Essential Boat Electrics

PAT MANLEY

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John Wiley & Sons, Ltd

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Contents

Acknowledgements

My first ‘proper’ book, *Simple Boat Maintenance*, which has been a terrific success, has served as a pattern for *Essential Boat Electrics.*

As with *Simple Boat Maintenance, Essential Boat Electrics* would not have been possible without the help and support of my wife Lynette. Photographing the ‘how to do it’ sequences needs two pairs of hands, one of which has been Lynette’s.

Tim Davison has kept me on my toes when I didn’t describe something in enough detail.

I hope this book gives you as much satisfaction in use as it has given me in its writing.

Pat Manley, Hythe, Southampton

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Introduction

I've a friend whose boat's appetite for amps is minimal. He has a small solar panel, but where he keeps his boat, the sun sets at 10 am, even in the summer. He has a small wind charger, but the mooring is so sheltered it rarely turns. He has an engine, but it has no generator. He has a battery, but he takes it home to charge. Peter has a cabin lamp, navigation lights and basic instruments and he wants no more. These days Peter is a rarity.

Whether power or sail, today's boats need quite a lot of electricity, be it low voltage DC or mains voltage AC. To the majority of yachtsmen, electricity is a bit of a closed book, and I hope that it's those people who will find this book useful.

Essential Boat Electrics is not intended to be very theoretical, quite the reverse. Where a formula might be useful, I'll give it. Where a bit of theory is likely to help understanding, I'll give that too. In the main, it's a matter of simple words and simple pictures, as I find that when I'm talking to other yachtsmen, that's what they want.

To many sailors, electrics is a black art. *Essential Boat Electrics* is intended to help remove the fog of mysticism from the subject. To the purist, I may use terms that they disagree with. I had a comment about my

Electrics Companion that you can't 'consume' electric power! The correspondent may have been technically correct, but it's an expression understood by all, so that's what I use.

However, I have a word of warning – if you don't understand AC power, leave AC circuits strictly alone.

Each chapter covers a specific range of topics. I had a bit of a problem in setting their order, as I often had to write about a topic not yet covered, no matter in which order I arranged them. So, where necessary, I tell you where to look for that bit of information.

I cannot stress too much that you should make a wiring diagram of any modifications you make. You won't find the professional doing that, I guess he doesn't have time, but if you're going to keep track of things, please do take the time to make one. It doesn't have to be pretty, all it needs to do is to tell the story.

It's also very easy to procrastinate and say, 'Oh! I'll tidy it all up later.' It works OK and so you put off the evil day that you make it all neat and secure. As soon as you know it works, finish it off properly there and then, or it won't get done.

That's finished the preaching, so get on and use *Essential Boat Electrics* to help you do all those electrical jobs that you wished you had the knowledge to do.

The Basics

To carry out most electrical work on your boat you really need very little theory. All you are ever likely to need is covered here, but in the main, all you need to know is how big a fuse needs to be, how much power an item uses, how thick a wire should be and how long you can run something from your battery.

The following formulae will allow you to calculate what you need to know.

DEFINITIONS AND FORMULAE

Resistance

Resistance is a measure of how difficult it is for electricity to flow through a wire or component. It's measured in ohms (Ω) using a resistance meter, normally found on a multimeter.

The higher the number, the more difficult it is for electricity to pass. Insulators have extremely high resistance and an open circuit has infinite resistance. An open circuit is like a switch switched off.

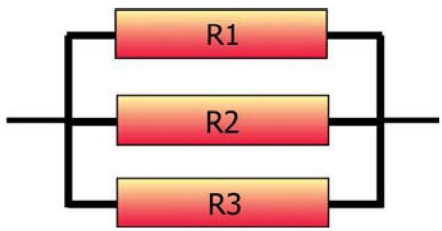
The lower the number, the easier it is for electricity to pass. A short circuit has no resistance at all and an extremely large current can flow. A short circuit is like a switch switched on.

There are several things worth noting about resistance:

- The longer the wire, the greater its resistance.
- Badly made or corroded electrical connections have high resistance.
- Resistance causes voltage loss along a wire.
- Voltage loss in a long wire run should not exceed 3%. On many boats the loss is as much as 10%, and this gives dim lights and wastes power. On components such as electric motors, this voltage loss can cause premature failure of the motor.
- Voltage loss can be reduced by shortening the wire or by using a thicker wire.
- High resistance causes heat.

Yachtsmen may occasionally need to calculate the effect of several resistances, so I'll cover this as well, just in case.

The resistance of several components connected in *series* (see p. 6) is the sum of their individual resistances. The same current flows through all of them. The system voltage acts over the complete string of components. ($R = R1 + R2 + R3$, etc.).



The resistance of components connected in *parallel* (see p. 6) is a little more complex and is found by: $R = 1 / (1/R1 + 1/R2 + 1/R3$, etc.). For only two resistances this is simplified to: $R = R1 \times R2 / (R1 + R2)$.

Voltage

Voltage drives the current through the wire. It's measured in volts (V) using a voltmeter.

For a particular piece of wire, a large voltage can drive a large current and a low voltage can drive a small current. For our uses, mains voltage is either 240 volts (Europe) or 110 volts (USA) and boat voltage is either 12 volts or 24 volts, depending on the boat.

Current

Current is the flow of electricity through the wire. It's a measure of the number of electrons flowing per second, but we don't stand there counting electrons. It's measured in amps (A) using an ammeter, but, just to be confusing, most formulae use I to indicate current. So a current (I) has a value (A) amps.

12 volt electronic instruments consume about 250 milliamps (mA) – that's 250 one-thousandths of an amp, i.e. ¼ amp. 12 volt fridges or radar consume about 4 amps each. A 240 volt mains electric kettle consumes about 8.7 amps, while the mains connector to the shore power will handle about 15 amps.

If you had a 12 volt shore connection handling the current (rather than the 240 volt/15 amp mains connector), the connection cable would be handling $20 \times 15 = 300$ amps and you'd need a very hefty cable. That's why we use high voltage for transmission cables.

There's a constant relationship between the voltage, current and resistance in any component and this relationship is called *Ohm's Law*. Ohm's Law tells us that the current through a wire is calculated by dividing the voltage by the resistance. Thus:

$$I = V/R$$

$$V = I \times R$$

$$R = V/I$$

Power

Power is the amount of electricity being taken at any one instant of time by a component. It's measured in watts and is calculated by multiplying the voltage by the current.

$$\text{Power} = VI \text{ watts}$$

For instance, a mains electric kettle might be 2000 watts (2 kilowatts) (240 volts × 8.3 amps) and a 12 volt fridge might be 48 watts (12 volts × 4 amps).

ELECTRICAL CONSUMPTION

What we store in our batteries, or what we pay the electricity company for, is the amount of power for however long we are using it. A light switched on for a short time costs us less than if we leave it on for a long time. Our navigation lights running all night will deplete our batteries much more than if they're on for only a couple of hours of evening sailing.

For mains electricity this quantity is normally expressed in 'units' or kilowatt hours – the power of the item multiplied by the number of hours for which we are using it. A 2 kW electric fire switched on for 2 hours would use 4 kilowatt hours (2 kW × 2 hours = 4 kW hours).

For low-voltage DC circuits, as found on boats, we express it a little differently: the number of hours it's switched on multiplied by the amps flowing. Thus, for our 12 volt radar, consuming 4 amps and running for 8 hours, it's consuming 32 amp hours (4 amps × 8 hours = 32 amp hours). Therefore, a 100 amp hour battery would have had 32 amp hours removed from it by having the radar switched on for 8 hours.

We may need to be able to estimate the electrical consumption of a component but know only its wattage and voltage.

Take a 12 volt, 25 watt navigation light bulb, for instance. 25 watts supplied by 12 volts draws just over 2 amps (25 divided by 12 = 2.08 amps). That bulb, switched on for 8 hours, consumes just under 17 amp hours of electricity (8 hours × 2.08 amps = 16.64 amp hours).

Let's see why an electric windlass, for instance, might fail prematurely if its wiring has too much resistance:

- Let's say it has a maximum power of 1000 watts and should be run at 12 volts.
- The current would be 83.33 amps (1000 watts divided by 12 volts = 83.33 amps) at maximum pulling power.
- Say the resistance of the wire is such that there is a 10% voltage drop.

- The current would now be 92.6 amps if required to pull its maximum load (1000 watts divided by 10.2 volts), because it would try to maintain power by drawing more current from the battery at the reduced voltage.
- With a 20% drop, the current would be 104.16 amps.
- This would give a 25% current overload, leading to rapid failure.

For the same reason, if you had the engine running, the voltage at the windlass would be about 13.5 volts. With the engine stopped and the battery down from overnight use, the windlass voltage could easily be reduced to 10 volts or so.

Engine running = 74 amps

Engine off = 100 amps

Which windlass is going to last longer?

BATTERY CAPACITY

The voltage of a battery gives no indication of how much electricity it can store. We might connect a 12 volt, 25 watt bulb to a battery and need to know how long the battery would power the light. We'll talk more about batteries later in the book, but from our amperage formula we can deduce that the current flowing through our bulb is 25 divided by 12, which is pretty close to 2 amps.

If the bulb stayed illuminated for 48 hours before the battery was flat, we would call that battery a 96 amp hour battery, because 2 amps flowing for 48 hours is $2 \times 48 = 96$ amp hours. If we ran four bulbs at the same time, the battery would last only a quarter of the time; in other words, 8 amps for 12 hours still equals 96 amp hours.

So, the capacity of a battery (to store electricity) is measured in amp hours. It's not quite as simple as that, as the amp hours capacity will vary according to the value of the current taken, but the principle holds good. As the battery ages, its capacity will fall, and when the capacity falls too much, it's time to throw the battery away.

But that's enough about batteries for now.

SERIES AND PARALLEL

Connecting in series

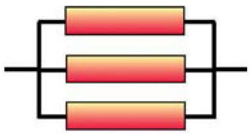
If we join components in line, holding hands as it were, we call this a *series* connection. For this type of connection:

- the same current passes through all the components;
- the system voltage is applied across all of them together, so none experience the full system voltage.

SERIES

Connecting in parallel

If you hold everyone else's left hand with your left hand and everyone holds everyone else's right hand, you will all be joined in *parallel.*

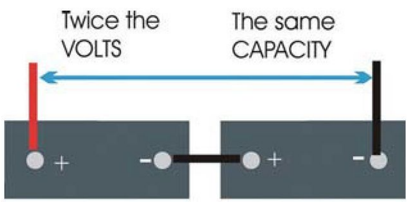


Parallel

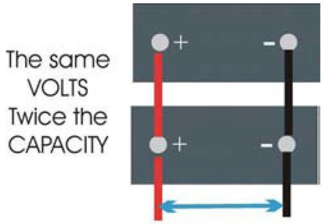
Generally, we needn't get too excited about this, unless we are joining a couple of batteries together.

Join two 12 volt, 100 amp hour batteries in series and you get ONE 24 volt, 100 amp hour battery,

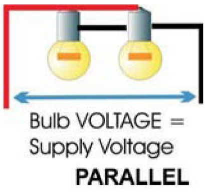
Join the same two 12 volt, 100 amp hour batteries together in parallel and you get ONE 12 volt, 200 amp hour battery.



SERIES

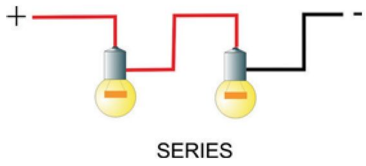


PARALLEL



Bulbs in the same circuit need to be joined together in parallel.

Join two 12 volt bulbs in series in a 12 volt circuit and they will be pretty dim! But if you find a couple of 6 volt bulbs and need to use them in your 12 volt system, join them in series and they'll work fine.



If you need the formulae to work out more complex circuits, you'll find them in the library.

The Tools

If you are going to carry out any basic electrical repairs, installation or troubleshooting, a suitable electrical toolkit is needed. For convenience, it's probably a good idea to keep this separate from your normal tool kit.

Installing instruments may also require some additional tools, such as hole-saws to cut mounting holes in instrument panels and an electric drill and drill bits.

MULTIMETER

When troubleshooting, a multimeter is almost essential.

PROBE-TYPE MULTIMETER

A probe multimeter is less versatile but more compact, and has the advantage that as one probe is the meter itself, it can be used in awkward places.

POLARITY CHECKER

If you haven't got an on-board polarity checker, this is essential every time you connect to shore power. It is also essential if you are going to fit any mains sockets.

SIDE CUTTERS

The best tool for cutting wire. With care, they can also be used for stripping wire, but you have to hold the handles just so that they will cut the insulation and not the wire.

WIRE STRIPPERS

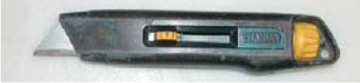
The only really satisfactory way to strip insulation from wire. Use the correct size 'notch' or you will sever some of the wire's strands, increasing its electrical resistance and weakening the wire.

LONG-NOSED PLIERS

Ordinary pliers are just too blunt-ended for electrical use. The long, tapered long-noses are indispensable for many electrical jobs.

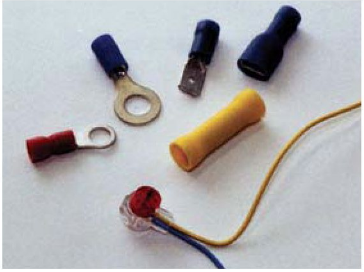
HOBBY KNIFE

Used for many odd cutting jobs. You will need this for cutting insulation on heavier cable where it isn't cost effective to purchase a bigger wire stripper. However, do be very careful not to cut through inner insulation where there's a sheath over multi-strand insulated wire.



VARIOUS CRIMP TERMINALS

The most versatile method of making electrical joints.



CRIMPING TOOL

The only proper way to make crimped joints – the cheap crimping pliers are not good enough for making proper joints. A ratchet crimping tool is the type to use. There are different makes of crimp terminals, so it's best to buy the crimper and the terminals from the same source.

HEAVY-DUTY CRIMP TOOL

If you have to crimp up some heavy-duty terminals and don't have the luxury of an expensive heavy-duty crimper, then this little beauty called the Crimpace by Tyco Electronics is much cheaper and can have the pressure applied either by a hammer or in a vice.

If you can take the wire to a vice, insert the wire into the terminal and then squeeze the crimper in the vice until the tool's end-stops touch. Make sure you hold the wire firmly in place in the terminal as you close the vice.

If you have to use a hammer, rest the crimper on a firm surface. This is probably a two-person job: one to hold the wire and terminal and the other to do the hammering. You will need good teamwork!

MAINS SOLDERING IRON

If mains power is available, a 25 watt mains iron is an asset. If you have heavier work to do, a 100 watt iron is necessary. See the chapter 'Soldering' for technique.

12 VOLT SOLDERING IRON

For use on board when no mains power is available, a 12 volt iron will do all that a mains one will do. However, it will take 2 amps at 12 volts, so you won't want to leave it on for long periods.

SOLDERING IRON STAND

You need somewhere to put the hot iron whilst you are using it. Some irons have a hook on the handle, so that you can hang them up somewhere safe. Probably a better bet is a purpose-made stand with a heavy base that can't tip over.

GAS SOLDERING IRON

For jobs where electricity isn't readily available, a gas soldering iron is a big asset. A professional one is a much better tool than its cheaper rivals, which, in my experience, suffer from rapid failure of their catalytic element. Although these 'irons' can have a naked flame if required, for soldering, the gas burns without a flame on a catalytic element, just as in a catalytic heater. This element heats the soldering tip. A rope-cutting heated tip is normally supplied as well.

GAS BLOWTORCH

For soldering heavy items, including starter cable, a gas blowtorch, as used by plumbers, will do the job. However, they produce a lot of heat, can melt the insulation and are a fire hazard. In any case, heavy-duty crimping is to be preferred.

SOLDER (MULTICORE ROSIN)

Reels of solder are obtainable in different solder diameters and are used according to the size of the items being soldered. Multicore 'rosin' flux solder is the most convenient to use for electrical wiring jobs.

DE-SOLDERING TOOL

If you have to 'unmake' a soldered joint, getting rid of the molten solder before it cools and prevents the joint from being taken apart is a problem. A 'vacuum' de-soldering tool is very useful if you expect to do much 'undoing'.

SCREWDRIVERS

Many connectors have small screws, as do junction boxes and the components themselves. A range of suitably sized screwdrivers – blade and cross-head – is essential. Include a set of small instrument screwdrivers.

CABLE TIES

Cable ties of various sizes are used to tidy up and support wiring runs.

INSULATION TAPE

Insulation tape is useful for initial tidying up and for temporary insulation. It isn't suitable as a permanent method of insulation, as in the marine environment it will become loose and sticky.

LIQUID INSULATION

Liquid insulation, which can be brushed on and built up to a suitable thickness, is very useful for use in awkward spots, especially to insulate individual connections in a small multi-wire plug and socket.

SILICONE GREASE

Use silicone grease to keep moisture at bay in screwed connectors and crimp connections which have no other means of protection.

CABLE THREADER

A nylon push threader allows cables to be run through conduits and awkward places. These are available from builders' merchants.

CLAMP AMMETER

Clips onto a cable to measure the current flowing through the wire. It's not especially accurate, but can measure high currents and you don't need to make any connections. It's especially useful for checking the output of the alternator. You just need to clip it to the alternator's output cable.

Multimeters

Troubleshooting and maintenance of the electrical system are enhanced by the use of a multimeter. These meters can be purchased for a modest price from electronics stores, and for general use, an auto-range meter is probably most appropriate, although it is more expensive than a manual one. With manual multimeters you need to estimate what the value is before you test it.

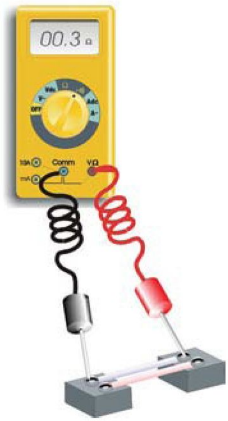
A small, probe-type multimeter frees up the hands, allowing the circuit to be tested and the meter to be read simultaneously.

The meter has an internal battery and so must be switched off when not in use. If you have an analogue meter with no 'OFF' switch, make sure you don't leave it set to resistance, otherwise there will be a continuous battery drain.

CHECKING CONTINUITY

- Set the meter to resistance (Ω) (and a low range for a manual meter).
- Hold the probes together in contact to check for a zero reading and a 'beep'. Analogue meters need to be 'zeroed' at this stage – if it can't be zeroed, the internal battery is low.

- Switch the circuit 'OFF'.
- Put the probes at each end of the wire to be tested. The resistance should be zero but will probably read several ohms because of the resistance of the wire.
- If set to 'bleep', you will get an audio warning of very low resistance for a continuity check. A 'blinking' reading indicates an open circuit (i.e. a break).
- If the length of circuit is longer than the probe wire, use a long length of wire to extend the probe (keep a long length of 10 amp wire especially for the purpose.) This allows a long single conductor to be checked.
- Measurement of the resistance of a *component* can be made only with the component isolated (otherwise the rest of the circuit may influence the reading).



TESTING A BULB

Set the meter to resistance. Hold one of the meter probes on either of the bulb's contacts and the other probe on the second contact of the bulb. If there's only one contact, the second is the metal neck of the bulb. The meter should read only a few ohms (the resistance

of the filament). If the bulb has failed, the meter will 'blink' or have a very high reading.

Fluorescent lamps can't be tested with a meter.

CHECKING DC VOLTAGE

- Switch the circuit 'ON'.
- Set to Volts DC.
- Put the probes onto the two points at which you wish to measure the voltage (red to positive and black to negative).
- A minus sign in front of the voltage indicates that the red probe has been put on the negative terminal.

CHECKING AC VOLTAGE

Do not expose live AC circuits unless you really know what you are doing. An error can be fatal.

- Switch the circuit 'ON'.
- Set to Volts AC (V~).
- Hold the RED probe to the positive wire (terminal) and the BLACK probe to the neutral wire. The meter will read the volts at that point.

CHECKING CURRENT

The circuit will have to be broken so that all the current flows through the meter. It will measure only DC current. A multimeter will measure only small currents, as the current has to pass through the meter and the probe wires.

- Select Amps DC.
- Put the red wire into the mA socket or 10 amp socket on the meter, according to the current expected. If in doubt, start with 10 amp.
- Switch the circuit 'ON'.

- Put one probe on the wire, the other on the terminal.
- The act of measuring the current will alter the current flow, so it's only an approximation.

Note:

- The non-electronics user has little need to measure current.
- Measuring alternator output needs a dedicated ammeter. A clip-on meter, although not very accurate, is ideal for troubleshooting.

Batteries

There are a number of different types of storage battery and people have differing ideas as to which is best. The information here is generally accepted, but the balance may change a little depending on whom you talk to. Unless your requirements are extreme, it's often most cost effective to use good quality, general purpose batteries, treat them properly and accept that you may need to replace them every four to six years.

A battery consists of a number of standard 2 volt (lead acid) cells joined in series in one battery case to make 'nominal' voltage.

TYPES OF BATTERY

Lead acid batteries

The standard 12 volt battery consists of six 2 volt cells. Each cell has a series of positive and negative plates suspended in a solution of sulphuric acid. The plates are kept apart by separators. Under load, electrons flow from the negative plates to the positive plates, and under charge, the flow is reversed. The amount of electricity that the battery can hold is determined by the surface area of the plates. So, a big battery will store more electricity than a small one. But that's not the whole story.

If a battery is required to give a very high current for a short time, such as when starting a diesel engine, the plates must be very thin so that the stored electricity is available at the surface of the plates very rapidly. These plates are fragile, and if a lot of electricity is taken from them, the plates will buckle. Also, they don't like vibration.

If relatively low currents are required, plates can be much thicker. They are much more robust but won't give high currents, because the electrons can't flow from deep in the plate fast enough.

The physical size of the battery is determined by how much electricity it stores (its capacity) and how quickly the electricity is required. A battery's capacity will decline slowly as it ages. Battery capacity will also vary with temperature, and at 0° C is only 50% of the nominal capacity compared with that at 30° C.

Types of lead acid (flooded) battery

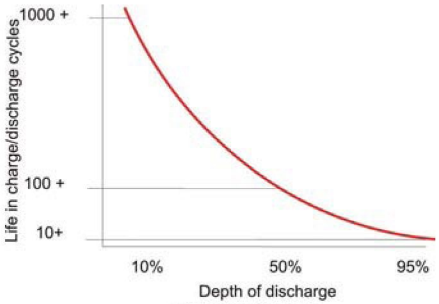
Engine start battery

The engine handbook will specify the start battery's capacity in amp hours, and also its current rating (often called cold cranking amps – CCA). The current rating will be high, typically 400 amps or more, but this current is required for a very short time, and to achieve this, the plates will have to be fairly thin.

This battery is not very suitable for supplying the general domestic services of a boat, but will be discharged by only a few percent at each engine start. For this reason, the plates don't have to be very robust, as long as they can withstand the vibration.

Service battery

This will need to deliver a relatively low current, mainly between 0 and 15 amps. The plates can therefore be thicker and thus more robust. It will need to withstand much deeper discharges between charges if it's going to power the boat's services when the engine isn't running or shore power isn't available. The thicker plates will allow it to achieve this. Even so, the service



BATTERY LIFE

battery shouldn't be discharged below about 50% of its capacity, because if it is, its life will be severely reduced in terms of how many times (or cycles) you can discharge it.

General purpose batteries

Unless the demands of engine starting are severe, you can use a battery that will fulfil both engine starting and service requirements satisfactorily. It will do neither job perfectly, but the average yachtsman will probably find this type of battery perfectly OK. They are often sold as 'marine batteries' or 'heavy-duty batteries'.

Deep cycle batteries

Deep cycle batteries have much thicker plates and are heavy. The 'deep cycle' adjective doesn't mean that you can discharge the battery much more than 50%, but it does mean that you can do so a greater number of times. Unless the battery is a 'traction' battery – extremely heavy duty and designed for fork-lift trucks, golf carts and the like – it will rapidly be destroyed by fully discharging it.

Some batteries are labelled 'heavy-duty' or 'deep cycle' when in reality they do not deserve the title, and it's often difficult to get the facts. One battery company that does publish information is Optima, from Sweden, whose Optima 'Blue Top' marine battery claims to have a BCI/SAE cycle life of 350 cycles of fully charged to 100% discharged. This is an excellent figure.

Batteries should be recharged as soon as possible after being discharged in order to prolong their life.

Maintenance-free batteries

Normal batteries lose water from their electrolyte during recharging and need to be regularly topped up with distilled or ionised water. Explosive hydrogen gas is given off in this process.

If the battery has more water to start with, has its charging current restricted and is almost entirely sealed, it will not need to be topped up during its lifetime. These 'maintenance-free' batteries have no means of being topped up. They must not be charged as rapidly as a standard battery and thus will take longer to charge, but if you have a standard regulator, you won't notice the difference. A mains battery charger will need to be set for maintenance-free charging. These batteries lose very little charge during storage and should be capable of starting an engine after being stored for 18 months. A standard battery will lose up to 1½% of its charge every week it's idle.

Some so-called 'maintenance-free' batteries have caps to each cell. If it's not sealed, it isn't maintenance-free and will need to be topped up as required.

AGM batteries

The thick plates are separated by fibreglass mats which absorb the electrolyte so are virtually spill proof and very robust. They have low self-discharge rates, are classed as deep cycle and are unsuitable for engine starting. They are tolerate high charging currents.

Gel batteries

The electrolyte is in the form of a gel and the plates are thin to allow the electrolyte to diffuse into the plates. Gel batteries are sealed, so can't be topped up, and the charge voltage must be kept low so that the battery does not gas. Very strict regulation of charging current and voltage is required and gel batteries take longer to recharge than wet ones.

Nickel Cadmium (Ni–Cd) batteries

Nickel Cadmium batteries are very robust and have a very long life, but are very expensive. They can be deep-cycled thousands of times, so are very suited to use on a sailing boat. Because they lose the ability to be fully recharged unless they are fully discharged, you really need two service battery banks so that one can be fully discharged before recharging. Each bank is used alternately. Their cost is justified only if you're going to keep the boat for a long time and are going to make heavy demands on your batteries.

MEASURING STATE OF CHARGE

The state of charge (how fully the battery is charged) can be determined by means of a hydrometer, which measures the specific gravity of the sulphuric acid solution, otherwise known as the electrolyte. The battery needs time to stabilise after charge, or discharge, before the state of charge can be determined.

Generally speaking, using a hydrometer is not convenient on a boat, and the specific gravity of fully maintenance-free batteries cannot be tested. It's much easier to determine the state of charge by measuring the battery's voltage, but to do so the battery must be 'at rest'. In reality, this means that the battery needs to have been neither 'on charge' nor discharge for around 3 hours and, again, this is not very practical.

Battery 100% state of charge

Meters that claim to be battery 'state of charge' meters just cannot work unless the battery has been at rest for 3 hours or so. In reality, they are just voltmeters with a different scale.

To get some idea of the instantaneous state of charge of your battery, you can use a voltmeter and an ammeter in conjunction. A fully charged battery at rest has a voltage of about 12.8 volts. Fully discharged, its 'at rest' voltage is about 11.8 volts. Both of these figures are reduced if a load is applied. In fact, try and start the engine with a fully charged battery and the voltage will drop to around 10 volts. Do that with a flat battery and the voltmeter will drop close to zero.

BATTERY STATE OF CHARGE	BATTERY VOLTS			
	RESTED	0 AMPS	5 AMPS	10 AMPS
100%	12.8	12.5	12.4	12.2
90%	12.7	12.4	12.3	12.1
80%	12.6	12.3	12.2	12.0
70%	12.5	12.2	12.1	11.9
60%	12.4	12.1	12.0	11.8
50%	12.3	12.0	11.9	11.7
40%	12.2	11.9	11.8	11.6
30%	12.1	11.8	11.7	11.5
20%	12.0	11.7	11.6	
10%	11.9	11.6		
FLAT	11.8	11.5		

If you observe the ammeter and the voltmeter together, this table will give a fairly good indication of the battery's state of charge, even while it's being used.

Using an amp hour meter

Another way is to use a sophisticated electronic circuit that integrates the current that has been flowing for a given time, does the sums and tells you how much has been used. With even more refinement, these meters can tell you how much charge you have put back into the battery by allowing for the efficiency of the charging process. They are not absolutely accurate, but are very effective (though expensive).

SULPHATION

Sulphation is a natural process during discharge and recharge cycles where a layer of lead sulphate is built up on the battery's plates and this layer reduces battery performance. Sulphation can be removed only by bringing the battery back to a full state of charge, and becomes a serious problem in deep cycle batteries that rarely get fully charged. Initially soft and porous, this layer hardens with time and, once hardened, it can't be removed, rendering the battery useless. For this reason, the battery should always be left fully charged.

Some charge regulators/battery chargers have an 'equalisation' or 'conditioning' setting that can be used monthly for those batteries that are regularly deep-cycled. Because high voltages (up to 16 volts) are used, all electronics must be disconnected during equalisation and must not be used for gel batteries.

SELF-DISCHARGE

Batteries not in use will discharge themselves over a period of time. Traction batteries self-discharge at as much as 1% per day – the higher the temperature, the higher the rate. General purpose batteries are better, and sealed lead acid batteries lose only 0.1% per day.

Because of this self-discharge, sulphation will occur and monthly recharging of non-maintenance-free batteries is required when the batteries are not in use.

AGEING OF BATTERIES

Lead acid batteries will last an extremely long time if they are never discharged more than about 5%. My last engine start battery was still going strong after 12 years. Service batteries, because of their regular cycling, will slowly suffer from irreversible sulphation and their effective capacity will fall. Regularly fully charged and never discharged below 50%, you may expect five or six years, maybe more. Mistreated batteries may not last two seasons.

If one cell fails, this will pull the voltage down, not only on that battery, but also on the whole bank. If the battery bank voltage has fallen to 12.5 volts or so, after being fully charged and rested for 12 hours, you can suspect a failure of one cell. There are three ways of checking which battery has the bad cell.

- Measure the specific gravity of each cell with a hydrometer. The bad cell will have a much lower reading.
- Disconnect all the batteries. Wait about 12 hours and measure the voltage of each battery. The bad battery will still be 12.5 volts or less, the others should have recovered a little.
- Disconnect all but one battery at a time and use it to turn the engine over. You'll need to prevent the engine starting by setting the stop control to stop or by decompressing the engine. The battery that drops below 9.5 volts has the bad cell.

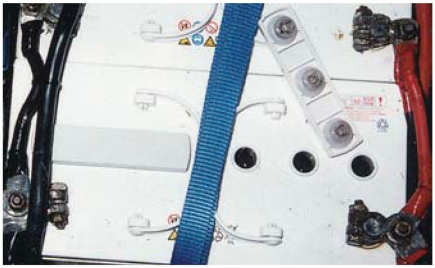
If the whole battery is suffering from sulphation, its real capacity will be reduced. To test this, discharge the fully charged battery by using a number of lights of known wattage for long enough to discharge it by 25% of its nominal capacity. Now measure its specific gravity or its 'at rest' voltage to determine its actual state of charge. The difference between the actual state of charge and the nominal 75% indicates the reduction in capacity.

So, for a nominal 200 amp hour battery, you want to remove 50 amp hours to reduce it to 75%. Four 10 watt bulbs on a 12 volt system would take 3.33 amps and would need to be run for 15 hours to remove the 50 amp hours. If, after 12 hours at rest, voltage is now 12.3 volts, the actual state of charge is only 50% rather than the nominal 75%. The lights have removed 50% of the capacity instead of the hoped for 25%, so the battery now has only half of its nominal capacity and it's time it was retired.

TOPPING UP LEAD ACID BATTERIES

Lead acid batteries (excluding genuine maintenance-free) need to be topped up with distilled water.

Batteries that are worked hard need attention more frequently, so start off by checking monthly and adjust the time period as necessary.



- Wipe the battery tops with a clean cloth.
- Remove the stoppers of each cell – these may be screw-in types or lift-off types.
- The liquid electrolyte should cover the plates by about half an inch (10 mm).
- Top up, if necessary, with distilled water – deionised water from a car accessory shop is the cheapest.
- Some batteries have a tube that reaches down to the correct top-up level descending from the filler neck – top up to the bottom of the tube.
- After you've finished, wipe the batteries down with a solution of bicarbonate of soda to neutralise any acid.
- Note the date that you topped up.

BATTERY BANK SIZE

Once you have calculated your likely electrical power consumption, you can start to consider the size of your domestic (service) battery bank. You need some more information before you can do this:

- How long do you wish to run without charging?
- Are you going to have a daily top-up without running your engine especially to do so?
- Do you have any other form of charging from, say, solar or wind power or a towed turbine?
- Do you have a fuel cell?

The easiest way to consider this is by illustration:

- You estimate that you have a need for 100 Ah per day.

- You will be sailing each day and anchoring at night and you have one 30 watt solar panel.
- Let us say that the engine will be running for a total of 1 hour per day, and that you have a 50 amp alternator with a 'smart' regulator. This should give you around 30 amp hours, or a little better if the battery is 'down a bit'.
- Assume that your solar panel will give 12 amp hours.
- With luck, you will have put 42 Ah back into the battery.
- This leaves a deficit of 58 Ah per day.

Now assume that you like to be out of the marina for four days, so you have a total need for 4 × 58 Ah = 232 Ah. Remember that we should not discharge our battery below 50%, so we need a service battery bank of 464 Ah. That's a lot of battery! Not only that, we now have to replace that 232 Ah.

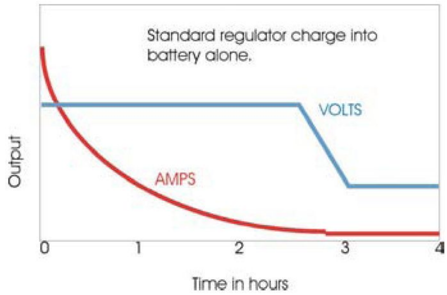
Obviously there are a number of factors over which you have control, such as fitting a bigger alternator and adding additional sources of charging.

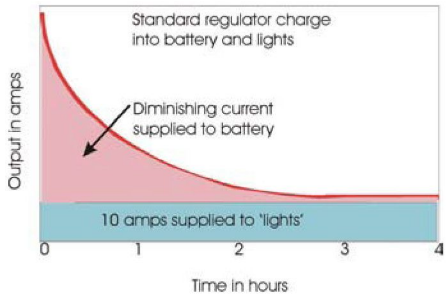
Another factor that can influence the size of the battery bank is that the rate of increase of charge is maximum from about 50% to 75% state of charge. If engine running is to be minimised or maximum effect from our charging source is to be achieved, then we should aim to maintain our battery's state of charge in this 50% to 75% range until we can recharge it from an external source. This means that you are effectively reducing the battery bank to only 25% of its rated capacity until you visit a marina or do a long passage under power.

On my own boat I have a 400 Ah service battery, a 110 amp alternator charging via a 'smart' regulator and two 32 watt flexible solar panels that I move around during the day to keep them out of shadow. Our use of power is modest at around 35 amp hours per day during the UK's summer, and as the solar panel can just about keep pace with the demands of our well-insulated fridge, we are just about self-sufficient. We have achieved eight days at anchor without running the engine, so I'm pretty happy with our set-up.

The biggest drain on our system is sailing at night, especially if we need to run the radar continuously, and in that situation we could have an average current draw of around 12 to 15 amps throughout the night.

BATTERY CHARGING





On a car, the alternator is used to supply the load, such as the lights and heater. The only battery charging it's designed to do is replenishment of engine starting load, which is pretty small, so if the battery gets really discharged, the car alternator is not really able to cope. This would be true on a boat that makes demands on its battery only when the engine is running. On most sailing boats the battery will need to be recharged, and this is true also on some motor boats.

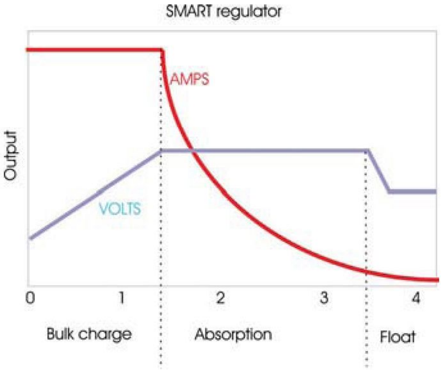
Unfortunately, the charge regulator on a marine engine is just the same as on a car. The alternator output is regulated in a very rudimentary manner and its output current is forced to drop sharply after a very short time in order not to overcharge the battery. So your battery never gets fully charged, and once your battery gets moderately discharged, you can't get it back above 70% in any reasonable engine running time.

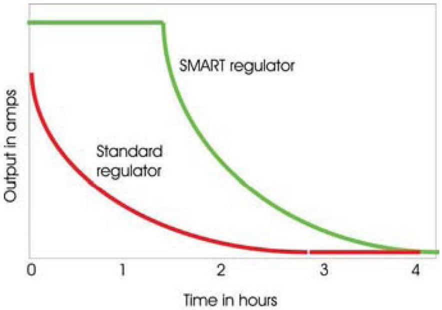
The charge entering the battery is about 90% of the area under the charging curve because of the inefficiency of converting the in-going current into battery charge. In 1½ hours' engine running you will be lucky to put 30 amp hours back into your battery with a 60 amp alternator. After 1½ hours, the in-going current will be little more than a 'trickle charge'.

If most nights will be spent connected to a shore power supply, this rudimentary charging system will be entirely adequate.

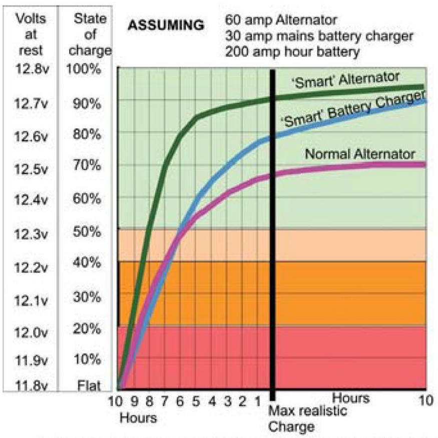
'Smart charge' regulator

The charging power of your existing alternator can be dramatically increased by fitting an external 'smart'





Charge into battery



TIME TO CHARGE THE BATTERY

Time to charge from 50% to 80% = 2 hours using 'Smart' alternator

regulator. Overcharging is prevented, while at the same time a high charging current is maintained for as long as it's safe, before the current tails off.

In any given time, the area under the charging curve is much greater, and the trickle charge stage is reached after a much longer time. This system will allow a battery to reach a 90% state of charge in a realistic time. In 1½ hours' engine running, our 60 amp alternator will put around 75 amp hours back into the battery, a considerable gain.

Whatever the type of regulator, the first hour of charging will give the greatest gain, because, after that, output is falling and it's not very effective to continue charging beyond 1 to 1½ hours, unless the engine would be running anyway.

However, when the battery is not fully charged, sulphation will occur, so the battery needs to be brought up to a fully charged state as frequently as possible. You need to balance maximum charging gain with sulphation and battery life to get the best possible cost effectiveness.

Charging from a mains battery charger

Cheap mains battery chargers recharge a battery in the same manner as a standard marine regulator. Unless you have plenty of time (days rather than hours) these are of little use on a boat.

Proper marine mains battery chargers work in the same manner as a 'smart regulator'. They have multiple stages of charge programme to enable the battery to be charged efficiently, i.e. to bring the battery to as high a state of charge as possible in the minimum time.

- *Bulk charge* maintains a constant current as the battery voltage increases up to the point at which 'gassing' occurs – typically 14.4 volts. Above this voltage the electrolyte begins to break down into hydrogen and oxygen gases, causing loss of electrolyte. This varies according to the type of battery and is normally set by a switch by the user.

- *Absorption charge* maintains the voltage close to the gassing point, and the charge current drops off as the state of charge rises, until the battery is fully charged.

- *Float charge* keeps the battery topped up and compensates for the battery's self-discharge. This float voltage is typically 13.5 volts.

Good battery chargers may be connected indefinitely without risk of overcharging, but do read the instructions.

At any time, the charger is able to supply any DC circuit that may be switched on, but this will prolong the time required to recharge the battery fully, especially during the bulk charge phase.

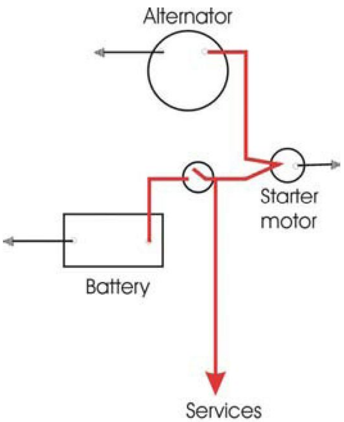
Some manufacturers refer to additional phases. In reality these are adding the inter-phase switching periods and the time supplying external loads as additional phases.

Most good chargers have the ability to run a desulphation programme, known as *equalisation*. This can harm the battery if used incorrectly, so make full reference to the charger's instructions, especially with regard to battery type, frequency of use and time the high voltage is applied.

If the requirement is to 'top up' your battery overnight, then its output in amps is as important as its programmed charge ability. For this you need to know how much you are likely to have discharged your battery or the capacity of the battery bank. Generally these two will be closely linked, so it's normal to match the charger output to the capacity of the battery bank.

A good starting point is that the charger's output should be about 10% of the battery capacity (ignore the engine start battery). If high battery loads will be applied at the same time as charging, you may need to add this extra load to the output of the charger.

If you have a 400 amp hour battery bank, then a 40 amp charger would be appropriate. If there were a continuous requirement for a further 10 amps for a fridge and a cabin heater, for example, this 10 amps should be added to give a 50 amp charger.



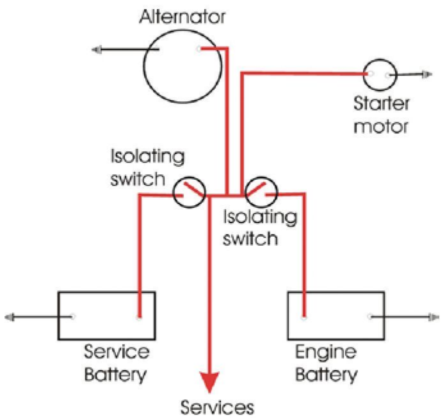
STANDARD SINGLE BATTERY CHARGING

Charging multiple batteries

Unless the electrical system is very basic, as above, there will be at least two batteries: an engine start battery and a service (house) battery. The service battery may comprise more than one battery, but these are permanently connected as one unit. Unless they are being charged, these battery 'banks' are always separated.

There are several ways of connecting and isolating battery banks, and each method has advantages and disadvantages.

- simple manual battery switching;
- using a blocking diode;
- using an 'ignition switch' controlled electrical relay;
- using a voltage-sensitive relay.



MANUAL SWITCHING multiple batteries

Manual battery switching

This is the simplest and best method of connecting battery banks for charging. You have complete control, and the only downside is forgetfulness.

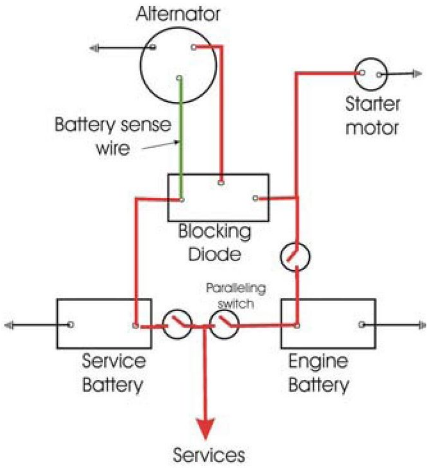
When you wish to charge your batteries, you decide which needs what and for how long. At the appropriate times, you make or break the various switches to control the charging procedure. This is the most efficient way of doing the job, and with proper control you can maximise battery life.

BUT, if you forget to isolate the battery banks after you stop the engine, you may not have enough charge left in the engine battery to start the engine.

Blocking diodes

Blocking diodes are solid-state, electronic 'non-return valves'. All the battery banks are connected to the charging system all the time, but electricity can flow in one direction only – from the charger to the battery. Electricity can't flow from battery to battery, so once the charger or alternator stops charging, the batteries are effectively isolated. Even when under charge, the batteries are isolated from one another, so it's possible to charge both maintenance-free and standard wet lead acid batteries at the same time. Being solid state means this system is very reliable and it's also completely 'fit and forget'.

Diodes have one inherent major disadvantage – there's a voltage drop across the diode's input and output terminals, so the battery gets about 0.7 volts less than the alternator's output. This prevents the battery from ever becoming fully charged. However, this problem can be overcome provided that the alternator is 'battery-sensed', i.e. that the alternator measures its output voltage at the external terminal rather than internally within the alternator. In this case, the 'sense' lead is attached to the output side of the diode, rather than the alternator's output terminal. The alternator will now produce more volts to compensate for the drop across the diode and the battery can become fully charged.



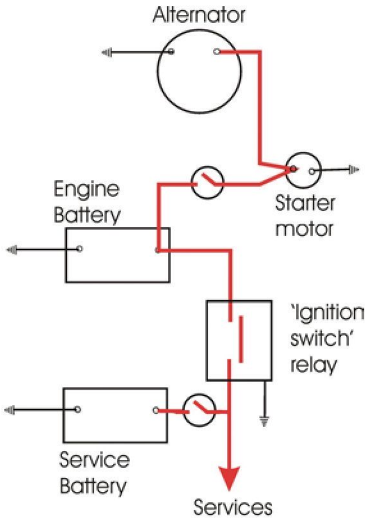
BLOCKING DIODE SPLIT CHARGE

Ignition switch controlled charging

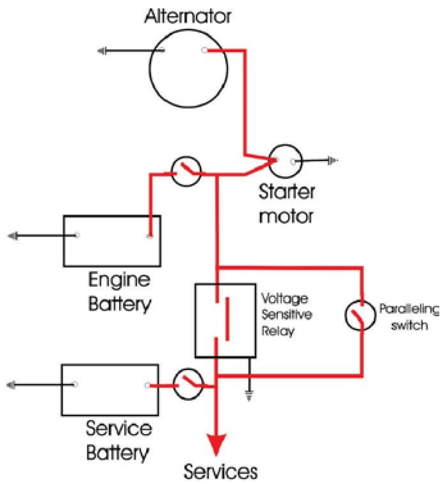
When the ignition switch is turned on, a relay is energised and the battery banks are connected for charging. With the ignition off, the battery banks are isolated.

While this sounds very simple, the disadvantage is that should you forget to turn off the ignition (some Volvos, for example, do not sound an alarm when the engine stops but the 'ignition' is still on), the batteries will continue to be connected, with the danger that the engine start battery may become discharged. Should the contacts stick, the battery banks will not isolate and, similarly, if the alternator fails, isolation will not occur until the ignition is switched off.

The relay's electromagnetic coils will take some power to hold the contacts closed.



'IGNITION SWITCH' CONTROLLED SPLIT CHARGE



VOLTAGE SENSITIVE RELAY
SPLIT CHARGE

Voltage-sensed relay

An electronic device operates the relay to connect the batteries together for simultaneous charging when it senses a rise in voltage, indicating the application of a charging source. When the charging voltage is removed, the device isolates the batteries. Connect and isolate voltages are sometimes user-selectable and they may protect against too high a charging voltage. Such a device is Heart Interfaces' *PathMaker*. Simpler devices are supplied by BEP and Blue Seas.

Although there is no voltage drop across the device and it can be used with any type of alternator, it does consume a small amount of power (0.3 watts–25 milliamps) when the batteries are isolated and there's no charging current.

Dual sensing VSRs allow any charging source on either battery to charge the other battery by combining the two. Useful if you have a mains battery charger or wind or solar charging.

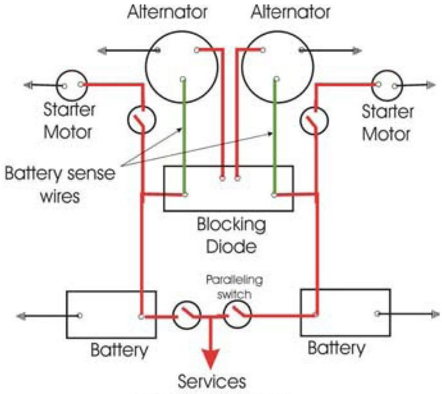
Method used	Advantages	Disadvantages
Simple manual battery switching	Very simple. Cheap	You may forget to do the switching. Engine battery may then become discharged.
A blocking diode	Fit and forget Can charge different types of wet lead acid battery at the same time. Medium cost.	Can't use with 'machine-sensed' alternators.
An 'ignition switch' controlled relay	Fit and forget. Cheap	Must remember to switch 'ignition' off.
A voltage-sensitive relay	Fit and forget. Can also sense other charging sources such as a battery charger.	Uses a small amount of power when 'off charge'.

MULTIPLE ALTERNATORS

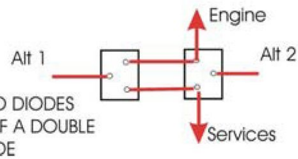
The easy way of harnessing the output of multiple alternators, either two alternators on one engine or separate twin-engine installations, is to have each alternator supplying separate battery banks.

A standard twin-engine installation has separate battery banks for each engine, with a temporary switch to join the banks together for engine starting should one battery be flat. This may be satisfactory when little demand is made on the batteries. It's a waste of alternator output if one alternator is charging its engine start battery while the other is charging the bigger service battery.

Because each alternator will have a slightly different output, it's not a good idea to join the two sets of batteries directly together, except for emergency engine starting. In this case, it's best to use a multiple-input split charge diode. This way, both alternators are charging all the batteries, but each battery bank is isolated from the others and each alternator is isolated from the other.



TWIN ALTERNATORS



USING TWO DIODES INSTEAD OF A DOUBLE INPUT DIODE

Electrical Supply

Power generation is always going to present a headache on a boat, unless it's permanently connected to a mains supply alongside.

The various elements of the electrical supply are interlinked in such a complex way that they need to be considered as one. How you interlink them will depend on how you use your boat and the demands put on the electrical system. The various elements are:

- engine-driven DC supply;
- wind-driven DC supply;
- solar panel DC supply;
- towed water generator DC supply;
- engine-driven AC supply;
- auxiliary on-board 'generator set';
- AC 'mains' supply.

These supplies are all intermittent, so an essential in the supply chain is an electrical storage battery.

A sailing boat differs from a motor cruiser only when underway, in that the motor cruiser will be generating electricity and the sailing boat often will not. Once they are moored or at anchor, they are equal.

Generally, new boats have only the most basic electrical supply system. The owner will have to upgrade the system if he is going to spend much time away from shore support. Even the boat's shore AC supply system is often an 'extra'. The only logical way to determine how, if at all, you need to upgrade your system is to calculate your electrical requirements. This requires two pieces of information for each item: how much power it consumes and how long it's switched on.

Then you need to see how the requirements compare with what electricity is available, if any, at the time you need it. This allows you to see if the requirement can be matched by a generation source, such as running your engine, or if electricity will need to be 'stored'.

You don't necessarily need to supply all your demands from the generating source. What you do need to do is to determine how long you wish to be able to run from your batteries before you need to recharge them from a 'primary' source, such as running the engine or shore power. Your 'secondary' charging sources just need to prevent your battery falling below a 50% state of charge in that time interval.

Power requirements underway – 8-hour trip

Item	watts	amps	hours	Ah/day	Duty cycle
Underway, Day, DC					
Instruments	3.6	0.3	8	2.4	
Radar	25–50	2.5–4.0	3	7.5–12	
Chart-plotter mono	3.6	0.3	8	2.4	
Chart-plotter colour	12–24	1–2	8	8–16	
Fridge	50	4	3	12	33%
VHF/DSC radio	3.6	0.3	8	2.4	
CD player/radio	12	1	2	2.0	
Autopilot	24–72	2–6	8	6–18	33%
Typically 40 Ah for 8-hour trip					
Underway, Day, AC					
Laptop computer	50	4	8	32	
Microwave	500	42	0.1	4.2	
Typically 36 Ah for 8-hour trip					

continued

Underway, Night, DC					
Cabin light (1 × 10 watt)	10	0.3	8	2.4	
Nav. lights (1 × 25 watt)	25	2	8	16	
Instruments	10	1	8	8	
Radar	25–50	2.5–4.0	3	7.5–12	33%
Chart-plotter mono	4	0.3	8	2.4	
Chart-plotter colour	12–24	1–2	8	8–16	
Fridge	50	4	3	12	33%
VHF/DSC radio	3.6	0.3	8	2.4	
CD player/radio	12	1	2	2.0	
Autopilot	24–72	2–6	8	6–18	
Typically 60 Ah for 8-hour trip					
Underway, Night, AC					
Laptop computer	50	4	8	32	
Microwave	500	42	0.1	4.2	
Typically 36 Ah for 8-hour trip					

A modern cruiser could easily consume 115 Ah for a 12-hour passage under sail. Frugal use of electrical power could reduce this to 35 Ah by using only essentials, such as navigation lights and instruments.

Power requirements moored for 16 hours – self-sufficient

Item	watts	amps	hours	Ah/day	Duty cycle
Moored, Day, DC					
Fridge	50	4	16	21	33%
CD player/radio	12	1	3	3	
				24	
Moored, Day, AC					
Laptop	50	4	0.5	2	
Microwave	500	42	0.2	8	
				10	

continued overleaf

Moored, Night, DC					
Cabin lights (4 × 10)	40	3.6	3	11	
Anchor light (1 × 10)	10	1	8	8	
CD player/radio	12	2	1	2	
Fridge	50	4	3	12	33%
TV	50	4	2	8	
				41	
Moored, Night, AC					
Microwave	500	42	0.1	4	
				4	

On a modern cruiser, 24 hours moored could typically consume 80 Ah. Frugal use of power could reduce this to 35 Ah per day. Additionally, if a diesel-powered heater is used, expect to consume 4 Ah per hour run.

Power requirements alongside with shore power

Item	watts	amps	hours	Ah/day	Duty cycle
DC 12 volts					
Cabin lights	60	5	4	20	
CD/radio	12	1	4	4	
TV	50	4	2	8	
Fridge	50	4	8	32	33%
				64	
AC 240 volts					
Microwave	600	2.5			
Electric kettle	2000	8.3			
Toaster	2000	8.3			
Battery charger	500	2.1			
Electric heater	2000	8.3			
Immersion heater	1500	6.3			
Total	8600	35.8			

Normal pontoon power is 15a. It is obvious that only selective use can be made of 240 volt items.

12 VOLT DC CIRCUITS

Except in the most basic boat systems, there will be at least two batteries. It is sometimes recommended that, for a twin-battery system having two batteries of the same capacity, alternate use is made of each battery for engine starting OR supplying the boat's services. This is to ensure equal life for both batteries. I don't go along with this method, as a battery used only for engine starting will last a very long time and engine starting is thus assured, which, to my mind, is very important. The other battery, which has constant discharge/charge cycling will not last as long, but its failure will not be as important and can be anticipated. As soon as the domestic battery gets much bigger than the engine battery, this debate doesn't arise.

Thus, one battery will be reserved for engine starting only, to ensure that there will always be sufficient electrical charge to start the engine. The other will be used to run the boat's services, such as lighting, instruments, radio, etc. This means that the engine circuit and the service (domestic) circuits are isolated. Some form of temporary connection will be required when charging the batteries (see Charging multiple batteries on p. 28, and the figures on p. 38) and for emergency starting should the engine start battery become discharged.

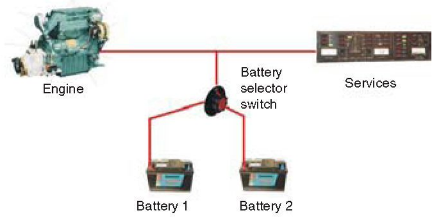
Battery switches

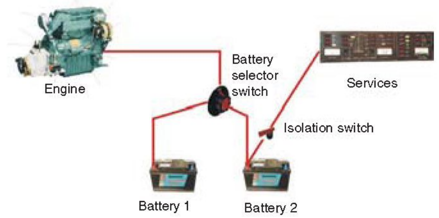
Switches are required so that circuits can be isolated from their batteries as a safety measure. A switch will also be necessary to combine the circuits for charging and emergency starting. These switches may be required to carry in excess of 300 amps in the case of engine starting, so high-quality, heavy-duty switches are required. Not all cheap switches meet the high-quality requirement, and wear may cause the circuit to break unintentionally. This can cause expensive damage to the alternator if the engine is running.

A common type of switch is the 'OFF-1-BOTH-2' battery switch, but this has a serious disadvantage on boats fitted with voltage-sensitive electronics such as a GPS.

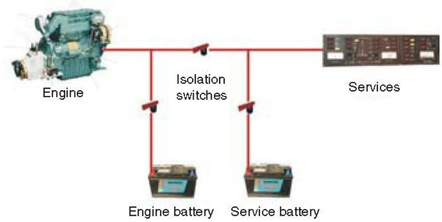
During engine start, the voltage on the engine battery may well fall to a value below that at which the GPS automatically switches off. The problem is that, however the switch is set, when wired conventionally, the engine starter motor AND sensitive instruments are all supplied by the same battery while the engine is started.

Many production boats suffer from this problem, and a modification should be made. This comprises supplying the services direct from the battery via an isolation switch, rather than from the existing switch, which is then used only for determining which battery is used to start the engine.





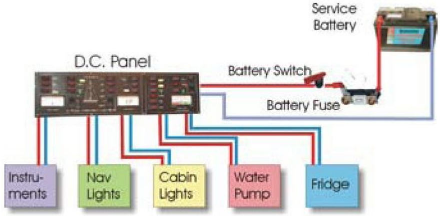
In fact, rather than fitting an 'OFF-1-BOTH-2' switch, three separate heavy-duty 'ON–OFF' switches are a better option.



An 'ignition switch' controlled 'battery combiner' has the same effect, in that sensitive instruments may switch off while the engine is started.

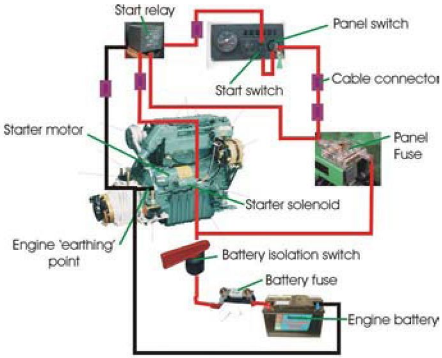
Service 12 volt DC circuit

The complexity of the service circuit will vary according to the size of the boat and the on-board systems. However, a simple block diagram can illustrate the basic principles.



12 volt Service Circuit

The EU 'Recreational Craft Directive' (RCD) requires boat builders to supply a wiring diagram with a new boat. Some builders' wiring diagrams are derisory. Wires will commonly be red or black, and unless they are labelled, tracing wiring to various components can be difficult.



Only the wiring associated directly with the engine start circuit is shown

Reproduced by permission of Volvo Penta Europe.

Engine 12 volt DC circuit

The engine manufacturer will have supplied a wiring diagram in the engine's handbook. Multicoloured wires are bundled in 'looms', but following the colour coding enables all wires to be identified.

Some installers are against fitting a battery fuse in the engine start circuit, because if it blows with the engine running, the alternator diodes may 'blow'. While this may be true, a fire due to a short circuit will be much more catastrophic than blown diodes. I prefer to fit a fuse.

ENGINE-DRIVEN 12 VOLT DC ALTERNATOR

Depending on the size of the engine, the alternator will usually have a maximum output of between 35 and 60 amps as standard, although it's possible to fit one of higher output. Higher outputs often require a multi-belt drive to prevent belt slip.

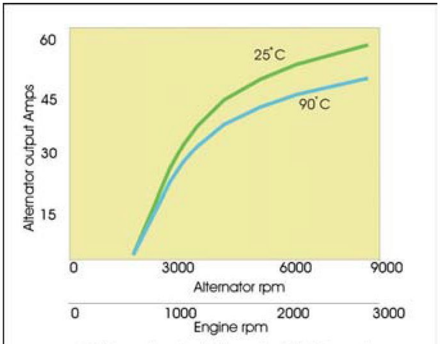
Modern alternators (as opposed to DC dynamos) generate alternating current (AC) and convert this into direct current (DC) to charge the battery. The voltage is regulated at a nominal 12 volts (or 24 volts) to charge the battery and supply the electrical loads.

The battery must *never* be disconnected from the alternator when the engine is running or the alternator's 'diodes' will be destroyed. In other words, DO NOT switch off the engine battery switch when the engine is running. Not all battery switches are of the same quality and unless yours is marked with a well-known maker's logo, one circuit may be broken before the next has been selected. If in doubt, don't even change the battery selection with the engine running. Some 'single' battery switches may lose contact, as they wear even when switched on.

Alternator output

You would be wrong to think that a 60 amp alternator will deliver 60 amps as a matter of course. Three things materially affect output: alternator speed, alternator temperature and the load to which it's connected.

Alternator output will depend on how fast it is turning (rpm). Any particular alternator has a maximum speed, and so its driving pulley size is calculated so that this maximum rpm is not exceeded at the engine's maximum speed. For instance, if the alternator maximum rpm was 9000 and the engine maximum speed 3000 rpm, the gear ratio would normally be chosen as 3:1.

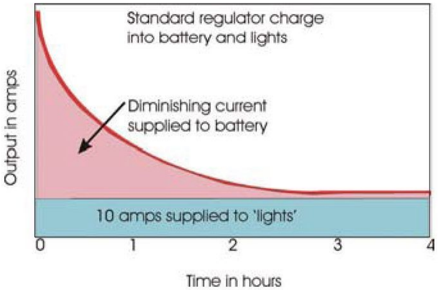


A 60 amp (nominal) alternator with 3:1 gearing

So, if we run our engine at 1500 rpm, the alternator speed will be $1500 \times 3 = 4500$ rpm. Its output will be less than 50 amps. If the engine compartment is very hot, then the output may be only 40 amps. If the engine is running at idle rpm, the alternator output is little more than a 'trickle' charge.

In order to control its output, the alternator needs to know the battery voltage. On many alternators it does this by sensing the output voltage inside the alternator. This is fine if the wiring runs are short, the terminals have good contacts and there's no split-charging diode. This is known as *machine sensing*. Far better is *battery sensing*, where the output voltage is sensed at the battery terminal, because there may be a considerable voltage drop between the alternator and the battery. If this is the case, the battery can never be fully charged.

The alternator must always supply any user of electricity via a battery. The alternator is never connected directly to the 'load'. Provided that the alternator has sufficient output, it will always supply enough amps to satisfy the load. In other words, if the lights need 10 amps, the alternator will supply them with 10 amps.



If the alternator was supplying 10 amps to the lights AND charging the battery, its output would be 10 amps constant for the lights PLUS a diminishing charge going into the battery.

How big should the alternator be?

There are two considerations here: What is the maximum load at any one time? How big is the battery bank?

- Normal electrical loads are always satisfied from the alternator's output.

- This normal requirement may reduce the charge going into the battery.
- The alternator will never satisfy high-current loads, such as anchor windlasses and bow thrusters.
- These high loads are supplied by the battery, with the engine running at the same time to reduce battery drain and a fall in battery voltage under this load.
- There's a relationship between the alternator output and the maximum size of battery bank it can realistically charge.

Charging batteries is a complicated science, but as far as we are concerned, it's easy to use a rule of thumb which says that maximum charging current (amps) needs to be about one-third of the battery capacity (amp hours) for efficient rapid battery charging. In other words, the battery capacity should be no more than three times the alternator output.

A standard 60 amp alternator is, therefore, suitable for charging a 180 amp hour service battery bank. It's usual to discount the engine start battery, because generally it's pretty full anyway.

If you are going to have heavy use of your battery over a weekend, but then take all week to charge the battery on mains power, the size of your alternator compared to the size of the battery is not so important.

You should never allow your battery to become more than 50% discharged, as discussed in the chapter 'Batteries'.

Generally, unlike a car, the size of the alternator is dictated by the size of the battery bank. If you increase the size of your battery bank, you may need to fit a bigger alternator or a second alternator.

A bigger alternator

The standard belt drive may need to be upgraded if you fit an alternator of higher output. Its capability will depend on the contact angle of the belt, its section and its tension. A wide 'poly belt' or multiple belts may be required. I have found that the capability of a single belt can be increased by using a high-temperature belt in combination with machined pulleys, rather than the standard pressed steel type. An overworked belt will shed a lot of black dust and will fail after only a few tens of hours.

A second alternator

By fitting suitable brackets to the engine, it may be possible to fit a second alternator being driven by a second belt and pulley system.

Consult the engine manufacturer to ascertain the maximum side thrust loadings allowed on the crankshaft.

Think about how you will connect them electrically, see the section on battery charging in the chapter 'Batteries'.

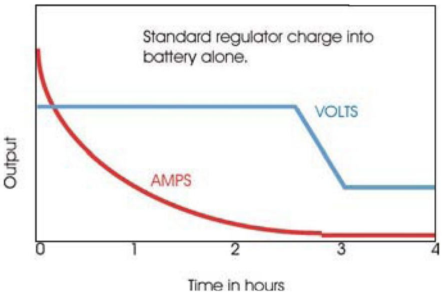
Starting load

A bigger than normal load on the engine when starting from cold with well-discharged batteries may have undesirable effects, such as difficult starting or black smoke after starting. It's almost certain that you will choose to fit a 'smart' regulator if you upgrade your charging system (see battery charging in the chapter 'Batteries') and some of these have a time delay before the alternator starts to charge to overcome these problems. This is a desirable feature.

These problems can occur even with a standard system and I've recently discovered that a modification to the Yanmar 1GM10 fitted with a saildrive leg was made in 1992 but not included in the handbook. To prevent problems with cold starting, the alternator does not produce a charge until the leg's oil temperature reaches 25° C. The alternator warning light was changed to illuminate when the alternator was producing current, rather than the normal warning function. This resulted in owners having undercharged batteries if the engine was run for only a short period of time, so you need to allow for the non-charging period when charging your battery.

Voltage regulation

A standard 12 volt alternator has a varying output voltage according to the state of charge of the battery. It will



charge at a constant voltage of around 14.2 volts with a diminishing charging current. When the charging current drops to a couple of amps, the voltage will reduce to about 13.2 volts. These voltages are doubled for a 24 volt system. As we have seen, this primitive system of regulation will never fully charge our batteries.

AC 'MAINS' SUPPLY

Being able to connect to a dockside mains-power system allows the use of mains-powered equipment, such as an electric kettle, and also provides a chance to charge the boat's batteries.

It is highly unsatisfactory to rely on an extension lead and 13 amp socket to supply the boat with AC power.

Any work undertaken on AC circuits by unskilled people is potentially lethal.

Normal mains AC supply is 'three wire' – live, neutral and earth – with the earth voltage at zero volts relative to earth. This is achieved by *grounding* the earth wire with a metal spike driven into the ground, hence its name.

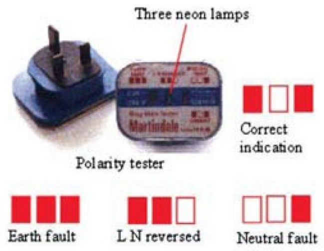
The boat's DC ground is achieved by connecting the DC circuit's negative wire to the hull's external anode, so that the 'negative' is the same 'zero' volts as the sea (or lake or river).

The shore supply

In the UK, the shore supply socket is normally rated at 15 amps, although some marinas have a 30 amp supply available at some berths. There are usually several 15 amp sockets at each supply point, and if you exceed the rated load for your socket, you may well 'trip out' the others at that point. Often, only the marina staff can reset these circuit breakers.

It is not uncommon to find some sockets incorrectly wired so that neutral and live contacts are reversed, so fit a polarity indicator to your boat's AC control panel.

If one is not fitted to the boat's AC panel, plug a domestic 13 amp socket tester into a 13 amp socket instead.



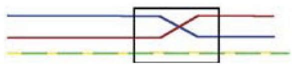
If you find a socket incorrectly wired, inform a member of the marina staff. To temporarily overcome the problem, your 'kit' should include a polarity reverser. Some upmarket boat control panels have a built-in facility to do this. Generally though, you will need to make up your own.

In the USA, where 115 volts is the norm, some marinas have a 240 volt supply available by using two phases of the 115 volt system. This will, by the nature of the wiring, indicate that you have reverse polarity. This is due to the way the 240 volts is obtained and the way the tester works, so you don't need to use your reverser lead.

If the reverse polarity of the shore supply is not corrected, all switches are operating in the neutral wire and the positive wires are unswitched. A fault in the wiring or appliance will not operate a single pole circuit breaker and a dangerous condition can result, especially in a damp marine environment.

DIY polarity reverser

Make up a short shore power lead and reverse the neutral connections on plug OR socket. Mark this reversing lead clearly so that you know what it does. The cable should be of the same current-carrying capacity as your shore-power cable. If you find that the polarity of a shore-power outlet is reversed, plug your reversing lead into the shore power outlet, and then your normal shore power lead into the reverser's socket. Now check that your final polarity is correct.



The shore-power cable

If you normally plug into a 15 amp socket, your cable must be capable of carrying 15 amps. The cable size will depend on its length as well, to prevent too much voltage loss. Unless the cable is very short, it should be of 2.5 mm^2 section. Use outdoor (flexible) round cable with a proper plug and socket to fit the shore-supply socket and the boat's connector. If you keep the cable on a reel, uncoil all the cable before you switch on the power, or dangerous overheating of the coiled cable is possible. For this reason, several shorter cables, rather than one very long one, are probably more convenient.

Always connect your cable to the boat first and the shore socket last. When disconnecting, disconnect the shore cable first, so that if the end should fall into the water, the free end will not be live.

If your shore-power cable plug or socket contacts look corroded, they could be much worse on the inside!

The boat's AC circuits

AC earthing (grounding)

The shore supply is grounded ashore, and there are different schools of thought as to whether it should be connected to the ship's DC ground. On many boats there's no interconnection between the AC and DC grounds. Recommended practice at the moment is to make a connection, but corrosion of underwater fittings is then a distinct possibility.

No interconnection between shore AC ground and ship's DC ground

If the AC and DC grounds are not interconnected, the only ground connection is via the shore-supply cable. *Any failure of that ground connection due to poor joints or corroded connections could cause the casing of an appliance to become live if a fault occurs, and bring danger of electrocution to anyone touching it.*

Connecting the AC ground to the ship's DC ground

- Should an AC short to earth occur on the boat, complete safety is assured to its occupants as there will always be a path to ground.
- Because it's unlikely that the shore-side ground and the ship's ground will be at exactly the same voltage, stray current corrosion is likely to occur to the boat's underwater metal components.

- Should an electrical fault occur in the AC circuit sending current to the ship's ground, nearby swimmers are at risk of an electric shock.

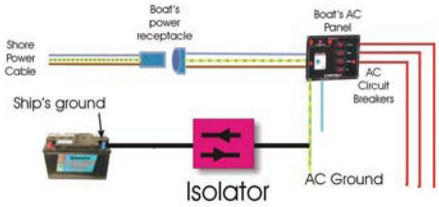
Stray current corrosion due to the difference in voltage between AC and DC grounds can be prevented by fitting a galvanic isolator between the two. This isolates the two circuits if a small voltage difference is present (up to about 1.5 volts) but allows free conduction for larger voltages, such as when a short to ground occurs. Even then, there are disagreements as to where it should be fitted.

Isolator between AC ground and DC ground

This would seem to be the ideal position, because, except in the case of a short to ground, there is no effective connection between the grounds, and stray current corrosion will not occur due to any voltage difference between the grounds.

However, if there is any interconnection between the grounds in any one piece of equipment, such as a generator set or a cheaper, non-isolated battery charger, the isolator is bypassed and may just as well not be fitted.

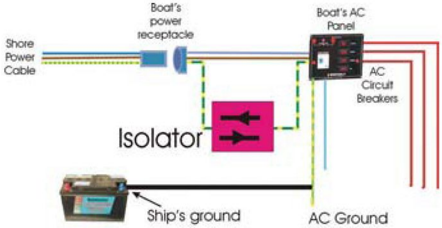
Provided that all AC equipment is isolated from the ship's ground, I believe that this is probably the best solution.



Isolator separating ship's ground and AC ground

Isolator fitted in the ground line as it enters the ship

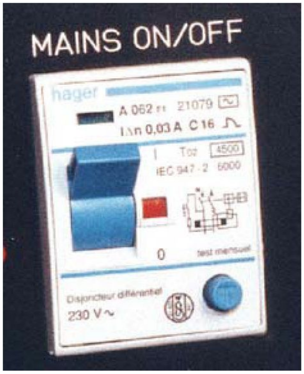
This effectively means that there is no ground connection to shore unless there is an accidental short to ground, so in normal circumstances, the ship's ground (anode) is the only one present. This means that any mains AC fault will be led to the ship's anode. It is safe for those on the boat, but not to swimmers nearby, if a short to ground occurs, as they could feel the full force of the mains 240 volts.



Isolator breaking shore supply ground line

As far as stray current corrosion is concerned, differences in voltage of the two grounds are avoided (because there's only one). However, it is argued that because of the resistance of the isolator, stray currents produced by on-board AC devices may actually increase corrosion to hull-mounted hardware.

If there is any chance of AC equipment having a connection to the ship's ground, this is the way to connect the isolator, but there may be increased corrosion of hull-mounted hardware.



The boat's AC wiring

Residual current devices (RCDs)

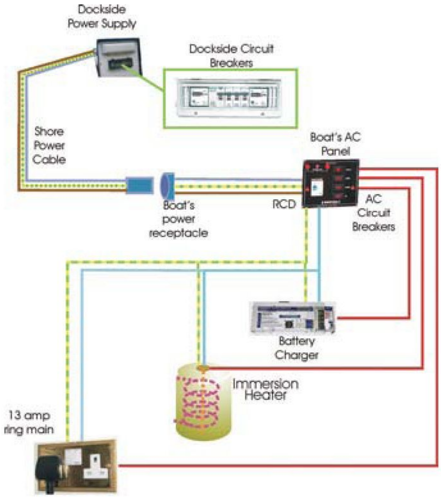
The boat's AC distribution panel should incorporate an RCD (or residual current circuit breaker – RCCB) In a circuit that is operating normally, the current flowing through the live and neutral wires is the same. If a short to ground occurs, current flows to earth, causing an imbalance in the live and neutral wires that is detected by the RCD, causing it to trip. RCDs are very sensitive, and in the marine environment, small earth leakages are common. These do not affect the operation of the appliance, but several small leakages together can cause the RCD to trip. This nuisance is often very difficult to cure and can cause the shore-side breaker to trip as well, much to the annoyance of other users.

To eliminate this problem, make sure all the terminals are clean and install them in a dry compartment. Don't install the AC shore connection or its breakers in a cockpit or transom locker because they are likely to be much damper than the inside of the cabin.

AC circuit breakers

Each on-board AC circuit should be protected by a circuit breaker. If a short circuit occurs, the high current flowing through the circuit breaker will cause it to trip. The size of the breaker, in amps, should be matched to the current-carrying capacity of the cable and the power consumption of the appliance. Normally on a boat, the shore supply will be 15 amps, which must not be exceeded by the appliances that are actually switched on at the same time. A correctly wired on-board AC circuit will use cable that will handle 13 amps (normally it will be 2.5 mm^2) so it would be usual for the

AC circuit breakers to be rated at between 10 and 16 amps. The maximum single appliance load, so that 13 amps is not exceeded at 240 volts, is 3120 watts.

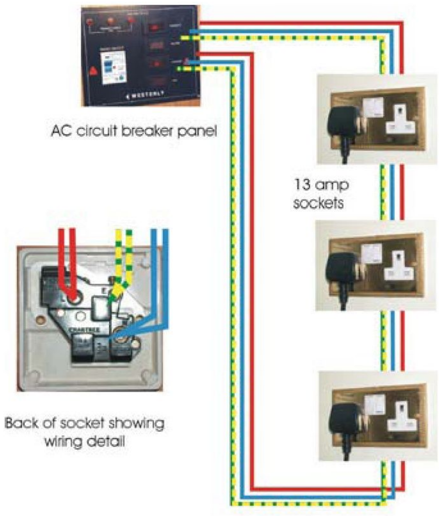


Boat's AC power circuit

Wiring electrical sockets (outlets)

Ring mains

Normal house wiring practice is to use a *ring main*. Current can be fed either way round the circuit, allowing current of double the rating of the wire, but this needs twice the length of wire. As normal domestic 2.5 mm^2 cable can carry 20 amps, because the current can arrive along both arms of the ring at the same time, wiring as a ring main means it can carry a maximum of 40 amps.

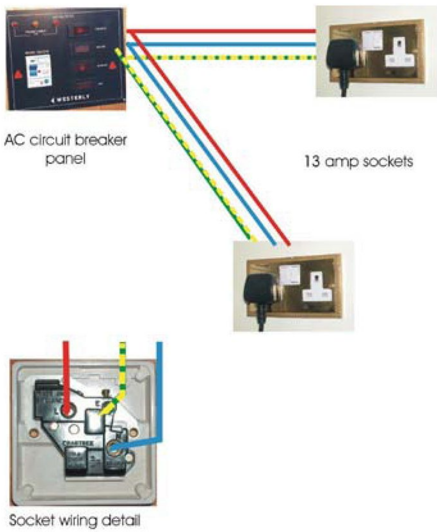


AC ring main

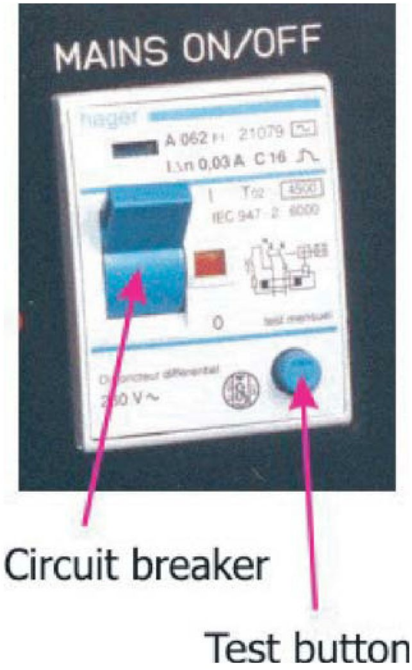
On a boat connected to a 16 amp shore supply, the maximum current available is less than the carrying capacity of a single 2.5 mm^2 cable, so running a ring main may be a waste of cable.

Spur wiring

Single 2.5 mm^2 cable is run from the circuit breaker to each socket. This may save cable, but if you have a lot of sockets, there will be a lot of connections to the circuit breaker. This may not be practical unless you use a junction box.



Spur wiring



Don't use domestic 'flat', single-core cable on a boat. It is too rigid and too brittle. Use 'round', multi-strand cable.

Most boats use domestic quality cable, circuit breakers and sockets in the AC circuits and these aren't designed for a marine atmosphere. You need to look out for corrosion and replace the components as necessary.

Isolating transformers

Some authorities recommend the use of isolating transformers. These are inserted between the shore supply and the boat's AC circuits, and the current is transferred from one to the other magnetically. There is no direct connection between the two.

The arguments for and against the use of isolating transformers are complex, but it is generally accepted that the use of an RCD gives excellent protection against the chance of electrocution, and fitting an isolating transformer is not common in Europe.

Test the RCD regularly by operating its test button. The circuit breaker should trip immediately the button is pressed.

AC FROM DC

When you're not tied up alongside with AC mains available, or if you haven't got an on-board generator, you can get mains AC current from your DC supply. Unless your AC demands are very modest, the drain from your batteries can be huge.

Conversion is done by using an electronic device called an *inverter*. AC voltage varies cyclically 50 or 60 times a second, and the steady voltage of a DC supply is changed into a varying voltage that resembles the AC's sine wave.

The current drawn from your DC battery is found by multiplying the AC current by the AC voltage divided by the DC voltage and dividing by the inverter's efficiency as a decimal.

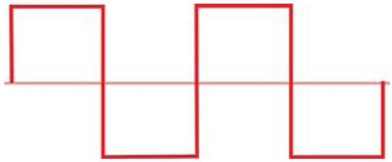
A 90% efficient inverter powering a 240 volt appliance requiring 10 amps will draw:

$$(240 \times 10) / (0.9 \times 12) = 222 \text{ amps}$$

Even when supplying no power, an inverter will have a small current draw from the battery, so needs to be independently switched.

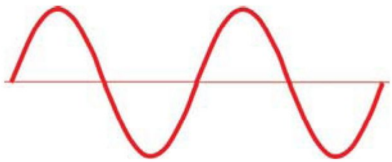
Square wave inverters

These cheap inverters change DC into a very crude square waveform that is often incompatible with the AC appliance.



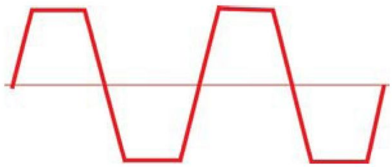
Sine wave inverters

These produce a waveform almost indistinguishable from true AC and are costly to produce, but will run any AC device.



Quasi-sine wave inverters

These form a 'half-way house' (often called modified sine wave). Some produce near sine wave AC, while others are much closer to a crude square wave, especially under load. Price is usually an indication of sine wave quality, but not always so. Sensitive electronic equipment, such as TVs and stereos, can be upset by poor sine wave quality. Ensure that the inverter you buy is compatible with its intended use.



Small, portable inverters, up to about 350 watts

These are usually plugged into a 'cigar lighter' socket and are suitable for powering laptop computers, telephone chargers and the like. At 350 watts, they are using 30 amps (12 volt DC), and the wiring and fuse must be capable of carrying this load.

There are many small inverters on the market, and some small, cheap inverters will not deliver their advertised power output continuously, so the sine wave may be poor.

Reproduced by permission of Victron Energy

Larger inverters, up to about 800 watts

Capable of running electric drills, blenders, small microwave ovens and the like, they really need to be permanently wired directly to their own circuit breaker and battery switch, because they draw up to 70 amps.

Using a 600 watt appliance for 10 minutes will take about 8 amp hours from your battery. Run for an hour, it will use 50 amp hours.

They should have one or two 240 volt outlets, completely separate from the mains 240 volt sockets.

Large inverters, up to about 3000 watts

At 250 amps, these are permanently wired to the battery system and supply the boat's AC 'ring main'. They must never be joined to the mains AC, so special switching is fitted to ensure automatic changeover to the mains when shore power is connected.

A 3 kW appliance will reduce a 400 amp hour battery to a 50% state of charge in around half an hour.

Some larger inverters double as mains battery chargers, so when connected to shore power, the batteries can be recharged.

AC equivalent of DC loads to size inverter

AC appliance	watts	start-up load watts	start-up current DC amps	running current DC amps	running time in 24 hr	DC amp hours in 24 hr
Blender	300	600	56	28	0.08	2
Desktop computer	300			28	2	56
Electric drill	350	600	56	32	0.08	3
Hairdryer	1000			93	0.08	7
Iron	1000			93	0.5	46
Kettle	2000			185	0.5	93
Laptop computer	50			5	2	9
Microwave oven	600			56	0.5	28
Midi Hi-Fi	100			9	4	37
Toaster	1000			93	0.08	7
TV	100			9	2	19
TV/video recorder/DVD	150			14	2	28
Vacuum cleaner	1000			93	0.08	7

Small inverters do not make huge demands on a boat's DC system. Anything more really needs a daily dose of shore power (or a generator running) to top up the batteries and is really suitable only for day use for those who must have more powerful mains appliances during day sailing.

ENGINE-DRIVEN AC SUPPLY

It's possible to have a 'mains' voltage AC alternator driven from the engine. These are of use where AC-powered equipment, such as a cooker, etc., will be used during periods of normal engine running. They are belt driven and absorb quite a lot of engine power, and the electricity from these units cannot be stored.

If you require an AC supply while underway with the engine running, fitting a mains-voltage, engine-driven alternator may be a sensible option. However, if you want AC power while the boat is moored, having to run the main engine to obtain it may be a poor option, as the engine will be running under too little load – a bad practice. A better, but more expensive, option is to use a *generating set*, where the engine power output is matched to the electrical load. Take specialist advice if you are going to have one of these.

GENERATING SETS

Generating sets comprise a diesel engine (sometimes petrol) driving an AC alternator and are often called *gensets*. They generate AC at mains voltage, either 110 V or 240 V, to supply domestic electrical equipment. They are usually supplied in a soundproof cocoon, and because on-board space is at a premium, they are often 'shoehorned' in, making access for maintenance severely restricted.

Built-in generator sets are normally powered by a diesel engine that will need to be supplied with cooling water and fuel, just like the propulsion system. They can produce an intrusive exhaust noise nuisance to other boats nearby and should not be run all night. Some harbour authorities limit their hours of use.

The boat's AC circuits will be supplied by either the shore power OR the genset. As the mains frequency may not be identical nor in phase with those of the genset, they must not be used to supply the boat's AC circuit simultaneously. Generally, this is prevented by an automatic interlocking system which ensures one is disconnected before the other is connected.

Gensets are designed to be self-monitoring and will shut themselves down automatically if a fault occurs. Failure of a genset to start may be due to a fault detected by the monitoring system or a fault in the monitoring system itself. The genset should be provided with a troubleshooting guide covering all these aspects.

The genset will normally use its own separate engine start battery, charged by a 12 volt DC alternator driven by the genset's engine.

Power output

These machines are rated not in kW but in kilo Volt Amps (kVA). The reasons need not concern us here, just think in terms of 1 kVA being equal to 1 kW. (Not strictly true, but near enough for our purpose.)

A small one will produce 2.5 kVA and larger boats may fit 10 kVA gensets. These machines take up a fair bit of room and are not cheap. If you must fit one, a 2.5 kVA machine will not supply very much AC power (several thousands of pounds is a lot of money to power just one electric kettle!) and a 4 kVA set is probably the lowest entry point.

Grounding (earthing)

The genset AC earth connection will be to the boat's AC grounding system, and thus to the shore power system if fitted. The genset's engine will probably be connected to the boat's DC earth system.

There are conflicting views on if and how the AC ground is connected to the boat's DC ground. This is sometimes done directly and sometimes via an isolator. The issues involved concern both electrical safety and electrolytic corrosion.

Professional advice should always be sought in the design and installation of a boat's genset system, which is beyond the scope of this book.

FUEL CELLS

Fuel cells bring a new technology to the marine leisure market. At the time of writing (2006), Max Power's AHD-100 is the only one on the market, and this compact unit burns methanol at the rate of 1.2 litres per kilowatt hour. The byproducts of combustion are water (non-potable) and a tiny amount of CO_2 (less than a baby would exhale in a night).

Reproduced by permission of Max Power

This fuel cell is designed to deliver a maximum of 100 amp hours per day, but actually produces electricity only on demand when connected to your battery bank, which acts as a buffer.

The use of a fuel cell can radically alter the design of your 12 volt DC power supply system, because the battery now has to be big enough only to supply demands of greater than 4 amps, the maximum output of the cell. Large battery banks could be a thing of the past!

If your total amp hour requirement per day is 120, then 100 could be supplied by the fuel cell and only 20 need come from electricity stored in the battery. However, if your daily requirement is 80 Ah, then the battery would need to temporarily supply any current in excess of 4 amps, but the fuel cell would need to generate only 80 Ah per day while keeping the battery fully charged.

Thus, the battery capacity need be only twice the daily deficit (above 100 Ah) for as many days as you want to be self-sufficient. For five days without running the engine, you would need a battery capacity of 200 Ah in the first example, rather than 1200 Ah without the fuel cell!

Advantages of fuel cells

- much reduced battery bank size and weight;
- very compact – the unit measures 150 mm × 380 mm × 260 mm and weighs 7 kg;

- very quiet – 47 dB at 1 metre;
- no installation costs or worries.

Disadvantages of fuel cells

- cost – around £3000 in 2006;
- cost of fuel – methanol costs £40 for 5 litres, which gives about 300 Ah;
- storage of flammable fuel – 5 l per 300 Ah.

RENEWABLE ENERGY

There are a number of ways that can allow a cruising yacht to be self-sufficient in its energy needs. Each is covered fully in the sections that follow.

1. Solar power
   Solar panels, otherwise known as photovoltaic panels, can convert the energy of the light falling on the panel into electrical energy. The process is not currently very efficient, the best being around 16%. The intensity of sunlight varies during the day and is dramatically reduced by the presence of shadows, from both clouds and structures. Along the south coast of the UK, the average number of hours of sunlight per day in July is about 7, but these will not all be equally bright. The panels must be kept clear of any shadows and need to be angled towards the sun.

2. Wind power
   A wind turbine can be made to drive a generator to produce electricity. In comparison with solar power, these are relatively efficient, but work only when the wind is blowing. They also need a minimum of 6 knots to start producing any electricity at all and produce only about 2 amps at 12 knots, the average wind found along the UK's south coast. They can, however, harness whatever wind is blowing for the full 24 hours each day.

   When used under way, the output is reduced considerably when running before the wind, due to the reduced apparent wind.

The turbine needs to be mounted clear of any wind eddies coming off the boat's rigging, structure and sails, and so needs to be mounted as high as possible. This also avoids decapitating the crew!

3. Towed water turbine
   A water turbine can be towed and driven by the boat's forward speed though the water. Outputs as high as 8 amps can be obtained at a boat speed of 8 knots. A conventional towed turbine has to be rigged after the boat has got under way, and de-rigged prior to stopping, so is generally used only for longer passages.

Satisfying the power requirements

Unless your power requirements are modest, it's unlikely that a single source of power will satisfy your demands. As an example, on the UK's south coast, a single 60 watt solar panel could contribute up to 30 amp hours per day, a wind turbine up to 24 amp hours per day and, on an 8-hour passage at 5 knots, a towed turbine 24 amp hours per day.

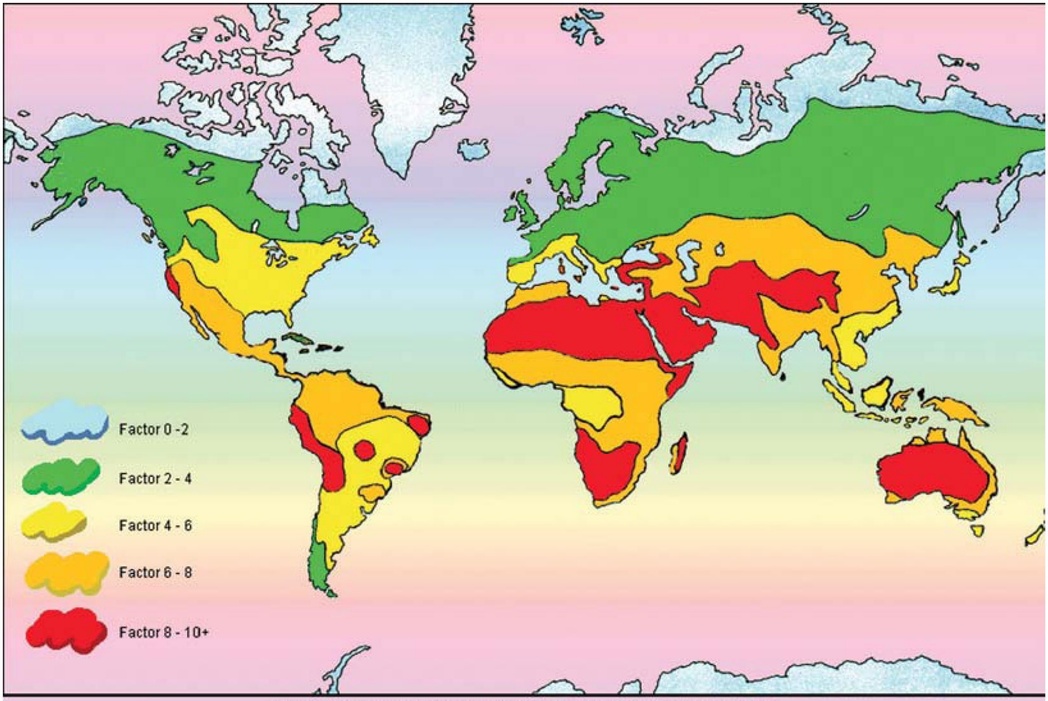
Each, under ideal conditions, could run a well-insulated fridge for 24 hours, but you'll need a combination to cater for 'real' weather if you wish to be self-sufficient.

A friend with a Prout 38 cruising cat left the UK with three solar panels, a wind turbine and a towed turbine. He added a further two solar panels, but is self-sufficient on the east coast of the USA and the Caribbean and doesn't need to run his engines for battery charging.

Solar panels

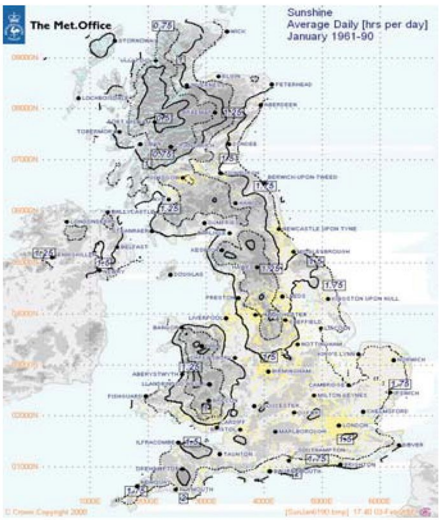
Like the wind, the sun is free, and solar panels can be used to harness its energy. Unlike the wind, you don't get sun for 24 hours a day and the output must take this into account.

Maximum output will be given only when the sun is high in the sky on a cloudless day, so various areas of the world are given ratings of 'hours of average daily peak sunshine'. Remember, though, that they are just



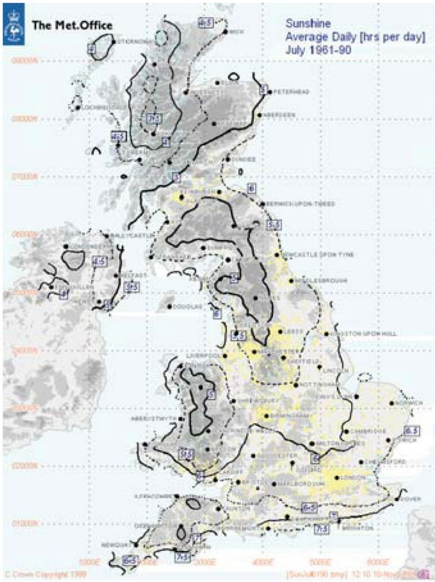
Map shows approximate Peak Sun Hours Around the World
i.e. hours of equivalent peak changing each day
Thus, daily energy gain (AH) =
Peak changing current of panel(A) X daily sun hours of location

Map courtesy of BP Solar



averages. To obtain the likely 'daily output' in watt hours per day, multiply the panel's peak output by the daily sunshine figure. Dividing the watt hours per day by the system voltage will give the amp hours per day.

To maximise the output of a solar panel, it should be mounted with its surface at right angles to the sun's rays. This is difficult to arrange on a boat, which will be continually changing its direction. Also, shadows of the sails, etc. will fall on the panel, reducing its output. Ideally, the panel should be fitted on a 'steerable' mount, or even not attached to a permanent mounting but placed where it's best sited. A fully flexible panel has advantages in this respect. Several cruising sailors have reported that in the tropics there's little benefit in adjusting the angle of the panel. This is probably, because during the time of peak power the sun is high and bright anyway. I suspect they would report differently if their sailing was restricted to higher latitudes.



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Types of solar panel

Development of solar panels is a continuing and important science, and we can expect further developments. There are three basic technologies:

- silicon monocrystalline;
- silicon polycrystalline;
- thin film.

Silicon monocrystalline

This is the oldest technology. Slices of a single crystal of silicon are connected in series, 36 of which give a 12 volt cell. The cost of the pure crystals is high and a large amount of energy is used in the manufacturing process. These crystals are brittle and normally mounted in a rigid frame, usually covered with toughened glass. They have the relatively high efficiency of 12–16%. One cell in shadow will cause a large reduction in output of the whole panel.

Peak power output approx. 60 watts (5 amps × 12 volts) / square metre of panel

Cost (2006) £565 / square metre of panel

Silicon polycrystalline

A modification of monocrystalline technology, with similar characteristics. These panels can be made slightly flexible to take up the curvature when fitted to the deck, and they can be walked on. The manufacturing process consumes less energy and the panels are more economic to buy per watt of output.

Peak power output approx. 110 watts (9 amps × 12 volts) / square metre of panel

Cost (2006) £950 / square metre of panel

Thin film

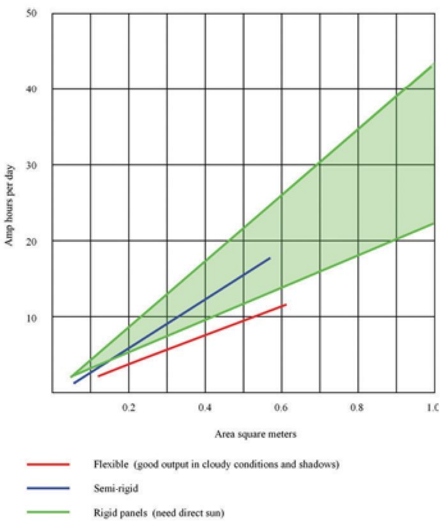
These use very thin layers of semiconductor laid down on a thin flexible backing, enabling very flexible but durable panels to be produced. This production process uses the fewest materials and energy, but efficiency

is only about 8%. However, because their response to various parts of the spectrum is different from the crystalline types, they give more output in the blue and green part of the spectrum. They therefore have more output in higher latitudes than is suggested by the wattage rating of the panels, especially in the winter or when overcast, where output can exceed that of the other types by as much as 30% in similar conditions.

Because of the construction, one cell in shadow will not have a large effect on the panel's output, unlike the crystalline types, which may lose up to 50% output from just the shadow of a rope.

Peak power output approx. 50 watts (4 amps × 12 volts) / square metre of panel

Cost (2006) £570 / square metre of panel



Solar Panel Output
Based on 6 hours peak output, typical of Equator or northern European summer

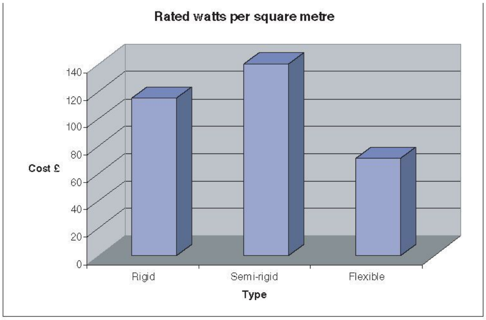
Comparing the three types of panel

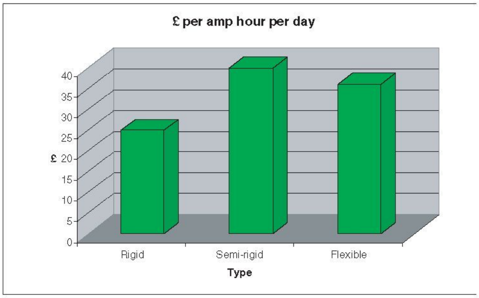
During tests that I carried out for *Practical Boat Owner* magazine in the summer of 2005, I came up with some interesting results.

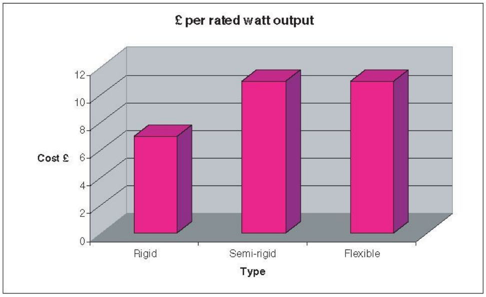
In determining the output of a panel, you can't necessarily rely on the rated wattage. I measured the amp hours per day output from May until September on the UK's south coast, under various cloud conditions, for rigid, semi-rigid and flexible panels, and the following charts show what you can expect, on average, throughout the summer.

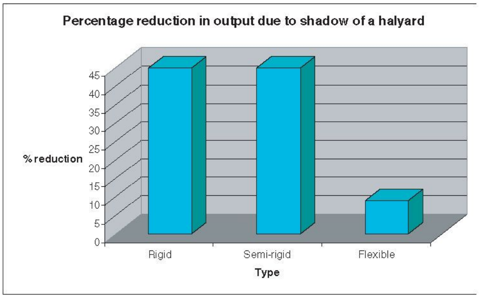
The role of solar panels on a yacht

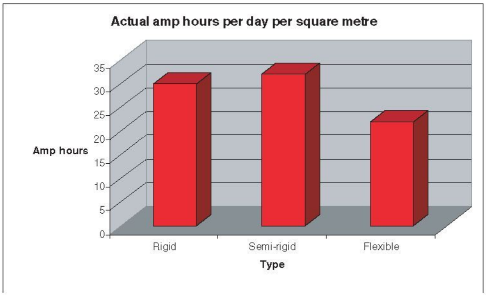
The daily output will depend on the location, season and cloud cover. Along the south coast of England in summer we may get six hours of peak sun per day, but, on the other hand, we may get close to zero. In good summer weather, output could be as high as 24 amp hours per day per square metre of panel from a thin film panel, and with the same panel on an overcast day, you could end up with 10 amp hours a day per square metre. On average it could keep a well-insulated fridge running without discharging the ship's batteries. We would need a large panel area to supply all our needs during a UK summer.



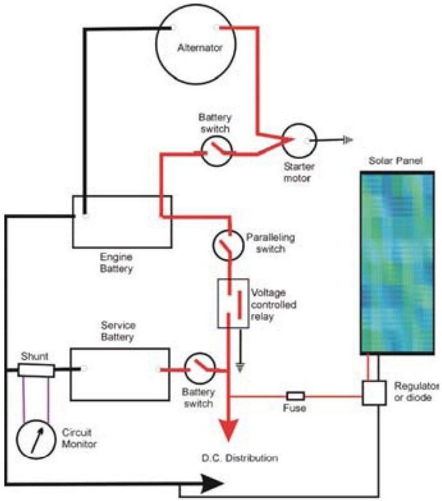








In most cases, it's unlikely that solar panels will wholly satisfy the boat's electrical demands, so other sources will be necessary. At around £570/square metre of thin film panel (2006 prices), giving a maximum of 24 amp hours per day in the UK summer, we can see the scale of the problem.



Solar Panel Circuit

Connection

Except for the very smallest output panels, a regulator is required. Some authorities also suggest a blocking diode, as at night the panels could work in reverse