Chapter 30

SOLAR & OTHER ELECTRICAL SYSTEMS

ELECTRICAL SYSTEMS

Most small to medium size vessels use Direct Current (DC) electrical systems supplied from one or more batteries. Voltages range from 12 volts for small craft, 24 volt for larger vessels and 36 or 48 volts for large vessels.

Vessels larger than these require Alternating Current (AC) electrical systems supplied by onboard Generator(s) (alternators driven by diesel engines) producing single-phase 240 volt for normal low power use and 415 volt three-phase for heavy duty use.

ELECTRICAL INSTALLATION

The electrical installation requires careful planning and care, keeping the design simple.

STARTING BATTERY CONNECTION:

The starting battery may be connected to the starter motor in one of two ways:

- In the ONE-POLE connecting system, the positive battery terminal is connected to the starter motor, while the negative terminal is connected to earth (the flywheel housing).
- In the TWO-POLE system, both the terminals are connected to the starter motor.

LIGHT SWITCH CONNECTION:

In AC light switches (with active, neutral and earth cables), it is common to connect only the active cable to the switch. Such switches are referred to as one-pole or single-pole switches. The main battery isolator switch, on the other hand, is usually a two-pole or double-pole switch, where both the active and neutral cables are connected to the switch. The added safety feature of the latter is that it not only cuts off the power supply, but also protects the neutral side from any feedback of power.

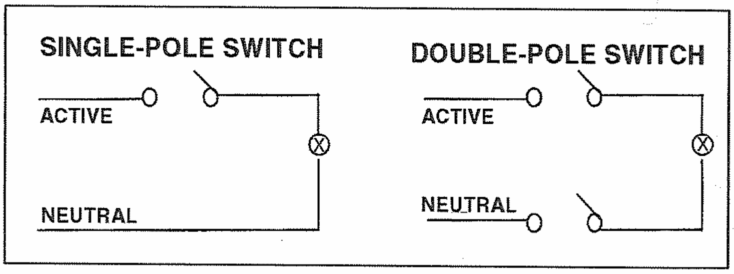


Fig 30.1

PRECAUTIONS

- In twin-engine installations or with separate battery banks, the engines must share the same battery ground for the synchronizing function to operate.
- All wires and connectors must be of types approved for marine use. The cable areas (sizes) and lengths should be as recommended in the charging distribution installation kit.
- Wires should be routed in a protective sheath and properly clamped. The leads should not be installed too close to heated parts of the engine or other sources of heat. The leads must not be subject to mechanical wear. If necessary, draw the leads through protective tubing.
- Keep the joints to a minimum, making sure the cables and joints are accessible for inspection and repair. None of the joints in the engine room should end up deep down.
  All cable joints should be higher than the alternator.
- Keeping a wiring diagram of the complete electrical installation will simplify fault tracing and installation of additional equipment.
- Spray all electrical equipment with a moisture repellent spray.
- Install the MAIN BATTERY SWITCH on the plus side. Provide the positive and negative cable leads with grommets as needed. Position the main switch outside but as close to the engine compartment as possible to

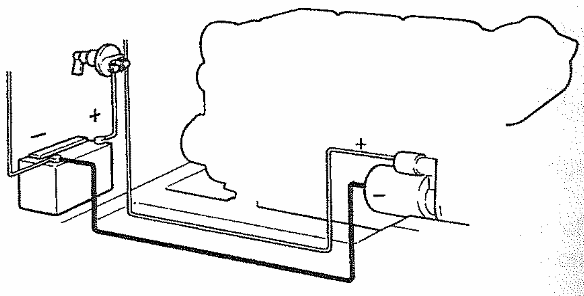


Fig 30.2: MAIN BATTERY SWITCH

keep the cable length to a minimum. Install it in a locked compartment to prevent theft of the boat.

- To avoid voltage drop in the charging circuits, the cables should be of correct dimensions and the terminals correctly finished. The cables between the charging distributor and the two batteries should be as short as possible, and should have the same length. However, if necessary, the cable between the charging distributor and the start battery (C) can be longer than the cable between the charging distributor and the accessory battery (B).

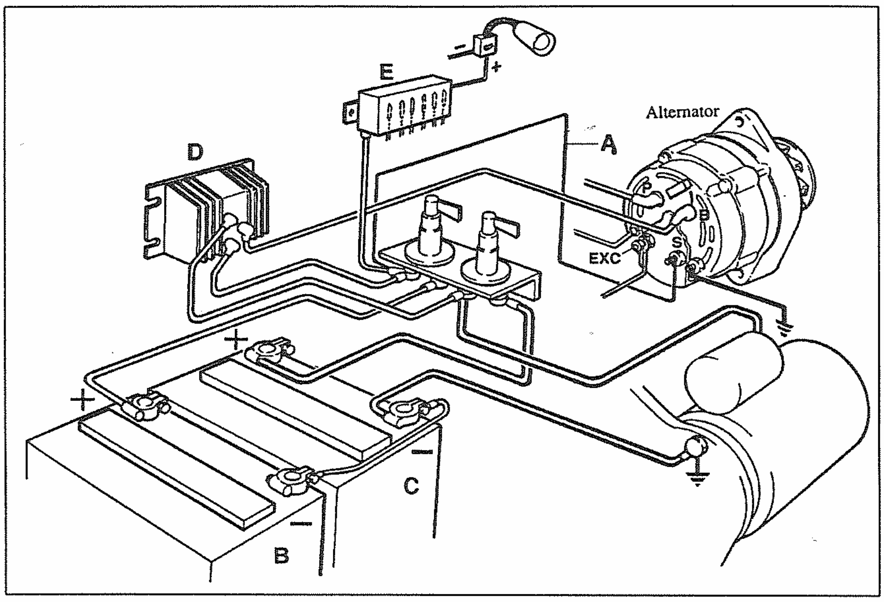


Fig 30.3
BATTERY CHARGING SYSTEM
(*Volvo Penta*)

Key
A. Sensor cable
B. Accessories battery
C. Starting battery
D. Charging distributor
E. Fuse box, other loads

COLOUR CODING OF ELECTRICAL WIRING

- Red/Brown – Active
- Black/Blue – Neutral
- Green - Earth

SHORT CIRCUIT: The connection between the positive and negative sides of an electrical circuit without going though the equipment itself is known as short-circuiting. The excessive flow of current thus caused generates heat. Unless protected by a fuse or circuit breaker, it often results in a fire, usually at the smallest wire in the circuit. Dropping a metal tool such that it lands on the two poles of a battery is a good example of a short circuit.

FUSES AND CIRCUIT BREAKERS: Fuses and circuit breakers perform a similar function. Both protect electrical wiring and equipment from failure or fire due to electrical overloads. The difference between the two is that fuses are designed to melt instantaneously when overheated due to excessive current flowing through an electrical circuit. The circuit breakers, on the other hand, are designed to trip (or open) to break the circuit. [There is a time delay]. Circuit breakers are more convenient because they can be re-set by simply re-switching them to the original position.

Only the correct size electrical fuses and circuit breakers must be used. In the event of repeated failure in either system, check the system for overloading, short-circuiting, major earth leakages and faulty equipment.

AUTOMATIC BATTERY CHARGING SYSTEM: Just as in motorcars, marine engines are fitted with a battery-charging unit, which automatically charges batteries when the engine is running. Sailing vessels need to run their motors periodically in order to recharge the batteries. The battery-charging unit consists of the following parts:

- **ALTERNATOR**: It is a dynamo producing AC current from the rotation of the engine. It is essentially a rotor, composed of an electromagnetic coil wrapped around an iron core. Six diodes convert the AC into DC current. Diodes are is a one-way valve for electricity. They allow the current to flow in one direction only, conducts during half of the AC cycle, and not conducting during the other half. Six diodes working together make a smooth flow of the DC current.
- **VOLTAGE REGULATOR (electronic or transistorised) (internal or external)**: It controls the output current of the alternator by controlling the supply of the field current to its magnetic coil. When the engine is running slowly or when the electrical demand is high, the regulator allows longer periods of the field current flow. As the engine speeds up, the regulator interrupts the field circuit as necessary to keep voltage within the required range.
- **CHARGING DISTRIBUTOR**: It is a double diode installed in vessels with high demand for electrical power. It

The alternator can generate quite a high voltage even with the engine just idling. The unit is really three alternators in one body. Each of the three sections generates its voltage out of phase with the other two sections. Therefore, one complete cycle (revolution) of the alternator puts out three separate voltages – each phase shifted by 120 degrees from the next. Each of the three phases has its own winding of the coil in the alternator and each winding has its own pair of diodes.

The failure of an alternator can thus be in stages. Each of its windings and/or diodes can fail, one set at a time. If this happens, the alternator can still charge the batteries, but only with two-thirds of its capacity. On failure of two of its systems, the alternator would put out one-third its rated capacity. This means that you may not immediately know of a failing alternator. It also means that you can go for a long time on a limping alternator.

TESTING AN ALTERNATOR: The best way to test an alternator is with a professional battery charging system tester. However, you can also test it with a simple voltmeter by checking the voltage across the terminals of the accessories battery. Connect a voltmeter across the battery terminals with the engine and all accessories off. Note the reading. Now start the engine and see if the voltmeter reading starts to rise. You may have to rev the engine to get some voltmeter relays to kick in. With the engine idling and with all accessories switched off, the voltage across the terminals of a 12-volt battery should read around 14 volts. A reading of 12 volts may indicate a failed alternator. Now test it under load by switching on as many accessories as possible. It should still read around 14 volts. If it reads lower than 13 volts the chances are the alternator is on its way out. If voltage continues to rise above the upper limit, the regulator is faulty.

ELECTRICAL ACCESSORIES: Before installing any additional accessory, such as a navigation instrument or a lamp, make sure that the additional power consumption can be met by the system's charging capacity. Clamp the equipment leads at close intervals and mark them at the junction box (1 and 2 in the illustration) with their purpose, such as radio, refrigerator, navigation lights, etc. Position the switches control panel (switch box) in a position free from moisture with easy access and close to the instrument panel. If a 220 V system is installed, clearly mark and identify its area in the control panel.

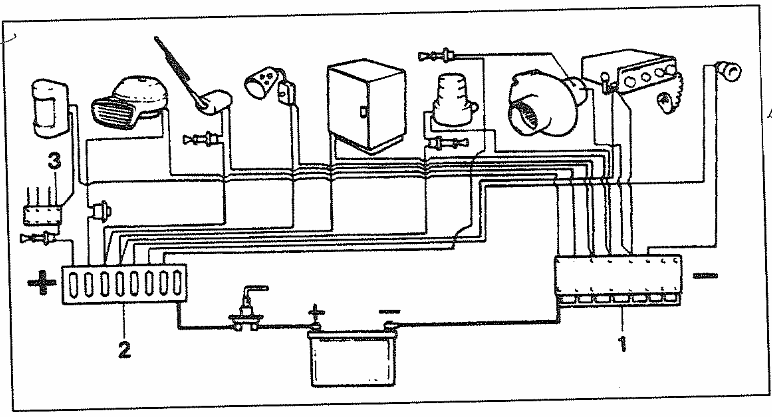


Fig 30.4
ELECTRICAL ACCESSORIES
(Volvo Penta)

1. Junction box for ground leads (-)
2. Fuse box (+)
3. Junction box for navigation lights

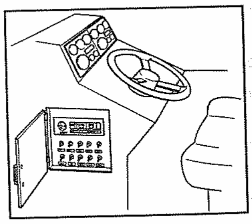


Fig 30.5
SWITCH BOX
(Volvo Penta)

CALCULATING THE FEEDER CABLE AREA: The length and area of the feeder cable (A) is dependent on how many accessories are to be connected to it. The more the power demanded by accessories, the bigger the area of the feeder cable. A feeder lead of 10 AWG (6 sq. mm) may be used for maximum 50 amps, while a lead of 8 AWG (10 sq. mm) may be used for maximum 70 amps alternator capacity. *(AWG = American Wire Gauge).*

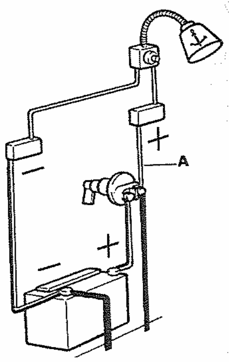


Fig 30.6
FEEDER CABLE
(Volvo Penta)

CALCULATING CABLE AREA FOR AN ACCESSORY

Measure and double the distance of the accessory from the terminal box. Then enter the appropriate table shown below. The table illustrates the example for a 12V refrigerator of 45W consumption and the distance between the terminal block and the refrigerator of 3 metres. The straight line drawn between the refrigerator's load of 45W and its cable length of 6 metres (i.e. 3 x 2)

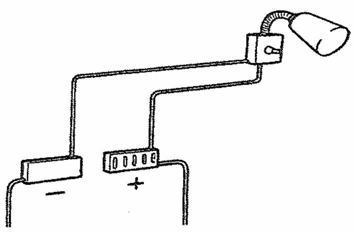


Fig 30.7: CABLE FOR AN ACCESSORY *(Volvo Penta)*

indicates the required size of cable being 1.5 sq. mm. *(This calculation is based on the maximum permitted total voltage drop in all cables between the positive terminal to the accessories and back to the negative terminal. The total voltage drop should not exceed 0.4V.)*

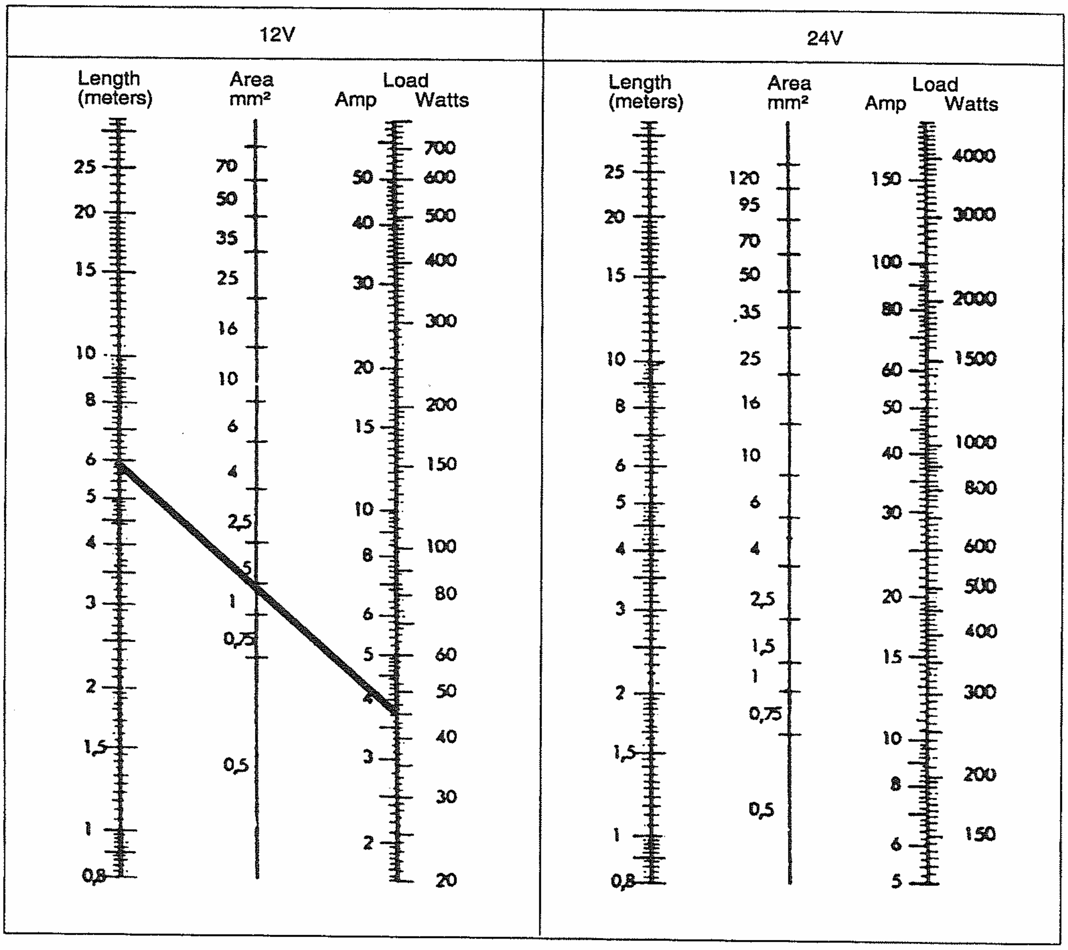


Fig 30.8: TABLE INDICATING CABLE AREAS FOR ELECTRICAL ACCESSORIES *(Volvo Penta)*

BATTERIES

Two dissimilar metals when immersed in a weak acid (known as *electrolyte*) form a 2 Volt battery cell. Six cells joined together form a 12 Volt battery, and 12 cells form a 24 Volt battery. Due to chemical reaction between the metals and electrolyte, a current flows from the less noble or *ignoble metal* (*anode*) to the one that is more noble (*cathode*). The circuit is completed by the current flowing through a circuit outside the battery from cathode (negative terminal) to anode (positive terminal). The process gradually corrodes (breaks down) the anode.

Battery capacity is measured in ampere-hours (Ah). If a battery can produce 3 amps current for 20 hours, its capacity is 60 Ah. This capacity is stated at 20°C. Decrease in temperature reduces battery capacity. For every degree drop in temperature, the battery capacity decreases approximately 1%. At -18°C, the battery capacity is reduced to 55%.

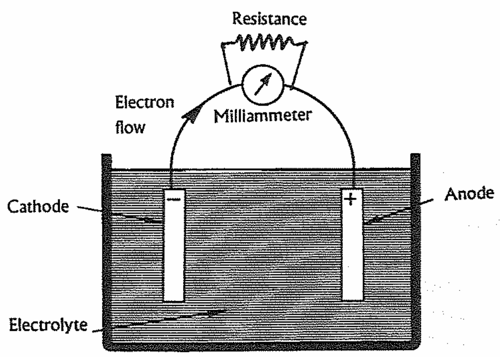


Fig 30.9
A SIMPLE ELECTROLYTIC CELL

MARINE BATTERIES differ from automotive-type batteries. They are constructed with additional plates to suit the variations in the rated performance levels. They are made vibration resistant by lock-bonding and fibreglass separators.

IN RESPECT OF THEIR APPLICATION, THERE ARE TWO TYPES OF BATTERIES:

- **SHALLOW CYCLE (or CRANKING) BATTERIES**: These are engine-starting batteries. They discharge a very large amount of current for a very short period of time to start the engine, and then immediately recharge as you drive. They use a large number of thin plates to maximise surface area, so that a very high current can flow from the battery for short periods of time. If put through slow discharge, such as for running a refrigerator all night, the thin plates of such a battery are likely to become warped and distorted. These batteries carry a "cc" (cold cranking) rating.

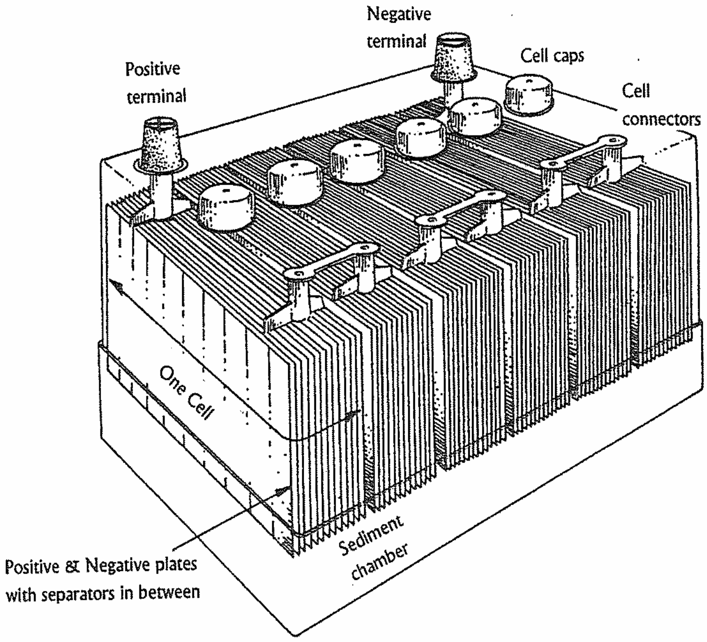


Fig 30.10: A 12-VOLT WET CELL BATTERY

- **DEEP CYCLE (or CYCLING) BATTERIES**: These are designed to provide a steady flow of current over a long period of time. They are used for running equipment requiring prolonged discharge of low amperage, such as radio, refrigeration and lighting. (Also see batteries in 'solar power' below). Their tubular or thicker plates can withstand several hundred complete discharge-and-recharge cycles, while a car battery is not designed to be totally discharged. Electrical WINCHES and other LIFTING EQUIPMENT also require deep cycle batteries, but of a higher rating. A deep cycle battery can provide a surge when needed, but nothing like the surge a car battery can. Deep cycle batteries are not "cc" rated. Instead their capacity is rated in amp-hours. They will also be heavier for a given rating due to the extra lead in their plates.

Batteries of smaller capacity than recommended will have a shorter life span, especially when subjected to non-regulated repeated charging. Apart from the resultant high voltages generated in a non-regulated system, damage can occur to sensitive electrical equipment.

Vessels whose engines are not fitted with a hand start should carry two sets of starting batteries. One set should be maintained at full charge to provide backup when needed.

TWO TYPES OF WET CELL BATTERIES

- Lead-acid batteries [the electrolyte is dilute sulphuric acid]
- Alkaline batteries [the electrolyte is potassium hydroxide]

BATTERY CHARGING

The three main methods of charging the batteries are:

- Alternator fitted to the engine (discussed above)
- Solar panels (discussed below)
- Battery charger powered by either mains or generator

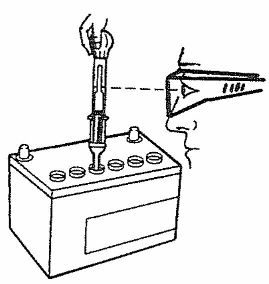
> NOTE: An alternator is sometimes fitted to freewheeling propshaft in cruising yachts. It can generate around 10 amp at 5-7 knots. Factors to consider are: propeller drag due to braking effect, friction in stern tube, propeller aperture & characteristics, type & likely damage to gearbox due to improper lubrication during freewheeling.

BATTERY MAINTENANCE & SAFETY PRECAUTIONS:

- Both types of batteries demand the same safety precautions.
- The alkaline battery cells can be damaged by the slightest contact with acid. Therefore, if both types of batteries are installed, they should be kept apart - in separate compartments - each with its own distilled water bottle, topping-up equipment and hydrometer, etc.
- The level of Electrolyte should be maintained 10 mm above the plates. The cells should be topped up with distilled water as necessary. The use of distilled water prevents the build-up of organic and iron particles during chemical changes in the normal charging and discharging activity. If distilled water is not available, use drinking water or other cleanest water you can find - rainwater would be better than drinking water. Don't use seawater. Get the battery checked at the first opportunity. If a battery requires constant topping up, the charging method is likely to be faulty.
- The batteries should be secured in brackets. Their terminals, cables, casing, and the sealing compound should be kept clean, free from dirt, moisture and grease. Dirt or moisture on top of the battery can form a conducting path,

which takes energy from the battery; and if allowed to become bad enough, it may eventually damage the battery. The terminals should be lightly coated with Vaseline to safeguard against corrosion. Corrosion and crystalline matter on terminals can be removed by dipping them in a solution of baking soda and hot water. Then rinse them clean, dry, and smear lightly with petroleum jelly. Build up of copper sulphate beneath the plastic shroud of battery leads will case the leads to appear swollen or distorted near the terminals. It will impair the efficiency of the system. The leads should be replaced immediately.

- A battery connected with incorrect polarity can damage the regulator, diodes and the alternator due to overheating. The positive terminal of a battery is coloured Red. It is also larger in size, and marked with a positive (+) symbol.
- Salt is a good conductor of electricity and it absorbs moisture. it can destroy and cause leakage and short-circuiting in electrical equipment. Therefore the insulation on electrical equipment must not be damaged. Once a battery is fully immersed in salt water, it should be replaced, as salt water will contaminate the electrolyte and can produce toxic gas. Replacing the electrolyte will not eliminate the problem.
- Batteries should be charged at a suitable **CHARGING RATE**, and they should not be overcharged. The charging system should charge the battery from fully discharged "flat" to charged within 16 hours (preferably less), but not at such a rate as to cause the battery to become hot or the electrolyte to boil. Fast charging should be particularly avoided for deep cycle batteries. The deep cycle batteries should never be discharged beyond 80% of their rated capacity. Overcharging causes the plates to corrode and fracture. The build up of sediment on the bottom may also bridge the plates and cause internal short-circuiting.
- Batteries give off explosive hydrogen gas, which is lighter than air. When charging, they should be protected from sparks, naked flames and heat. The gas hangs above the electrolyte at all times. This is due to a continuous weak chemical reaction in the battery, even when disconnected. The most dangerous time is just after charging. To prevent a spark igniting it, caps should be on cells when connecting or disconnecting a battery. The battery charger or ignition should be turned off before disconnecting a battery.
- Wash any battery fluid, accidentally splashed on skin or clothing, with running water. It can cause burns. Seek medical advice if serious. Usually it is not serious on healthy skin. If splashed in the eyes, flush eyes and under eyelids with cold flowing water. Cover the eye. Seek medical advice. It can be serious.
- Don't leave a battery in a discharged condition for too long, particularly a lead-acid battery. The capacity of such a battery will be reduced due to the "sulphating" of its plates, i.e., a hard white layer of lead-sulphate will form on the plates.
- An over-discharged battery may require bench charging, i.e. charged independently of the operating system. Should two or more batteries require charging it is essential that all batteries be of similar size. If not, the smaller battery will govern the rate of charge and absorb more of the available energy, whereby the larger battery may not fully respond.
- Likewise, multiple parallel charging in *Solar Systems* is not recommended because minor internal differences are difficult to balance out, and uneven discharging and recharging will occur. Should one cell in any battery become defective, all other cells will discharge into the faulty battery.
- The *Density* (used to be referred to as *Relative Density or Specific Gravity*) of batteries should be checked regularly with a *Hydrometer*. A good quality float hydrometer is essential. Cheap hydrometers with red and green markings tend to be misleading. A fully charged battery will lift the glass float to around 1.26 Density (1260 SG) in each cell. An even reading in all cells below 1.26 indicates a need for charging. An uneven reading, e.g., 5 cells at 1.26 and 1 cell at 1.20 indicates the battery failure. The figures may vary slightly due to variations in manufacturing techniques. The density should not be measured immediately after topping-up with water. Charging for thirty minutes or more after topping-up will mix the electrolyte to give accurate readings. Batteries should not be tested immediately after coming off charge as the temperature has increased and immediate readings will not be accurate.



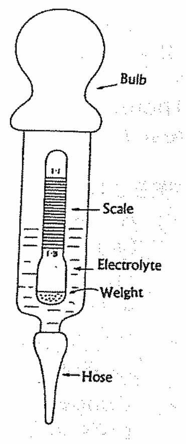


Fig 30.11: MEASURING ELECTROLYTE DENSITY WITH A HYDROMETER

DENSITY READINGS FOR VARIOUS STATES OF CHARGE

1.260	Fully charged
1.230	75% charged
1.200	50% Charged
1.170	25% Charged
1.100	Completely discharged

Consistent readings below 1.200 would indicate the battery is being over discharged and could be under capacity for the particular function or the charging pattern is irregular.

In the case of a sealed battery, use a voltmeter to measure **VOLTAGE** across the battery terminals. However, this measurement should be carried out only when the battery is on-load. For a 24 volt battery, the terminal voltage should not fall below approximately 23.2 volts when on-load. It is considered discharged if it measures 21 V with a light load applied to it. Measuring the off-load voltage across the terminals of a battery is not appropriate. It overlooks the health of individual cells.

A 12 V battery on charge and nearing full charge will measure about 14 V across its terminals. When charging is stopped, the voltage will drop to between 12 and 12.5 V almost straight away. Battery is considered discharged if it measures 10.5 V with a light load applied to it.

AN ALKALINE (NICKEL-CADMIUM OR "NICAD") BATTERY has many times longer commercial life than a lead-acid battery. However, its condition of charge cannot be measured with a hydrometer. The density of its electrolyte does not vary during charge/discharge cycle. It should normally be in the range of 1.190 to 1.250, and the electrolyte should be replaced when it falls below 1.160.

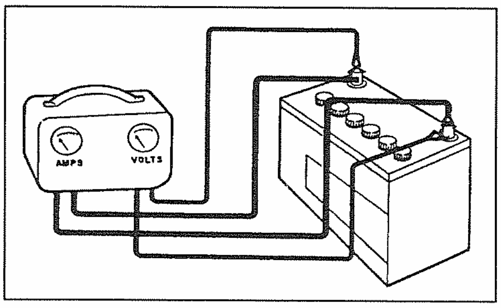


Fig 30.12
MEASURING BATTERY VOLTAGE

BATTERIES IN SERIES & PARALLEL
Two or more batteries can be connected together in two different ways for two different functions.

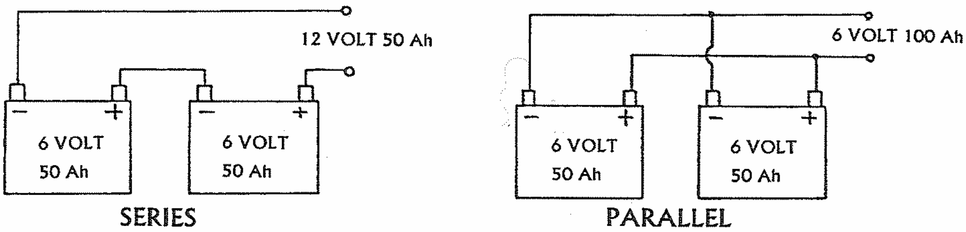


Fig 30.13: BATTERIES CONNECTED IN SERIES & PARALLEL

Batteries connected in series (i.e., Positive (+) terminal of one battery connected to the Negative (–) terminal of the next) add up their voltages. But their capacities (i.e. current in ampere-hours) do not add up. Therefore, a vessel with a 12-volt electrical system may install a single 12-volt battery or hook up two 6-volt batteries in series.

The opposite is the case for batteries connected in parallel (i.e., all Positive (+) terminals connected together and all Negatives (–) connected together). They add up their capacities (i.e., current in ampere-hours), but their combined voltage supply remains the same as of a single battery. This arrangement is suitable when there is a need to run electrical equipment requiring high amperage, or when a vessel wants to start an engine with two half discharged batteries. It will combine their current in ampere-hours, while maintaining the designed voltage.

Batteries are also connected in parallel when using jumper cables to jump start an engine from an external battery: Negative (–) of the vessel's battery is connected to the Negative (–) of the external battery; and Positive (+) of the vessel's battery is connected to the Positive (+) of the external battery.

It is a common misconception that two half discharged 12-volt batteries can be hooked up in series to provide one 12-volt circuit. The voltage of a battery, whether charged or discharged, remains close to its designed value. Even a fully discharged 12-volt battery reads 10.5 volts on a voltmeter. What a discharged battery loses is its current supply. Therefore, two 12-volt batteries should never be connected in series in a vessel with a 12-volt electrical system. The resulting high voltage will seriously damage the equipment.

PRECAUTIONS WHEN INSTALLING BATTERIES

- A vessel seeking a 24-volt electrical system would usually connect two 12-volt batteries in series. The two batteries must be similar in capacity and voltage. They must be of the same age (The charging rate changes with age). The loading on the two batteries must also be equal. Even a small load such as a radio connected across only one battery can soon destroy the batteries.
- For connecting in parallel, the batteries must have the same nominal voltage, but they may have different capacities and ages.
- Copper nails and fastenings in timber boats are particularly vulnerable to corrosion if electrolyte leaks out of batteries. Metal hulls have the same problem.
- Install the batteries in a tight-fitting, acid proof battery box, protected by a cover to prevent tools dropping on them. Vent the box with 25 mm hoses into the outside atmosphere. If batteries are installed in the engine

compartment, its ambient temperature must be kept down to avoid battery boiling during charging.

- The ventilation hose must end up outside the vessel to allow highly volatile battery gas to escape.
- Secure the batteries so that the do not move more than 10 mm
- Locate them above the level of the bilge and away from ignition sources.
- Locate them as near as practicable to starter motor.
- Do not install alkaline and lead-acid batteries in the same compartment - as discussed above.
- Don't top-up whilst on charge. Wear safety goggles when topping up or handling electrolyte.
- Fit only non-sparking ventilation fans.
- Install away from motors and other sources of sparks or heat.
- Do not install batteries in living areas.
- Install battery-monitoring gear: ammeter, voltmeter, etc.
- Fit fuses or circuit breakers on the accessory wiring. Do not fit them to the main battery leads to avoid the risk of a spark igniting the hydrogen gas.

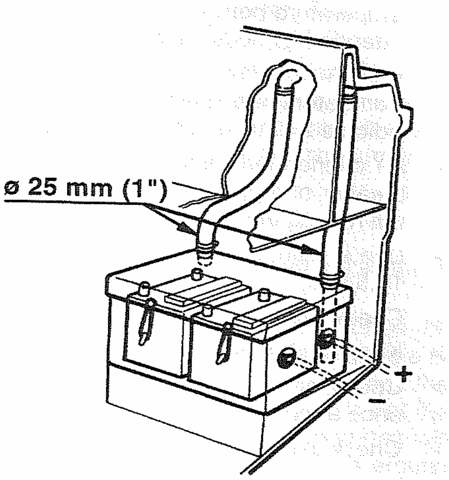


Fig 30.14: A VENTILATED BATTERY BOX (Volvo Penta)

PRECAUTIONS WHEN REMOVING OR REPLACING BATTERIES

- Switch off all sources of power drain (switch off isolating switch).
- Mark the terminals and the battery leads [+tive terminal is red and the –tive is black].
- Disconnect the black return terminal first and reconnect it last to prevent the risk of shorting.
- Use non-metallic carry strap or suitably designed handles to lift the battery.
- The replacement battery must be of correct voltage.
- Secure it against movement.

STORAGE OF BATTERIES WHEN NOT IN USE: Disconnect and remove the battery from service, check electrolyte levels, add distilled water as necessary to the required levels. Give the battery a full bench charge. Clean and dry the battery top and terminal posts. Store in a cool, dry place (not directly on a concrete floor). Recharge fully at least every two months and immediately before putting into service. Ensure vent plugs are free of dirt or grease.

BATTERIES - TROUBLESHOOTING

BATTERY NEEDS TOPPING UP TOO OFTEN

- Overcharging. Solution: Seek expert assistance.
- Cracked casing. Solution: Replace battery.
- High surrounding temperature. Solution: Find better location.

BATTERY NOT FULLY CHARGING

- Drive belt slipping. Solution: Adjust it.

THE AUXILIARY GENERATOR

In large sailing vessels and motor cruisers, it is usually uneconomical to run a vessel's main engine just to charge the batteries. Some diesel engines dislike running with a light load, and this can cause glazing of cylinder walls, leading to a major overhaul. Some vessels are therefore fitted with a separate diesel powered auxiliary generator producing 240-volt AC power supply. It is suitable to run most appliances on board, including refrigerators and microwave ovens. A transformer is fitted to convert the 240-volt AC to 12 volt DC for charging batteries.

- Generators are like main engines in operation and maintenance. They need cooling, lubrication, fuel and filters like any other 4-stroke engine. A generator should be supplied with a separate starting battery, so that it can be started if the main engine is out of service. Such a battery can also provide emergency back-up power for the main engine.
- On starting a generator, always visually check the seawater cooling overboard discharge.

- Run the generator for five minutes to reach its normal operating temperature before putting on load. But don't run on light or no load for extended periods. It causes cylinder glazing and deposits within the engine.
- Generators are usually fitted with a voltmeter and an amp meter to indicate 240 volts output and the amperage being drawn.
- An overloaded generator will run at reduced RPM, tripping the circuit breaker or tripping the machinery. Switching off some of the equipment will reduce the load.
- Use a voltmeter to ensure the charge voltage is approximately between 13.5 and 14.5 volts.
- Check rubber mountings for fatigue and cracks.
- Keep the battery and starter connections tight and clean.
- Check and tighten alternator, water pump and fuel pump drive belts once a month.
- Check the condition of the sacrificial anodes in the cooling system twice a year.

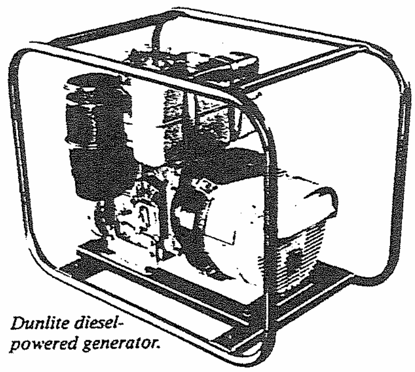


Fig 30.15: DUNLITE DIESEL-POWERED GENERATOR

Some vessels are fitted with a generator that is coupled to the main engine. One such brand is AUTO-GEN. It has the advantage of a lower installation cost because it does not require separate cooling, exhaust or fuel tank.

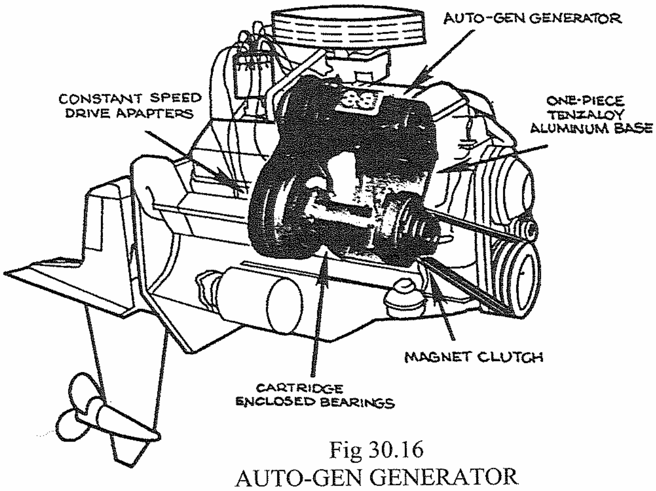


Fig 30.16
AUTO-GEN GENERATOR

GENERATOR PROBLEMS:

See diesel engines.

SHORE POWER SUPPLY

Vessels equipped with a 240-volt electrical installation are usually fitted to take a power supply from shore outlets with the necessary circuit protection and monitoring devices for safety. Care must be taken when connecting to shore power supply. The polarity of the shore connection must match with that of the vessel's switchboard. This can be done either with a polarity changeover switch (if fitted) on the vessel or by changing the polarity in the shore cable, in order to connect "active with active". The shore power must not be grounded (earthed) to the engine or any part of the vessel. Instead, draw the connection cabinet's ground terminal to the shore.

Only an electrician qualified to work on high voltage installations may carry out installation and work using shore-connected equipment. Incorrect installation can result in danger to life.

SOLAR POWER

Although the initial investment in solar energy equipment is high, it is an excellent and silent way of maintaining the battery charge, thus minimising the need for running the generator, and when vessel is left unattended.

Solar panels are made up of small PV (photovoltaics) cells, typically measuring 5 or 10 cm across and 0.25 mm thick. They are solid-state semiconductors that convert light directly into electricity. A cell measuring 5 x 1.25 cm (6.45 sq. cm or 1 sq. inch) can produce 70 milliwatts of power depending on the season and location.

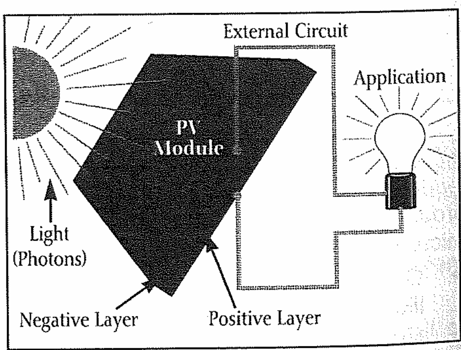


Fig 30.17
PV MODULE CONVERTING LIGHT INTO ELECTRICITY (*BP Solarex*)

PV cells are usually made of silicon with traces of other elements in

them. The bulk of the cell is doped with a small quantity of boron to make it a POSITIVE or *p-type* layer. But a thin layer on the face of the cell is doped with phosphorous, which makes it a NEGATIVE or *n-type* layer. The interface between the two layers contains an electric field and is called a JUNCTION.

A PV MODULE is made by connecting several cells (usually 36) in series and parallel to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with a glass cover and positive and negative terminals on the back. The photovoltaic process of the module of converting particles of light (photons) into electricity (volts) is completely solid-state and self-contained. There are no moving parts and no materials are consumed or emitted.

WHY ARE SOLAR CELLS INEFFICIENT?

There are two types of solar cells: Single-junction and Multi-junction. Both types are inefficient. The efficiency of *single junction cells* is only about 13%, and that of the *multi-junction cells* a little higher.

As indicated by the colours of rainbows, light is made up of different wavelengths or energy levels. Not all the photons in the light spectrum are of a suitable energy level (measured in electron-volts or eV) to become either the n-type electrons or the p-type holes of the opposite charge. Photons with too much or too little energy do not suit the *band-gap energy* of the cell. Using a material of a really low band-gap, so that more photons can be used, is not the answer. The band-gap determines the strength (voltage) of the electric field of the cell. Lowering the band-gap will certainly provide extra current, but at a low voltage. The optimal band-gap, balancing voltage and current, is around 1.4 eV for a cell made from a single material.

Multi-junction cells use two or more (usually three) layers of materials of different band-gaps. This allows the higher band-gap material on the upper surface of the cell to absorb the high energy 'blue' photons while allowing the middle energy 'green' photons and the lower energy 'red' photons to pass through so that they can be absorbed by the middle and lower band-gap materials. Such cells can have more than one electric field. The ability of multi-junction solar panels to split the light spectrum certainly improves their efficiency, but only to a degree. 60 - 70% of the radiation energy is still lost to the atmosphere.

There are other losses as well. The electrons have to flow from one side of the cell to the other through an external circuit. The bottom of the cell can be made a good conductor by covering it with metal, but if we did the same with the top surface, the photons wouldn't be able to get through the opaque conductor. The silicon cover is only a semi-conductor. It is not as good as a metal for transporting current. Improvements are being made in this area by using transparent conductors in the top surface of some of the cells, but not in all. Silicon, being a very shiny material, is also very reflective. It thus loses many of the photons. An antireflective coating is applied to the top of the cell to reduce loss due to reflection to less than 5%.

CALCULATING SOLAR PANEL REQUIREMENT

Solar panels on the market range from 2 watts to 83 watts. In considering a solar panel's output, the following should be taken into account:

- P (watts) = V (volts) x A (amps)
- Solar panels are generally rated at 17 volts. If they produced only 12 volts they would not be able to push the charging current into a 12 volt battery. Therefore, a 60-watt panel produces approximately 3.5 amps charging current (60 = 17 x 3.53).
- Solar panels provide their full power when placed in full sun. Shade, cloud cover and the angle of the sun relative to the panel influence their power output. On overcast days, a panel's charging current drops down to 25 to 50% of its capacity.
- If you need a system only to maintain a charge in a battery when not in use, solar panels in the range of 2 watts to 30 watts would be sufficient. These panels are either self regulating or not sufficiently powerful to require a regulator. For power production for continuous use, on the other hand, you would need panels in the range of 40 to 83 watts. Larger panels are more economical to purchase because their price per watt is lower than that of smaller panels. The higher power rated panels require a regulator between the panels and the bank of batteries to prevent overcharging. Regulators range from 5 amps upwards.
- If AC appliances are to be used, the solar panel's power rating would have to be increased by 20% to reflect an 85% inverter efficiency. (Inverters convert DC power into AC, as discussed below).

BATTERIES FOR SOLAR SYSTEM

- A PV system can be as simple as a solar panel and a load (such as a direct driven fan). However, most PV systems are designed to supply power on demand. Therefore, deep cycle batteries (discussed above) are employed to charge during the day and then supply a small current for many hours during the night. These can be lead-acid (sealed or vented) or nickel cadmium batteries. The latter are more expensive, but they also last longer and can be discharged more completely without harm.
- Not recharging batteries until they are fully discharged shortens their life. It is better to recharge them at regular

intervals when they are only slightly discharged. Therefore, a good quality charge-controller (discussed below) is employed in a solar system to ensure that the batteries are not discharged to more than 40-50% of their total charge. In a well-controlled system, the daily load should not discharge the batteries more than 20%. In the event of extended cloudy periods, the batteries should never be discharged more than 80% of their capacity.

- The amount of energy that a battery provides depends on its rate of discharge. For example, a typical 12-volt deep cycle battery may have a rating of 100 amp-hours when discharged over 20 hours (i.e., at a discharge rate of 5 amps). If the discharge rate is reduced to 1 amp, it may be possible to receive 120 amp-hours from the same 100 amp-hour battery (i.e., a discharge period of 120 hours).
- Battery power (amp-hours) can be converted to photovoltaic power (watt-hours) by simply multiplying the battery voltage by the amp-hour rating. Thus, a 12-volt, 100 amp-hour, battery is capable of providing 1200 watt-hours of energy.
- The term BATTERY AUTONOMY refers to the length of time a bank of fully charged batteries could operate its electrical load without input from the solar panel. Applications requiring 2 or 3 days of battery autonomy need a smaller battery bank than those requiring 7 or 8 days of autonomy.

INVERTERS

- ➢ Solar panels and batteries are inherently DC devices. Therefore, larger solar systems usually employ a power inverter to convert 12 or 24 volt DC power into 230-240 volt AC. This allows the boat owner to make use of standard household appliances. Without an inverter, only DC appliances may be used. Some PV modules, called AC modules, have an inverter built into each module. This eliminates the need for a large central inverter and simplifies the wiring requirements.
- ➢ Inverters of the past had a bad reputation for eating up batteries, producing poor quality power and for being generally unreliable. However, today's electronic inverters are both efficient (85% to 95%) and reliable. You would need to consider the following points when purchasing an inverter:
- ➢ Inverters are rated by their wattage output, varying from 150 watts to 1500 watts and more. They will always have a surge rating at least double their continuous rating to allow them to handle loads requiring large start-up currents.
- ➢ SINE WAVE INVERTERS produce negligible RFI (radio frequency interference) and have quite a pure waveform. They run all appliances, including television sets, computers, refrigerators, microwave ovens, power tools and other kitchen appliances, at their maximum efficiency. They generally have many features and if they are within your budget they are definitely worth the extra investment.
- ➢ The MODIFIED SINE WAVES INVERTERS are also capable of running most of the appliances. However, they do create some RFI that can affect TV reception and create some noise in audio equipment. Cheaper, less known, brands usually give more problems.
- ➢ Some of the larger inverters are bi-directional. They also act as battery chargers. They are a better option in larger systems as they reduce complexity and save on components cost.
- ➢ Loads requiring continuous high power such as air conditioners, heaters and some cooking appliances are not practical to use with inverters as they pull too much power from the batteries.

OTHER COMPONENTS

- As mentioned earlier, solar systems with batteries need to install a CHARGE CONTROLLER to control the charging and limit the discharging of batteries. Even the nickel cadmium batteries last longer if they aren't overcharged or drained too much. Sometimes, charge controllers are referred to as CHARGE REGULATORS. However, make sure they perform both the above functions.
- The installation of a solar system would require mounting hardware, wiring, junction boxes, grounding equipment, overcurrent protection and DC and AC disconnects. Ensure that the equipment is manufactured and fitted in compliance with the national PV electrical safety codes.

INSTALLATION

- ➢ Seek advice on the solar panel size and secure installation. The sighting of the panels on a boat must be considered carefully. Shading due to booms and dodgers etc. should be avoided, if possible. Laying them flat on the deckhouse may be the most suitable alignment for unattended operation at anchorages and moorings. But make sure the panels are in a well-ventilated place, because although they thrive on light, they deteriorate in heat. For their operation underway, mounting them on the aft guardrail would

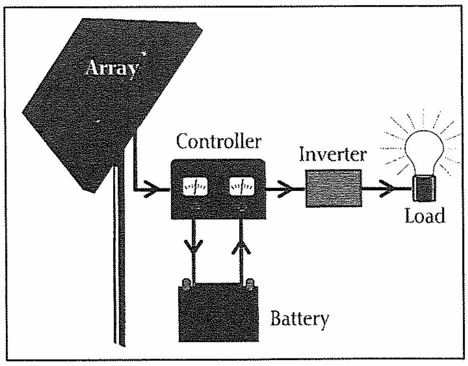


Fig 30.18
A SOLAR SYSTEM (*BP Solarex*)

allow you to trim them several times during the day. But, they might need to be taken in whenever going alongside.

- It is recommended that a licensed electrician with experience in PV systems should carry out the installation.
- Safe installation of battery bank including DC fusing of all loads is essential.
- Pay particular attention to power flow from the alternator, including correct wire sizes and cable routes.
- The inverter installation should include high capacity DC fusing and correct 240-volt connections.

RATING OF PV MODULES

PV modules are typically rated by their peak power output when exposed to the following Standard Test Conditions (STC):

- Temperature of PV cell = 25° C
- Air temperature = 0° C
- Intensity of solar radiation = 1000 watts/sq. metre.
- Spectral distribution of light through air mass (AM) = 1.5. (This is the spectrum of light that has passed through 1.5 thickness of the earth's atmosphere.)

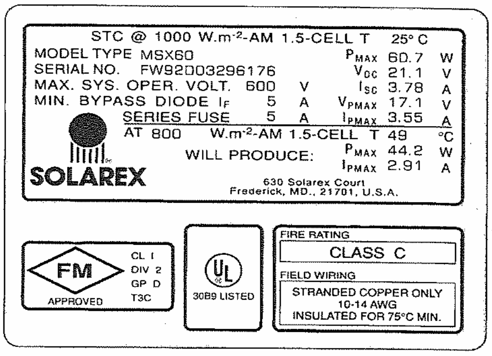


Fig 30.19: A RATINGS CARD
(BP Solarex)

These conditions correspond to noon on a clear sunny day with sun about 60° above the horizon, the PV module directly facing the sun, and an air temperature of 0° C. In production, PV modules are tested in a chamber known as a flash simulator. This device contains a flash bulb and filter designed to mimic sunlight as closely as possible. Because the flash takes place in only 50 milliseconds, the cells do not heat up appreciably. This allows the electrical characteristics of the module to be measured in the ambient temperature of the factory and the cell, which is 25° C. Solar cells become less efficient as the air temperature rises. In summer, cells can easily reach 45° C, reducing power output to 92% of STC. The BP Solarex rating card illustrated below provides the additional rating information at operating condition of 80% sun and a cell temperature of 49° C, which represents conditions more common in actual operation.

DOES PV WORK IN THE COLD? Yes, very well in fact. PVs are electronic devices that generate electricity from light, not heat. Like all electronics they work better at lower temperatures. They generate more power at low temperatures. The fact that they generate less electricity during winter months than in the summer is due to the shorter days, lower sun angle and greater cloud cover in some areas.

DOES IT WORK IN CLOUDY WEATHER? In cloudy weather the output of PVs diminishes linearly down to about 10% of the normal full intensity. Since flat plate PVs correspond to a 180° window, they do not need direct sun and can generate 50-70% of their rated output under a bright overcast. A dark overcast might produce only 5-10% of the full sun intensity. So, the output could be diminished proportionally.

DOES IT WORK INDOORS?: PVs designed for the outdoor light intensity, which is several hundred times more than that produced by the indoor lights, will not work indoors. Similarly, PVs designed for lower light intensity, like those found on calculators, will perform poorly in full sunlight.

DOES TRACKING IMPROVE PERFORMANCE? The effectiveness of tracking depends a lot on the climate and the application. Areas with a lot of haze or clouds won't get much benefit from tracking because the light is scattered. Tracking also can't improve the performance during the poor weather periods where the application needs the same load every month.

Under ideal conditions, the tracking equipment can improve PV output per day up to 40%, but it adds to the system complexity and expenses, and it is generally not as strong as the fixed mounting system. The use of tracking equipment is generally limited to applications where the increased output matches the output demand (such as livestock watering) in areas that are dry (such as central Australia).

DO REFLECTORS INCREASE OUTPUT? Reflectors can increase the output of PV arrays. However, the improvement is not linear because the increased light intensity also increases the module temperature, which reduces its efficiency. More importantly, the increased module temperatures and light intensities can lead to premature failure of the module. The use of artificial reflectors is therefore not recommended and will in fact void the module's warranty.

HOW LONG DOES THE PV SYSTEM LAST? Top quality polycrystalline PV modules last over 30 years. They can withstand arctic cold, desert heat, tropical humidity, winds in excess of 125 mph and 25 mm hail at terminal velocity. The power output of most modules falls off a little during their operating life. They are usually warranted by

manufacturers to produce only 80% of their original minimum rating for 20 or so years of their life. However, some types of PV modules, using thin film silicon, have a predictable fall-off in output in the first few months of operation. They then become stabilized. However, they are usually warranted to produce 80% of the initial output for only about 5 years.

With regard to batteries, the user has a choice to purchase the industrial strength units, which will last up to 7 years, or the smaller sealed units that will last 3 to 5 years. As discussed earlier, automotive batteries are a poor substitute for deep cycle batteries and will generally last only a year or so.

WHAT ABOUT BREAKAGES? The most reliable, long life, PV modules use a glass superstrate (glass front). It is usually a low-iron tempered glass, laminated with layers of plastic. Although durable and strong, it is still breakable. If the glass is shattered or punctured, the module will eventually fail due to water getting into the solar cells and causing corrosion. It may take years for the module to completely fail (produce no power). On the other hand, if the electrical connections between any given pair of cells are severed, the module's output will cease immediately.

Some lightweight modules, designed for lightweight and rugged activities such as camping, use an aluminium substrate and a plastic superstrate. They are shatterproof, but do not last as long as the modules with glass front. This is because the plastic covering is not as inert as glass, and the aluminium is not a good thermal expansion match for solar cells made of silicon.

WHAT TO LOOK FOR WHEN PURCHASING PV MODULES

- The equipment should be approved and verified for long-tem reliability by the appropriate testing and safety authorities.
- The manufacturer should regularly qualify production units (rather than laboratory samples) to international standards.
- Check out the module. It should have a solid feel. The frame should not twist easily.
- The junction box should be suitable for marine use. It should be solidly attached (glue the conduit with silicone). It should be capable of taking heavy gauge wire and accommodate standard electrical fittings. It should also be capable of accommodating diodes and regulators, if needed.
- The solar cells should not be perilously close to the module frame, which can lead to electrical breakdown and premature failure.
- The module bus bars should be open and well isolated. They should not be folded behind the cells where they can cause electrical shorts and delamination.
- Study the label. It should not be a generic label. The actual tested power of that individual module should be printed on the back. The manufacturer's tolerance on power should be stated, making it clear how far below the nominal can the power be and the module still be considered within specifications.
- The module should have enough voltage to charge batteries under all conditions. It should be at least 16.5 volts at maximum power.
- The warranty document should not be vague. It should guarantee a specific level of performance.
- Check to see if the manufacturer and distributor are reputable. Would they still be in business in, say, 10 years?

MAINTENANCE: Although arrays of PV modules can be wired for higher voltages, they are generally low voltage DC devices with no moving or wearing parts. They thus require no maintenance other than occasional cleaning to help them work more efficiently. The maintenance and care of batteries has been discussed under 'batteries'.

The PV systems are generally subject to the same safety codes that govern the installation of electrical wiring and equipment in vessels. Properly installed PV systems with safety approved components are covered by most insurance policies in the same way as any other electrical equipment installed in the vessel, but individual policies should be consulted to determine the limit of the coverage.