling systems known as 'aliasing' errors.
- Digital to analog conversions are done with a resolution of better than 0.025% of full scale.
- A temperature compensated reference with guaranteed drift over time is used.
- Critical measurements, such as battery current are done with precision shunts which only lose 0.05 Volts at rated current. These shunts are connected in the negative side of the battery since there is no economical method to attain accurate measurements in the positive side of the battery.

Besides being the most accurate, the Ample Power instruments will remain that way far longer due to superior packaging techniques.

## About "Loops"

Current sensors are made with a magnetic loop which circles the wire and generates a signal proportional to the current flowing in that wire. The "loops" have the advantage that they are isolated from the current being measured, and as a result, are widely used

to sense currents in AC/DC operated motor leads in the industrial environment.

Sensing current in motor leads is done to detect high currents that may damage the motor or the motor drive electronics. No great precision is required, and measurement of low currents isn't even of interest. In the battery system, measurement of low currents is of great interest, and precision a mandate.

## Which Battery?

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### Many Types of Batteries Exist

We're fortunate to live in an economy that offers abundant choices, however confusing some of those choices may be. Few are more confusing than the choice of batteries. No doubt you know someone who lights up every battery conversation with the subject of golf cart batteries, and another who thinks heavy duty 8Ds are electrifying. Others get charged up talking about gel batteries, while some offer weighty opinions about traction batteries. Just what are the positives and negatives of the different types?

### Batteries are Purpose Built

The concept of 'purpose built' is useful to describe the differences in battery designs. Just like a hydroplane isn't the best of cruising boats, not all batteries are built for cruising.

### Starting Battery is Simplest Type

The simplest, and least expensive battery is the starting battery. It is constructed with many very thin plates. The combined surface area of the many plates allows high currents to flow through the battery . . . great for the purpose of starting engines. The starting battery can't be deeply discharged without a significant risk of destruction. A recent study showed that no starter battery survived more than 18 deep discharge cycles . . . most survived no more than 3 deep discharges.

### Deep Cycling Requires Thicker Plates

To enable deep discharges, the plates must be made thicker and the insulating separators made from more expensive materials than the paper used in starting batteries. Thicker, but fewer plates means that the battery won't sustain as high a rate of current, but will permit deeper discharges without imminent failure. Golf cart batteries and heavy duty 8D units are thus designed with the purpose of supplying moderate currents for sustained periods. They aren't a true deep cycle battery, however, and should be charged soon after any extensive discharge.

By making the plates thicker yet, and using expensive fiberglass

Why would loops be introduced as mechanism for measuring battery currents? With a marginal isolation advantage, and so many inaccuracies and increased power consumption resulting from loop use, we can only conclude that marketing won the day over good engineering practices. The day that loops can do a better job of accurately measuring both low and high level currents than can shunts, will be the day that they will be part of the Ample Power product line.

matte separators, a battery can be made which provides a great many deep cycles . . . 400 or more 100% discharges. This kind of unit is called a traction battery and will cost several times as much as golf cart batteries in the same capacity range. Batteries made by Surrrette and Rolls use very thick plates and offer great longevity when low rate discharges are followed by long slow charges.

### Gel Units are Lead–Acid

Gel batteries use the same lead–acid chemistry of conventional liquid units. The acid is captured in a silica gel. Other sealed batteries capture a small amount of acid in a fiberglass matte separator. When deeply discharged, the active material in liquid units tends to wash out of the plates and fall onto the floor of the battery. Because there is no liquid to slosh around the plates of a sealed battery, plates can be made thinner and still withstand deep discharges. A gel battery is thus capable of high rate charge and discharges, and offers a great many deep discharge cycles.

### Choose Battery Type of Use

The battery you choose should match the way you use it. The very thick plate liquid batteries can provide years of trouble free service if they are used mostly for weekend trips where most of the recharge is done at dockside using a small charger. That is, low rate discharges and long slow charges. If you stay out for longer periods and use a high output alternator or battery charger on a daily basis to recharge, then golf cart or heavy duty 8D batteries are appropriate. They'll take a daily discharge and accept a fairly high rate of charge so that you won't need to run a genset forever. Expect to replace the units frequently if used extensively.

### Gel Batteries can Charge Fast

The ultimate battery is the gel unit. It will accept a very high rate of discharge and charge. Its charge absorption rate is twice that of a liquid battery . . . with an alternator or battery charger of sufficient size and smart regulation, daily charge can be a one hour affair.

## The Battery Charge Process

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### Introduction

Batteries are complex mechanisms that can even fool the experts at times, so it comes as no surprise that non–technical people have a hard time understanding the charge process. Ask a typical crowd of battery users when their batteries are full charged and at least ten answers will surface.

In both *Living on 12 Volts with Ample Power*, and *Wiring 12 Volts for Ample Power* the authors explain that a battery is fully charged when the voltage is about 14.4 Volts and current through the battery has declined to less than 2% of the capacity of the battery in Amp–hours . . . 2 Amps for a 100 Ah battery.

That information is substantially correct, however, a more intuitive feel for the charge process is necessary, not only to under-

stand when the battery is full, but also to know when the battery is not behaving normally. It is the intent of this application note to provide enough information about the charge process so that the average user can judge how well the batteries are charging.

## The Bulk Charge Step

When a charge source is first applied to a well discharged battery, charge current begins to flow, typically at the maximum rate of the charge source. If a true 40 Amp charger is connected to an 8D battery which is completely discharged, about 40 Amps of charge current would flow for some period of time. Because most of the charge is delivered at the maximum charger rate, the first step of the charge cycle is called the bulk charge step. NOTE: During the bulk step, battery voltage will steadily rise.

## The Start of the Absorption Step

At the instant battery voltage has risen to the maximum allowable voltage of the charge source, current through the battery begins to decline. This simultaneous event of reaching maximum voltage and the start of current decline marks the beginning of the absorption step.

For instance, if the 40 Amp charger is set to 14.4 Volts, then when battery voltage has risen to 14.4 Volts, the charger will now hold the voltage constant. Current through the battery will begin to decline. NOTE: The charger, (or alternator), is not limiting the current at this point. The battery is ‘absorbing’ all it can at the voltage setpoint.

## The End of the Absorption Step

The absorption step should continue until current through the battery declines to about 2% of battery capacity in Amp-hours as mentioned above. Without knowing what the current is through the battery, you can’t know when it’s full. Just because that fancy charger, (or inverter/charger), has kicked out to float is no sign that the battery is full . . . *there is no charger on the market that measures battery current!*

It’s a given, then, that you need to measure battery current to know when the battery is full. With a battery current meter, you can discover some very interesting details about the charge process. For instance, you can discover that once the charger voltage limit is reached, battery current begins to decline. If the current decline is rapid, either the batteries are nearly full, or they are NO GOOD! If the current decline is slow, then either the charge source has more output than the batteries can reasonably absorb, or the batteries are NO GOOD! Here’s where Amp-hour instrumentation

is particularly valuable.

Given enough time at the absorption voltage, charge current will decline to a steady-state value, that is, a low current that either stays constant, or declines very little. At the point where charge current has gone as low as it is going to, then the batteries are truly full. While 2% of Ah rating is close, good batteries will reach a steady state current at less than 1% of Ah rating.

## The Float Step

Once a battery is full, a lower voltage should be applied that will maintain the full charge. Depending on the type of battery, (liquid, gel), and the age of the battery, 13.4 – 13.8 Volts is appropriate as a float voltage.

## Temperature Compensation

The voltage given above are good only at 77°F, (25°C). For high temperatures, voltage will be less. It is important to charge batteries with temperature compensation. To learn more about this aspect of charging, refer to page 70 in the revised edition of *Wiring 12 Volts for Ample Power*.

## A Very Common Problem

Your batteries are only four months old. You discharge them until their voltage is less than 11 Volts and then crank up the engine. The alternator brings up the voltage to 14.4 Volts very quickly, but the current begins to decline immediately and in a few minutes is down to a few Amps. You:

- suspect your voltage regulator and immediately call the factory and ask for a replacement to be sent out; OR
- realize that something has happened to the batteries because the alternator and regulator are operating as expected.

## Conditioning Batteries

How do batteries that are only four months old die? Perhaps they weren’t broken in properly; maybe they sat deeply discharged for a few days or more; perhaps they were allowed to self-discharge over the last four months . . . there’s plenty of ways to murder batteries.

All batteries that refuse to accept a charge are not necessarily ready for the scrap heap. Often, a deep discharge followed by a slow charge will recover lost capacity and charge acceptance. For more information, refer to *Wiring 12 Volts for Ample Power*.

# Battery Temperature Compensation

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## Introduction

Performance is not usually economically viable. As many engineers can attest, ‘it’s not performance, stupid, it’s cost’. That is, after all the discussions of why some performance issue is important, the final decision is to go with the least-cost design. Often the least-cost design doesn’t really work too well, but as long as cost is the motivating factor behind a product, performance isn’t offered by anyone who expects to be competitive in the marketplace.

Be that as it may, Ample Power introduced the first alternator

regulator that was temperature compensating in early 1987. The sensors were not very installation friendly, but, once installed, performance was superior to any other regulator.

If temperature compensation is so important, why is it not universally offered? If this were a computer program, we’d tell you to go to the top and start reading again. Temperature compensation is important for battery longevity, particularly for sealed batteries. It isn’t universally available, because Ample Technology is ahead of the competition, and isn’t afraid to produce products that perform, *even if they do cost slightly more*.



## Universal Physics

An interesting phenomenon happens in the physical world. Many 'things double every 10°C.' Before you conclude that this is a hen without lips talking, let's elaborate. If a particular mechanism has a determined failure rate at 25°C, then the failure rate will more than likely double at 35°C. A transistor that has a specific leakage current at 50°C will exhibit twice the leakage at 60°C. A battery that forever accepts 5 Amps of charge current at 14.4 Volts and 77°F, will maintain 10 Amps at the same voltage if the temperature is raised to 95°F.

Now consider this. Power is equal to Volts times Amps. For 14.4 Volts and 5 Amps, power is equal to 72 Watts. If we double the current to 10 Amps, power is equal to 144 Watts. Have you ever noticed the difference in the heat generated by a 75 Watt light bulb versus one of 150 Watts?

## Thermal Run Away

In a typical situation, a vessel or vehicle will have a high capacity alternator and a limited capacity battery bank. During the bulk charge step, the battery can accept most of the alternator current and convert it back to available capacity. Once the battery nears a full charge, excess charge current becomes heat. Small at first, the heat begins to accumulate in the mass of the lead plates. As the heat accumulates, temperature of the battery begins to rise. That means . . . yup!, current through the battery begins to double for every 18°F! But wait . . . that means more power is dissipated in the battery which means more heat is generated, which means more current flows, which means more heat, which means . . . double trouble! If you're lucky you won't be looking at the battery when the caps lift off into outer space with acid following in close formation!

## How Common Is It?

When alternators are small compared to the battery banks being charged, and regulator voltages are typically low because they are designed for starting batteries, thermal run away is not much of a threat. It only becomes a threat when the size of the alternator is larger, and regulator setpoints are higher to achieve a full charge. We know that thermal run away happens from conversations with cruisers who report batteries too hot to touch. We expect more in the future as more high voltage regulators are sold without temperature compensation. Thermal run away may be the reason that

those four month old batteries are no longer any good. It may explain why you only get 3–4 years from a set of batteries; why you add water on a regular basis; why gel batteries don't give you superior service.

## The Thermal Run Away Solution

Prevention of thermal run away is easy. As the battery begins to heat, reduce its terminal voltage. This defeats the doubling effect of charge current. As the voltage goes down, the battery will accept less current. That means less heat buildup. It also means longer battery life and less electrolyte loss.

## The Ample Power Solution

While the Ample Power solution is more costly due to its battery temperature sensor, it works 'like a Swiss watch.' The temperature sensor attaches to the positive post of the battery, typically the hottest point in a battery under charge. As the battery temperature rises, the Ample Power regulator decreases the charge setpoint. The temperature rise may be from daily or seasonal variations, or from the mere fact that the battery is being charged. The net result is a perfect charge.

The following table shows the voltage applied for any given temperature. For intermediate temperatures, extrapolate between the values in the table. (Gel batteries, as well as AGM batteries are slightly different.)

Temperature F/C	Absorption Voltage
122/50	13.80
104/40	13.98
86/30	14.19
77/25	14.34
68/20	14.49
50/10	14.82
32/0	15.24
14/(-10)	15.90
(-4)/(-20)	17.82

While any standard 2-step regulator can charge batteries, only an Ample Power temperature compensated multi-step regulator can provide a fast, full charge and also extract maximum battery life. For a nominal difference in price, you can save many times more in ultimate battery cost . . . not to mention peace of mind.

## Electrical System Alarms

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An alarm may save your life. If your electrical system is on the verge of collapse, wouldn't you want to know? The Energy Monitor II provides alarms for high and low battery voltage, high battery temperature, and both 50% and 80% depth of discharge. You can also program an alarm to occur at any depth of discharge.

All alarms can be individually enable or disabled.

A high voltage or high temperature alarm indicates a runaway regulator. A low voltage or low capacity alarm indicates a need to charge. Since the voltage and temperature alarms are programmable, you can set them at meaningful values . . . 12.6 Volts is low for a starter battery, but obviously not for a house bank. Don't let a disaster sneak up on you!

Amps	Distance – Feet						
	10	15	20	25	30	40	50
	Wire Gauge						
5	18	16	14	12	12	10	10
10	14	12	10	10	10	8	6
15	12	10	10	8	8	6	6
20	10	10	8	6	6	6	4
25	10	8	6	6	6	4	4
30	10	8	6	6	4	4	2
40	8	6	6	4	4	2	2
50	6	6	4	4	2	2	1
60	6	4	4	2	2	1	0
70	6	4	2	2	1	0	2/0
80	6	4	2	2	1	0	3/0
90	4	2	2	1	0	2/0	3/0
100	4	2	2	1	0	2/0	3/0
120	4	2	1	0	2/0	3/0	4/0
140	2	2	0	2/0	2/0	4/0	4/0
160	2	1	0	2/0	3/0	4/0	4/0+4
180	2	1	2/0	3/0	3/0	4/0+10	4/0+2
200	2	0	2/0	3/0	4/0	4/0+4	4/0+0

AWG/MM Size Conversion				
AWG	MM	–	AWG	MM
26	.12826		11	4.156
25	.162		10	6.271
24	.205		9	6.626
23	.255		8	8.350
22	.322		7	10.544
21	.411		6	13.292
20	.516		5	16.755
19	.653		4	21.137
18	.823		3	26.653
17	1.039		2	33.606
16	1.308		1	42.384
15	1.652		0	53.454
14	2.088		00	67.399
13	2.629		000	84.004
12	3.302		0000	104.091

## Wire Gauges

### Observe Proper Wire Size

The most important wiring practice is to observe proper wire size. Failure to use adequate size can result in fire. Even if fire doesn't result, wires that are too small will cause marginal performance of electrical equipment.

### Using the Table

The table shows the wire size required for a 3% voltage drop in

12 Volt circuits. To use the table, first calculate the total length of the wire from the source to the device and back again. Next, determine the amount of current in the wire. The wire gauge is found at the intersection of Amps and Feet. In most load circuits, a 3% drop is quite acceptable. In charging circuits it often pays to have less of a drop. Always use one size bigger if practical.

## Evaluating AC Power Generation Methods

### Introduction

Power on demand requires storage of some sort. DC energy can be stored in batteries. How is AC stored?

Storing AC directly isn't easy . . . a large flywheel would be necessary. Indirectly, AC can be stored as fuel to run an engine when AC is needed.

Starting and stopping an engine to generate AC on-demand is not the kind of treatment engines thrive on. Neither is running an engine for long periods with little or no load. Engines prefer to operate from 50 to 85% or their rated horsepower.

Short duration loads such as microwave ovens, coffeemakers, toasters, hair dryers and other such devices can be operated from a DC-AC inverter that gets stored energy from a battery bank.

When is an inverter sufficient for all AC loads, and when should an AC generator be considered? To answer these questions, some background information is necessary.

### AC Start-Up Loads

Many AC loads require an in-rush of current to get started. For instance, a motor that will run on 1000 Watts of energy may take 5000-7000 Watts to get started. This starting surge will depend

on the motor used, as well as the device being driven by the motor. Some air conditioning compressors require the motor to start the compressor under full load, requiring a healthy surge rating from the AC source, be it a generator or an inverter.

### The AC Generator

AC generators come in all sizes and models are available to run on gasoline, natural gas, propane, and diesel. Small gasoline operated units can be amazingly inexpensive. We'll call these generators, gas-gens. Such units are found as emergency power sources, and may be used by contractors for light duty needs as construction sites. The gasoline engine on gas-gens is not designed to operate for many hours, and may be fickle to operate soon after it's new. Because gas-gens are built for light weight, capability to start heavy loads is limited . . . perhaps as low as 1.2 times its steady-state capability.

Natural gas and propane engines are first cousins of the gas-gen, although typically higher quality engines are used, and they may have larger flywheels to accommodate higher surge demands. They are generally easier to start, and burn cleaner so that spark plug maintenance is lessened.

Diesel fuel is the safest of all fuels to store and won't lose it

volatility over time as does gasoline. Diesel engines are built heavier and will run longer than other engines. They are more efficient fuel-wise. Offsetting these advantages is higher initial cost.

Many people have a general prejudice regarding diesels because they aren't as familiar as the engine under the hood of most cars. And, diesel does have a smell that many people find objectionable. This is made worse by the fact that small diesel leaks are more often tolerated because the hazard of explosion isn't immediate.

Besides more rotating mass in a diesel engine that can supply surge power to start AC loads, diesel engines also have more torque for an equivalent horse power than do gasoline of gas engines.

Except for very rare intermittent use, the gas-gen isn't a good choice. If it's only to be used in an emergency, then fresh fuel must be available as well. This creates a storage and recycling problem.

Choosing between a propane or natural gas unit and a diesel unit may hinge on fuel storage. If there is already a supply of propane available, and propane costs are reasonable, then a propane fired engine makes some sense. Propane engines will definitely start better in sub-zero weather than a typical diesel, even one with glow plugs.

Diesel is the logical choice for many stationary applications, as well as in vessels and vehicles where economical operation and safety are major considerations.

## The DC-AC Inverter

The DC-AC inverter is an electronic way to produce AC. Today's inverters can be efficient, and most of them have surge capacities that are over twice their steady-state ratings. This means that inverters can start much larger AC loads than they can run indefinitely.

Naturally, any long term AC load requires a battery bank that may not be reasonable in size or cost, so the inverter is generally limited in application to available battery power.

## The Engine/Alternator DC System

One way to provide DC power to the inverter is to recharge the battery bank while the inverter is operating. Ample Power has made the Genie since 1989 with this purpose in mind. Presently sold in a 12-volt unit capable of a sustained 150 Amps, a larger unit is now available. The Genie-4024 unit is able to provide 175 Amps continuously for a 24-volt system. As such, it can supply over 4000 Watts of continuous AC through an appropriate DC-AC inverter such as the TRACE SW4024 sinewave inverter.

## Pattern of Power Usage

At this point, AC can be obtained with an engine/generator, an inverter/battery system, or with an engine/alternator combined with a battery system. Depending on your pattern of AC usage, one of these methods will be most appropriate.

If your need for AC is intermittent, and no loads run for long periods, then an inverter makes the most sense. There needs to be some way to charge batteries, however. If you're not fortunate to live by a fast flowing stream, near a wind tunnel, or in a place the sun shines abundantly, then an engine of some sort is probably

also required.

If your needs for AC are almost constant, then an AC generator makes sense. The generator may run continuously except for some well planned intervals for maintenance. This need for constant AC might result from operating a remote business with a large power demand such as air conditioning.

If the need for AC can be satisfied from an inverter, such as is the case for most vessels, vehicles, and remote homes, and the need for AC power is typically not for long periods, then the most economical device to deliver power to the inverter for extended periods will be the engine/alternator system.

## System Tradeoffs

Assuming that there are batteries and an inverter in the system, what are some of the tradeoffs in choosing between the engine/alternator and the engine/generator?

The engine/generator can be used during the time that demand for AC is heavy and continuous. At the same time, batteries can be charged through the inverter/charger, or a separate battery charger. One drawback of this setup is the limited surge capacity available from the generator. How big a generator is really necessary to start the AC load? Getting realistic surge ratings for generators is not always easy, so they are often specified with more power than actually needed.

A second drawback of the system is the inefficiency of battery charging in general, and the additional losses incurred with the AC operated charger. It takes a large generator to drive most chargers at their current limit. Considering that the AC generator is loaded with another appliance, charger performance will not be as high as most expect it to be unless the generator is massively oversized. An oversized generator is not an elegant solution to the power equation.

With high capacity inverters, and high capacity battery banks, the engine/alternator is a good choice for extended engine charging and AC generation. Load distribution is automatic. That is, the alternator can run at its maximum rating; the inverter draws what it needs to power the load, and the rest of the alternator output is battery charge current.

Surge specifications for inverters can be quite accurate, and the surge capability of the system is predominately that of the inverter assuming a reasonable battery bank. That means an inverter can be specified that is not grossly overrated for the AC loads.

The engine/alternator doesn't need to be rated for the AC start-up requirements . . . if necessary, the inverter can 'dip' into the batteries for surge power. An engine/alternator system can be sized for the average AC load resulting in less engine horsepower, less noise, and lower operating costs.

Since the engine/alternator is normally used to charge batteries and/or power longer term AC loads, it is operating under a greater load when it does run compared to an AC generator. This type of operation is easier on the engine, and also results in less total fuel consumption.

What is the drawback to the engine/alternator? The battery bank will be larger than a system that makes minimal use of DC power in favor of long hours of AC generator time. In many situations, however, a large battery bank is required for DC storage anyway.

Inverter reliability also is a factor in system resiliency. With an AC generator, if the inverter/charger fails, then there is still AC available from the generator. You may not be able to charge batteries, however.

With the engine/alternator system, an inverter failure eliminates AC power, but not battery charging capability. An alternator failure knocks out battery charging, and eventually AC power when the batteries are discharged. Alternators are readily available in most areas, and just about anyone can change out an alternator . . . this failure is more easily fixed than either a failed inverter or an AC winding for the generator. It's also easy to operate two alternators from the engine, so that a spare is already running.

While no clear cut answer can be given to the reliability/resiliency issue, the engine/alternator with an inverter for AC needs has much merit, especially when DC is the primary power and AC needs are intermittent. When AC loads are continuous, but moderate, the engine/alternator may be the best choice, particularly if battery charging is also done by renewable resources such as solar and wind.

One way to illuminate the argument further is to rate both AC and DC power consumption. If DC power needs prevail, then the engine/alternator is favored. If AC power needs are greatest, then the issue is how many engine hours are expected on a yearly basis from either the AC generator or the engine/alternator. The latter will be more economical to operate, and will charge batter-

ies faster, so expect fewer hours unless AC needs are significantly higher than DC needs.

## What about the Main Engine

Vessels and vehicles have a main engine that can also supply electrical power to charge batteries. Typically, it is difficult to get AC power from the main engine because the RPM varies. An AC generator needs to be rotated at a fixed RPM. The DC alternator can operate over a wide RPM range, although available power is dependent on RPM and may be very little at low RPM.

Where there is a main engine, then the auxiliary engine/alternator makes good sense. Both the main and auxiliary can be equipped with the same alternator. Not only does this provide redundancy, but it keeps system engineering down. Implementing two identical systems is also less costly than two different systems.

With both main and auxiliary systems producing DC for battery charging and inverter use, the same amount of AC can be available at all times. Users will find this more friendly since there is only one set of limitations to live with . . . maximum inverter load.

## And the Winner Is You

Choices can sometimes create anxiety . . . fear of making a bad choice strikes everyone at some time. However, a choice implies that one selection is better than another for any given set of circumstances. Who doesn't want to choose the best? We hope the information presented here will let you make the best choice.

# Emon/Next/Elim System

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## Drawing AT9610281

Drawing AT9610281 shows a system with the Energy Monitor, Smart Next Step Regulator and Eliminator. This system is suggested for most vessels, especially power boats. Consider also the newer Smart Alternator Regulator, V3 as an upgrade for the Next Step Regulator.

## Eliminator

In the EMON/NEXT/ELIM system, the starter bank is maintained with an Eliminator. It continuously looks at the voltage of the house bank and whenever there is enough voltage to charge the starter bank, the Eliminator siphons some of the charge current to the starter bank. Any charge source can be charging the house bank . . . the alternator, solar panel, wind generator, or charger. They may even be charging all at once!

Unlike the other systems, where only the alternator can charge the starter bank via the parallel solenoid, any charge source in the EMON/NEXT/ELIM system can charge the starter bank. Furthermore, the Eliminator senses the temperature of the starter bank and compensates the voltage applied to the starter bank.

The Next Step Regulator can also be integrated with the Energy Monitor II. A signal is provided by the EMON II, telling the Next Step to stay in the absorption step until the batteries are full. The

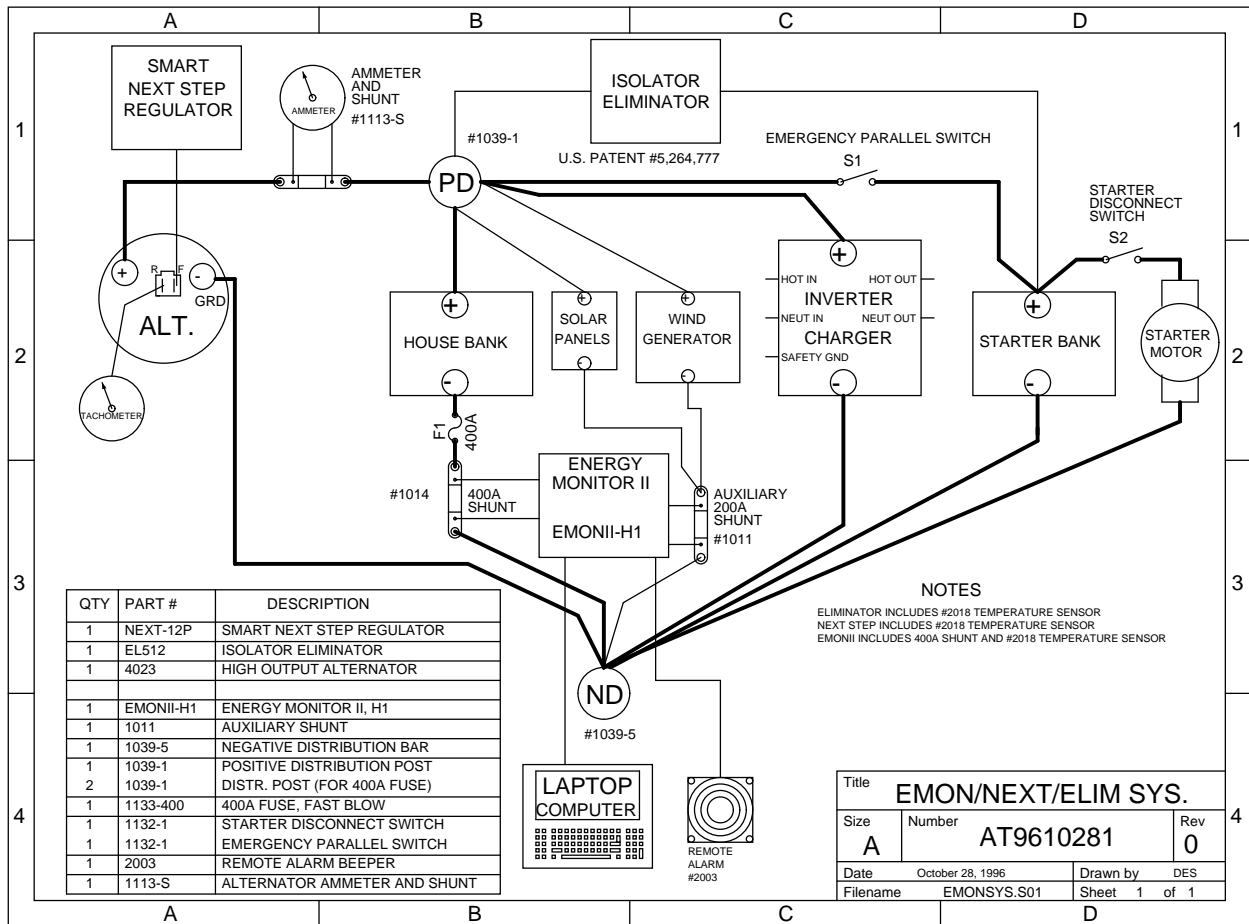
EMON II knows present battery state of charge and battery temperature.

## Auxiliary Shunt

Current from the solar panels and the wind generator is measured using the auxiliary shunt. The Amp-hours that these devices produce are accumulated by the Energy Monitor II in non-volatile memory. If knowing solar and wind generator production isn't necessary, the EMON II, H1A allows an Alternator Current Sensor and shunt to be used instead. The Alternator Current Sensor can share the same shunt that is shown connected to the ammeter. The Alternator Current Sensor translates the Amps signal into a voltage that is referenced to ground. A 0.05 Volt signal across the shunt is converted to a 2.00 Volt signal at the output of the sensor. This voltage is measured by the H1A and displayed as alternator Amps.

## Pamper the Starter Battery

While a system with the Eliminator cost slightly more than the Next Step Regulator with a parallel solenoid, the starter battery is treated better since it doesn't have to see the same high absorption voltage as the house bank. Temperature sensing also improves the care given the starter bank. While starter batteries are usually inexpensive, they may fail at a most inopportune time.



# Next Step System

## Drawing AT9610287

The Next Step System is our most economical solution to the power equation. Refer to drawing AT9610287. The Next Step system offers a fast full charge with an alternator of your choice, regulation for solar and wind chargers, and complete monitoring of a house bank and a starter bank.

### Parallel Solenoid

The Next Step Regulator, shown in the top left of the drawing, controls the alternator and the parallel solenoid which connects the house and starter banks together during the charge process. The Next Step drives the parallel solenoid when it finds that the house bank voltage has risen above 12.9/25.8 Volts. This voltage indicates that the house bank is charging. The solenoid is opened should the house bank voltage fall below 12.8/25.6 Volts.

NOTE: The SAR-V3 regulator operates the solenoid even when the engine isn't running, so by using it instead of the Next Step Regulator, charge distribution for the AC charger will also be accomplished.

### Temperature Sensing

The Next Step Regulator senses the temperature of the house bank and corrects the charge voltage accordingly. Note also that the Next Step Regulator is connected to the Energy Monitor II, H1 which holds the Next in the absorption mode until the house bank is full. The full criterion is programmed on the EMON II. To

be full, the battery voltage must reach the programmed voltage value and the current through the battery must decline below the programmed current value.

### Fuse Protection

The house bank is protected by a 400 Amp fuse. A common problem is a battery short caused by the output wire from the alternator loosening from the alternator and shorting the battery. The 400A fuse protects such a drastic fault, and will prevent an electrical system fire. Operating a large house bank without a fuse is an open invitation to fire at sea with all of its consequences including loss of life.

### Amps Shunt

The Energy Monitor II, H1 completely monitors the house bank, reporting Amp-hours remaining as well as the more familiar Volts and Amps. Current through the battery is measured via the 400 Amp shunt in series with the negative side of the battery.

### Remote Alarms

Shown connected to the EMON II is a remote alarm. While the EMON II includes an internal alarm, it may not have the volume to attract the attention of a helmsman. Alarms from the EMON II are individually enabled or disabled, and the setpoints are programmable.

Not shown are alarms which can be connected to the Next Step Regulator. This regulator has no an internal alarm, but can drive

external alarms to report abnormal conditions.

The importance of alarms can't be overstated. No one has the time to monitor all meters on a timely basis to prevent any abnormal condition from persisting. Alarms can prevent 'sudden failures'. That is, an alarm can alert you to a fault before the whole electrical system collapses . . . before an undetected condition kills the batteries from over or undercharge.

### Laptop PC

Also shown connected to the Energy Monitor II is a laptop computer. With the optional PC software, electrical system data can be displayed on the computer screen and/or logged to disk. What is displayed and what is logged are independent. That is, you can look at one set of information, while logging another set. The laptop computer can serve as a second display 'head' for the electrical system. By logging data over time, a profile of energy usage and replenishment can be developed.

### Simple Battery Switching

Note the two switches, S1 and S2 on the diagram. S1 allows the house and starter battery to be connected which will allow engine starting from the house bank if necessary. S2 is used to disconnect the starter battery from the starter motor in the event that the starter solenoid sticks shut and continues to drive the motor. S2 can also be used as a security switch, preventing unauthorized engine starting.

### Alternator Current

Also shown on AT9610287 is an ammeter and shunt that shows the alternator current. Typical alternator ammeters use a bi-metal

strip that deflects the meter according to the temperature of the bi-metal piece. These are economical, but rarely rated above 60 Amps. They also require that heavy wire run to the ammeter and back to the battery. By using a shunt, large wire is only required to and from the shunt which can be located close to the alternator and batteries. Two small wires connect the shunt to the meter.

### Eliminator

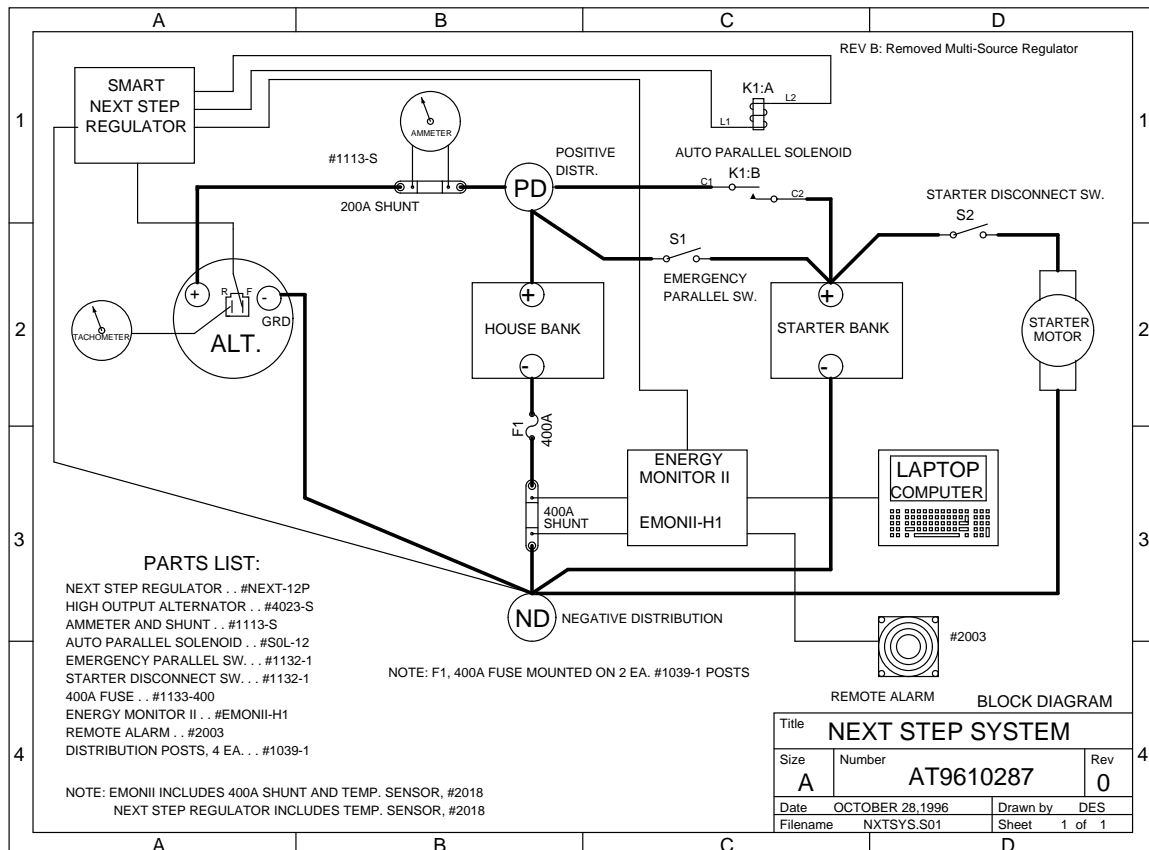
As mentioned, the Next Step System offers high performance, yet is economical. The starter battery is forced to accept the charge regimen of the house bank due to direct parallel connection, but this is often acceptable. For ultimate performance, the Eliminator can be used in place of the parallel solenoid if desired. The solenoid does have the advantage, however, of permitting loads to be drawn from the starter battery when the alternator is charging. For RV's, including fifth-wheel rigs, this system is recommended, since the alternative of re-wiring all loads to the house bank isn't attractive.

### Fifth Wheel Compatible

Note that when the fifth-wheel tow vehicle is disconnected, the Next Step Regulator must sense the starter battery, instead of the house battery. This is done automatically by installing a simple relay in the system.

### Halogen Lamp Protection

The Next Step Regulator has an input that prevents high absorption voltages whenever headlights (or other halogen lights) are on. This will prevent premature failure of the lights. For RV's, and many marine applications, the Next Step System is a logical choice.



# Multi-Hull System

## Two House Banks – AT9610283

Drawing AT9610283 shows a two house bank system. A two house bank system is less reliable than a single house bank system, and uses the batteries less efficiently. The drawing is called the Multi-Hull System, because one can argue that a two house bank system is appropriate for multi-hulls in the interest of maintaining balance if the batteries must be mounted in the two hulls.

### Two Alternator Regulators

In this system, both engine/alternators are completely independent, each with a Smart Next Step Regulator. An Energy Monitor

II, H2 monitors the two house banks.

### Tachometer Problems

Shown on the diagram are tachometers connected to the alternators. If the battery selector switch is placed in the "both" position, then the house banks will be charged in parallel by both alternators. As soon as the batteries are full enough to allow one alternator to carry the load, the other alternator will quit charging. The tachometer attached to the idle alternator will also quit operating.

To avoid an idle alternator and the loss of the tach signal, refer to drawing AT9601284 and the discussion below.

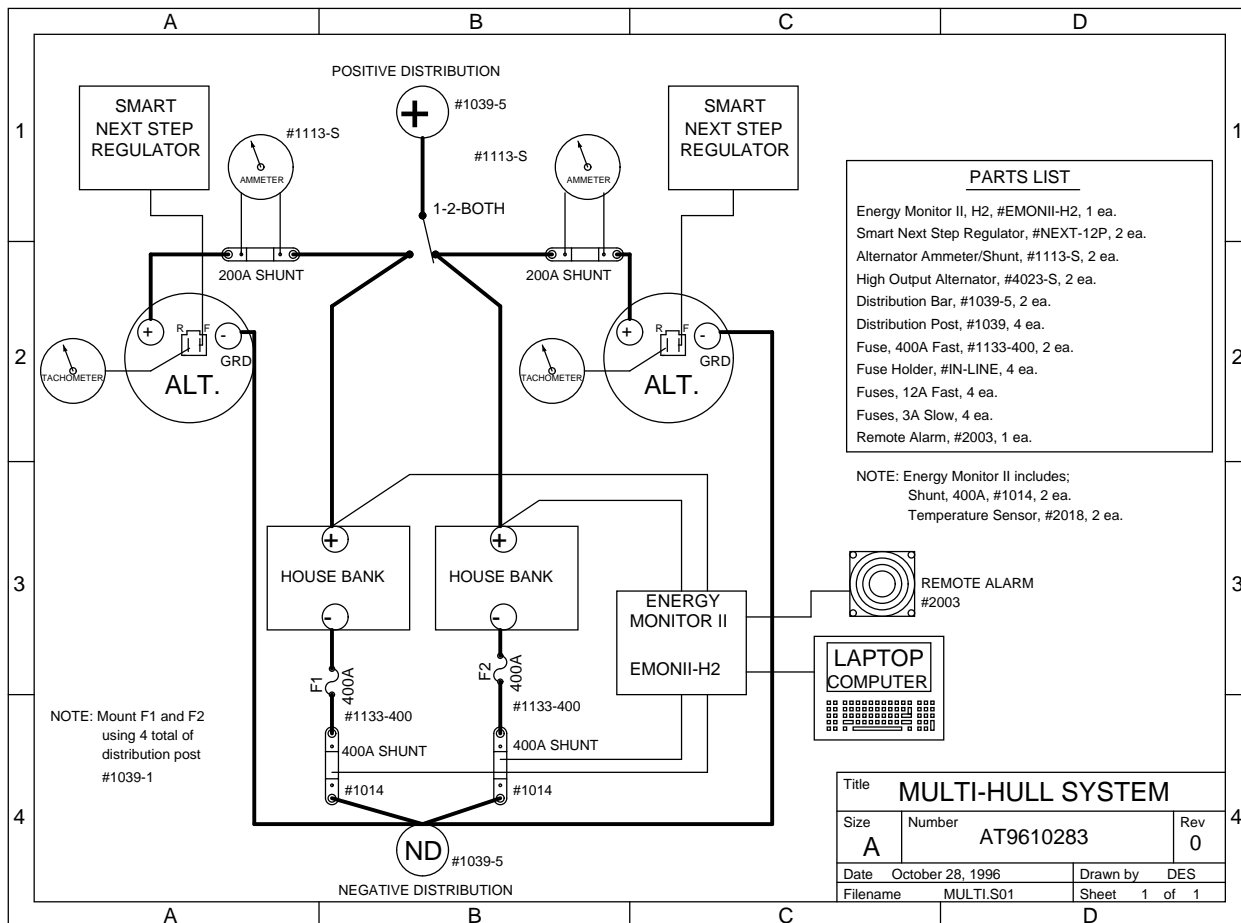
# Preferred Multi-Hull System

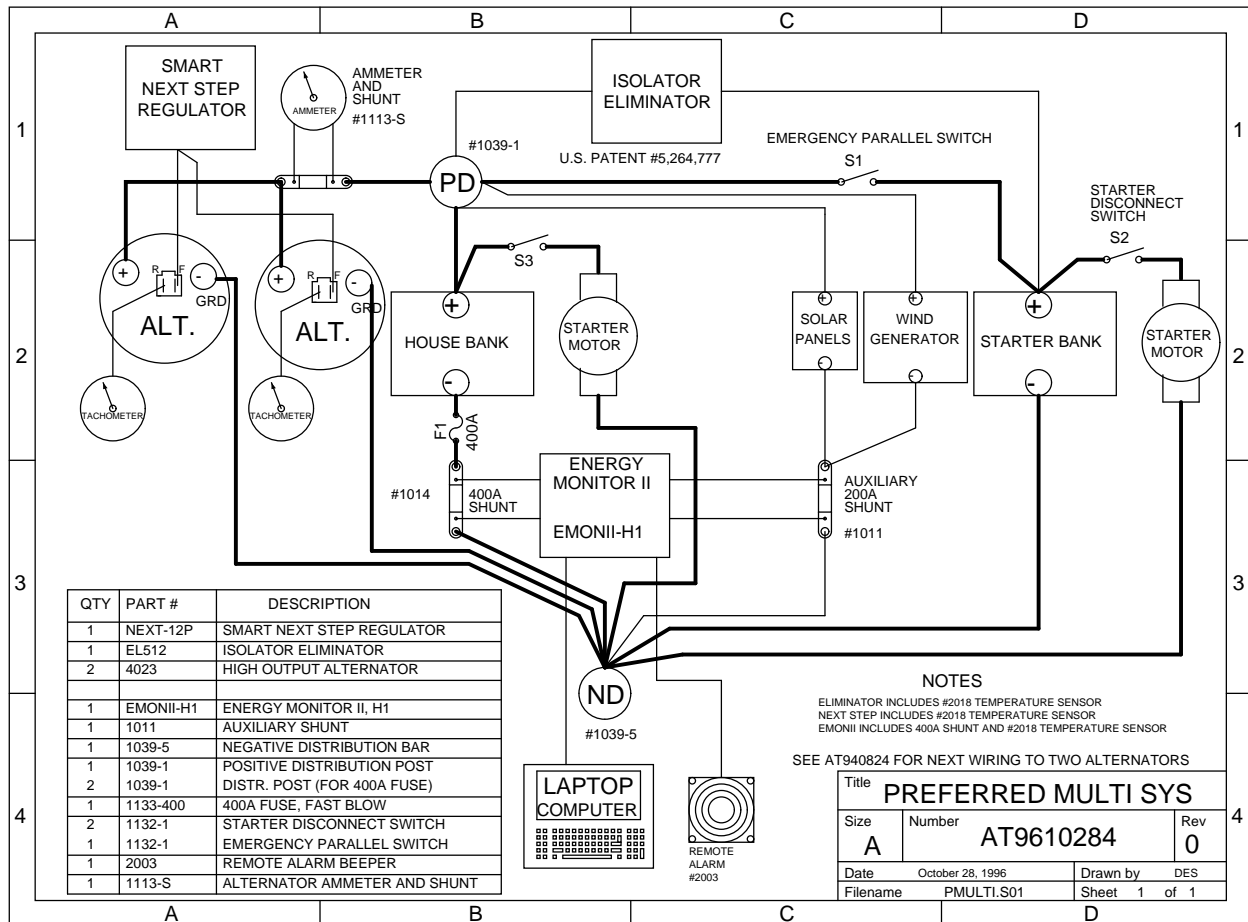
## Single House Bank – AT9610284

Drawing AT9610284 is the preferred system for multi-hulls. The house bank is located in one hull, and the starter bank in the other. (Many multi-hulls allow both banks to be mounted in the aft center. Refer to AT9610285 and the discussion of Power Boat Systems below for this alternative.) One engine is started from the starter bank, while the second engine is started from the house

bank.

As shown, both alternators are wired to charge the house bank. An Eliminator is used to charge the starter bank from any of the charge sources shown. Alternately, a parallel solenoid driven from the Next Step Regulator can be used to charge the starter battery from the alternator.





## Killing Batteries

There are many ways to kill batteries ... even very expensive batteries. Below are a few ways to treat batteries ... **NOT!**

- Overcharge the battery by applying a voltage above 13.8 Volts for extended period
- Undercharge the battery by never charging it beyond 13.8 Volts.
- Discharge the battery and leave it that way for a few days or weeks.
- Let the battery sit unattended without charging for 3 weeks or longer.
- Repeatedly discharge the battery beyond the optimum 50%.
- Slosh the battery around when it is deeply discharged.
- Boil enough electrolyte from the battery that the plates are exposed to air.
- Periodically add more acid, or unpure water.
- Use a ferroresonant charger in a liveaboard situation.
- Sock the battery with a high output alternator that produces more than 40% of the Ah capacity of the battery.
- Mount the battery where it regularly gets above 90° F.
- Charge it hot until you can't even touch the case anymore.
- Use a big inverter on a small battery and run the inverter until it cuts out from low voltage.
- Freeze the battery in a discharged state.
- Use a starter battery in a deep cycle application.

## Battery Equalization

Liquid electrolyte batteries that have been floated at a low voltage for long periods need to be periodically equalized. Equalization is the process that equalizes the specific gravity in all the cells. Basically, equalization amounts to a controlled overcharge.

### Current Limiting Required

To equalize a battery, you need a charge source which can be current limited, such as the Smart Alternator Regulator. Set the current limit at 3-7% of the Amp-hour rating of the battery. That

is, for a 100 Amp-hour battery set the current limit at 3-7 Amps. Apply that current to the battery for about 4 hours, or until the battery voltage rises to 16.2 Volts. The Smart Alternator can equalize batteries automatically.

### Turn Off Voltage Sensitive Loads

Since the battery voltage rises to 16.2 Volts, be sure to turn off all loads which are voltage sensitive. Battery temperature should also be observed during the process to prevent overheating.



# Power Boat Systems

## Twin Engines – AT9610285

Drawing AT9610285 shows the preferred system for twin engine power boats and multi-hull vessels when the battery banks can be located midway between the engines. Note that both alternators are regulated by a single Next Step Alternator Regulator. The alternators are connected in parallel and charge the house bank.

### Single Starter Bank

Both engines are started by a single starter bank. That bank is charged with an Eliminator which siphons charge current from any source that is charging the house bank. The Eliminator is especially popular with boats in charter programs since it reduces the amount of systems that need tending by unskilled operators.

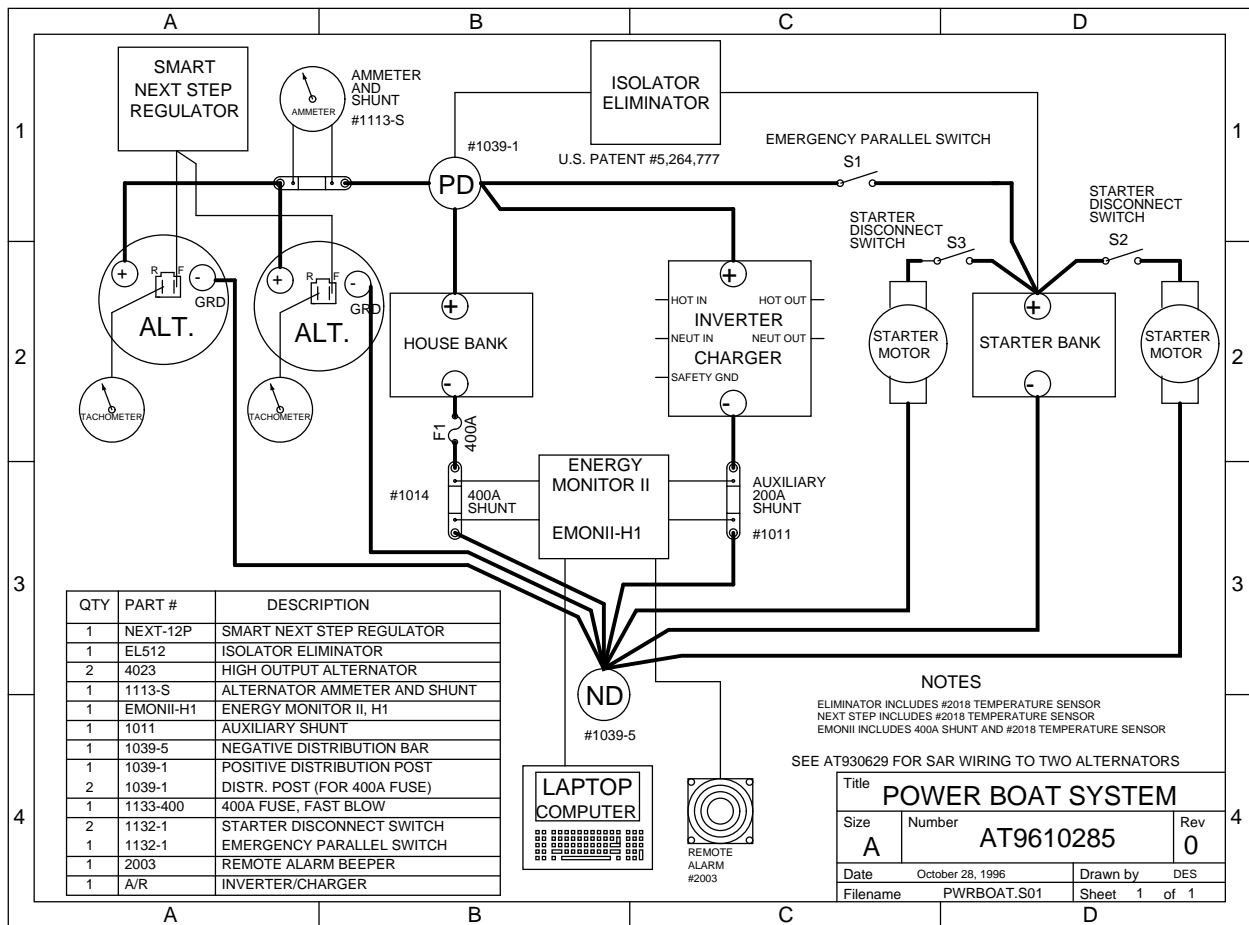
Engines can be started from the house bank by first closing switch S1, the emergency parallel switch.

### Instrumentation

The system is monitored with an Energy Monitor II, H1. The system can be any mix of 12 and 24 Volts, with power for the EMON II drawn from either.

### Auxiliary Shunt

Inverter/charger draw and charge current is measured by the auxiliary shunt in series with the negative side of the inverter/charger. A 400 or 600 Amp shunt can be used by programming the proper scale factor in the Energy Monitor II.



# Two Engines . . . . One Regulator

## Drawing AT940824

Drawing AT940824 shows the circuit for regulating two alternators with one Next Step Regulator when the alternators are mounted on separate engines. In this circumstance, it is expected that only one engine will be running some of the time. It isn't good practice to apply field voltage to an alternator that isn't spinning since it will heat up and may cause field winding deterioration.

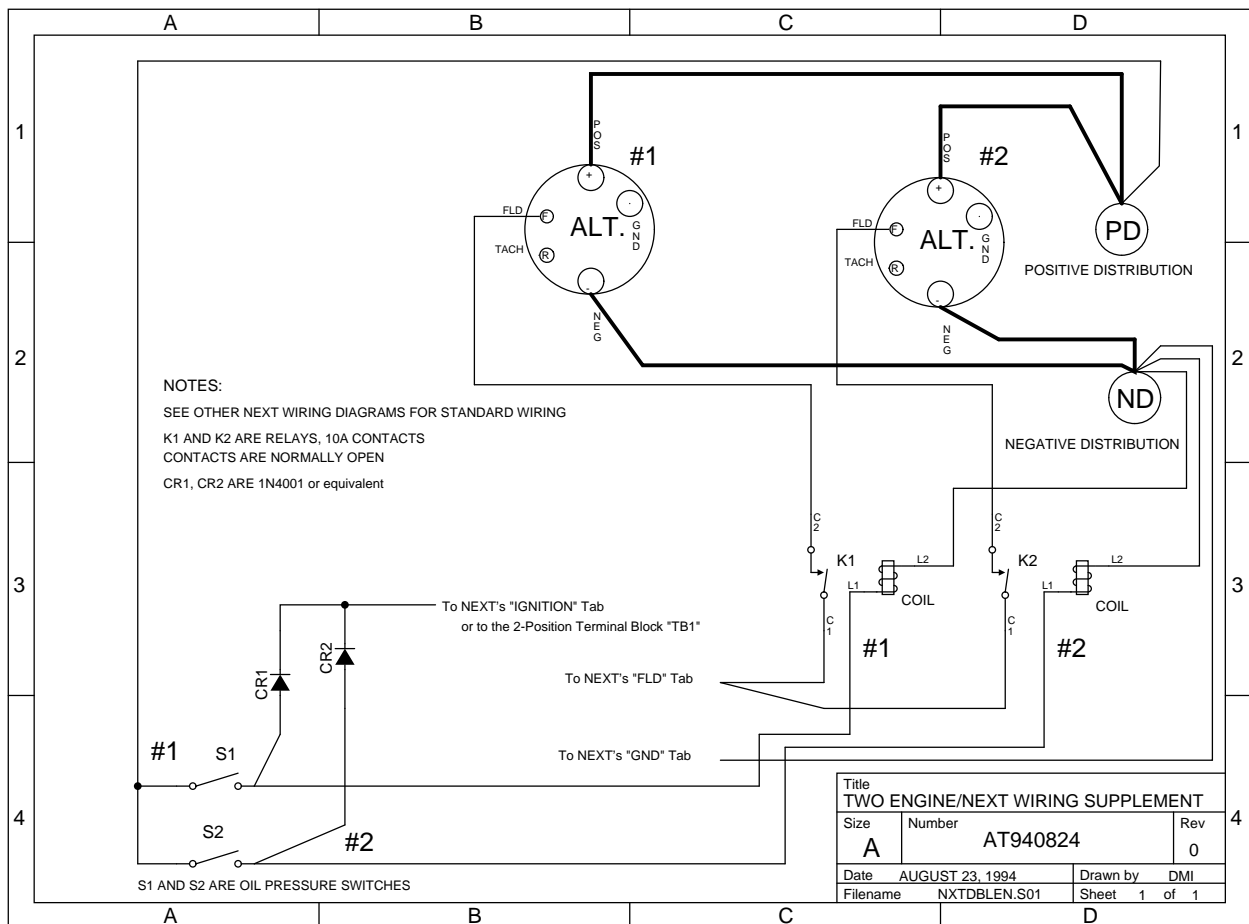
### Oil Pressure Switches

In the drawing, two oil pressure switches are used that are acti-

vated when the engine is running. The Next Step Regulator is turned on when either engine runs through the diodes CR1, or CR2. The oil pressure switches also activate relays, K1 or K2. When a relay is activated, it switches field voltage to the corresponding alternator.

### Alternators in Parallel

The alternator outputs are connected in parallel at the positive distribution terminal. If desired, a shunt can be placed in the output lead of each alternator so that there is an indication of output from each. The two alternators can also be connected together at the input side of a shunt where only one ammeter is used.



# Hydrometers and Specific Gravity

## Hydrometer Measures Weight

A hydrometer measures the specific gravity, SG, of electrolyte, that is, how much the electrolyte weighs compared to pure water. The heavier the electrolyte, the higher the state of charge. There are several reasons why SG readings are misinterpreted. First, if you don't know the SG of the electrolyte when it was poured into the battery, then you have no way of knowing what the SG should be for a full charge. Even if you know the original SG, chances are good that your hydrometer is not very accurate. Even if your hydrometer were accurate, you'd still have to correct for temper-

ature of the electrolyte. One last caveat is the fact that the battery must have been rested before any SG reading is reliable. Resting a battery means no charge or discharge for 24 hours preceding the SG sample.

## Battery Health Determination

Despite problems obtaining valid state of charge measurements, the hydrometer is easily used to determine battery health. In a healthy battery all cells will have about the same SG. If there are small cell to cell variations, then an equalization charge is needed. A typical SG is 1.265. That is the electrolyte weighs 1.265 times

as much as water. Usually the decimal point is dropped and the SG is referred to as 1265 points. Cell to cell differences of up

to 30 points can be corrected by equalization. A difference of 50 points or more from cell to cell indicate a bad battery.

## Retrofitting An Existing System

### Existing 1–2–Both Switch

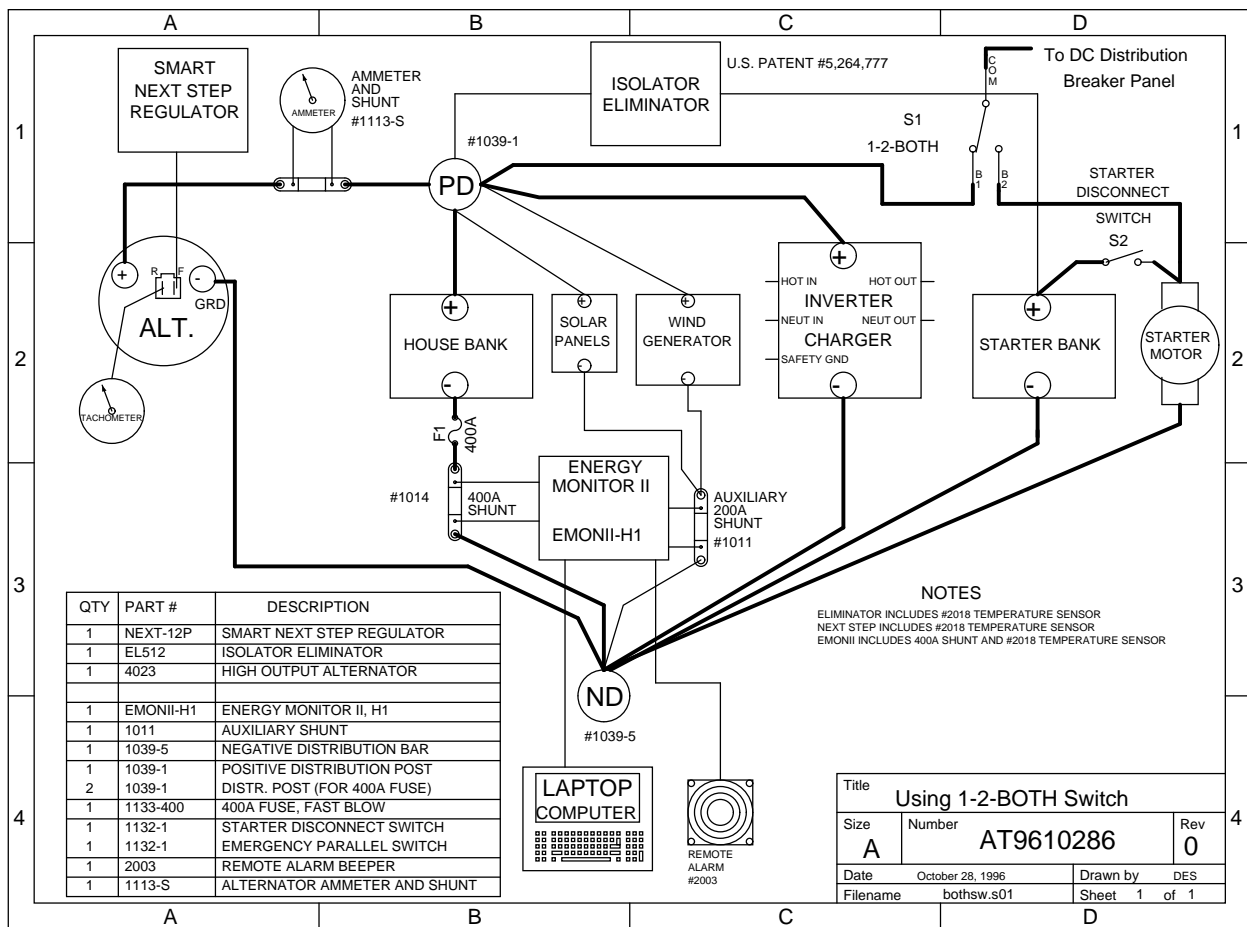
Drawing AT9610286 shows the circuit for retrofitting a system using an existing battery selector switch. The switch, S1 is now used as an emergency parallel switch, and should be left in the #1 position which selects the house bank. When needed, the switch can be placed in the both position to start the engine from the house bank. If desired, S2 can be turned off to prevent connecting the starter battery to DC distribution. S1 can also be turned off to disconnect the DC breaker panel.

### Alternator Wiring

Note that the alternator is re-wired directly to the house bank. This can be done as shown, or the wire from the alternator can be connected at the switch.

### Starter Battery Wiring

The starter is wired directly to the starter battery, as shown. A separate disconnect switch may be used as an emergency shut-off, or as a security device.



## Remote Solar System

### Simplicity – AT9312111

Drawing AT9312111 shows how simply a remote solar system can be assembled using the Energy Monitor II, H1. Solar panels charge the house bank under control of the EMON II. The solar panels are controlled by a relay that connects and disconnects the solar panels according to limits programmed into the EMON II.

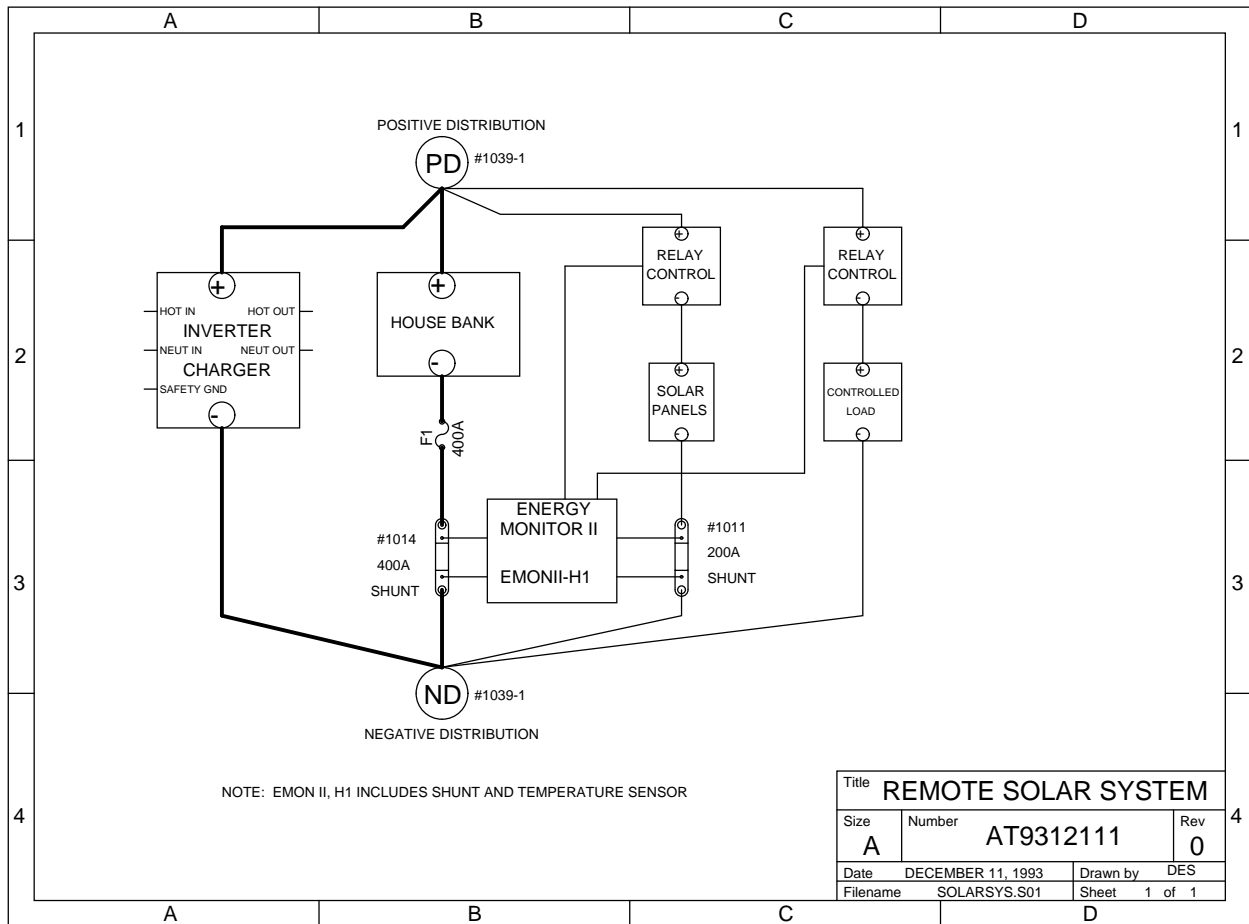
### Load Control

The EMON II also controls load devices, disconnecting and connecting them at programmed capacity limits. For instance, an

irrigation pump can be turned off at a selected low capacity remaining and back on again when the battery capacity returns to a selected value.

### Temperature Compensation

Since the EMON II is fully programmable, and includes temperature compensation for voltage and battery capacity, a superior control system results. Normal solar panels controllers and load disconnect devices sense voltage only, not capacity. They normally don't have temperature compensation either.



## AC Wiring Example

### Introduction

Drawing AT9610291 shows wiring for a relatively simple, (and imaginary) electrical system. Power is available from either an on-board generator of about 6500 Watts, or from a 30 Amp shore power connection. When neither of those sources are available, AC power can be provided by an inverter.

### Schematic Walk Through

Ship/shore power selection is done with a two-position switch. Since the generator is rated for 54 Amps, the switch must be rated at least for 54 Amps . . . 60 Amps is a standard rating. Immediately following the ship/shore switch is a main breaker, also rated for 60 Amps.

Remember, breakers are present to protect wires from burning in the event of a short circuit. If the circuit is protected with a 60 Amp breaker, wires following the breaker must be capable of carrying the 60 Amps. Refer to the wire gauge tables presented earlier to determine proper wires sizes.

The power is split after it leaves the main breaker to feed the inverter/charger circuit, and a distribution panel serving such loads as a jacuzzi.

Output from the inverter goes to another set of breakers which distribute power to the water heater and other appliances.

Note that the neutral and safety wires are terminated on separate buses which serve to collect and connect green and white wires

from on-board appliances. These wires should never be internally connected.

### Inverter Transfer Switch

Most inverter/charger combinations have an internal relay that either switches AC power through the inverter, or switches inverter power onto the output wires. The relay is typically rated at 30 Amps . . . most inverters include an internal circuit breaker so that the transfer relay won't be overloaded.

### Inverter Breakers

Circuit Breaker 2, and CB3 are used in the inverter circuits. CB2 permits all power going to the inverter and beyond to be turned off . . . sort of a 'inverter main breaker'. Opening CB2, of course, shuts off power to the charger circuits inside the inverter/charger.

On the output side of the inverter/charger is CB3. It permits all the circuits beyond the inverter/charger to be shut off at once. This is useful if you're going to leave for awhile and don't want a utility power failure to cause the inverter to kick in and try to drive the water heater.

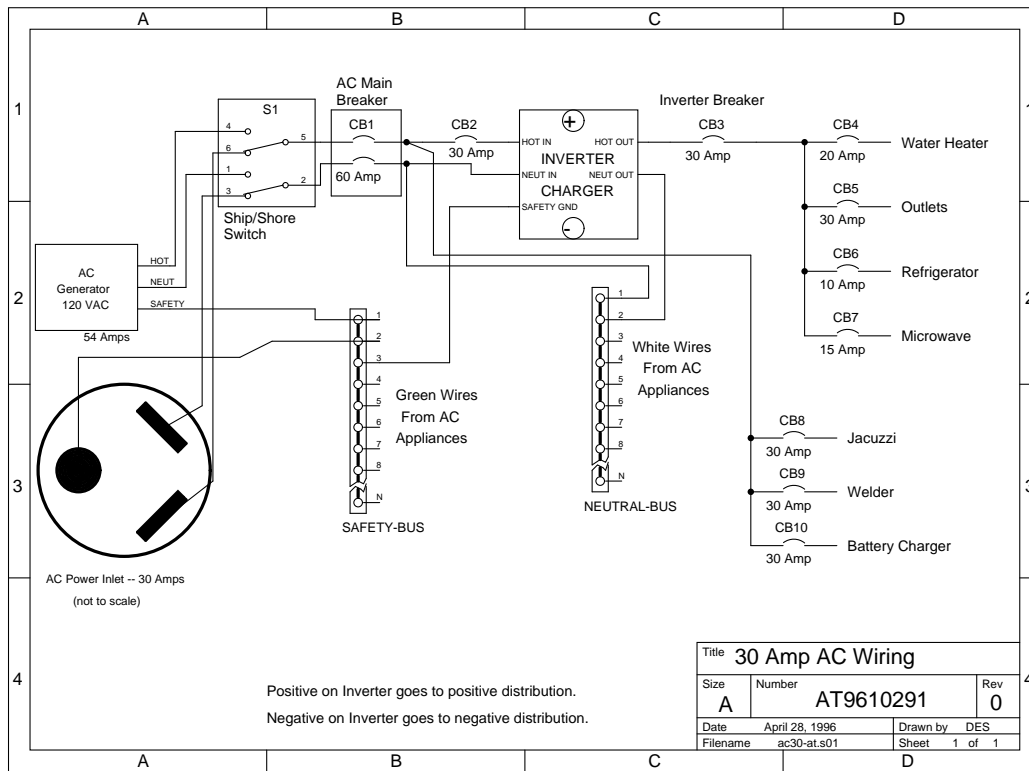
Why is the water heater wired to the inverter anyway? While not normally run from the inverter, it's very possible to run a water heater from an inverter if the batteries are also being charged by a high output alternator.

### It's Your Choice

As usual, there are many choices to be made about how the AC

system should be wired. Lifestyle impacts the AC system just as it does the DC system. Sometimes the choices are too confusing,

and it takes an expert to make them clear. What ever you do, just don't omit the jacuzzi!



## Managing A Battery Bank

### You mean it's not Automatic?

Despite all the hours of engineering that have been devoted to electrical system design in the last 10 years, we have yet to achieve complete automation. This means that the user still plays a very important part in how well the system functions.

With today's tools, however, those users who expend a little effort to understand batteries, and how alternator regulators and battery chargers interact will have no problem managing their electrical system.

The users who wish to rely on a single parameter presented on their digital monitor will be disappointed when they discover that batteries can still go dead at inopportune moments, and even expensive batteries can be destroyed. It is still necessary that users understand several readings from their monitoring system and be able to correlate that information into meaningful judgments about battery state-of-charge, and long term health.

The most basic parameters to be understood are Volts and Amps. While Amp-hour information is very useful, without an understanding of Volts and Amps, one can easily be mis-lead by reported Amp-hours.

### A Full Battery

Every human endeavor begins with a reference point. If you're leaving for a long trip, the reference point is home. If you're intent on discovering the meaning of life, a common reference point may be a conviction that there is a supreme designer. While a reference point may change while undertaking either a physical

or metaphysical journey, the lack of a reference point indicates trouble ahead.

The reference point for a battery operated system is hardly profound. Like a fuel tank, knowing when it's full is the very most important piece of information knowable. If you know when a battery is full, then all else is as easy as counting to two if you know how to count to one.

A battery is full, when the voltage between its terminals is high enough to cause electrolyte gassing, and the current through the battery has declined to a low and steady-state value. For typical liquid electrolyte batteries, a potential of 14.4 Volts across the terminals is high enough to cause gassing at 77° F. At this voltage, current will naturally decline to a relatively low percentage of the Amp-hour rating of the battery. What that current declines to is easily determined. Apply 14.4 Volts until the current stabilizes . . . that is, shows very little decline as time goes on. For healthy batteries, expect the final steady-state current to be less than 2% of the Amp-hour rating. That is for a 100 Amp-hour battery, steady state current should be less than 2 Amps.

Your regulator may not reach 14.4 Volts, in which case, you will not reach a full charge. However, no matter what voltage your system eventually achieves, when the voltage is a maximum, and current no longer declines, the batteries are as full as they are going to get. This is your reference point!

### Amp-Hour Information

Without a full charge reference point, all the Amp-hour informa-

tion in the world is as meaningless as any single grain of sand in the Sahara desert. So what if your meter displays 65 Amp-hours consumed. Did it read zero when the batteries were full? Conversely, when it read zero, were the batteries full? If you can't answer these questions, then you actually know nothing about the state of your batteries because you have no reference point!

OK, assume that your batteries reached a full charge, and coincidentally, the Amp-hours remaining showed 100%. Since then, you've gone through several charge and discharge cycles. How accurate is the present display that may show 75% remaining? That depends on a host of uncertainties. Has the rate of discharge been properly accounted for by calculations using Peukert's equation? Is battery recharge efficiency accurately determined by your monitor? Have you programmed the monitor with accurate battery capacity? If you can't answer affirmatively for all of these questions, then, once more, you don't really know the state of your batteries.

### Keeping it Manageable

To keep your system manageable, you need to become familiar with the voltage and current readings as the battery discharges and charges. You need to be able to determine full charge, and

from that reference point, you need to know how many Amp-hours have been discharged, not only for a simple Amps times time calculation, but also one using Peukert's equation for rate of discharge effects. You also need to know the temperature of the battery.

### Don't Forget Alarms

Only a brain dead philosopher could derive some enjoyment over the question surrounding sound, or lack thereof, of a tree falling without an observer. Can a battery go dead if you aren't there to observe it? If you don't think so, turn on all your lights and leave for a week. A philosopher may argue that the battery only went dead the instant you returned and observed it's state of charge, but warm beer in the refrigerator may tell a different story.

Unless you have the freedom to observe your electrical system 100% of the time, you need alarms. To satisfy the philosopher, we might suggest that the alarm system is the observer, and therefore the batteries can go dead before a human observer make notes. In any case, alarms can notify you that something unwanted is happening to your electrical supply. An alarm could even save your life.

## Break In Those Old/New Batteries

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### Introduction

Most of us know that new cars should undergo a break-in period where parts are allowed to "adjust" to one another. During this break-in period, usage is limited to mostly moderate demands on performance.

For similar reasons, it's not good practice to brake hard after getting new brakes installed . . . break in those brakes!

Do new batteries need to be broken-in? If so how? Are gel batteries different?

### Increasing Surface Area

New batteries often present problems for users. Because the battery doesn't accept charge current readily, and voltage may sag with even small discharges, many users think that other parts of the system have failed . . . after all, the batteries are new!

How well a battery accepts charge or discharge current is dependent on the surface area of the plates. You may not think you can change plate surface area, but you can. When a battery is discharged, plate surfaces are etched. This etching takes place on the smooth surface of a plate that came out of a mechanical press. Surface area is gained by this etching.

With additional surface area to conduct electrical ions, current passes more readily through the battery. High rate discharges, without excessive voltage loss, are made possible. Charge current is also accepted at greater values without overheating.

Old batteries can also benefit from the break-in process. Batteries that haven't been cycle for a few months may show resistance to high rate charges. Don't throw the batteries away until you tried to rejuvenate them with a break-in process.

### How To Break-In a Battery

Just like a car engine should be used moderately during the break-

in period, so should a battery. High rate discharges and charges should be avoided.

The first step to the break-in process is a good charge, including a short period of overcharge. The overcharge will tend to equalize the specific gravity in all the cells.

Now that the battery is thoroughly charged, turn on enough loads to approximate a discharge of 5% of capacity. That is, for every 100 Amp-hours of capacity in your bank, discharge by 5 Amps. For instance, an 8D would be discharged using about 10 Amps.

Assuming that your batteries have the expected Amp-hour capacity, the break-in discharge(s) will take about 20 hours. Let the discharge continue until the battery voltage reaches 10.5 Volts.

With a now depleted battery, recharge using a current of about 10-20% of Amp-hour capacity. Avoid high rate charging during the break-in period.

### How Many Break-In Cycles?

The discharge and charge process should be done at least three times, preferably five times on new batteries. Old batteries can usually be rejuvenated with one or two break-in cycles.

### Stubborn Gel Batteries

You tried bringing an older gel battery back to life, but the break-in process has failed. Now what? Sometimes rejuvenating a gel battery takes extraordinary measures to bring it back to life . . . like operating it upside down! This is not for the weak of heart, and you should remove the battery from the vehicle or vessel first and do this procedure where an accident won't have ill consequences. We'd also advise wearing eye protection when working around the battery, and minimizing time around the battery while it is charging.

CAUTION!!!! The vent caps on gel batteries are supposed to be

up so that if they do vent, no active material will be expelled. If you're going to operate the battery upside down, you must make sure that the battery doesn't gas. To prevent gassing, you must apply the correct charge voltage for the battery temperature! See the application note dated February 1996 for more details.

If you're positively sure that you can charge the battery properly, proceed by turning the battery completely upside down. Discharge and charge it as described earlier. If you haven't noted a significant capacity gain by the third discharge, the battery is probably too far gone to recover.

## Testing Batteries

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### But They're Almost New!

The conversation usually goes something like this. Caller: "There's something wrong with your regulator. It just doesn't charge my batteries. It put in a few Amps right after I turn on the engine, but then the alternator quits producing and the batteries never get full".

Us: "What is the voltage on the batteries when the Amps go down"?

Caller: "About 14.5 Volts".

Us: "Your batteries are the problem. The regulator has brought the batteries to an appropriate voltage. Now it's up to the batteries to accept a charge. They refuse to accept a charge, so they are either full already, or defective in some way".

Caller: "But they're almost brand new".

Us: "Have your broken them in"?

Caller: "What"?

Yes, batteries need to be broken in. When a battery is new, the plates are smooth from the active material being pressed into the grids. During discharge, the smooth plate surfaces increase in area due to etching of the active material. In effect, valleys and mountains are carved into the plates. With this increase in surface area, higher currents can be conducted, and an increase in capacity results. As a result, the battery will accept higher charge rates, and also support rapid discharges better.

We've seen brand new 8D batteries that won't crank a diesel fast enough to start it, but after a couple of deep discharges, the engine spins so fast that it starts almost immediately.

### Breaking Batteries In

As noted, new batteries need to be broken in before they start accepting a fast full charge. A special feature of Ample Power regulators prevents them from overdriving a battery that won't readily accept a charge. Besides monitoring temperature and making adjustments to charge voltage, Ample Power regulators employ special microcomputer hardware and software that sense when a battery doesn't accept charge normally, and backs off to prevent permanent battery damage.

Breaking a battery in properly will not only permit faster charging and discharging, but it will also provide a 15 to 30% gain in Amp-hour capacity.

To break a battery in requires from 1 to 5 complete discharges,

### Stubborn Liquid Batteries

We don't know of any process that will recover a liquid battery which has stopped accepting high rates of charge. As a rule, liquid batteries accept charge at about half the rate of a similar capacity gel battery, so slow charge is part of the territory to begin with.

If you tried the normal break-in process for a liquid battery and it hasn't helped, it's time to breakout something you can really charge with . . . a credit card!

followed by a full charge. Fully charge the batteries before performing a complete discharge. To discharge fully, turn on a load that is approximately 5% of the Amp-hour rating of the batteries. That is, for a 100 Amp-hour battery discharge at about 5 Amps. Continue the discharge until the battery voltage falls to 10.5 Volts.

The Ample Power Energy Monitor/Controller is ideally suited for break-in discharges since it not only monitors current, but can sound an alarm when voltage falls to 10.5 Volts. In the process of breaking in the battery you can also determine what's its actual Amp-hour capacity is. Just read it off the Energy Monitor/Controller when the alarm goes off.

Even after one complete discharge and recharge you'll note an improvement in charge acceptance. Do at least three, however, to give your batteries a good initial workout.

### Are They Still Any Good?

When batteries aren't new, and aren't accepting current as expected, either they need another deep discharge activation cycle, or the batteries are at the end of their life.

Batteries that are inactive for long periods don't act normal on the first discharge. They need a deep discharge followed by a vigorous charge to start accepting current normally. It may take more than one discharge and recharge cycle to make the batteries work as expected. If you've done this, and the batteries still refuse to charge and discharge properly, they are probably ready for the recycle bin.

### The Overnight Test

One way to evaluate battery health is to fully charge the batteries and then disconnect them so that you know there is no way they can be discharged by sneak loads. After a resting period of 24-hours, measure the voltage across the terminals with a good digital voltmeter. If the batteries aren't holding 12.6 Volts, (12.8 for gel cells), then they are in poor health.

We've talked to people who own batteries that drop to about 12-Volts after a 24-hour rest. Because the batteries were only a few months old, they refused to believe they were bad. After two years of complaining about poor battery service, they are still ruining vacation time by excessive engine running, and we might add, wasting our time trying to find some alternative explanation.

### Capacity Testing

The best way to determine the health of a battery is a full blown capacity test. As previously mentioned, this involves charging the battery fully, and then placing a load on the battery which is about

5% of the expected capacity.

We suggest a capacity test at least once a year. Typically the test would be done prior to the vacation season, and most certainly before one leaves for an extended trip. Remember to log the capacity test in your record book so that you can compare capacity later.

## Winterizing Battery Banks

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### Introduction

In many places, boats and motor coaches are layed up for the winter months. The question always arises, what should be done to the batteries? Should the charger be left on or off? Can all the batteries be hooked in parallel and charged from a single charger? Should the charger be placed on a timer?

Unfortunately, there's no one right answer to any of these questions. Different battery technology and winter circumstances dictate an individualized regimen.

### Charge Fully before Lay-Up

Always charge batteries fully before leaving them unattended. When you layup batteries for any length of time beyond a few weeks leave some sort of charger attached which will keep up with battery self-discharge. Ideally the battery voltage should be maintained between 13.2 and 13.6 Volts. A small solar panel is often sufficient to maintain a battery. Solar panels can overcharge, however, so be sure to use a regulator on larger panels. If you can't leave a charger attached, apply a full charge every 3-4 weeks. Self-discharge is less in cold weather, so the time between full charges can be longer, perhaps 8-10 weeks during northern winters.

Basically, a full charge is a process where a temperature corrected absorption voltage is applied to the batteries until battery current declines to a low percentage of battery Amp-hour capacity.

Batteries which are fully charged won't freeze in weather typical of the U.S., except perhaps in Alaska. Batteries that are not fully charged may freeze, and the expansion of the ice will probably fracture the cases.

### Battery Types

As you may know there are four distinct types of lead-acid batteries. They are:

- liquid electrolyte, lead/antimony plate;
- liquid electrolyte, lead/calcium plate;
- gelled electrolyte, lead/calcium/tin plate;
- absorbed electrolyte, lead/calcium/tin plate;

### Lead-Antimony Batteries

Antimony is used as a stiffener in the grids of lead plates of deep cycle batteries. While antimony makes the plates stronger, it also causes battery cells to self-discharge more rapidly. Self-discharge is a deleterious discharge because it creates a hard lead sulfate that crystallizes and ultimately destroys the battery.

The only way to avoid self-discharge is to keep lead-antimony batteries on a charger when not in use. Self-discharge lessens

### It's Your Choice

Instrumentation and regulation equipment is available to take the mystery out of battery management. Techniques are available to determine battery capacity and ultimate health, and Ample Technology can provide assistance where necessary to sort out what may be confusing information. If you choose to have Ample Power, you will!

as temperatures decline, so if it's cold enough, then a full time charge isn't necessary. Be sure to do a full charge at least once a month in very cold weather, and every two weeks if it gets above freezing.

### Lead-Calcium Batteries

Batteries made with lead-calcium plates, such as the so-called maintenance free types, have low self-discharge as long as the weather isn't too warm. These batteries can be left fully charged for several months without experiencing sulfation. It is good to bring them to a full charge a couple of times during the winter.

### Absorbed Electrolyte Batteries

Absorbed electrolyte batteries have most of their electrolyte captured in a fiberglass mat. Plates are made of lead and calcium and some tin may also be used. Because there is no antimony in the grids, self-discharge is quite low. Fully charge the batteries before laying up the system for the winter, and apply at least one full charge during the winter.

### Gel Batteries

Gel batteries have the lowest rate of self-discharge, and can be left months without a charger attached. Just be sure to bring the batteries to a full charge before leaving them.

### Mixed Battery Systems

Many systems have two different types of batteries for house and starter. Follow the recommendations for the type of battery that requires the most charging during the winter. If you leave a charger hooked up, it's permissible to connect all the batteries in parallel. If your area is subject to frequent power outages, be sure to check charger operation frequently, since it isn't a good idea to have different battery types connected unless they are being charged.

### Don't Forget Small Loads

Often, there are a number of small loads on the batteries such as clocks, instrumentation, and control panel indicators. If you're going to leave the batteries without a full-time charger attached, then it would be wise to lift one of the battery leads to make sure that there are no stray loads discharging the batteries.

### Don't Forget Temperature

When you charge the batteries for the last time before lay-up, be sure to get a voltage high enough to fully charge the batteries at their present temperature. Refer to the publications mentioned earlier.

Just as important is actually reaching a full charge when called for during the lay-up period. If the batteries are really cold, it will take a high voltage to reach that full charge.



# Troubleshooting Electrical Systems

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## Introduction

Is there anything more frustrating than a breakdown? Without warning, a trusted piece of equipment just quits working! There is something more frustrating . . . that tool you need to fix the problem is sitting at home in the tool box!

Breakdowns always seem to happen at the worst possible moment, and having the right tool to fix the problem doesn't help the initial feeling of letdown. But, when the dust settles, and it's either fix the problem or call the repair technician, having the right tool onboard makes the decision a little easier. If there isn't a technician to be called, frustration at leaving the right tool behind will be strong.

Considering the number of connections, wires and other components in an electrical system, reliability is quite good for most installations. We've seen many systems that makes us wonder if neat wiring with appropriate connections aren't just a waste of money . . . *if this system runs, anything will!*

Failures can be expected in systems where the installation practices were poor, and little or no maintenance has taken place, but even the best installed equipment will fail. What does it take to fix an electrical failure?

## A Sharp Set of Eyes

Electrical failures are often the result of a mechanical failure. A broken splice, a loose crimp lug, or a missing screw in a terminal block can interrupt electricity and your vacation.

Knowing what to look for is the first hurdle. Don't you wish you'd made a list of all the terminals that had wires on them before the trouble began? Wouldn't it be nice if all the wires were labelled and you knew where each of them went?

In a large system, knowing all the wires and their function can only be done a piece at a time, and only by someone highly skilled in the trade. However, it's a good idea to inspect the system when it works so you won't be so daunted by it all when it fails.

## A Digital Voltmeter

Many years ago we were driving an old pickup in the desert east of San Diego, CA. We'd been camping miles from the nearest paved road and hadn't seen any other people for 3 days. Without warning, the truck quit running. Inspection of the distributor gave us the answer . . . the rubbing block on the points had broken.

A spare set was in the toolbox, and minutes later we were ready to set the timing and be on our way. There was only one problem . . . the voltmeter I used to indicate when the points actually opened was at home! After swearing, kicking the tires a

bit, and fruitlessly trying to eyeball the difference between open and closed points at the timing point, some semblance of rational thought returned. My companion smoked, and cigarette paper was a thin insulator that worked between the point to indicate when the points gripped the paper, (closed), and when the points released the grip, (open). A voltmeter has been standard in my toolbox ever since!

Learning how to use a voltmeter is almost as simple as learning how to read a thermometer, or tell time using a digital watch! Don't know what a Volt is? So what, other than keeping everything from happening at once, even science can't explain time.

Not knowing what to do with the information derived from the voltmeter is a more serious problem. However, perhaps you can contact a technician by phone or radio and have them tell you what to measure and what it means! Telling a tech that a light doesn't work isn't very illuminating . . . telling him that there is voltage on one side of the light and not on the other may get the light to go on over the tech's head.

Here's a simple test that anyone can make. An external alternator regulator is enabled from the ignition switch, or an oil pressure switch. Find that wire by measuring voltage on all the pins of the regulator with the ignition switch off and then with it on. You should find a wire that has voltage on it when the ignition switch is on and no voltage with the switch off. You will probably find two such wires if the regulator works . . . one of them is the field wire going to the alternator.

Digital voltmeters are fairly inexpensive, and should be in every toolbox! Learn how to take readings . . . you may even surprise yourself and learn a little about electricity while you're at it. You can't usually hear or see electricity, so when it comes to explaining symptoms to a long distance tech, nothing is better than a simple voltmeter.

## A Clamp-On Ammeter

Voltage readings can be used to tell if a battery is being charged or discharged, but if you want to know how fast, you need an ammeter. Ammeters are made that have opening jaws so that they can be 'clamped' over a wire. They don't really clamp onto the wire, rather the wire goes through the center of the jaws. Once clamped over a wire, the jaws measure the strength of the magnetic field produced by flowing current, and translate the measurement into Amps.

If you want to know how well the alternator or battery charger is operating, the ammeter is the tool. Want to know how much the inverter draws with the microwave cooking? The ammeter can tell you.

# Alternator Tachometer Signals

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## Introduction

Most alternators provide a signal that can be used to indicate how fast the alternator is turning. The signal is a half-wave rectified output which has an amplitude about one-half the DC output voltage.

Using a signal from the alternator as a reference to engine RPM is not without problems. The purpose of this application note is to clarify these issues.

## Pulley Ratios

The alternator typically rotates faster than the engine because the

engine has a larger pulley than the alternator. A rough idea of the ratio can be obtained by measuring the outside diameters of the two pulleys. However, the depth that the drive belt seats into each pulley must also be considered.

### Number of Poles

The frequency of signals from the alternator depends on the number of magnetic poles in the alternator. Ample Power alternators have seven poles in the small frame units and six poles in the large frames. These produce seven and six signals per revolution.

### Belt Slip

It's not uncommon to experience a small amount of belt slip even in well tensioned applications. Obviously, if slip gets too much, the belt will fail from overheating. Because of the possibility of belt slippage, many people choose not to use alternator signals for RPM indication.

### Signal Strength

Alternator tachometer signals are derived from the stator windings. The signal is thus dependent on the amount of energy being produced by the alternator. When batteries are being charged, signals are strong enough to produce good tach stability.

When multi-step regulators are used to charge batteries, the tach signal strength can vary according to the charge state. When the regulator switches from the absorption state to the float state, there may be complete loss of tachometer signal during the time that battery voltage decays. During this period most regulators shutdown completely, and the tach signal does likewise. Ample

Power regulators step down from the absorption voltage in several steps, keeping the tach signal strength at a sufficient level to drive the tachometer.

### Full Batteries

In the past, full batteries were more of a concept than a reality. With Ample Power regulators, batteries do get charged to a full state.

When the regulator finds that the battery is full, alternator field current is reduced as necessary to avoid overcharging the batteries. This often results in a tach signal which is too weak to trigger some tachometers. Erratic tachometer readings result, particularly at low RPM. One possible solution is to turn on some electrical loads, forcing the alternator to produce more output, and hence, more tachometer signal strength.

### Tachometer Pickup

Because the alternator's prime function is to charge and maintain batteries, and because some regulators can actually provide a full charge, loss of tach signals is a given . . . the regulator favors the battery. No one wants a boiling battery just so the tachometer reads properly.

Virtually all diesel engines have a port which will accept an RPM sensor. This mechanism produces a reliable tach signal without regard to battery state of charge. The RPM sensor does not suffer from belt slippage, and continues to operate even if the alternator has failed. We strongly recommend RPM pickups rather than using a signal from the alternator.

## Exploding Batteries and Boats

### Introduction

There have been many tons of tons of batteries destroyed from overcharging, so don't feel lonely if you just replaced a relatively new set.

Liquid electrolyte batteries have been around for over a hundred years, so they are understood better than gel batteries which are a relative newcomer.

Are gel batteries that much different than liquid types? It's always difficult to give a yes or no answer to any question more complicated than "do you sleep" but for the gel battery question we tend to favor a "no" answer.

Actual differences are subtle . . . what complicates the subject for many people is the *claim* that gel batteries are sealed.

In 1996, a sailboat operating in the Caribbean had an explosion in the battery compartment . . . gel batteries. Fortunately, no one was injured, but the repair bill was significant, and as a result there will now be a flurry of discussions about the place of gel batteries in boats, and you can expect greater scrutiny of electrical systems from the insurance companies. Let's review some basics.

### Using Liquid Batteries

- Liquid batteries should be located in a cool, well ventilated space, preferably not in living quarters because of emissions of arsine and stibine gasses.
- The batteries should be secured so that movement is not possi-

ble in expected conditions. This means more than a single nylon strap with plastic buckles routed over the top of the battery. Batteries should not be enclosed so tightly, however, that normal expansion and contraction of the case is impeded.

- The batteries should be mounted in a watertight tray big enough to hold all of the electrolyte in the event of battery case fracture.
- The battery should be maintained with a charging system, (charger, alternator, etc.), that actually measures battery temperature and corrects the applied voltage accordingly.
- An instrumentation system should be connected to the battery that provides alarms for the following abnormal conditions:
  - high battery voltage;
  - low battery voltage;
  - high battery temperature;
  - high battery current; and
  - low state of charge.
- If multi-step charging is used, the systems should be designed so that it trips from the absorption voltage to the float voltage based on Volts and Amps through the battery, rather than just timing the absorption charge.

### Using Gel Batteries

For the most part, gel batteries should be used *exactly* the same as liquid batteries. The possible exception is the requirement for an electrolyte container. First, gel batteries use a tougher case than typical liquid batteries, so case fractures are infrequent, and the

electrolyte is much like a paste and will only ooze from a fracture. Obviously, using a container is playing it safe.

## Case by Case Analysis

- Keeping batteries cool is always, well cool! Typically gel batteries don't gas, but in the event they do, the same explosive mixture is produced. Planning for the day that the charging systems fails, and no one is around to hear the alarms from the instrumentation system is prudent . . . provide plenty of ventilation.
- Gel batteries are no more sensitive to temperature than liquid batteries, and might even be less sensitive regarding gas emissions. However, effects from gassing a liquid battery can be hidden by the addition of water to the cells. That can't be done with a gel battery. Conclusion: There is no safety difference related to temperature between gel and liquid batteries, just an economic difference.
- Instrumentation System: Operating any electrical system without alarms is for risk takers, not for the prudent. Battery type makes no difference.

## What Went Wrong?

In the case of the explosion mentioned earlier a plethora of things probably went wrong. From reliable sources we've heard that the batteries weren't secured properly, insufficient ventilation was provided, temperature measurement and compensation was lacking, instrumentation was limited, no alarms for abnormal conditions were present, and multi-step charging was being used without battery state-of-charge controls. While there was an Ample Power Energy Monitor onboard, battery temperature sensors had not been connected, and no alarms had been activated in the Energy Monitor. Had the sensors been wired, and alarms enabled, the Energy Monitor would have sounded and alarm long before an explosion happened!

The first temperature sensing alternator regulator was the original 3-Step unit introduced by Ample Power Company in 1987. Alarms have been available since 1989. Monitor/Regulator interfaces to smartly terminate absorption charging have been offered since 1992.

In 1996, a lot of Ample Power gear could have been purchased for the reported \$100,000.00 repair bill!

## Miscellaneous Problems

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### Leaks in Sealed Batteries

Sealed batteries normally operate at slight positive pressure. They are fitted with overpressure valves which operate should the battery be overcharged. Defective valves are possible, and a valve can open under an overcharge and not reclose. This failure is usually recorded by a fine white powder that exits through the valve and is deposited on the case.

The positive and negative posts are sealed around their exit from the case. Loss of this seal can cause the battery to dry out and become worthless. Loss of a seal around the post usually turns the post black. If there is any doubt about the seals, brush a little soapy water around the post and then push on the battery cases. If any bubbles appear, return the battery to your dealer.

### Big Alternators . . . Small Batteries

A customer reports that after installing a large frame alternator in place of the small frame unit that he had been using with a Smart Alternator Regulator, SAR, the SAR began acting strange. During the absorption cycle, the voltage kept declining on the battery. Since that never used to happen with his small frame alternator, what could have gone wrong?

Nothing . . . the SAR uses battery temperature sensors. If a battery is charged so fast that temperature starts to build up, then the SAR reduces the absorption voltage. As a minimum, temperature compensation prolongs battery life. Without temperature compensation, a hot battery can go into thermal runaway. Thermal runaway works like this . . . the hotter the battery gets, the more current it accepts, heating it further. Soon, the battery will be boiling hot, spewing acid steam. It may even blow the case apart.

It's our opinion that high performance charging without battery temperature sensing is a lurking time bomb. We have witnessed

thermal runaway once when we induced it purposely by removing temperature sensors during a fast charge. The batteries were 6-Volt liquid electrolyte units in series. Thermal runaway may not happen in the Northwest where most regulator testing takes place. It may not happen until battery usage is heavy, such as during an ocean passage. If Murphy's law is applicable, it will happen to you a long way from help. Does your performance regulator have battery temperature sensing?

### Killing a High Output Alternator

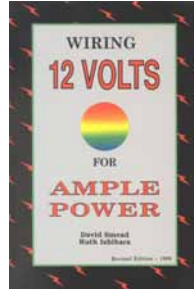
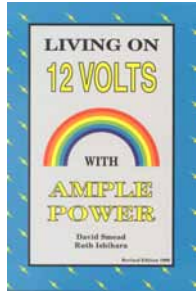
Alternators spin a rotor inside the stator windings. The rotor is an electromagnet. The strength of the magnetic field that it produces is directly proportional to the *magnetic permeance* of the rotor material. Permeance is temperature sensitive, and a very high temperature can permanently reduce it to the point where it is no longer effective. A slipping belt will overheat the rotor shaft, and eventually, the rotor magnetic material will cease to function.

Most high output alternators come with nylon lock nuts on the output studs. They help prevent loose connections. When a loose connection does develop, it acts as an arc welder, generating lots of heat. Eventually, the stud melts, and the wire drops away. If it falls against the engine, and you're not protected with a fuse prepare for a fire!

High output alternators need to be connected with large wires. The wires are usually quite stiff, so as the engine vibrates, the wire applies twisting torque to the nylon lock nut and may eventually loosen it. To avoid such problems, use fine stranded and flexible wires. Welding cable works well for this. A long service loop should also be left so that the wire can move with the engine vibrations. Naturally, it is good practice to check the alternator connections on a regular basis. A second nut on the output stud is a wise safety measure.

## Power Knowledge ... avoid costly mistakes!

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This book contains the most authoritative information about AC, DC and refrigeration systems within small energy systems. Applicable to boats, RV's and remote homes. Covers conventional lead-acid batteries as well as new sealed technology. Battery chargers explained; how they work, and why they don't. The DC alternator and proper regulation is thoroughly discussed. Essential facts regarding wind generators are presented. The workings of solar panels and how to use them effectively is explained. AC within the alternate energy system is explained with a special section devoted to electrolysis prevention aboard boats. All aspects of refrigeration are thoroughly detailed. The concept of a balanced energy system is introduced and details on how you can achieve it are presented. Special appendices are provided to allow you to design the optimum system for your needs.

### Wiring 12 Volts for Ample Power

Revised, updated and expanded in 1995... now better than ever. If you plan to install your own Ample Power System, then *Wiring 12 Volts for Ample Power* is just the book to get you started and help you do it right the first time. Presented are general schematics, wiring details and troubleshooting information not found in other publications. Even if you don't do your own wiring, *Wiring 12 Volts for Ample Power* is a must book. Chapters cover the history of electrics from 600 BC to the modern age.

Covered are DC electricity, DC magnetics, AC electricity, electric loads, charge sources, batteries, wiring practices, system components, tools and troubleshooting. A chapter devoted to schematics presents many of the electrical wiring diagrams necessary in a boat of the 1990's. With thorough coverage, and easy to read style, *Wiring 12 Volts for Ample Power* has become another marine best-seller.

### Living On 12 Volts with Ample Power

Revised, updated and expanded in 1998, *Living on 12 Volts with Ample Power*, has been a marine best-seller for over 10 years and is a must for anyone seriously interested in electrical and refrigeration systems. Here's what others say about *Living on 12 Volts*. In the April 1988 issue of National Fisherman Technical Editor John Gardner writes, "There is not a shred of technical jargon in the whole book. Elementary electrical concepts are explained for the benefit of those to whom the subject is new, as is so seldom done in technical writing."

After a thorough review of the book, Mr. Gardner concludes, "An extensive index makes reference easy and completes a book that is outstanding for systematic organization. And finally it should be said this book is a model of lucid expository style - meaning it is easy and agreeable to read."

Nigel Calder, noted marine author of three books, *Refrigeration for Pleasure Boats*, *Marine Diesel Engines: Maintenance, Troubleshooting and Repair*, and *Repairs at Sea*, writes about *Living on 12 Volts*. He says, "a book of this kind is long overdue and should be compulsory reading for boat builders." We agree.

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Ample Power Products are manufactured by Ample Technology, 2442 NW Market Street, #43, Seattle, WA 98107 USA

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